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CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES THROUGH EFFICIENT WATER MANAGEMENT IN AGRICULTURE

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Climate Change Mitigation and Adaptation Strategies through Efficient Water Management in Agriculture

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Preface

As per IPCC estimate, the average global temperature is going to increase by 1.8 to 4.0^0C by the end of twenty first century. Frequency of extreme events is likely to increase further in our country. Already we have started experiencing delayed onset of monsoon, early withdrawal and long dry spell in between in many parts of India. As per IPCC report, number of cold days and nights has decreased and number of warm days and nights has increased globally. Similarly frequency of heat waves has increased in many parts of the world. All these climate related extremes are likely to influence world agriculture in general and Indian agriculture in particular because of our dependence on *rainfed* production system. Water being the single most important factor whose timely supply in optimum quantity is highly essential for getting higher productivity. Per capita per annum water availability has decreased from 5177m^3 in 1951 to 1869m^3 in 2001 and is likely to reduce further to 1140m^3 by 2050. It has been estimated that by the year 2050, agriculture sector including fishery and animal husbandry would require 74 per cent of the total water requirement of the country for ensuring future food security of the country. It may be difficult to get such huge quantity of water for agricultural sector in future because sectors like domestic and industry are competitors to agriculture and are also considered as priority sectors of the government. So efficient water management strategies need to be evolved for enhancing agricultural production with reduced water consumption in the context of climate change. Keeping together the effects of climate change as well as reduced allocation of water to agricultural sector in view, a manual to practice climate change mitigation and adaptation strategies for efficient water management has been prepared based on lecture notes of training "Climate Change Mitigation and Adaptation Strategies through Efficient Water Management in Agriculture", sponsored by Directorate of Extension, Dept. of Agriculture, Cooperation & Farmer Welfare, Ministry of Agriculture & Farmers Welfare, Government of India. We hope the manual will be helpful to the researchers, policy makers, extension workers to achieve more production per drop under the regime of climate change.

Editors

An Overview on Irrigation Water Management Scenario in India

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Water has played vital role for evolution of human being, agriculture, urban as well as industrial development. In fact, all great ancient civilizations be it Mesopotamian, Egyptian or Indus flourished along the rivers as water is the most important natural resources. Globally, the potential availability of water has decreased from 12900 m^3 per capita per year in 1970 to less than 7000 m^3 in 2000 and projected to hit as low as 5100 m^3 per capita by the year 2025. However, this availability is not uniform and has wide variations. In densely populated Asia, Africa, Central and Southern Europe, current per capita water availability ranges between 1200-5000 m^3. By the year 2025, about 3 billion people will be in water stress category with 1700 m^3 of available water. India receives an average annual rainfall of 119.4 cm amounting to about 4000 billion cubic meter (BCM) ofwater that generates an average annual runoff of 1869 BCM. Due to various constraints about 1121 BCM of water can be put to beneficial use of which 690 BCM is through surface water and 431 BCM by groundwater. Out of 690 BCM of surface water, so far about 253.4 BCM of storage are built through major and medium irrigation projects. Another 51 BCM of storage are under construction /consideration. Similarly, out of 431 BCM of groundwater resource, about 360 BCM of groundwater is expected to be available for irrigation, out of which present usage is about 222 BCM. The per capita water availability in the year 2005 was 1703 cubic meter which is projected to further reduce to 1401 and 1191 cubic meter by the years 2025 and 2050, respectively. The projected total water demand of the country is estimated at 1447 BCM by the year 2050, which is more than the present availability of utilizable water resources (CWC 2010). In that the share of agriculture itself will be 1072 BCM. Thus, there is a need for proper planning, development and management of water resources.

Further, the availability of water for agriculture in India is projected to decline from 84% in 2010 to 74% by 2050. Therefore to produce 350 M t food grain from shrinking water resources would put existing water sources under immense pressure. It has been estimated that about 1% annual increase in water productivity (quantity per unit consumptive water use) would meet additional water demand for grain production and its further increase to 1.3% would satisfy all crops water demand. Present low crop water productivity provides enough scope for improving present low crop water productivity through scientific agricultural water management practices and the demand of water from other sector can be met with present water resources. Improvised better water governance, introduction of participatory approach, public-private participatory mode and involvement of private sector would be few key issues in this direction. It is expected that the government will further withdraw from this sector in the coming years, while empowered regulatory authorities would be expected to monitor the water resource system in next decades. Reduction of drudgery in agricultural operations, negotiating changing climate change scenarios, reduction of cost of energy in irrigation will be key future researchable issues in next four decades. The increased feed grain demand to 38 Mt in 2025 and 111 Mt in 2050 will provide an opportunity of more productive utilization of our land resources in the ecosystems challenged either by quality of water or by soil and land resources. This will require identification of non-conventional feed resources which can be grown in these challenged ecosystems. This approach has a potential of altering the landscape of these ecosystems which will be more climate resilient as well as would prevent degradation of natural resources base.

As the total projected demand for irrigation sector will be 324 BCM more than the present level of utilizable water resources, the challenge will be (i) more production from less water by efficient use of utilizable water resources in irrigated areas, (ii) increased production from sub-productive challenged ecosystems, *i.e.*, rainfed and water logged areas, and (iii) making use of grey water (waste water) for agriculture production. In addition, there is need of improving productivity of two sub-productive challenged ecosystems rainfed and flood prone/waterlogged areas through efficient irrigation and drainage network development in rainfed areas and combined approach of engineering, crop selection, crop management and aquaculture practices in waterlogged areas would be critical. Moreover, the water resource is fast undergoing change due to increasing population, industrialization, urbanization, pollution, deforestation and above all climate change, which will alter the paradigm of natural resources in which our production system operates. Certainly the business as usual will not suffice. Thus it is essential to visualize the future scenario and prepare strategies for equipping ourselves with technologies which will provide solution for maintaining our food and nutritional security in changing/projected scenarios. This will give us an idea of institutional, technological and financial path to be followed to achieve the national objectives without endangering the sustainability of our production systems.

Agricultural Scenario

India has net sown area of 140.9 M ha and with a cropping intensity of 138.7 its gross sown area is 195.2 M ha. As surface water resources are quite important for crop cultivation through development of large or medium irrigation projects, rainwater harvesting and groundwater recharge, the distribution of annual rainfall is given in Table1. The net irrigated area is 65.3 M ha with gross irrigated area is 91.5 M ha. The remaining 85.78 M ha area is rainfed which is nearly 61% of the net sown area. The irrigated area constitutes 39%. The development of groundwater accounts for 58% of annual replenishment, it needs to be developed further for crop production keeping in mind the sustainability aspect. The distribution of cropped area in different category based on rainfall received clearly indicates prospect of bringing at least 70% area under assured irrigation by developing various means of water resource development (Table 2).

Irrigation Scenario

In India, irrigation development has received high priority in the successive five year plans and has the second largest irrigated area in the world. The ultimate irrigation potential of the country through major, medium and minor irrigation projects has been assessed at 139.9 M ha by conventional storage and diversion works. About 113 M ha of irrigation potential has already been developed through construction of 382 major projects, 1147 medium projects, 146 Extension, renovation and modernization schemes and millions of minor schemes. The overall irrigation efficiency in most of the major and medium irrigation projects is 30-40% which is quite low (Table 3).The prevailing inequity, irregularity and non-reliability of canal water supply and poor efficiency at conveyance, distribution and application of irrigation are considered as a main cause for the low productivity (1.5-4.0 t/ha against achievable 5-6 t/ha) of irrigated agriculture. Over irrigation in some of the canal command areas has also resulted in waterlogging and salinity. Being, major consumer of water, even a marginal improvement in the efficiency of water use in irrigation sector will result in saving of substantial quantity of water. The performance of the irrigation sector thus needs an improvement through improved water delivery and application systems. Presently, about 2.32 M ha of cultivated land have been put under micro-irrigation and needs to be further intensified for improving the overall efficiency.

Groundwater played a major role in the success of green revolution and contributes 60% of the total irrigated area of the country. In case of groundwater irrigation efficiency is estimated at 65-70%. Over exploitation of groundwater has reached at alarming levels in Punjab, Haryana, Rajasthan and Tamil Nadu. The Punjab-Haryana region could lose its production potential in a few decades if current patterns of groundwater extraction and pollution, soil salinization and rice-wheat monoculture persist. Groundwater remains underdeveloped in regions where surface water is adequate. But it is mined in some blocks. A recent estimate reveals that in 15% of the blocks, the annual extraction of groundwater exceeds annual recharge. In 4% of the blocks, it is more than 90% of the recharge. Groundwater extraction in such blocks needs to be better regulated. Conjunctive use of surface and groundwater is desirable to fulfill the irrigation requirements of crops by judiciously utilizing the water from both the sources. The optimal conjunctive use of the region's surface and ground water resources would help in minimizing the problem of waterlogging and groundwater mining. The conjunctive use also facilitates the use of highly saline groundwater which can't be otherwise use without appropriate dilution. Strengthening of knowledge base on geology and aquifer characteristics, hydrology of surface' and groundwater, and existing surface and ground water facilities is required to develop appropriate conjunctive use system.

The Challenges

The projected total water demand of 1447 BCM in 2050 will outstrip the present level of utilizable water resources (1123 BCM) out of which 1074 BCM will be for agriculture alone. Since the total projected demand will be 324 BCM more than the present level of utilizable water resources, the challenge will be to (i) produce more from less water by efficient use of utilizable water resources in irrigated areas, (ii) enhance productivity of challenged ecosystems, i.e., rainfed and water logged areas, and (iii) utilize a part of grey water for agriculture production in a sustainable manner.

Most of the irrigation projects are operating at an overall efficiency of only about 30 to 40% against the achievable efficiency of more than 50%. Thus, there is enormous scope to improve the productivity and efficiency of irrigation systems which can be achieved both by technological as well as social interventions. It is estimated that with 10% increase in the present level of efficiency in irrigation projects, an additional 14 M ha area can be irrigated from the existing irrigation capacities which would involve a very modest investment compared to what is required for creating equivalent potential through new schemes.

Groundwater is the largest source of irrigation contributing about 60% of the net irrigated area of the country. Overall, only 58% of the total groundwater resources have been developed indicating scope for its further development. However, there exists wide variability in its development across different geographical regions of the country. The over-exploitation of groundwater resources in North-western states coexist with under-utilization in the water abundant Eastern region. Further, government policies of providing free/subsidized electricity and pumps in many states are adding fuel to the water crisis. Reduced farm profitability via increasing pumping cost, deceleration in productivity of irrigation water and equity issues in groundwater distribution are also being considered as major challenges in this context. Groundwater pollution is another emerging threat to the sustainability of water resources.

About 350 Class I and Class II urban centres having >50,000 population generate around 38,254 million litres per day (mld) of waste water out of which only 11,787 mld (31%) get treated. It has been projected that wastewater generation will cross 170,000 mld (62 BCM) by 2051 in addition to 30 BCM wastewater generated per year from various industries (CSE 2010). Recycling and reuse of this huge wastewater resource is a challenge for maintaining food security and restore health of the natural resources vis-à-vis the environment.

The country has huge area under two challenged ecosystems, i.e., rainfed and flood prone/ waterlogged areas which have low productivity. Presently about 78 M ha area is under rainfed and it is estimated that even with exploiting all utilizable water resources, approximately 55% of the gross cropped area will remain rainfed. Presently rainfed production system accounts for 91% production of coarse cereal, 49% of rice, 91% of pulses, 80% of oilseed and 65% of cotton. Thus, to ensure food and nutritional security, it is essential that the productivity of rainfed areas is increased significantly. However, the approach cannot be uniform for all rainfed areas. It is noteworthy that about 33% of rainfed area receives more than 1100 mm of rainfall and another 33% between 750-1100 mm. Enhancing productivity from this region will help in modifying the approach for other two rainfed zones receiving 500-750 mm and less than 500 mm rainfall. It has been found that in these two regions, farmers tend to go for water guzzling crops replacing traditional crops which have more resilience against climatic variations. This has led to unsustainable cropping system.

The other challenged ecosystem is waterlogged areas which account for about 8.5 M ha in India. There are two types of waterlogged areas: one where the water table has risen due to over irrigation up to within root zone (approx 2.16 M ha) and another where water congestion occurs due to high rainfall coupled with land topography which hinders drainage. While the first situation can be remedied through efficient irrigation and creating drainage network, the second situation requires a multipronged approach of having an optimal mix of engineering, crop selection, crop management and aquaculture practices supported by market intervention, processing and value addition.

Improving Water Productivity in Irrigated Environment

Performance evaluation of irrigation systems: Space-borne remote sensing measurement can provide information on agricultural and hydrological conditions of the land surface for vast areas at regular intervals. An application of remotely sensed data in the Sone Low Level Canal (SLLC) system in India for assessing irrigation system performance have been used to evaluate the extent of cultivated area, water availability and its distribution, crop yield performance and water productivity for each branch canal and distributaries (Ambast et al., 2008). Even though the capability of satellite remote sensing to monitor agricultural and hydrological conditions of the land surface has undergone major improvements in the past decade, it remains under-utilized by practicing water resource managers.

Conjunctive use of canal and groundwater: In the arid and semi-arid regions, where canal water availability is scarce and groundwater quality is marginally poor, conjunctive use of waters is quite common. Earlier studies for conjunctive use of canal water with saline water were conducted for well-designed treatments of cyclic and blending mode of irrigations under controlled conditions (Sharma and Rao, 1998). However, canal water supply is highly unreliable and inadequate in the region that leaves limited scope for application of recommendations emerged from earlier studies. Therefore, SWAP model has been calibrated and validated in the Kaithal irrigation circle, Haryana in the northwest India (Mandare et al., 2006)to accommodate farmers' fields observation on canal water availability and groundwater applications to suggest (i) water management options for improving productivity of wheat crop during rabi season. Further, there is a need to assess long term impact of various combinations of saline water applications in different wheat based crop rotations feasible in the region.

Irrigation scheduling: Judicious use of water resources is sine-qua-non for enhanced productivity, improved economy and environment. It becomes all the more critical when water supply is scarce. How productive and safe is the water use, largely depends on the quality of the land levelling accomplished by the farmers. Precision land levelling becomes even more important when both the quality and the quantity of available water are limiting. Such a situation exists in the northwest India, where protective canal irrigation supported by good/marginal quality groundwater is in vogue. In such situations, use of saline/alkaline water supplies often requires the application of smaller depths at relatively more frequent intervals (Mandare et al., 2006). Since the total depth water applied per irrigation is greatly influenced by the quality of land levelling, it is important to achieve precision land levelling for efficient irrigation. Salinity and non-uniformity in irrigation water have much the same effect on the yield-water response function and both result in consuming larger volumes of irrigation water to produce the same yields as can be obtained with non-saline water and uniformly applied water (Fig.1).

Deficit irrigation supplies: Alternative cropping patterns have been evaluated for their water productivity and economic returns to improve irrigation system performance (Ambast, 2001). After the modernization of the SLLC system and release of Govt of Bihar share of water from Bansagar project, it is expected that an additional parallel canal will run during *kharif* season, whereas the existing canals will run with designed capacity of water throughout the *rabi* season. The proposed cropping pattern after modernization and the alternative cropping patterns during *rabi* season are given in Table 4. Cropping patterns, CP1-CP2-CP5 have increased cropping intensity, however, CP3-CP5 have the maximum intensity (100%) with increased area for the wheat crop due to deficit irrigation practiced (Table 5).

Pressurized irrigation system: Pressurized irrigation system is proved to be an efficient method in saving water and increasing water use efficiency as compared to the conventional surface method of irrigation, where use efficiency is only about 35-40%. The field experiments conducted across the country under AICRP on Water Management have indicated saving of irrigation water depending upon the soil type, e.g, in clay, the saving is from 30 to 48%, leading to increased area by 1.4 to 1.9 times, in sandy loam, from 40 to 50% saving with 1.7 to 2.0 times increased irrigated area, in silt loam, from 55 to 61% water saving with 2.2 to 2.6 times enhanced irrigated area, in silty clay loam 38 to 47% water saving leading to 1.6 to 1.9 times enhanced irrigated area and in clay loam from 21 to 39% with 1.3 to 1.6% irrigated area (Table 6).Drip fertigation reduces the wastage of water and fertilizers, optimizes nutrient use by applying them at proper place and time which increases the water and nutrient use efficiency. In sandy loam soil, the increase in yield due to fertigation was from 47 to 50%, in clay loam from 32 to 87%, in silty clay loam around 14 %, in silt loam around 34% and in clay from 28 to 59% over conventional fertilizers.

The Opportunities

There are ample opportunities that will revolve around efficient as well as productive utilization of available water both in terms of food per unit of water and energy requirement, waste water utilization, sustainable and quality recharge of ground water, reduction in water use of crops, and productive utilization of land and water resources in challenged eco-systems. Some of the recent developments that will provide new opportunities are:

- The sensor technology along with communication technology is being upgraded continuously. A major constraint in automation and improving efficiency in surface irrigation system is combining sensors with operation of irrigation system for field conditions. A simpler and rugged sensor technology for estimating on-field surface irrigation requirement and coupled with control system will be a breakthrough in irrigation management.

- A major problem in pressurized irrigation system is clogging of drippers, high energy requirement and higher cost. Breakthrough in material science will provide new materials which will be helpful in dealing with these problems. This issue will have to be dealt in close collaboration with R & D of private sector. Development of pressurized irrigation system for higher water requiring crops like rice, sugarcane etc will be among other opportunities for exploration.
- A viable option for enhancing the use of existing utilizable water resource will be recharge of ground water from runoff water, storing runoff water in underground aquifers. However, for maintaining aquifer's health, it is essential that the quality of recharge water is maintained as per acceptable standards. This will be a major challenge in the planning and designing of ground water recharge structures. Advancement in material science has potential for developing filters which can take care of this problem, and this will alter the paradigm of ground water recharge research.
- One of the major areas is development of water use efficient cultivars of different crops through biotechnological approach. Both breeders and scientists from NRM division need to work together rather than developing variety first and then looking for its water management practices later, so that compatible design and operation of irrigation systems are developed simultaneously.
- With an objective of enhancing productivity of water, applying the concept of deficit irrigation, can achieve greater economic gains under a water deficit scenario than maximizing yields per unit of water for a given crop. With increasing sectoral demands of water from industry, energy, urban development sectors, water scarcity in agriculture is increasingly felt. Aerobic rice is an emerging agronomical production system that uses less water than conventional flooded rice. Efforts would be made for standardizing water management practices for aerobic rice cultivation in irrigation Directorate of Water Management
- Similarly use of modern tools like GIS, remote sensing and modeling tools will also be intensified for upscaling of the technologies at higher level.

Conclusions

The natural resource scenario is changing fast both in terms of availability as well as quality. Looming climate change will alter the paradigm of natural resources in which our production system operates. Water has been and will remain a critical resource which is being affected by increasing population, industrialization, urbanization, pollution, deforestation and above all climate change. Certainly the business as usual will not suffice. Thus it is essential to visualize the future scenario and prepare strategies for equipping ourselves with technologies which will provide solution for maintaining our food and nutritional security in changing/projected scenarios.

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Table 1. Distribution of annual rainfall in different season

Season	Duration	Rainfall (%)
Pre-monsoon	March - May	10.4
SW Monsoon	June - September	73.7
Post-Monsoon	October - December	13.3
NE Monsoon	January - February	2.6

Table 2. Distribution of cropped area according to rainfall

Rainfall (mm)	Category	Area receiving rainfall (%)
0-750	Dry	30
750-1150	Medium	42
1150-2000	High	20
Above 2000	Very High	8

Table 3. Irrigation efficiencies in some of the existing Indian projects

Project	Conveyance Efficiency				Application Efficiency	Project Efficiency
	At MC	At Dy/Minor	At FC	Overall		
Harsi system, MP	92	79	68	49	77	38
Sarda system, UP	84	83	64	44	69	31
Kaldiya system, Assam	85	75	72	46	83	38
Pazhassi system, Kerala	94	75	-	70	58	41
Kangsabasti system, WB	86	89	67	51	59	30
Overall	88	80	68	48	68	36

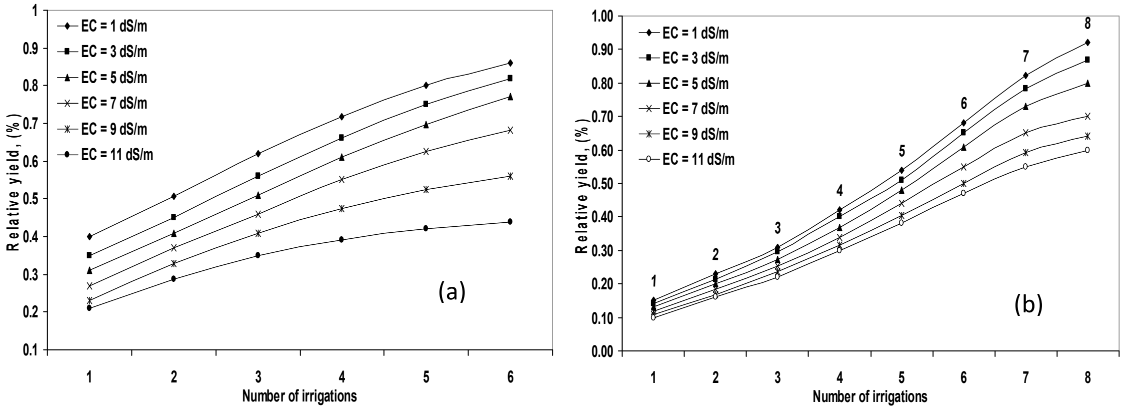

Fig.1. Relative wheat yields due to change in irrigation frequency (a) in conventionally levelled (6 cm/irrigation) and (b) in precision levelled (4 cm/irrigation) fields

Table 4. Proposed and alternative cropping patterns

Cropping pattern	Area (%)					
	Wheat I	WheatII	Pulses	Oilseeds	Vegetables	Perennial
CP1 (proposed)	35.0	20.0	15.0	5.0	3.0	2.0
CP2	40.0	25.0	15.0	5.0	3.0	2.0
CP3	45.0	30.0	15.0	5.0	3.0	2.0
CP4	50.0	35.0	5.0	5.0	3.0	2.0
CP5	60.0	40.0	0.0	0.0	0.0	0.0

Table 5. A summary of irrigation scheduling for different cropping patterns

Crop	ETc (mm)	Net Irrig. (mm)	Lost Irrig (mm)	Prod Loss (%)	Production (kg)	WP (Kg/m^3)
CP1 - Wheat-I	401.9	460.0	96.3	0.0	1575	0.98
Wheat-II	446.6	460.0	87.5	1.5	887	0.96
Pulses	230.5	208.0	0.0	2.8	194	0.47
Vegetable	357.5	391.0	50.5	2.5	585	5.11
Sugarcane	88.4	90.0	0.0	0.0	1000	-
CP4 - Wheat-I	385.7	340.0	48.9	4.3	2153	1.27
Wheat-II	401.2	340.0	45.1	12.0	1386	1.17
Pulses	100.5	78.0	0.0	7.2	93	1.28
Vegetable	357.5	391.0	50.5	2.5	585	5.11
Sugarcane	88.4	90.0	0.0	0.0	1000	-
CP5 - Wheat-I	385.7	340.0	48.9	4.3	2584	1.27
Wheat-II	401.2	340.0	45.1	12.0	1584	1.17

Table 6. Percent saving of irrigation water with drip irrigation & enhanced cultivated area

Centre & State	Test Crops	Soil type	% saving in water	Increase in area (times)
Dapoli (MS)	Brinjal	Lateritic	38	1.6
Navsari (Guj)	Onion	Clay	30	1.4
	Turmeric		32	1.5
	Brinjal		40	1.7
	Chillies		48	1.9
Bhawanisagar (TN)	Jasmine	Sandy loam	50	2.0
	Sugarcane		40	1.7
	Tomato		42	1.7
	Banana		48	1.9
Madurai (TN)	Sugarcane	Clay loam	21	1.3
	Red Gram		39	1.6
Kota (Raj)	Onion	Clay loam	23	1.3
	Garlic		22	1.3
	Turmeric		23	1.3
Faizabad(UP)	Sugarcane	Silt loam	59	2.4
	Marigold		55	2.2
	Cowpea		61	2.6
Palampur (HP)	Broccoli	Silty clay loam	47	1.9
	cauliflower		38	1.6

Table 7. Fertigation vs conventional method of fertilizer application

Centre & State	Test Crop	Soil type	Yield (kg/ha)		% yield increase over conv. method
			Conv method	Fertigation	
Dapoli (MS)	Brinjal	Lateritic	1876	3234	72
Jorhat (Assam)	Assam Lemon	Sandy Loam	10100	14880	47
Palampur (HP)	Broccoli	Siltyclayloam	7400	8440	14
Navsari (Guj)	Onion	Clay	28740	45690	59
	TurmericRo	Clay	13100	16800	28

	und melon	Clay	12000	15300	28
	Sugarcane	Clay	140000	183000	31
	Tomato	Clay	48000	68000	42
Bhawanisagar (TN)	Coconut	Sandy loam	10974 nuts	16461 nuts	50
	Sugarcane		115300	171700	49
Madurai (TN)	Red Gram	Clay loam	1108	1515	37
Kota (Raj)	Onion	Clay loam	16350	24960	53
	Cabbage	Clay loam	17756	23373	32
	Garlic	Clay loam	6953	10575	52
	Turmeric	Clay loam	14670	27360	87
	Bitter Gourd	Clay loam	21226	30139	42
Faizabad (UP)	Marigold	Silt loam	161	216	34

Climate change and its impact in agriculture and water resources

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Introduction

Water and food security are the key challenges under climate change as both are highly vulnerable to continuously changing climatic patterns. Climate change has resulted in increases in globally-averaged mean annual air temperature and variations in regional precipitation and these changes are expected to continue and intensify in the future. The projected changes in climate patterns over India include increase in surface temperature, variations in rainfall, increasing occurrence of extreme weather events like floods and droughts, rise in sea levels and impact on the Himalayan glaciers. Sectors of the Indian economy are most likely to be impacted by such changes in climate are those dependent on natural resources, namely agriculture, water and forestry. The likely impacts such as reduction in food production, water scarcity, loss of forest biomass Climate change is expected to bring more intense and more frequent extreme weather events including droughts and floods in India. The global atmospheric concentration of CO_2 for increased from pre-industrial value of about 280 ppm to 390 ppm at the present (2011). The global increase in CO_2 concentration is primarily due to fossil fuel use and land use change. Atmospheric methane was 1803 ppb in 2011, this is 150% greater than before 1750. Atmospheric N_2O was 324 ppb in 2011, this is 150% greater than before 1750 (Table1). These increase in GHGs have resulted in warming of the climate system by 0.74 ^{0}C between 1906 and 2005.

2.0 Climate change trend

As per the fifth assessment report of the IPCC (IPCC-AR-5), increase of global mean surface temperatures for 2081–2100 relative to 1986–2005 is projected to likely be in the ranges derived from the concentration-driven CMIP5 model simulations, that is, 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5) (Table-1).

The IPCC (IPCC-AR-5) concluded the warming of earth's climate system based on direct observation of changes in temperature, sea level and snow cover in the northern hemisphere during 1850 to the present (Table-2). (IPCC 2014).

The accelerated increase in the greenhouse gases (GHG) concentration in the atmosphere is a major cause for climate change. As per the IPCC (2007) report, the maximum growth in the emission of greenhouse gases (GHG) has occurred between 1970 and 2004, i.e. 145% increase from energy supply sector, 120% from transport, 65% from industry, 40% from change in land use patterns and during this period global population increases by 69%. As per the WMO (2013), the world experienced unprecedented high-impact climate extremes during the 2001–2010 decade that was the warmest since the start of modern measurements in 1850.

So, far much attention has been given to climate change adaptation as an anticipatory and planned process, managed through new policies, technological innovations and development interventions. But these policies and strategies need to be implementation because most of the fresh water resources are depleting at a very fast rate due to unprecedented escalation in demand from domestic, irrigational and industrial sectors. Impact of climate change such as depletion of water resources (Shallow & deep aquifer depletion) and decline in agricultural production has increased and has escalated food inflation globally. The condition is extremely severe in continents like Africa, where most of the northern portion is extremely dry. Western India, Middle East and Arab Countries, where most of the domestic, irrigational and industrial demands are met by Surface and groundwater are facing severe crisis due to depletion of water resources.

3.0 Sources of major Greenhouse Gases from agricultural activities

The three major GHGs are carbon dioxide, methane and nitrous oxide which emit from different agricultural activities. A brief description about their sources and sinks is given below.

Carbon Dioxide

The main sources of carbon dioxide emission are burning of fossil fuels, deforestation and land-use changes,decay of organic matter, forest fires, eruption of volcanoes. Within agriculture, soil is the main contributor with factors such as soil texture, temperature, moisture, pH, and available C and N, influencing CO_2 emission from soil. Emission of CO_2 is more from a tilled soil than from an undisturbed soil (no till). Temperature has a marked effect on CO_2 evolution from soil by influencing root and soil respiration. It may be mentioned that plants, oceans and atmospheric reactions are the major sinks of carbon dioxide.

Methane

Methane is about 25-times more effective as a heat-trapping gas than that of CO_2. The main sources of methane are: wetlands, organic decay, termites, natural gas and oil extraction, biomass burning, rice cultivation, cattle and refuse landfills. The primary sources of methane from agriculture include animal digestive processes, rice cultivation and manure storage and handling. The removal in the Stratosphere and soil are the main sinks of methane.

In ruminant animals, methane is produced as a by-product of the digestion of feed in the rumen under anaerobic condition. Methane emission is related to the composition of animal diet (grass, legume, grain and concentrates) and the proportion of different feeds (e.g., soluble residue, hemicellulose and cellulose content). Mitigation of methane emitted from livestock is approached most effectively by strategies that reduce feed input per unit of product output.

Nutritional, genetic and management strategies to improve feed efficiency increase the rate of product (milk, meat) output per animal. Because most CH4 is produced in the rumen by fermentation, practices that speed the passage of feed from the rumen can also reduce methane formation.

Methane is also formed in soil through the metabolic activities of a small but highly specific bacterial group called 'methanogens'. Their activity increases in the submerged, anaerobic conditions developed in the wetland rice fields, which limit the transport of oxygen into the soil, and the microbial activities render the water-saturated soil practically devoid of oxygen. The upland, aerobic soil does not produce methane. Water management, therefore, plays a major role in methane emission from soil. Altering water management practices, particularly mid-season

aeration by short-term drainage as well as alternate wetting and drying can greatly reduce methane emission from rice cultivation. Improving organic matter management by promoting aerobic degradation through composting or incorporating soil during off-season drain-period is another promising technique.

Nitrous Oxide

As a greenhouse gas, nitrous oxide is 298-times more effective than CO_2. Forests, grasslands, oceans, soils, nitrogenous fertilizers, and burning of biomass and fossil fuels are the major sources of nitrous oxide, while it is removed by oxidation in the Stratosphere. Soil contributes to the largest amount of nitrous oxide emission. The major sources are soil cultivation, fertilizer and manure application, and burning of organic material and fossil fuels. From an agricultural perspective, nitrous oxide emission from soil represents a loss of soil nitrogen, reducing the nitrogen-use efficiency. Appropriate crop management practices, which lead to increased N-use efficiency, hold the key to reduce nitrous oxide emission. Site-specific nutrient management, fertilizer placement and proper type of fertilizer supply nutrients in a better accordance with plant demands, thereby reduce nitrous oxide emission.

4.0 Impacts of Climate Change on Agriculture and allied sectors

4.1 Impacts of climate change on crop

Global climatic changes can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. An increase in atmospheric carbon dioxide level will have a fertilization effect on crops with C_3 photosynthetic pathway and thus will promote their growth and productivity. The increase in temperature, depending upon the current ambient temperature, can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer-use efficiencies, and increase evapo-transpiration rate. Indirectly, there may be considerable effects on land use due to snow melt, availability of irrigation water, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. Equally important determinants of food supply are socio-economic environment, including government policies, capital availability, prices and returns, infrastructure, land reforms, and inter and intra-national trade that might be affected by the climatic change. In brief the impacts of climate change on agriculture and allied sectors are given below:

- Yield of major cereals crops, especially wheat are likely to be reduced due to decrease in grain filling duration, increased respiration, and / or reduction in rainfall/irrigation supplies.
- Increase in extreme weather events such as floods, droughts, cyclones and heat waves will adversely affect agricultural productivity.
- Reduction in yields in the rainfed areas due to changes in rainfall pattern during monsoon season and increased crop water demand.
- Incidence of cold waves and frost events may decrease in future due to global warming and it would lead to a decreased probability of yield loss

associated with frost damage in northern India in crops such as mustard and vegetables.

- Quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants may be affected.
- Incidence of pest and diseases of crops to be altered because of more enhanced pathogen and vector development, rapid pathogen transmission and increased host susceptibility.
- Agricultural biodiversity is also threatened due to the decrease in rainfall and increase in temperature, sea level rise, and increased frequency and severity of droughts, cyclones and floods.

Simulating the effects of elevated temperature and CO_2 on growth and productivity of winter maize- a case study

The climate change impacts on crop growth and yield were assessed with weather series representing both the current (average of 24 years, 1985-2008) and changed climates (Current maximum and minimum temperatures + 1 ^{O}C and + 2^{O}C). The weather series for simulations in the changed climate was modified accordingly and run under both present (370 ppm) and enhanced CO_2 level (550 ppm). The impact of change in CO_2 concentration i.e. from 370 ppm to 550 ppm, under current climatic condition (average of 24 years, 1985-2008) on phenology, grain yield and total dry matter of maize was also studied (Table-3 and 4).

In this investigation, DSSAT 4.5 model was calibrated and evaluated to study the effect of elevated temperature and carbon dioxide and their interaction on growth and productivity of maize crop. Study revealed that 1.0°C increase in temperature from the current (average of 1985-2008) reduced crop duration of November sown crop by 8 days under both 370 ppm (current) and 550 ppm CO_2 concentrations. Higher days of reduction in crop duration was observed (13 days) when 2.0°C temperature was increased from the current. According to model simulations with 2.0°C increase in current temperature, yield of maize will be reduced up to 13.8% under 370 ppm CO_2 concentration. The increase in temperature had negative effects on leaf area index (LAI), total dry matter and yield; however these effects were found lesser under 550 ppm CO_2 concentrations as compared to 370 ppm.

4.2 Impact of climate change on water resources

Changing global climatic patterns coupled with declining per capita availability of surface and ground water resources have made sustainable agricultural a great challenge in India.

Warming of the climate system in recent decades is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global sea level (IPCC 2014).

The Inter-Governmental Panel on Climate Change (IPCC) in its 5th Assessment Report (2014) has observed the following impacts of climate change on water resources.

- The global water cycle will be affected in response to the warming.
- The contrast in precipitation between wet and dry regions and seasons will increase.
- The ocean will continue to warm causing heat to penetrate deeper to affect ocean circulation.
- Global mean sea level will continue to rise. .
- Arctic and Antarctic ice cover will continue to shrink.
- Global glacier volume will further decrease.
- Some of the impacts of climate change on water resourcesare given in table-6.

Impact of elevated temperature on crop evapo-transpiration and water footprints of some winter season crops

Climate change due to increase in temperature rise will demand higher amount of water for irrigation. At the same time the higher temperature will change the crop physiology and shorten the crop growth period which in turn will reduce the irrigation days. These contradictory phenomena will change the total irrigation water demand which is required to quantify for long-term water resources planning and management. Assuming the same crop duration, as a case study the crop evapotranspiration of some winter season crops of Dhenkanal, Orissa under current and projected climate change scenario (RCP 8.5) were determined and are given in table-5.

Irregularities in onset of monsoon, drought, flood and cyclone

Indian agriculture is highly dependent on the onset, retreat and magnitude of monsoon precipitation, particularly in the rainfed areas of east, north-east and south India. Climate modelers and IPCC documents have projected possibilities of increasing variability in Asian Monsoon circulation in a warmer world. Despite expansion of area under irrigation, droughts, caused by inadequate and uneven distribution of rainfall, continue to be the most important climatic aberrations, which influence the agricultural production in India. The severity of a drought will be intensified in a warmer world. Intense and frequent floodings due to climate change would be a major problem in the Indian subcontinent.

Rise in sea level

In South, South East and East Asia about 10% of the regional rice production, which is enough to feed 200 million people, is from the areas that are susceptible to 1 m rise in the sea level. Direct loss of land combined with less favourable hydraulic conditions may reduce rice yields by 4% if no adaptation measures are taken, endangering the food security of at least of 75 million people. Saltwater intrusion and soil salinization are other concerns for agricultural productivity.

4.3 Effect on Livestock

Climate change will affect fodder production and nutritional security of livestock. Increased temperature would enhance lignification of plant tissues, reducing the digestibility. Increased water scarcity would also decrease production of feed and fodder.

- Major impacts on vector-borne diseases will be through expansion of vector populations in the cooler areas. Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of diseases.
- Global warming would increase water, shelter, and energy requirement of livestock for meeting the projected milk demands.
- Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.

4.4 Effect on Fisheries

- Increasing temperature of sea and river water is likely to affect breeding, migration and harvests of fishes.
- Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish.
- Coral bleaching is likely to increase due to higher sea surface temperature.

4.5 Impact of climate change on soil fertility and microbes

- Soil temperature affects the rates of organic matter decomposition and release of nutrients. At high temperatures, though nutrient availability will increase in the short-term, in the long-run organic matter content will diminish, resulting in a decline in soil fertility.
- Organic matter content, which is already quite low in Indian soils, would become still lower. Quality of soil organic matter may be affected.
- The residues of crops under the elevated CO_2 concentrations will have higher C:N ratio, and this may reduce their rate of decomposition and nutrient supply.
- Rise in soil temperature will increase N mineralization, but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.
- There may be a change in rainfall volume and frequency, and wind may alter the severity, frequency and extent of soil erosion.
- Rise in sea level may lead to salt-water ingression in the coastal lands, turning them less suitable for conventional agriculture.

4.6 Impact of climate change on pests and diseases

As temperature increases, the insect-pests will become more abundant through a number of inter-related processes, including range extensions and phonological changes, as well as increased rates of population development, growth, migration and over-wintering. The climate change is likely to alter the balance between insect pests, their natural enemies and their hosts. The rise in temperature will favour insect development and winter survival. Rising atmospheric carbon dioxide concentrations may lead to a decline in food quality for plant-feeding insects, as a result of reduced foliar nitrogen levels. The epidemiology of plant diseases will be altered. The prediction of disease outbreaks will be more difficult in periods of rapidly changing climate and unstable weather. Environmental instability and increased incidence of extreme weather may reduce the effectiveness of pesticides on targeted pests or result in more injury to non-target organisms.

The role of weather in outbreak of plant diseases has been realized from early 20th century. In the last years of the Second World War (1943), Bengal had to face a serious famine due to outbreaks of *Helminthosporium* in rice (Brown spot). The high yielding, short duration and more fertilizer responsive varieties have been found more susceptible to diseases and have caused great havoc in time to time in many parts of the country. The incidence of wheat rust in Madhya Pradesh in 1947, ergot disease of bajra (pearl millet) in Haryana in 1976. Downy mildew in Rajasthan in 1994, Tungro virus of rice in U.P and Bihar in 1966, Virus diseases of rabi in Karnataka and Andhra Pradesh are worth mentioning. The studies of weather in relationship with disease infestation are necessary to take preventive measures. Early detection of inoculums of infection is very often necessary in determining whether a given or anticipated weather situation will cause an outbreak of a disease in epidemic form. Short and medium range forecasts on disease infestation based on eminent weather will be useful for farmers to take protective measures. In case of air borne diseases where the infective spores get emigrated from distant regions, aeromycological observations are required to issue warning about the arrival of inoculumn.

5.0 Need to develop climate resilient agriculture

The Indian agricultural production system faces the daunting task of having to feed 17.5 percent of the global population with only 2.4 per cent of land and 4 per cent of the water resources at its disposal. With the continuously degrading natural resource base compounded further by global warming and associated climate changes resulting in increased frequency and intensity of extreme weather events, "business as usual" approach will not be able to ensure food and nutrition security to the vast population as well as environmental security (the need of the hour). The challenge is formidable because more has to be produced with reduced carbon and water footprints. To achieve this task of paving the way for climate smart agriculture we need to take several measures that will have enabling policies, institutions and infrastructure in place and the farming community be better informed and empowered with necessary resources.

Climate resilient agriculture (CRA), encompassing adaptation and mitigation strategies and the effective use of biodiversity at all levels - genes, species and ecosystems - is thus an essential pre-requisite for sustainable development in the face of changing climate

CRA means the incorporation of adaptation, mitigation and other practices in agriculture which increases the capacity of the system to respond to various climate related disturbances by resisting damage and recovering quickly. Such perturbations and disturbances can include events such as drought, flooding, heat/cold wave, erratic rainfall pattern, long dry spells, insect or pest population explosions and other perceived threats caused by changing climate. In short it is the ability of the system to bounce back. Climate resilient agriculture includes an in-built property in the system for the recognition of a threat that needs to be responded to, and also the degree of effectiveness of the response. CRA will essentially involve judicious and improved management of natural resources viz., land, water, soil and genetic resources through adoption of best bet practices

References:

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Table-1: Abundance and lifetime of green house gases in the atmosphere

Parameters	CO_2	CH_4	N_2O	CFCs
Average concentration 100 years ago (ppbv)	290,000	900	270	0
Current concentration (ppbv)((2007)	390,000	1774	324	3-5
Projected concentration in the year 2030	400,000-500,000	2800-3000	400-500	3-6
Atmospheric life time (year)	5-200	9-15	114	75
Global warming potential (100 years relative to CO2)	1	25	298	4750-10900

IPCC (2014)

Table-2: Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century relative to the reference period of 1986–2005.

		2046–2065		2081–2100	
Global Mean Surface Temperature Change (°C)	**Scenario**	**Mean**	**Likely range**	**Mean**	**Likely range**
	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
Global Mean Sea Level Rise (m)	**Scenario**	**Mean**	**Likely range**	**Mean**	**Likely range**
	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Table-3: Summary of observed and simulated results during model calibration with crop data of 2007-08 under current climatic condition

Crop parameters	Unit	Observed	Simulated	RMSE	Error (%)	d-index
Anthesis	days	55	54	0.42	- 1.81	0.96
Maturity	days	113	112	0.58	- 0.88	0.87
Maximum LAI	-	6.4	6.0	0.36	- 6.25	0.80
Grain yield	kg ha^{-1}	5847	5805	198.7	- 0.72	0.94
Total Biomass	kg ha^{-1}	13440	13250	245.6	- 1.41	0.92

Table-4: Impact of temperature and CO$_2$ scenarios on phenology, growth, yield and yield component of maize (cv. Novjyot)

Temperature	Current (av. of 1985-2008)	1.0 °C	Difference (absolute)	2.0 °C	Difference (absolute)
CO$_2$ Concentration : 370 ppm					
Crop duration (days)	114	106	8	101	13
Maximum leaf area index	6.1	5.6	0.5	5.45	0.65
Total above ground dry biomass (kg ha^{-1})	13600	12306	1294	11515	2085
No. of grains m^{-2}	2357	2340	17	2314	43
Grain yield (kg ha^{-1})	5800	5318	482	4996	804
CO$_2$ Concentration : 550 ppm					
Crop duration (days)	114	106	8	101	13
Maximum leaf area index	6.3	5.8	0.5	5.65	0.65
Total above ground dry biomass (kg ha^{-1})	14304	12805	1499	12374	1930
No. of grains m^{-2}	2445	2345	100	2325	120
Grain yield (kg ha^{-1})	6094	5504	590	5298	796

Table-5: Impact of elevated temperature on crop evapo-transpiration (ETc, mm) of some winter season crops under scenario of RCP 8.5 (Study area: Dhenkanal, Odisha: Sowing – last week of November)

Crops	Current ETc (mm) 2010	2050 RCP (8.5)	% Increase from Current	2070 RCP (8.5)	% Increase from Current	2095 RCP (8.5)	% Increase from Current
Potato	409.4	429.8	4.7	443.4	8.3	459.3	12.2
Blackgram	332.5	342.7	3.1	362.4	9	378.1	13.7
Sunflower	426.7	444.7	4.7	461.7	8.2	476.2	11.6
Wheat	396	418.3	5.3	434.0	9.6	447.1	12.9
Chickpea	377.6	395.8	4.8	410.1	8.6	419.5	11.1
Safflower	414.1	434.8	4.5	450.1	8.7	470.0	13.5
Mustard	375.1	398.1	5.9	409.2	9.1	417.1	11.2
Linseed	281.2	295.4	4.7	309.9	10.2	315.5	12.2
Rapeseed	331.4	348.7	4.5	360.2	8.7	366.5	10.6
Tomato	514.6	545.4	5.1	565.0	9.8	574.3	11.6
Cabbage	500.5	526.2	4.3	551.6	10.2	557.6	11.4
Cauliflower	496.1	523.7	4.4	539.8	8.8	564.1	13.7
Okra	420.7	441.4	3.9	461.9	9.8	474.1	12.7
Carrot	398	420.8	4.8	442.6	11.2	447.4	12.4

Table-6: Impact of climate change on India's water resources during the next century.

Region/location	**Impact**
Indian subcontinent	Increase in monsoonal and annual run-off in the central plains No substantial change in winter run-off Increase in evaporation and soil wetness during monsoon and on an annual basis
Odisha and West Bengal	Sea-level rise by 1 m inundating 1700 km^2 of prime agricultural land
Indian coastline	One metre sea-level rise on the Indian coastline is likely to affect a total area of 5763 km^2 risking 7.1 million people
All-India	Increases in potential evaporation across India
Central India	Basin located in a comparatively drier region is more sensitive to climatic changes
Kosi Basin	Decrease in discharge of the Kosi River and decrease in run-off by 2–8%
Southern and Central India	Soil moisture increases marginally by 15–20% during monsoon months
Chenab River	Increase in discharge in the Chenab River
River basins of India	General reduction in the quantity of the available run-off, increase in Brahmini basin
Mahanadi river basin	Increasing run-off and intensities of flood
Damodar Basin	Decreased river flow
Rajasthan	Increase in evapo-transpiration
Kasnabati river basin	Increase in potential evapo-transpiration and lateral flow
Lower Brahmaputra	Increased peak flow with less frequent low flows
Sutluj Basin	Little change in total stream flow but substantial change in the distribution of stream flow

Source: Mall et al. (2006)

Groundwater recharge for climate change adaptation

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1. Introduction

The total annual replenishable groundwater resources of the country have been reassessed as 433 Billion Cubic Meters (BCM) and the net annual groundwater availability is estimated as 398 BCM. Annual groundwater draft as on March, 2011 for all uses is 245 BCM. The Stage of groundwater development is 62%. The development of groundwater in different areas of the Country has not been uniform. Highly intensive development of groundwater in certain areas in the country has resulted in over-exploitation of groundwater resource. The state-wise status of groundwater development is given in Table 1 (CGWB, 2014). The level of groundwater development is very high in the states of Delhi, Haryana, Punjab and Rajasthan, where groundwater development is more than 100%. This implies that in these states, the annual groundwater consumption is more than annual groundwater recharge. In the states of Himachal Pradesh, Tamil Nadu and Uttar Pradesh and the Union Territory of Puducherry, the level of groundwater development is 70% and above. In rest of the states, the level of groundwater development is below 70%. Over the years, usage of groundwater has increased in areas where the resource was readily available. This has resulted in an increase in overall groundwater development from 58% in 2004 to 62% in 2011 (CGWB, 2014).

As per the latest assessment of groundwater resources, out of 6607 assessment units (Block / Mandals / Talukas/Firkas) in the country, 1071 units have been categorized as over-exploited i.e. the annual groundwater draft exceeds the annual replenishable groundwater resource, 217 units are critical where the stage of groundwater development is 100% of annual replenishable groundwater resource, 697 semi-critical units, where the stage of groundwater development is between 70-90%. In these areas, significant decline in long term water level trend has been recorded in either pre-monsoon or post-monsoon period or both. Apart from these, there are 92 blocks completely underlain by saline groundwater.

Table 1: Status of state-wise groundwater development

State	Groundwater development in 2011 (%)	State	Groundwater development in 2011 (%)
Andhra Pradesh	45	Mizoram	3.52
Arunachal Pradesh	0.08	Nagaland	6.13
Assam	14	Odisha	28
Bihar	44	Punjab	172
Chhattisgarh	35	Rajasthan	137
Delhi	137	Sikkim	26
Goa	28	Tamil Nadu	77
Gujarat	67	Tripura	7
Haryana	133	Uttar Pradesh	74
Himachal Pradesh	71	Uttarakhand	57
Jammu & Kashmir	21	West Bengal	40
Jharkhand	32	Andaman & Nicobar	4.44
Karnataka	64	Chandigarh	0
Kerala	47	Dadara & Nagar Haveli	22
Madhya Pradesh	57	Daman & Diu	97
Maharashtra	53	Lakshdweep	67
Manipur	1.02	Puducherry	90
Meghalaya	0.08	**Total**	**62**

Source: Dynamic groundwater resources of India, 2014, CGWB

2. Groundwater Extraction and Use:

In India, the availability of surface water is greater than groundwater. However, owing to the de-centralized availability of groundwater, it is easily accessible and forms the largest share of India's agriculture and drinking water supply. About 85 percent of India's rural domestic water requirements, 50 percent of its urban water requirements and more than 50 percent of its irrigation requirements are being met from groundwater resources. About 91% of groundwater extracted is used in the irrigation sector, making it the highest category user in the country and 9% of the extracted groundwater is used for domestic and industrial use (CGWB, 2014).

The largest component of groundwater use is the water extracted for irrigation. The main means of irrigation in the country are canals, tanks and wells, including tube-wells. Of all these sources, groundwater constitutes the largest share. Wells, including dug wells, shallow tube-wells and deep tube wells provide about 61.6% of water for irrigation, followed by canals with 24.5%. Over the years, there has been a decrease in surface water use and a continuous increase in groundwater utilization for irrigation. The dependence of irrigation on groundwater increased with the onset of the Green Revolution, which depended on intensive use of inputs such as water and fertilizers to boost farm production. Incentives such as credit for irrigation equipment and subsidies for electricity supply have further worsened the situation. A low power tariff has led to excessive water usage, leading to a sharp fall in water tables.

3. Climate Change

It is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time (i.e., decades to millions of years). Climate change may refer to a change in average weather conditions, or in the time variation of weather around longer-term average conditions (i.e., more or fewer extreme weather events). Climate change, which includes global warming due to increase in temperature, changes the patterns of rainfall, evapotranspiration and greatly increases the risks of floods as well as the frequency and severity of droughts.

3.1 Causes of Climate Change

Climate change is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, volcanic eruptions, greenhouse gases, deforestation, urbanization, industrialization and different activities of living organisms. Certain human activities have also been identified as significant causes of recent climate change, often referred to as global warming. These factor causing climate changes include:

a. Greenhouse Gases

The most important GHGs directly emitted to atmosphere include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and several others. The main greenhouse gases include:

Water vapour: The most abundant greenhouse gas (GHG), however because it spends just a short time in the atmosphere, and humans have a very impact on the amount of water in the atmosphere, it is not considered the most important GHG.

Carbon dioxide (CO_2): It is actually only a small part of the atmosphere, but one of the most important GHGs. CO_2 is released naturally into the atmosphere through volcanic eruptions and animal respiration but it is also released through human activities such as deforestation and the burning of fossil fuels for energy. CO_2 also spends a long time in the atmosphere increasing its impact.

Methane: This is the most important GHG, is produced both naturally and through human activities. The most significant sources of methane come from the decomposition of organic matter e.g. in landfills and in agriculture. Another large source is from the digestion of ruminants (cows, goats etc). Methane is a stronger GHG than CO_2 because it can absorb more heat; however it is much less abundant in the atmosphere.

Nitrous oxide: A very powerful greenhouse gas which is heavily produced in the agriculture sector, specifically in the production and use of organic fertilizers. It is also produced when burning fossil fuels.

Chlorofluorocarbons (CFCs): These man-made compounds were produced for industrial use, mainly in refrigerants and air conditioners. Fluorinated gases produce a very strong warming effect, up to 23000 times greater than CO_2. They are now regulated under the Montreal Protocol due to their adverse effect on the Ozone Layer.

b. **Cutting down forests (deforestation).** Trees help to regulate the climate by absorbing CO_2 from the atmosphere. So when they are cut down, that beneficial effect is lost and the carbon stored in the trees is released into the atmosphere, adding to the greenhouse effect. It affects the change in rainfall pattern over the period.

c. **Increasing livestock farming.** Cows and sheep produce large amounts of methane when they digest their food.

d. **Agriculture sectors:** more and more utilization on chemical fertilizers containing nitrogen produce nitrous oxide emissions to atmosphere. The land use pattern changes that encourage the deforestation and hardening of the land surface resulting less recharge and heavy runoff. Pumping of water for irrigation purpose also emits the GHGs that causes global warming.

e. **Anthropogenic factors:** activities of human beings and other living organisms affect the climate change. Heavy utilization of vehicles emits GHGs to environment.

f. **Urbanization:** increase in population, increases the concentration of CO_2 gases causing the global warming. It also causes the deforestation, as a result rainfall pattern decreases over the period. The natural recharging area decreases that affect the lowering of groundwater level below ground surface.

g. **Industrialization:** it emits heavy GHGs to environment with encouraging land degradation, deforestation and pollution.

4. Impacts of Climate Change on Groundwater

The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2^{o} C since 1861, and predicts an increase of 2 to 4^{o} C over the next 100 years. Global sea levels have risen between 10 and 25 cm since the late 19th century. As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. Predictions include higher incidences of severe weather events, a higher likelihood of flooding, and more droughts. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India.

Groundwater will be less directly and more slowly impacted by climate change than surface waters. This is because rivers get replenished on a shorter time scale, and drought and floods are quickly reflected in river water levels. The key area where climate change affects groundwater is through recharge, discharge and storage. Groundwater resources are related to climate change indirectly through the process of recharge, and directly through the interaction with surface water bodies such as rivers and lakes. Irrigation dominates current groundwater use by volume, and the effects of future climate variability and change on groundwater may be greatest through indirect effects on irrigation- water demand. The climate change affects the groundwater in as follows:

a. **Groundwater storage:** Groundwater storage is controlled by the intrinsic aquifer properties such as storativity, transmissivity and aquifer geometry. The unconfined shallow aquifers are affected by the climate change. The impact of climate change on storage depends on whether or not groundwater is renewable or non-renewable (fossil) resource. Even though there is no direct climate change impact on fossil groundwater, the impact would encourage over-abstraction of fossil water during the stress period. Shortage of recharge due to climate change results in reducing the renewable storage. Due to climate change the aquifer geometry changes that results the blockage of fissures and decreases the storativity, hence groundwater storage.

b. **Groundwater recharge:** Global warming due to temperature increase is important in directly controlling evapotranspiration and thus the portion of precipitation that may drain through the soil profile into aquifers. Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rains result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff and hence flooding. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundations during floods. Recharge is very important in regulating the volume of groundwater. Reduction in recharge will reduce the volume of renewable groundwater.

c. **Discharge:** Extreme climatic variation has a control over the hydrologic balance through reduction or increase in input and output components. Output components include evapotranspiration, runoff, groundwater discharge into streams and springs, and groundwater pumped from boreholes. The impact of climate change on groundwater discharge is related to lowering of the groundwater table, which is linked to base flow to rivers and springs. The impact can be most readily observed through changes to groundwater dependent ecosystems.

Another cause for decrease in discharge is the over-pumping of renewable groundwater in order to cope with the water stress as a result of climate change. Increased pumping lowers the water table, and thus reduces discharge to base flow. Due to the increase in temperature, evapotranspiration will increase, but there is no guarantee of an increase in precipitation. If precipitation decreases, runoff will decrease, and in addition groundwater recharge will decrease, thus leading to a decrease in groundwater base flow into streams and springs.

For evapotranspiration, direct climate change impacts include:

- Changes in groundwater use by vegetation due to increased temperature and CO_2 concentrations, and
- Changes in the availability of water to be evaporated or transpired, primarily due to changes in the precipitation regime. Increased duration and frequency of droughts is likely to result in greater soil moisture deficits. Where soil water becomes depleted, vegetation may increasingly depend on groundwater for survival (if groundwater occurs in proximity to the root zone). During dry periods this may lead to increased evapotranspiration from groundwater.

d. **Water quality:** In arid and semi-arid areas increased evapotranspiration may lead to soil salinization, which will affect the quality of soil moisture and associated groundwater system. In coastal aquifers, sea level rise and storm surges are likely to lead to sea-water intrusion and salinization of groundwater resources especially in areas with over-abstraction of groundwater resources. In areas where rainfall intensity is expected to increase, pollutants (pesticides, organic matter, heavy metals, and pit latrines) will be increasingly washed into water bodies, including the groundwater. In addition, recharge from polluted surface water bodies will further compromise groundwater quality.

5. Climate Change Scenario for Groundwater in India:

Impact of climate change on the groundwater regime is expected to be severe. The most optimistic assumption suggests that an average drop in groundwater level by one meter would increase India's total carbon emissions by over 1%, because the time of withdrawal of the same amount of water will increase fuel consumption. A more realistic assumption reflecting the area projected to be irrigated by groundwater, suggests that the increase in carbon emission could be 4.8% for each meter drop in groundwater levels (Mall et al., 2006).

Climate change is likely to affect groundwater due to changes in precipitation and evapotranspiration. Rising sea levels may lead to increased saline intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. Sea-level rise leads to intrusion of saline water into the fresh groundwater in coastal aquifers and thus adversely affects groundwater resources. For two small and flat coral islands at the coast of India, the thickness of freshwater lens was computed to decrease from 25 m to 10 m and from 36 m to 28 m, respectively, for a sea level rise of only 0.1 m (Mall et al., 2006).

It is projected that most irrigated areas in India would require more water around 2025 and global net irrigation requirements would increase relative to the situation without climate change by 3.5–5% by 2025 and 6–8% by 2075 (Kumar, 2012). In India, roughly 52% of irrigation consumption across the country is extracted from groundwater; therefore, it can be an alarming situation with decline in groundwater and increase in irrigation requirements due to climate change. Change in climate will affect the soil moisture, groundwater recharge and frequency of flood or drought episodes and finally groundwater level in different areas. In a number of studies, it is projected that increasing temperature and decline in rainfall may reduce net recharge and affect groundwater levels. By taking the impact of climate change on groundwater, to meet the demand of water, it requires to recharge the water for enhancing the level of groundwater in the aquifer.

6. Groundwater Recharge

Recharge is a sensitive function of the climate (precipitation and temperature regimes), local geology and soil, topography, vegetation, surface-water hydrology, coastal flooding, and land-use activities (such as urbanization, woodland establishment, crop rotation, and irrigation practices). Recharge will be affected under forecasted changes in precipitation patterns.

6.1 Groundwater Recharge Techniques:

The water may be recharged to sub surface by naturally or artificially. Due to urbanization and industrialization, the natural recharging land surface decreases, which results in the lowering of the groundwater level. Therefore to increase the groundwater level, there is a need to recharge the water artificially in small land surface by adopting suitable recharge techniques as per the location of site along with various sources of recharge to a groundwater system.

6.2 Artificial Recharge Techniques

Various techniques practiced for groundwater recharge are broadly categorized as follows (CGWB, 2007):

a. Direct surface techniques

- Flooding
- Stream augmentation
- Ditch and furrow system
- Over irrigation
- Runoff Conservation Structures
    - i) Bench Terracing
    - ii) Contour Bunds and Contour Trenches
    - iii) Gully Plugs, *Nalah* Bunds, Check Dams
    - iv) Percolation Ponds

b. Direct sub surface techniques

- Injection wells or recharge well
- Recharge pits and shafts
- Dug well recharge
- Bore hole flooding
- Natural openings, cavity fillings.

c. Indirect Techniques

- Induced recharge from surface water source.
- Aquifer modification.

d. Combination surface and sub-surface techniques

- Basin or percolation tanks with pit shaft or wells.

Besides above, in hard rock areas rock fracturing techniques including sectional blasting of boreholes has been practiced to inter-connect the fractures and increase recharge. Cement sealing of fractures, through specially constructed bore well has been utilized in Maharashtra to conserve sub-surface flow and augment bore well yield.

7. Impact of Climate Change on Groundwater Recharge

Climate and land cover largely determine precipitation and evapotranspiration, whereas the underlying soil and geology dictate whether a water surplus (precipitation minus evapotranspiration) can be transmitted and stored in the subsurface. Recharging of groundwater from precipitation, increase in irrigation to meet food security and groundwater pumping are interlinked through the impact from climate change. Climate change affects the sea level rise, changing precipitation patterns, and more frequent incidences of heat waves and other extreme weather events.

Precipitation: Precipitation is the primary climatic driver for groundwater recharge. Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rains result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff and hence flooding. In semi-arid and arid areas, however, increased rainfall variability may increase groundwater recharge, because only high-intensity rainfalls are able to infiltrate fast enough before evaporating, and alluvial aquifers are recharged mainly by inundation during floods. During high intensity rainfall events the infiltration capacity of soils may quickly be exceeded, resulting in increased runoff and stream flow with less rain infiltrating to groundwater. More frequent droughts or reduced rainfall during summer months can result in larger soil moisture deficits, and consequently recharge periods may be shortened.

Evaporation: Due to increase in global temperature, the evaporation from surface water and land surface increases. So the soil moisture and volume of surface water depleted that results the decrease in recharge water to aquifer.

Evapotranspiration: Global warming due to temperature increase is important in directly controlling evapotranspiration. Temperature and CO_2 concentrations are also important since they affect evapotranspiration and thus the portion of precipitation that may drain through the soil profile to aquifers. Due to increase in temperature in environment, the evapotranspiration gets increased, due to which soil moisture depleted by the vegetation. Also the surface water reduced as the source for recharge water decreases that results the less recharge to sub surface.

Detoriation of quality of recharge water: The quality of water detoriates by saline water intrusion to coastal aquifer. An indirect impact of climate change is salt-water intrusion into coastal aquifers due to sea level rise, which represents a major threat to coastal groundwater quality. It leads to a reduction of available fresh groundwater resources and contamination of the recharge water. Rising sea levels may lead to increased saline intrusion into coastal and island aquifers, while increased frequency and severity of floods may affect groundwater quality in alluvial aquifers. The recharge water also gets contaminated due to the release of waste water from industries and excessive utilization of chemical fertilizers in the agricultural lands.

macro pores gets blocked to infiltrate the water to sub surface. This decreases the recharge of water.

8. Adaptation to Climate Change for Groundwater Recharge:

Groundwater recharge areas may be managed to protect or enhance water resources and to maintain or improve water quality. It includes:

- Managed aquifer recharge (MAR): It involves building and modifying the landscape for enhancing the groundwater recharge. Aquifer conditions must be appropriate and suitable water sources (e.g. excess wet season surface water flows or treated waste water) are also required.
- Land use: The pasture land may be developed for artificial recharge along with suitable vegetation. Change land use or management to increase woody or other higher water use vegetation cover.
- Creation of recharge structures: Recharge structures must be created to store surface runoff water for a long time period which will enhance the volume of recharged water to subsurface.
- Managing saline water intrusion to the aquifer and land surface along coastal shores.
- Afforestation: Planting of new trees or conserving the existing forest for decrease of GHGs level from the atmosphere and balancing the precipitation and evapotranspiration.
    - Reuse of waste or storm water for recharge with adaptation of suitable treatment.
    - Agriculture: Utilization of chemical fertilizers hardens the soil that retards the infiltration. So chemical fertilizers may be replaced with organic bio fertilizers which help to increase the soil health as well as productivity.

Land: Due to climate change, natural hazards of land slide, earth quake and flood may occur which leads to deposition of sedimentation and also the hardening of the soil. As a result the fissures and

- Consumptive use of surface and groundwater: it may increase the demand of surface water with the sustainability utilization of groundwater.
- Establish deep rooted vegetation in areas subject to instability if seasonally water-logged.
- Construct surface or sub-surface drainage in discharges to intercept groundwater and drain to appropriate location (e.g. stream for fresh water, evaporation basin for saline water).
- Groundwater pumping to hold water table at a safe depth in the vicinity higher value agricultural or environmental assets and population centers.
- Establish high water use vegetation in groundwater discharge areas (that are adapted to soil and water salinity) to increase groundwater discharge.
- Establish salt tolerant vegetation (with commercial use in grazing or cropping) in salinized, shallow water table areas.
- Irrigation management by creating new water harvesting structures or renovating existing structures. This may enhance the utilization of surface water instead of groundwater. The water in these structures will be stagnated for a more recharging.
- Research and development to introduce farming and other management systems that reduce the vulnerability of natural and human systems to the consequences of increased recharge.
- Capacity building and training–To improve community and stakeholder understanding of climate risks and their capacity to participate in management responses and/or generate, modify or apply adaptations.

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Engineering Measures of Soil and Water Conservation for Development of Climate Resilient Agriculture

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The success of a nation and safety of livings lie in the efficient utilization of its natural resources basically soil and water resources. Ancient civilizations like Mohenjo-Daro and Harappa, Mesopotamia etc. have flourished due to efficient management of their natural resources. Decline of these ancient civilizations took place, when the misuse and improper exploitation of natural resources took place. Thus, conservation of natural resources more importantly soil and water is of paramount requirement for achieving sustenance of crop ecosystem.

Control measures

- Vegetative measures: Any live bund or vegetation established across the slope to reduce runoff and soil loss.
- Mechanical measures: any earthen, stone or masonry structure constructed across the slope as a preventive measure to arrest soil and water flows.

Principles for proper conservation and utilization of water:

- Increasing the time of concentration and thereby allowing more runoff water to be absorbed and held in the soil profile.
- Intercepting a long slope into several short ones so as to maintain a less than a critical velocity for the runoff water.
- Protecting against damage owing to excessive runoff.

Contour/ graded bunds

Contour bunds are preferred in soil slopes of between 1 and 8 % and are used in low rainfall areas (less than 800 mm), whereas graded bunds are preferred in soil slopes of between 1 and 8 % and are used in high rainfall areas (more than 800 mm).

Design of bunding

- Cost in Rs. /ha = Cross section of the bund (m^2) x length of bund / ha (m) x unit cost of Earth work (Rs. /m^2)
- Cross section of the bund = (Top width + bottom width)/ 2 x height
- Top width = 30 to 60 cm

Recommended top width and side slope for different soils

Type of soil	Top width (m)	Side slope (V:H)
Gravelly soil	0.30-0.45	1:1 – 1:0.75
Sandy loam or clay	0.30-0.45	1:1.5
Very shallow and shallow	0.45	1:1 – 1:1.3
Medium soils	0.50-0.60	1:1.5 – 1:2
Medium to deep soil	0.30-0.45	1:1.5 (downstream)
Black soil	0.30-0.45	1:5 (upstream)

- Height of the bund = $h_d = \sqrt{(R_e * V.I. /50)}$, where, h_d = Design height, m; R_e = Rainfall excess, cm received in 24 hours; V.I. = Vertical interval, m; V.I. = 0.3 {(S/3) +2} for areas with rainfall below 800 mm and V.I. = 0.3 {(S/4) +2} for areas with rainfall above 800 mm; and S = land slope in percent

Terracing

When the degree of slope is changed and brought to near zero by making fields of narrow width in a step like manner it is known as terracing. When the terrace is made table top, without any slope in any direction, then it is called as level terrace and is mainly used for paddy cultivation. When the terrace is made with mild inward slope to facilitate quick disposal of rainwater from the field, it is called as inward sloping terrace. When the terraces are made with a mild outward grade, it is called outward sloping terrace.

Stone wall

These are barrier of stones pitched as a short wall across the slope. These are used on any slope where stone and rocks are available in plenty and are used for slow runoff and control erosion in plantation areas.

Design of contour stone wall

V.I. = (S/10) +2 for the area receiving rainfall up to 1500 mm per annum

= (S/10) + 1.5 for the area receiving rainfall more than 1500 mm per annum

Cost of contour wall per ha (Rs.) = {Earth work in foundation (m^3) x Unit cost of earth work (Rs. /m^3)} + {length of wall per ha (m) x cross section of contour stonewall (m^2) x Unit cost of contour wall including the cost of stone and labour (Rs. /m^3)}.

Contour trenches

Trenching can be adopted up to 30 percent slope. When the trenches are given a grade are called graded trench. In medium rainfall areas with highly dissected topography, staggered trenches are usually adopted.

Design

Earth work per ha (m^2) = Cross section of the trench (m^2) x length of trenches per ha (m). The dimensions are: 20 to 30 cm wide, 20-30 cm deep, side slope vertical or 1:1 or 1:0.5 and length between 2 to 4 m.

Temporary gully control structures

The purpose of these structures are to collect sufficient soil and water to enable proper growth of vegetative cover and to check channel erosion until sufficient stabilizing vegetation can be established at the critical point. Gully control structures depend upon slope, rainfall (amount and distribution), soil type and depth, water holding capacity, location of impervious layer and agricultural practices. These engineering measures are adopted for land slopes greater than 2 %.

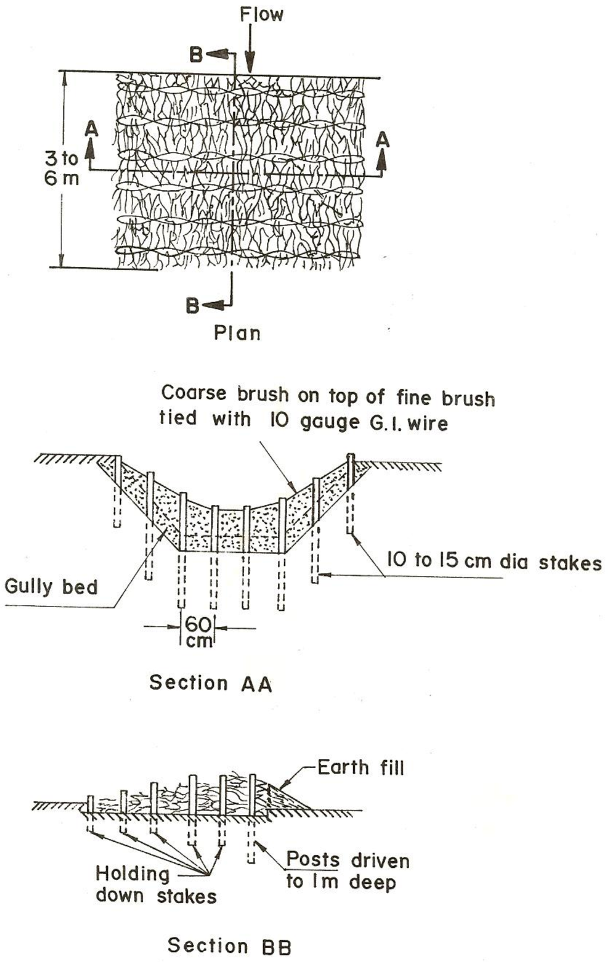
Principles

- Increasing the time of concentration and thereby allowing more runoff water to be absorbed and stored in the soil profile.
- Intercepting a long slope into several short ones, so as to maintain less than the critical velocity for the runoff water.
- Reducing the steepness of slope.
- Terracing / bunding are the most effective and widely used practice for controlling erosion on agricultural lands.

First order channels receiving small amount of runoff can be stabilized with temporary structures constructed of loose stone masonry, brush wood etc. Satisfactory results are obtained through series of check dams in the drainage channel. Their design life is usually 3-5 years. They are constructed across the gully to serve retard of the flow of water. Being cheap, requiring locally available material and involvement of less technical skill, these structures are widely accepted.

Brush wood dam

Brush wood dams are constructed in small gullies (1.2 to 2.1 m deep) where wooden posts are abundantly available. Such dams may be i) single post row brushwood check dams and ii) double post row brushwood check dams. The double post row brushwood check dam is used when the expected runoff is in larger quantities. The construction of the single row post dams begins by easing the side slope of a gully to 1:1 (Fig. 1). Then the wooden posts of about 10-15 cm diameter are driven into the bed and banks of the gully to a depth of about 0.75-0.9 m below the surface and about 0.6-0.9 m apart. However, for the construction of double row-post brush dams, the gully sides are sloped back and two rows of wooden posts are erected across the gully. The distance between the rows is not kept more than 0.9 m. the posts are driven at a distance of 0.5m apart in a row to go at least 0.9-1.2 m into the hard bed of the gully. The space between two rows of posts is filled with brush laid across the gully. This is compressed tightly and held in position with the wire. Litter is placed on the upstream side of the dam.



Plan

Section AA

Section BB

Fig. 1 Single post row check dam

Semi-permanent structures

These usually have a longer life of 10-15 years and normally do not require maintenance. The depth of the gully is usually less than 4 m.

Loose boulder dam

Construction of loose boulder dams begins by converting the slope of side wall of gully into 1:1 at purposed location of the dam (Fig. 2). A trench is then dug across floor of the gully and into the banks into which the large stones are placed to form toe of the structure. The dam is built upward from the toe, using flatter rocks on down stream face. Rocks smaller than 100 mm diameter should not be used as they will be quickly washed out. A second trench should be made to mark the down stream end of the apron and field with heavy rocks. A 100 mm thick layer of litter such as leaves, straw or fine twigs is laid on the floor of the apron and covered with a solid pavement of rock. A thick layer of litter is also placed on the up stream face of the dam.

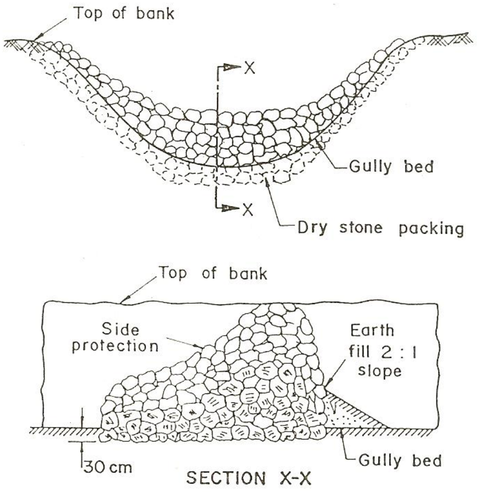


Fig. 2 Loose rock dam

Gabion structures

These are dams made of wire woven baskets filled with stones, constructed across steep sloped gullies to trap erosion debris during heavy rains. These are located in active gullies carrying large sediments and causing scouring and cutting of banks.

Permanent structures

Concrete and masonary structures are efficient supplemental control measures. Functions are to dispose off safely the peak rate of runoff for a given frequency from a higher elevation to a lower elevation and to dissipate the kinetic energy of discharge within the structure in a manner and degree that will protect both the structure and downstream channel from damage. When volume of runoff is very large and high degree of safety is required for stabilization of the gully, permanent structures are recommended. There are especially three types of gully control structures available namely Drop structure, Chute spillway and Drop inlet spillway.

Design of the drop spillway

In order to get a full proof gully control structure, hydrologic, hydraulic and structural design aspects of a structure are to be taken into account very judiciously.
Hydrologic design: The peak rate of runoff is calculated by using rainfall data for a 25 year frequency.

Hydraulic design: Design of weir length, depth of flow, and dimensions of the structure such that maximum energy dissipation occurs.

Components: Head wall and head wall extension, side walls, wing walls, apron, longitudinal sills, end sills and cut off walls (Fig. 3 and Fig. 4).

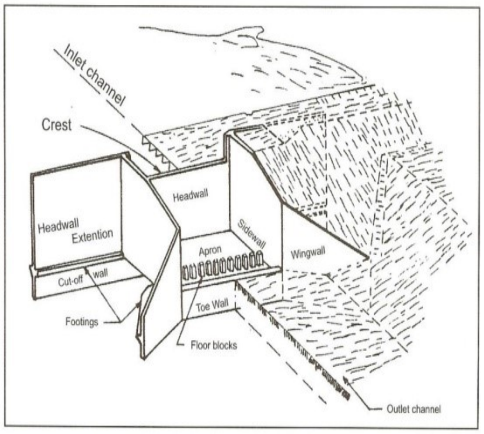


Fig. 3 Typical lay out of a drop spillway

*Functional Use:*Gully stabilization, Protection of fields, roads etc. from gullies, Grade control for stabilizing channels and waterways, Reservoir spillway and Control of irrigation water. The adaptability is efficient structure for controlling low heads, normally up to 3 m.

The crest length is calculated using the weir formula, $Q= CLH^{3/2}$, where Q= Peak discharge, cumec, L=length, m, H=height, m, C= Constant = 1.66 (Fig. 4)

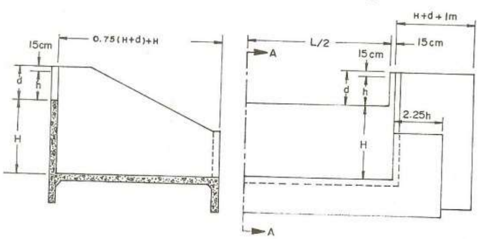


Fig. 4 Dimensions of the drop spillway

Structural Design: The stability of the structure is checked. The structural design depends upon the construction materials used. Reinforced concrete, brick and stone masonry are the material used for the construction of drop structure. Mostly headwall is important part of the structure, which designed in such a way that the failure due to overturning, sliding and piping are avoided.

Check against overturning

The weight of the structure is depended on the density of the material and the uplift pressure is depended upon the nature of substrata. The uplift pressure acts upwards from the centre of gravity of the uplift pressure diagram. The moments of all the forces are taken over the point 'O' (Fig. 6). The weight of the structure creates restoring moment (R.M.), whereas water and uplift pressures cause turning moments (T.M.). For the structure to be safe against overturning, the ratio ΣR.M./ ΣT.M.should not be less than 1.2. In case the condition is not satisfied base width of the head wall should be increased.

Check against sliding

The horizontal forces acting on the structure in the downstream direction may cause failure of the structure by sliding. The main force resisting the sliding action is the frictional resistance of the foundation. Therefore, the sum of the horizontal force ΣH, should be less than the forces resisting sliding. The forces resisting sliding consists of the friction forces f ΣV and the cohesion forces CA. Mathematically, it is expressed as;

$$\Sigma H < f\,\Sigma V + CA$$

Where, f = tanΘ, (Θ = angle of internal friction of the soil) and V = total vertical forces, C = cohesion resistance of foundation material and A = area of plane of sliding.

To provide a safety f ΣV + CA is made 1.5 times ΣH. If it does not happen, then the cutoff wall and toe wall are made deeper. The bottom of the structure is also made uneven so that the frictional resistance is increased.

Check against piping

Piping is the removal of material from the foundation by the action of seepage water. Removal of the soil material from below the structure will ultimately lead to the failure of the structure. Lane, an American scientist (USDA, 1957) found that the majority of the failure occurs due to piping along the line of creep (Fig. 5). For different soil types, Lane recommended values of safe weighted creep ratio (C_w). It is expressed as;

$$C_w = \frac{\sum L_H + 3\sum L_V}{3H}$$

where, C_w = weighted creep ratio, $\sum L_H$ = sum of all horizontal directions, $\sum L_V$ = sum of all vertical directions and H = difference between water surface of upstream and downstream side, i.e. head of water

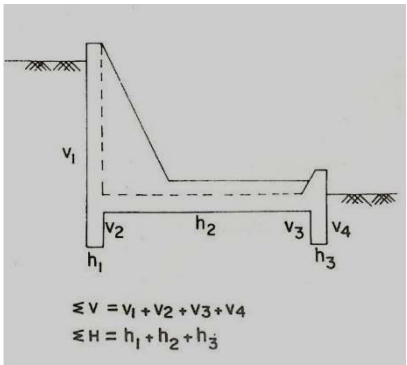


Fig. 5 Weighted creep ratio computation

The weighted creep ratio for a structure should be equal or higher than the recommended values. If the condition does not satisfy then the depths of cutoff or toe wall is to be increased.

Farm Ponds

Depending on the source of water and their location with respect to the land surface, farm ponds are grouped into four types. These are: (1) dugout ponds or excavated ponds, (2) surface ponds or watershed ponds, (3) spring fed ponds, and (4) off-stream storage ponds. Dugout ponds are excavated at the site and the soil obtained by excavation is formed as embankment around the pond. The pond could either be fed by surface runoff or ground water wherever aquifers are available. Surface water ponds are the most common type of farm ponds.

Components of a farm pond: The ponds consist of the storage area, earthen dam, mechanical spillway and an emergency spillway. The mechanical spillway is used for letting out the excess water from the pond and also as an outlet for taking out the water for irrigation. The emergency spillway is to safeguard the earthen dam from overtopping when there are inflows higher than the designed values.

Capacity of the pond:The capacity of the pond is determined from a contour survey of the site at which the pond is to be located. From the contour plan of the site, the capacity is calculated for different stages using the trapezoidal or Simpson's rule (Simpson's rule gives more accurate values than the trapezoidal formula). For this purpose, the area enclosed by each contour is measured using a planimeter. According to the trapezoidal rule, the volume V between two contours at the interval H and having areas A_1 and A_2 is given by:

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$$V = \frac{H}{2}(A_1 + A_2)$$

Using Simpson's rule the volume between any odd numbers of contours is given by:

$V = \frac{H}{3}$ [Twice the area of odd contours + 4 times area of even contours + area of the first and last contours]

This formula is also known as the prismoidal rule. For using this equation, the number of contours should be odd, i.e., the number of intervals considered should be even

Water scenarios of the Mahanadi River basin: a statistical look

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Introduction

In the context of the growing socio-economic conflicts over water sharing within India and also across, particularly with the neighboring countries, it is important to assess the changing scenarios of water dynamics at the basin scale. It is because river basins are climatologically homogeneous in contrast to the climatology of the administrative units. The peninsular river basins of India are vital for the socio-economic developments, as a major proportion of the Indian population depends on it for irrigation, electricity generation and drinking water requirements. More importantly, they sustain the coastal ecosystems of the country through sedimentation and aquifer replenishment. While unabated deforestation and land-use changes have continuously fluxed sediments, reducing the storage capacity of major reservoirs of the country and also caused siltation of riverbeds, recurrent failure of monsoon rainfall in recent years requires more stored water for agriculture and electricity generation. In contrast, extreme rainfall induced runoff more often leads to breach of bonds at weaker points, inducing flood scenario every year. Therefore, it is necessary to analyse the hydroclimatic variables in the river basis scale to guide the implementation of water-saving options. Salient features of the non-Gangetic (i.e., peninsular) major river basins are presented in Table 1.

We focus our analysis to the hydroclimatic variables of the Mahanadi River basin, which is one of the major east flowing river of peninsular India (Fig. 1). The Mahanadi River originates at an elevation of about 442 m above MSL (near Pharsiya village in Raipur district of Chattisgarh) and drains an area of 1,41,589 km^2 between 80° 26′ E to 86° 50′ E longitude and 19° 20′ N to 23° 35′N latitude. The Mahanadi basin lies in the states of Chhattisgarh (75,136 km²), Orissa (65,580 km²), Bihar (635 km²) and Maharashtra (238 km²). The total length of the river from its origin to confluence to the Bay of Bengal is about 851 km. The main tributaries (a total of 12) such as the Seonth, the Jonk, the Hasdeo, the Mand, the Ib join the upstream of Hirakud reservoir while only the Ong and the Tel join the downstream of it. Because there is no major control structure upstream of the Hirakud reservoir, the streamflow at most of the gauging stations can be considered as unregulated. The basin is characterized by a tropical monsoon (June to September) climate with an average rainfall of 1360 mm; more than 80% of the annual runoff occurs during the monsoon season. The average annual flow is 1895 m^{3}s^{-1}, with a maximum of 6352 m^{3}s^{-1} during the monsoon season and a minimum of 759 m^{3}s^{-1} during the dry summer pre-monsoon season (January to May). Before discharging into the Bay of Bengal, the Mahanadi River segregate into several distributaries and channels, thus creating a coastal waterlogged ecosystem. The synoptic disturbances over the Bay of Bengal contribute bulk of the rainfall, and generates flash flood in the densely-populated (400-450 people per km^2) and agriculturally-intensive coastal delta. Geology of the upstream region is mostly characterized by the pre-Cambrians hard rock of Eastern Ghats, while the downstream is dominated by the recent deltaic alluvium of the river. Temperatures show a large variation with the winter (December to January) minimum temperature ranging from 4^0 C to 12^0 C, and the hottest month of May experiences a maximum temperature ranging from 420 C to 450 C.

The Mahanadi River basin is of particular importance to study the hydroclimatic changes because of its location adjacent to the northwest Bay of Bengal, which makes the basin vulnerable to recurrent flash floods, droughts and cyclones (Swiss, 2002; Dilley et al., 2005). In order to protect the downstream coastal plains from the flash floods, the multipurpose Hirakud earthen dam was constructed in 1957 with the water storage capacity of 5.82 km3. Moreover, the reservoir irrigates an area of 1554 km2, and has an installed capacity of power generation of 347 MW. Owing to the hydroclimatic sensitivity of the Mahanadi River basin, several studies have investigated the impacts of climate change and variability on the hydrology mostly using the simulation outputs of General Circulation Model (GCM). Majumdar and Ghosh (2008) predicted decreases in extreme and total monsoon streamflow, which could be due to the effect of high surface warming. The operation of the Hirakud reservoir is likely to pose a major challenge as the predicted decreasing inflow to the reservoir under climate change scenario may reduce the electricity generation and irrigation water availability (Raje and Mujumdar, 2010). Although the annual rainfall did not show any pattern, a gradual decrease in streamflow was observed at two gauging stations representing the upper and lower catchment (Rao 1993). However, Gosain et al. (2006) predicted a comparatively higher level of rainfall and water yield for the basin.

Rainfall variability of the Mahanadi River basin

Figure 2 reveals that the pre-monsoon (Jan-May) rainfall shows an increasing pattern during 1971-2006, although it was experiencing a random fluctuation during the pre-1970s. It should be noted that a noticeable transition (shift) in atmospheric variables has occurred since the early 1970s, which correspond to the most warming period of the last century (Houghton et al., 2001). It is worth pointing that the active monsoon month of July has registered a decrease in rainfall during the global warming era (1971 onwards) in conjunction with high variability. Moreover, the month of August also exhibits high interannual variability. Since rainfall in the active monsoon months of July and August modulates the overall hydrology of the basin, and also irrigates the predominant rice crop during its critical phase of growth, the observed tendency could seriously impact the agriculture and coastal ecosystem. The monsoon rainfall also indicates that most of the drought years of the last century have occurred from 1971 onwards, in addition to a general decrease since the 1940s. The annual rainfall indicates an increasing trend, although rainfall has decreased during the active monsoon months of July and August. Therefore, it is misleading to consider the annual rainfall for the success of the crop. Recent increases in the post-monsoon (Fig. 2) rainfall appear to have contributed to the annual increases.

Streamflow variability of the Mahanadi River basin

The monthly runoff (106 m3) data of 19 gauging stations adequately representing the sub-basins of the Mahanadi River basin with a command area of 1,42,589 km2 during the period 1972-2004 was analyzed to investigate the runoff variability and trends of the basin. Table 2 shows the descriptive statistics of the annual runoff (106 m3) of different stations of the Mahanadi River basin. The difference between the minimum and maximum annual runoff (i.e., range) is very high for most of the stations indicating the extreme nature of flow regimes. The standard deviations of the annual runoff are around half of the average. The Yule-Kendall skewness (Sk), a resistance measure of the shape of the distribution was calculated using the 25th percentile (Q1), 50th percentile(Q2), and 75th percentile (Q3) as (Q1 -2Q2+Q3)(Q3 -Q1)-1. Higher cases of positive Skindicate a tendency for lower runoff years to out number the higher runoff years, but a few unusually high flow events have influenced the shape and consequently the average values. The minimum annual runoff is around half the Q1 and the maximum annual runoff is around half the Q3, which are also the indicator of the low and high anomalous years.

In order to see the departures of the runoff, the standardized departure index was computed by subtracting the mean from the flow values for each station and then dividing by the respective standard deviation. The standardized departures then are averaged over the stations for the pre-monsoon runoff (February, March, April, May), monsoon runoff (June, July, August, September), post-monsoon runoff (October, November, December, January), and annual runoff, respectively (Fig.3). The pre-monsoon runoff (Fig. 3a) shows more numbers of positive departures indicating high runoff in recent years. The monsoon runoff, however, show a decrease in flow in recent years as obvious from the higher number of negative standardized departures.

Since most of the anomalous weather events are observed during the 1990s (Fig. 3), the runoff time series has been subdivided into two sub-series i.e., pre 1990s and post 1990s (1990-2004). The average annual runoff during the period 1990-2004 exhibits an increased runoff in comparison to the previous sub-series for all the stations. However, this increased runoff is also associated with an increase in the variability (standard deviation), which indicates that the wet period is more prone to uncertainty in comparison to the corresponding dry period. The minimum and maximum annual rainfall have moved towards opposite direction in the recent period in comparison to the earlier period suggesting that both drought and floods have become more severe. The t-test, to test the significance of the mean runoff difference during the sub-periods shows that the runoff of the recent sub-period is not significantly higher in comparison to the previous sub-period. This means that the shift in the mean runoff has not taken place. The runoff of the monsoon season during June-September also experiences a non-significant increase in runoff in the recent period. Higher cases of positive Skindicate a few unusually high flow events have influenced the shape.

Patterns in extreme rainfall indices

The interpolated trend magnitudes through the inverse distance weighting (IDW) method and the location of the significant (α=0.1) trends (Fig. 4) indicates that the wet day (rainfall ≥1mm) frequency has increased in the middle portion of the basin, which is the erosional plain of the central table land traversed by the river and its tributaries.

The rainfall intensity (SDII, Simple daily intensity index i.e. the average precipitation on wet days) has increased over most of the coastal basin, but not the wet days. The moderate rainfall (RM) is characterised by an increasing tendency in the northeastern and western parts in contrast to the decreases over the coastal and southern Eastern Ghats of the basin. It should be noted that the 1-day maximum rainfall (RX1D) has increased in large parts of the basin except for the south eastern sector. For details of other extreme rainfall indices and their responses, Panda et al. (2013) may be referred.

The most notable feature of the changes in rainfall pattern is the vulnerability of coastal basin to the extreme rainfall events. The Hirakud dam, the only structure that safeguards the densely populated (more than 400 people per km2) downstream coastal plain, has been under risk due to the recent climate evolution in the form of the climatic extremes. The storage capacity of the dam has reduced by 1953.7 mcm (i.e. 24% of total) due to siltation since the impoundment of the reservoir in 1957 to 1989. This situation decreases substantially the flood controlling capacity of the reservoir. The contradictory rainfall patterns in different months of the monsoon season as illustrated in Figure 2 compel the reservoir managers to store water based on the flow curve to meet the requirements of the existing hydropower plant, industrial and irrigation facilities. But, heavy rainfall induced huge inflow necessitates the dam authorities to open gates abruptly in order to safeguard the Hirakud dam, thereby causing flash floods in the coastal basin within a few hours of release. This extreme rainfall induced flash floods in 2003, 2008 and 2011 has led to heavy economic and environmental losses in the coastal basin, with around 6 million populations being affected by each of the events primarily due to the lack of contingency planning and preparedness.

Conclusion

The hydroclimatic variables of the Mahanadi River basin has reflected several interesting features of changes at the sub-seasonal and spatial scales, consistent with the hypothesis of the global climatic changes. It should be noted that analysis of the annual and seasonal (monsoon) for planning and management in particular provides little information about the contrasting characteristics at the sub-seasonal scale. The vulnerability of coastal basin to the extreme rainfall events is evident from the extreme indices. While the southern and southern parts are prone to water deficits.

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Table 1. General information of the tropical river basins of India

River basin	Drainage area (105 km2)	Length (km)	Annual flow (km3)	Annual rainfall (mm)	Population density per km2	Storage capacity (km3)
Godavari	3.13	1465	110.5	1085	217	31.33
Krishna	2.59	1400	69.8	800	295	49.55
Mahanadi	1.42	851	66.9	1360	202	14.21
Brahmani	0.39	799	28.5	1200	204	5.25
Cauvery	0.87	800	21.4	800	389	8.87
Normada	0.99	1312	45.64	1180	187	23.6
Tapi	0.65	724	14.9	1000	245	10.26
Mahi	0.35	583	11.0	1000	324	4.98

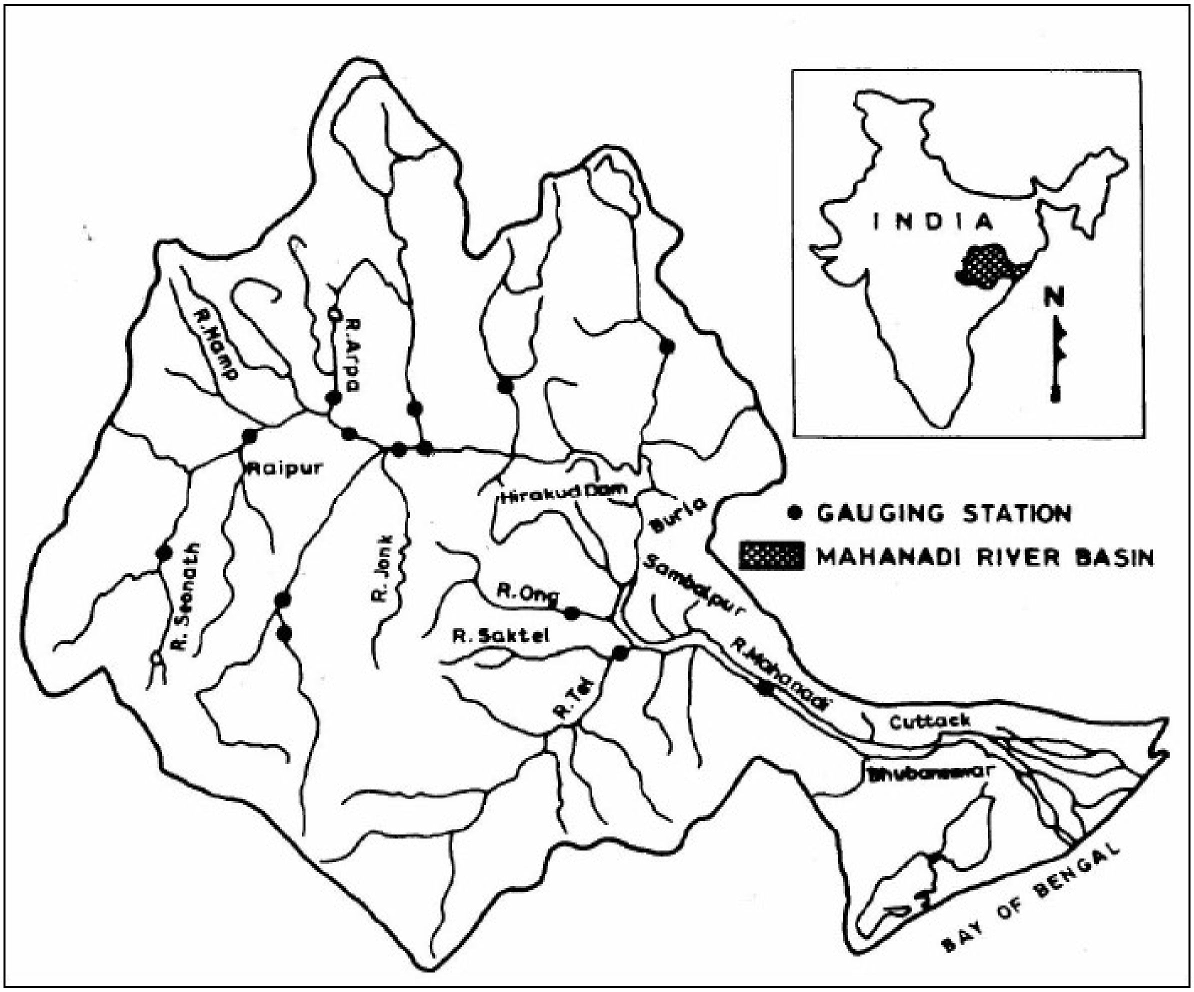


Figure 1. Geographical map of the Mahanadi River basin of India (inset).

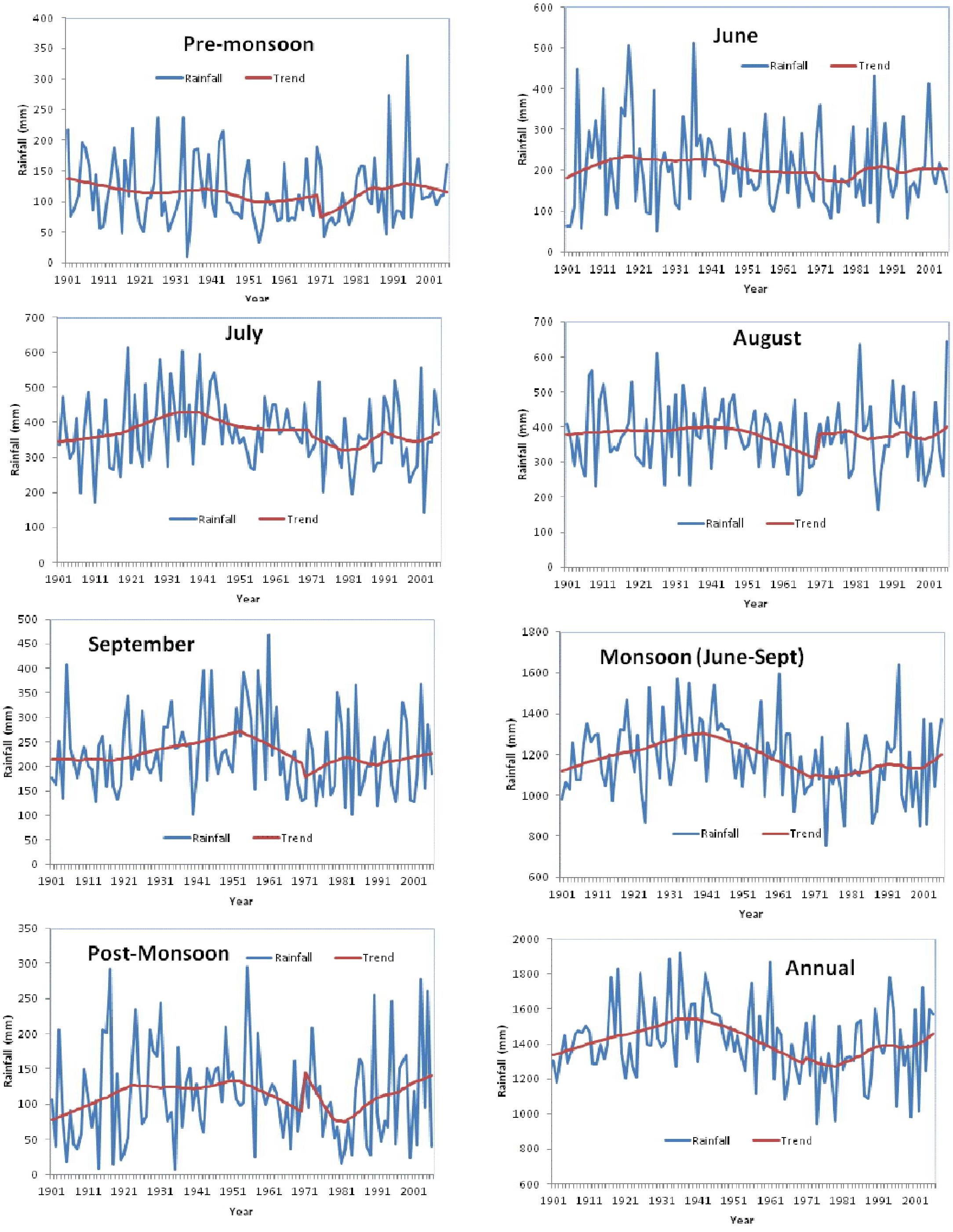


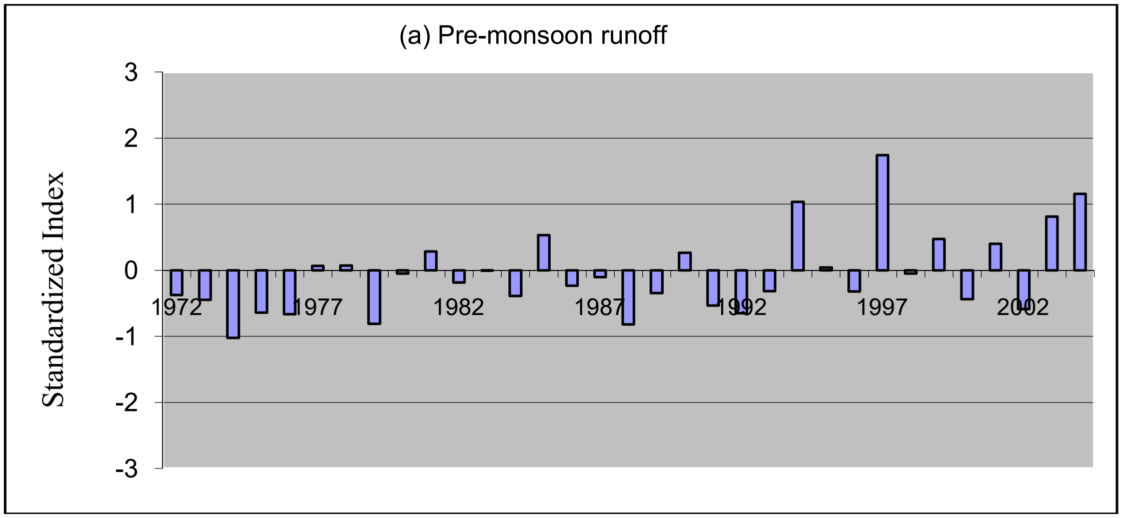
Figure 2.The temporal evolutions of the seasonal and subseasonal rainfall over the Mahanadi River basin during 1901-2006.

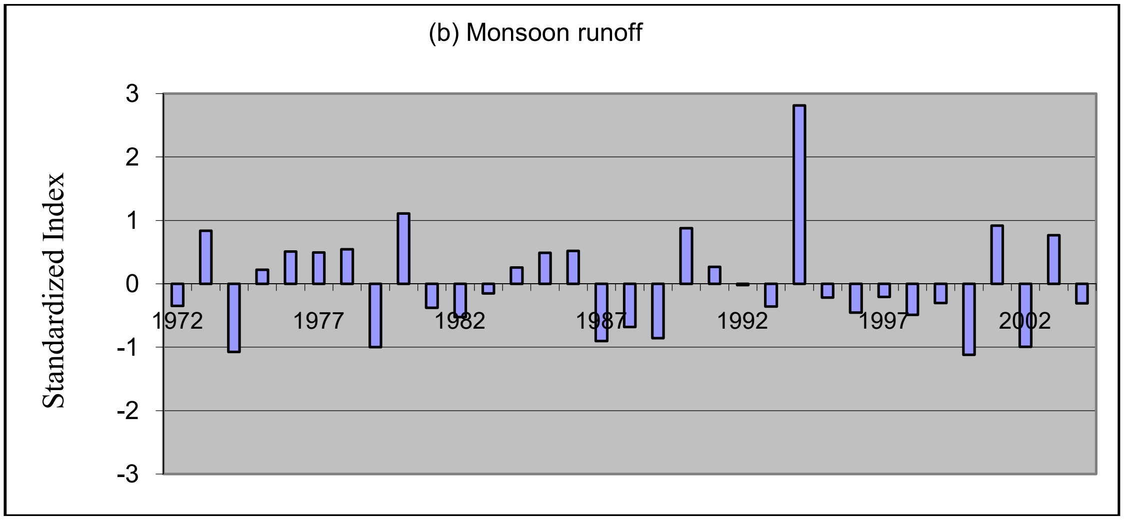
Table 2. Descriptive statistics of the annual runoff (106 m3) of different stations of the Mahanadi River basin

Station	Period	Mean	S.D.	Min	Q1	Median	Q3	Max	Sk
Baminidhi	1972-2004	4706	2214	1268	3089	4267	5343	11843	-0.05
Baronda	1978-2004	1256	861	161	529	1179	1980	2985	0.10
Ghatora	1980-2004	990	490	339	571	1027	1155	2730	-0.56

Jondhra	1980-2004	8433	4253	2195	5954	7585	9778	21092	0.15
Kotni	1979-2004	1862	1285	364	866	1536	2508	6265	0.18
Kurubhata	1978-2004	2481	853	878	1873	2503	2852	5114	-0.29
Rajim	1972-2004	2822	2002	428	1386	2116	4201	6828	0.48
Salebhata	1972-2004	1905	1127	232	1196	1549	2647	4946	0.51
Sundergarh	1978-2004	3315	1205	921	2274	3116	4095	6683	0.08
Andhiarkore	1978-2004	350	172	108	239	303	445	821	0.37
Basantpur	1972-2004	20759	9541	7564	14175	19072	24996	51360	0.09
Kantamal	1972-2004	10004	5470	3356	5996	8562	13067	22637	0.27
Kesinga	1979-2004	6229	3674	2231	3375	5088	8017	15585	0.26
Mahendragarh	1990-2004	381	127	216	288	397	464	599	-0.24
Pathardhi	1989-2004	1004	529	314	661	880	1244	2170	0.25
Rampur	1972-2004	1352	924	130	777	1148	1657	4041	0.16
Seorinarayan	1986-2004	15984	9423	4402	7964	14512	20125	42883	-0.08
Simga	1972-2004	4850	2693	1195	2698	4615	6542	13301	0.00
Tikarpara	1972-2004	47623	21392	18655	34358	48147	59497	124765	-0.10

Q1: 25th percentile;Q2: 50th percentile (median);Q3: 75th percentile;Sk: Yule-Kendall skewness


(a) Pre-monsoon runoff


(b) Monsoon runoff

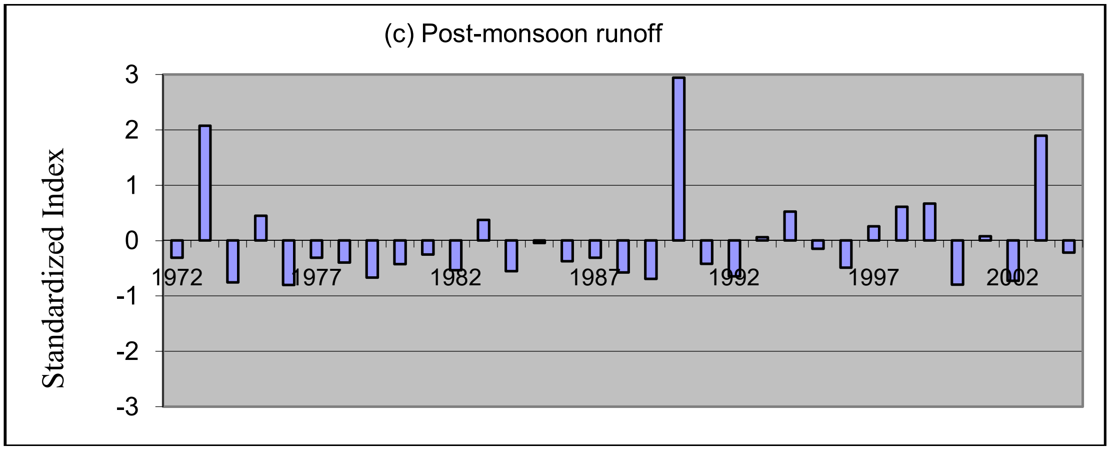


Figure 3. Mean standardized departures of (a) pre-monsoon runoff, (b) monsoon runoff, and (c) post-monsoon runoff in the Mahanadi River basin.

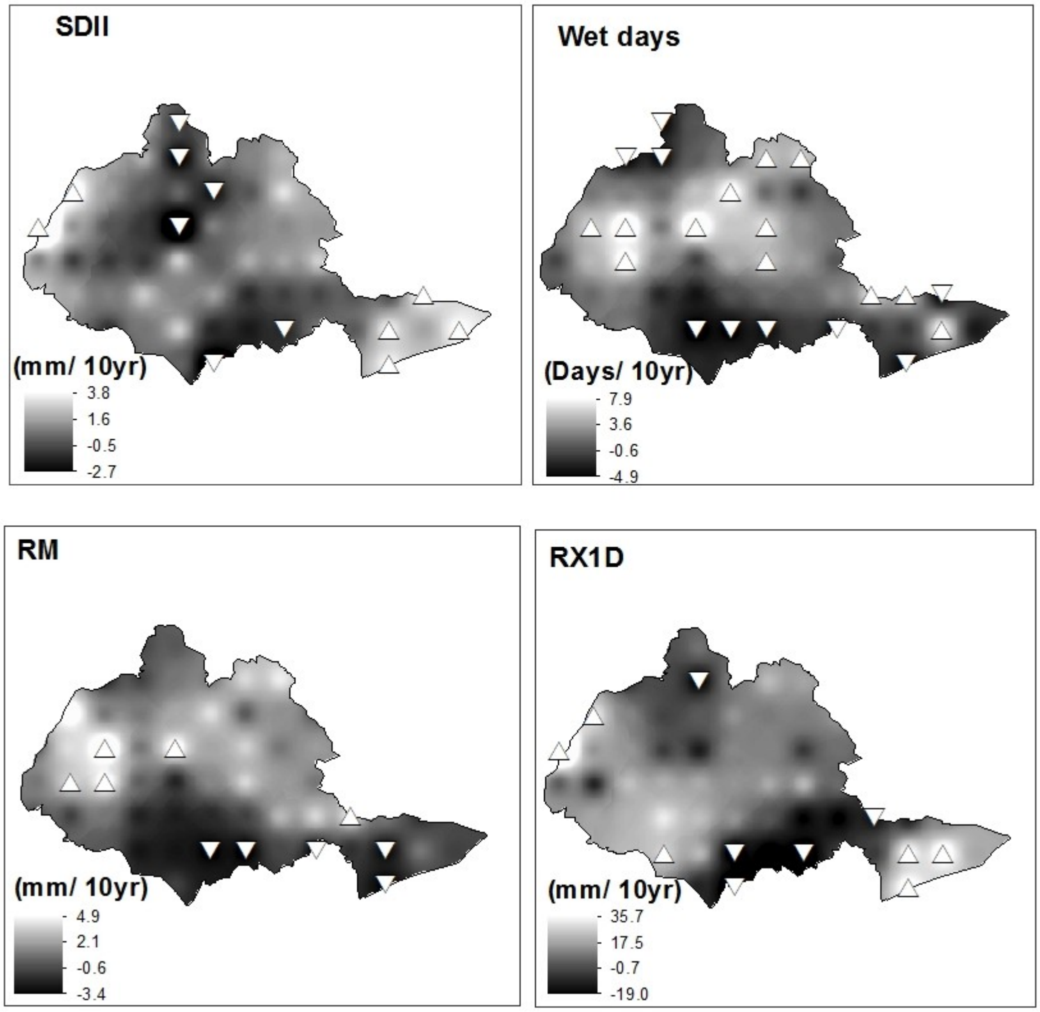


Figure 4.The spatial pattern of the trend magnitude in extreme rainfall indices. The significant ($\alpha=0.1$) increasing (decreasing) trends are denoted by the upward (downward) pointed triangles.

Extreme Weather events and Climate change related to Water Management

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Introduction

Odisha is located in the Eastern coast roughly between Lat. $17^{0}49^{'}$ N and $22^{0}36^{'}$ N and Long. $81^{0}36^{'}$ E and $87^{0}18^{'}$ E and it is also one of the most natural disastrous prone states in India as well as in the world. In view of its tropical location and the long coast line, Odisha is vulnerable to major natural hazards like Cyclones, floods, heat waves, cold waves and droughts. All aspects of life is affected by weather and climate. Besides these, some parts of Odisha also fall under seismic zone III. Actions in the field of agriculture, aviation, energy, industry, ecology and urban designs require climatological information for planning and successful execution of the projects with a view to derive maximum advantage out of climatological information. The importance of meteorology and climatology for economic and social benefits of the society is being realized increasingly all over the world. Apart from general information required by common man, hundreds of enquires received by the India Meteorological Department from the general public, decision makers and the electronic and print media are about current weather as well as extreme weather conditions.

Different types of weather are experienced in four seasons over Odisha. Effect of western disturbance with cold wave and fog in winter season, rise in day maximum temperature with heat wave, thundersquall activities accompanied with hailstorm and tropical cyclone in Hot weather or pre-monsoon season, heavy rainfall accompanied with flood in rivers in south-west monsoon season and prominent tropical disturbances in post-monsoon season are different meteorological features in different seasons.

In view of different hazardous weather in different seasons, India Meteorological Department has developed methods of weather forecasting to meet the requirement of general public for early warning system for each of these meteorological hazards.

Weather Forecasting Methods

There are different types of weather forecasting methods especially Long range forecast for a season only, short range forecast valid for 48 hours, medium range forecast valid from 3 to 7 days and now casting for a few hours. Long range forecast in India by IMD is only for South-west monsoon season.Due to increase in extreme events, now time has come to predict the extreme weather just before 3 hours of it occurrence for saving the life of human beings and animals. Keeping in view that, IMD has developed now casting system in India including Odisha. To achieve the goal, 55 Doppler Weather Radar (DWR) networks are being established in India and four such systems at Balasore, Gopalpur, Sambalpur and Paradeep will be installed in Odisha during next 2 to 3 years. Moreover, IMD has installed 37 Automatic Weather Stations and 177 Automatic Raingauge Stations spreading over all the districts of Odisha which will provide hourly meteorological parameters in connection with forecasting of flash flood and extreme weather events.

In India, SW monsoon is the principal rainy season in India except in Jammu and Kashmir and Tamil Nadu. It comprises of 4 months from June to September. It receives about 80% of its total annual rainfall during the summer monsoon season, from June to September. The Long period average rainfall over the country as a whole for the period 1941-1990 is 89 cm. The All India normal monthly rainfall for these months is 16.3, 29.3, 26.2 and 17.5 cm, which comprises about 18.2, 32.9, 29.3 and 19.6 % of seasonal rainfall, respectively .During the season rainfall varies from day to day, from one spell to another and from month to month. Also there were several years when monsoon rainfall was low causing droughts as well as years when it was excessive causing several floods in the country. Two main approaches are used for the long range forecasting (LRF) of the ISMR. The first approach is based on the empirical statistical method and the second approach towards long range forecasting is based on the dynamical method, which uses General Circulation Models (GCM) of the atmosphere and oceans to simulate the summer monsoon circulation and associated rainfall. The GCM simulation is primarily driven by the sea surface temperature (boundary) conditions provided in the models. In 2003, a new strategy for issuing LRF for the monsoon rainfall was adopted. Accordingly the long range forecasts are issued in two stages. The first stage forecast issued in April consisted of forecast for seasonal rainfall over the country as a whole and the second stage forecasts issued in the end of June consisted of update for April forecast along with seasonal rainfall forecast for the geographical sub regions of the country and July rainfall forecast for the country as a whole. During 2003 to 2006, the operational first and update long range forecasts for the seasonal rainfall over the country as a whole was issued using the 8 and 10 parameter models based on power regression and probabilistic discriminant analysis techniques. The operational forecast for July rainfall over the country as a whole was also started to issue along with the update forecast from 2003 onwards. In 2004, the country was reclassified into 4 sub geographical regions. In 2007, a new statistical forecasting system based on the ensemble technique was introduced for the seasonal rainfall forecasting over the country as a whole. In 2009, forecast for August rainfall over country as a whole was started issuing along with other second stage forecasts issued in June. From 2010, operational long range forecast for the rainfall during the second half of the monsoon season (August-September) and that during the September over the country as a whole were also started. The forecasts issued in the second stage are (i) update for the forecasts for the Southwest Monsoon season rainfall over the country as a whole, (ii) forecasts for the monthly rainfall for July & August over the country as a whole, and (iii) forecast for the season rainfall for the 4 broad geographical regions of India (NW India, NE India, Central India and south peninsula.

For the benefit of farmers, medium range forecast is implemented by IMD which provide forecast of meteorological parameters for next five days for all the districts of India and this forecast combined with agricultural advisories known as Agrometeorological bulletin issued twice in a week on every Tuesday and Friday. In addition to these, city forecast for about 200 cities and tourism forecast for about 100 cities containing main meteorological parameters are issued everyday for next five days. But in Odisha, 5-days forecast of 11 cities and tourism forecast of 2 tourist spots are uploaded in IMD website.In view of frequent adverse weather due to global warming. It is also planned to extend five days forecast upto seven days and also increase few more cities and tourist spots in India.

In practice, IMD issues short range forecast for meteorological sub-divisions of the country for next 24 hours with warning for next 48 hours but now it has been changed for next three days with outlook for subsequent two days. It will help the common people to plan their day to day programme of social gathering, religious congregation, journey within the locality or outside the region etc.

Weather hazards and its warning system over Odisha

Among all meteorological hazards, tropical cyclone, flood and heat wave cause more devastation and casualty as compared to other weather events. Let us study its meteorological factors with its warning system of IMD in Odisha.

Due to global warming, there is decline in monsoon rain in Odisha especially for last 4 to 5 years and rainfall is also not uniform in the whole monsoon season. So, both drought and flood are experienced in the monsoon season as in case of 2010 and 2011 monsoon rain. Untimely excess rain is caused due to climate change and which is responsible for the damage of crops in Odisha.

India with its long coastline is vulnerable to the impacts of tropical cyclones that develop in North Indian Ocean (Bay of Bengal and the Arabian Sea). These systems are classified as depressions, deep depressions, cyclonic storms, severe cyclonic storms, very severe cyclonic storms and super cyclonic storm.

A cyclonic storm is a rotational low pressure system which forms over warm ocean surface in tropics and is a vast violent whirl 150 to 800 Km across 10 to 17 Km high, spiralling around a centre in anticlockwise direction in Northern Hemisphere and progressing along the surface of the sea at a rate of 300 to 500 Km a day. In a low pressure system when the central pressure falls by 5 to 6 hPa from the surrounding and wind speed reaches 34 Knots we call it a cyclonic storm. Tropical cyclones are macro scale systems with meso-scale impact. Since the extent of the core of the cyclone hardly exceeds 100Km, the major impacts are generally localized.

In the tropics, weak pressure waves move from east to west. These are called easterly waves. Under favourable conditions a low pressure area forms over the area of an easterly trough. This gives rise to low level convergence. If the sea is warm i.e. sea surface temperature is $\geq 27^0$C and there is sufficient upper level divergence, the pressure gradually falls. Low level convergence coupled with upper level divergence gives rise to vertical motion taking moist air upwards. These moistures condense at higher levels (middle troposphere) and give out latent heat of condensation. Due to release of heat of condensation, the area warms up resulting into further fall in pressure. This process continues and a low pressure system gradually intensifies into a cyclonic storm. The following conditions are generally required to be satisfied for a cyclonic storm to intensify further in the northern hemisphere:

(a) North of latitude 5^0N
(b) Small vertical wind shear
(c) Pressure convergence upto 400hpa level
(d) Large area of 10 days mean sea surface temperature is greater than 27^0c
(e) Presence of upper level divergence

The storm surges, strong winds and flooding due to torrential rains associated with cyclones are the major causes of destruction and damage. Cyclone Warning Centre (CWC) Bhubaneswar is responsible for the Odisha Coast in the East Coast of Bay of Bengal. People of Odisha especially coastal districts of Jagatsinghpur and Kendrapara have not yet forgotten the tragedy of 1999 super cyclone which took the life of about 10000 people and 3,70,297 cattleheads besides damaging crops about 16,17,000 hectares.

The following bulletins and warnings are issued by Cyclone Warning Centres (CWC):

1. Port Warnings for ships in the coastal waters to Paradeep, Gopalpur, Chandbali and Puri ports.
2. Fisheries Warnings are issued to fishermen for not to venture into open seas.
3. Four Stage Warnings are also issued to State Govt. officials.
4. Bulletins for broadcast through AIRs, TVs for general public.
5. Press Bulletins are also issued to local and national newspapers.

Cyclone warnings are communicated to Govt. officials and other parties including both print as well as electronic media by Fax, e-mails, SMS, high speed data terminal(HSDT) and Telephones. Police wireless are also used as and when required.

The general public, the coastal residents and fishermen are warned through State Govt. officials and broadcast of warnings through AIRs, CWDS and telecast programmes in national and regional hook up. The cyclone warnings are issued to State Govt. officials in four stages.

(a) **Pre-Cyclone Watch-**

This first warning is issued by Director General of Meteorology himself to Cabinet Secretary and other senior officers of Govt. of India including the chief Secretaries of concerned maritime states about development of Cyclonic disturbance, its likely intensification and coastal belt likely to experience adverse weather.

(b) **Cyclone Alert-**

This 2nd stage warning is issued at least 48 hours in advance about expected commencement of adverse weather over the coastal areas. It is issued by ACWCs/ CWCs.It contains about the location, direction of movement, intensification, coastal districts likely to experience adverse weather and advice to fishermen.

(c)**Cyclone Warning-**

This 3rd stage warning is issued at least 24 hours in advance. Likely time and point of land fall, impact of strong winds and heavy rain and advice to fishermen and general public are also issued. These warnings are issued by ACWCs and CWCs.

Post Landfall Outlook-

The 4th stage warning is issued at least 12 hours in advance of expected time of landfall by the concerned ACWC. It is given likely direction of movement of the cyclone after its landfall and adverse weather likely to be experienced in the areas away from the coast.

In recent years, the forecasting techniques and cyclone warning services are improved a lot and there has been considerable reduction of the loss of human lives and damage to properties caused by cyclones. One of its examples of recent events of very severe cyclonic storm Phalin which crossed Odisha coast in the night of 12th October,2013.

New scheme as Cyclone Warning Dissemination System (CWDS) using INSAT is also in use for dissemination of cyclone warnings. 35 CWDS receivers have been installed in the cyclone prone areas in coastal districts of Odisha. The cyclone warning messages are broadcast in local languages of the area likely to be affected. Messages for Odisha are broadcast from ACWC Kolkata in odiya language.

Odisha is a flood prone state and predominantly a flat deltaic and river-irrigated land. The whole Odisha is criss-crossed by seven rivers the Mahanadi, the Subarnarekha, the Budhabalang, the Brahmani, the Baitarani, the Bansadhara and the Rusikulya with their tributaries which ripped the state. Rainfall is abundant from June to September and occasionally tropical cyclone strikes the coastal area, bringing the torrential rainfall. Odisha faces flood every year during monsoon. Unprecedented floods in 2008 and 2011 in Mahanadi will tell about the devastating phenomena in Odisha. While normal monsoon floods are beneficial for the state, severe one damages agriculture, infrastructure and also human lives. The short range forecasts are useful in deciding an early release of water in a phased and regulated manner so as to avoid sudden floods and consequent misery. There should be regular dialogue between the reservoir manager on the one hand and the operational meteorologists and hydrologists on the other, before appropriate management decisions are taken.

Rainfall during southwest monsoon is caused due to mainly:

(1) Axis of monsoon-trough lies on normal position and also south of normal position.
(2) Low pressure areas and monsoon depressions form in the Bay of Bengal
(3) Strong winds of 40 knots with horizontal and vertical wind shear
(4) Lows or cyclonic circulations are embedded on the monsoon trough
(5) Strong pressure gradient
(6) The axis of monsoon trough tilts southward with height

Flood Meteorological Offices are set up at ten locations viz. Agra, Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna. During the flood season, FMOs provide meteorological support to the Central Flood Forecasting divisions (CFFD) of Central Water Commission (CWC) by issuing hydromet bulletins. FMOs keep round the clock watch during the flood alert situations. During Flood Alert for specified catchment and also during the adverse weather situations where there is expectations of significant rainfall leading to floods in a particular catchments, Quantitative Precipitation forecast is issued by FMOs and it is issued for the following ranges: 01 – 10 mm , 11-25 mm , 26- 50 mm , 51- 100 mm and more than 100 mm.

The following informations are prepared by FMOs during flood season:

1. Catchment's rainfall summary
2. Chief synoptic situation
3. Forecast valid for next 24 hours
4. Heavy rainfall warning over catchment areas
5. QPF for next 24 hours for different catchments
6. Outlook for subsequent 48 hours

The most common rain giving systems over the state during post monsoon season are the depression and cyclonic storm originating in the Bay of Bengal. The storms and depressions cause heavy to very heavy rainfall and contribute substantially to the season's total rainfall.

During winter, the state receives about 4cm. of rainfall. This rainfall though small in amount, is of utmost significance for agriculture. This rainfall generally occurs in association with induced low pressure areas over the surface due to western disturbances move from west to east, across the northern parts of the country.

During Pre-monsoon period, the rainfall occurs due to low pressure, depressions and cyclonic storms originating from Bay of Bengal. Thunderstorm accompanied with squall due to strong convection current also cause heavy rainfall.

The weather forecasts alongwith heavy rainfall warnings if any are supplied to A.I.R. stations of the state, Doordarshan Kendra, News Papers, Special Relief Commissioner of Orissa State, Orissa State Disaster Management System, The Superintending Engineer, Hirakud Dam Circle, Burla, The EE, Mahanadi Division, Burla and also to the Sub-Divisional Officer, Hydrology, Burla.

The incoming solar radiation absorbed at the earth's surface is converted into heat and warms the ground. The warm ground radiates as heat back to space which is called as long wave or infra-red radiation. The narrow zone of air in contact with the warm ground is heated subsequently by conduction. As warm air is less dense than the cooler air above, the former rises through the latter by convection. The rising of surface temperature as a result of counter radiation from the atmosphere is known as the greenhouse effect. Carbon dioxide, water vapour etc. play the important role for rise of surface temperature. Temperature of the air at a place mainly depends on time (relation to sun), altitude, latitude, proximity to sea, temperature of the sea, persistent wind flow pattern etc.

Altitude plays a dominant control. It has been found that in the lowest kilometer above sea level, temperature falls at the rate of 6^0C per kilometer of station altitude.

Latitude determines the annual distribution of insolation by controlling the angle at which the sun's rays strike the surface. When the sun is low in the sky, the sun's rays impinge on the earth's surface at an oblique angle. Such rays deliver less energy at the ground than vertical rays, when the sun is high in the sky (low latitudes).

Heat wave is a recurring phenomena in Odisha. The last couple of decades have seen several of the hottest years on record. Global warming plus local warming are contributors. As places urbinize, they heat up (urban heat island).

Temperature sensors in an urbanizing area will warm more than they otherwise would. Add to this global warming and it is no surprise that the hottest years in history have occurred recently. As compared to other years, heat wave in 2012 is extreme in Odisha. Both coastal and interior districts experienced unprecedented continuously 32 days heat wave in Odisha which affected the normal life of human beings as well as domestic animals. All time record temperature 46.7 degree Celsius is observed at Bhubaneswar on 5th June,2012.

Country experienced significantly above normal temperatures during January and February of the year 2016 (monthly anomalies of 1.53^0C & 2.0^0 C respectively from 1961-90 normal). The year 2015 was the third warmest year ever recorded since 1901. Severe heat wave condition continuously for 22 days with effect from 7th April,2016 was experienced over Odisha and human casualty were very minimum as compared to 1998 due to precautionary measures taken by Government and NGOs..

In addition to insitu heating mechanism, Northwesterly dry hot wind from Northwestern part of India towards Bay of Bengal through central India cause intense heat wave over districts of coastal Odisha due to advection of heat which support for increase of 2 to 3 degree of temperature.

It has been characterized by IMD to declare heat wave under certain conditions. These are (1) heat wave need not be considered till maximum temperature of a station reaches at least 40^0C for plains and at least 30^0C for hilly regions, (2) heat wave for the places where maximum temperature is less than or equal to 40^0C and its departure from normal is 5^0C to 6^0C and severe heat wave for the departure from normal is 7^0C or more, (3) heat wave for the places where maximum temperature is more than or equal to 40^0C and its departure from normal is 4^0C to 5^0C and severe heat wave for the departure from normal is 6^0C or more and (4) heat wave is to be declared when actual maximum temperature remains 45^0C or more irrespective of normal maximum temperature. On the basis of above criteria, analysis of heat wave over Orissa from 1998 to 2005 is given below:

Heat wave warning is issued for 48 hours with outlook for subsequent two days and these warnings are issued to state government dignitaries and both print and electronic media for creating awareness among people for their precautionary measures using e-mail, fax and telephones.

Conclusion

In view of the global environmental changes, it is likely that the frequency and impact of disasters will increase the world over. The population pressure is causing degradation of environment by interrupting the water flow, hydrological cycles, causing either landslides, floods, soil erosion etc. As a welfare state, the Government will have to take the lead in disaster prevention and reduction and mitigating their impact, enhancing the awareness of the coping mechanisms among the people and to prevent loss of lives and property.

The public awareness will have to be also created through the NGOs apart from the local administration. It should be the combined effort of the Government at Centre, the State, the District and the Panchayats. NGOs and people are to pool their resources, capability and put in their best efforts to face the situation and to mitigate the losses.

Efficient natural resources management with remote sensing and GIS to develop climate resilient agriculture

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1.0 Introduction

Remote sensing refers to the acquisition of information about an object /phenomena, without there being any physical contact. Generally, the information were acquired remotely by scientific devices called "sensors" which are generally mounted on platforms like aircrafts or satellites and can thus obtain a synoptic view over a vary large area. The most widely used remote sensing techniques are based on the detection/sensing of electromagnetic radiations, which are reflected/scattered or emitted by objects. The reflections or emission of radiations at different wavelengths by objects depends on the physical structure of the objects and their condition. The whole edifice of remote sensing is built on the premise that all objects have characteristic spectral signatures. By analyzing these spectral signatures, it is possible to detect, identify and classify various objects/phenomena. The remotely sensed data thus furnish information which, in turn, leads to better knowledge of the earth's environment an its resources and will be useful for watershed management.

2.0 Components of remote sensing

The Science of remote sensing has three essential components

(A) **Signals** (from a source/target): Signals are carriers of information about an object. For remote sensing purposes, four different types of signals are used. *viz*.,(i)disturbance in a force field;(ii) acoustic signal, (iii) particulate signal, and (iv) electromagnetic signal. For agricultural remote sensing from a comparatively large distance electromagnetic signals are usually used. The entire range of electromagnetic spectrum is given in Table –1.

(B) **Sensors** (from a platform): A multitude of sensors is available today for monitoring our natural endowments: land, water and air. Some of the sensors data available with IRS and other missions are presented in Table-2.

The sensors are mounted on platform, which can be classified into three different categories.

(i) Ground observation platform: Hand-held, cherry picker, portable masts, towers;

(ii) Air-borne observation platform: balloons drones (short sky spy), aircraft, high altitude sounding rockets.

(iii) Space-borne observation platform: Manned and unmanned satellites.

(C) Sensing (through analysis)

Based on spectral signature and radiometric resolution, different objects are identified on the image. Earlier people used to analyse the data through visual interpretation. Now a days several image processing software (ERDAS, GEOMETICA etc.) are available for digital image processing. Digital image processing has the distinct advantages over visual interpretation because (i) Digital processing has the greatest potential for preserving the correct radiometry and the maximum resolution of the images. (ii) Digital processing is faster and accurate (iii) it allows users to perform repeatable and quantifiable analysis on common imagery.

Two types of classifications are generally used for terrain characterization (i) supervised classification (ii) unsupervised classification

(i) In supervised classification, one must rely on his own pattern recognition skills and a prior knowledge of the data for classification. The location of a specific characteristics, such as a land cover type, may be known through *ground truthing* . Ground truthing refers to the acquisition of knowledge about the study area from fieldwork analysis, aerial photography, or personal experience. Ground truth data is considered to be the most accurate (true) data available about the area one wants to study. Ground truth data should be collected at the same time as the remotely-sensed data, so that the data corresponds as much as possible. Some ground truth data may not be accurate due to errors, inaccuracies, and human error. Global positioning system (GPS) receivers are useful tools to conduct ground truth studies and collect training sites.

(ii) Unsupervised image classifiers do not always provide the desired number of truly representative classes. Aggregation can be used to combine separate classes into one class after a classification.

A common approach in unsupervised classification is to generate as many cluster classes as possible. With the benefit of reference data or first-hand knowledge of the scene, the analyst then aggregates the spectral clusters into meaningful thematic classes.

The clarity of understanding about an object is dependant on certain fundamental properties of images such as (i) scale and (ii) resolution.

(i) The scale for remote sensing purpose can be delineated into (i) small scale (>1:500,000) 1cm=5km or more (ii) Intermediate scale (1:50,000 to 1: 500,000) 1cm=0.5 to 5 km (iii) Large scale (<1:50,000) 1cm=0.5 km or less

(ii) Another important property for determining accuracy about the information is resolution. Resolutions may be (a) spatial resolution, (b) spectral resolution, (c) radiometric resolution and (d) temporal resolution.

(a) Spatial resolution: it is the minimum distance between two objects that a sensor can record distinctly. The spatial resolution depends on (i) The geometric properties of the imaging system, (ii) the ability to distinguish between point targets, (iii) the ability to measure the periodicity of repetitive targets and (iv) the ability to measure spectral properties of small finite objects.

(b) Spectral resolution: Spectral resolution is determined by the bandwidths of the channels used. High spectral resolution is achieved by narrow bandwidths which collectively are likely to provide more accurate spectral signature for discrete objects than by broad bandwidths. However, narrow band instruments tend to acquire data with low signal-to-noise ratio lowering the system's radiometric resolution.

(c) Radiometric resolution: It is basically the ability of the sensor to distinguish two objects radiometrically. It is determined by the number of discrete levels into which a signal may be divided (quantization). However, the maximum number of quantizing levels possible from a sensor system depends on the signal-to-noise ration and the confidence level that can be assigned when discriminating between levels.

(d) Temporal resolution: Temporal resolution is the receptivity of the sensors and useful to monitor change through time.

3.0 Spectral Indices

The earth's surface cover receives both direct and indirect solar irradiance (i.e. radiation that is incident on the surface of interest). Some of this irradiance is reflected, some is absorbed and some is transmitted. The ability of different surfaces to reflect, absorb and transmit this radiation varies considerably thus presenting a method of identifying and extracting information about these surfaces. The radiation reflected by these surfaces, termed as the radiant existence is usually expressed in unitless reflectance values as given below :

$$\text{Reflectance} = \frac{\text{Radiant existence}}{\text{Irradiance}}$$

The spectral reflectance in terms of indices is useful for crop growth and development monitoring, yield predictions and extracting phonological information. Some of the important spectral and thermal indices for natural resources management are presented in Table 1 (a-c).

4.0 Geographical Information System (GIS)

Literally the 'GIS' comprises three words viz., 'Geographical' means relevance of location, 'Information' means data (textural or graphical) and 'System' means tools for manipulation. GIS is a data base system in which most of the data are spatially indexed and upon which a set of procedures are operated in order to answer queries about spatial entities in the data base. Geogrpahic information system can be used for integrated study of resource management study of resource management because of its capacity to design, organise an error free digital data base for natural resources in the form of separate

Burrough (1987) specified GIS as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world.

In general there are three basic notations used in geographic information system for representing the spatial location of geographic phenomena i.e. points, lines and polygons. As for example, a road is represented by line or arc comprising a starting XY co-ordinates and an end XY co-ordinates. A pond could be represented by an area or polygon entity consisting of a set of co-ordinates whereas, a well could be represented by a point entity consisting of a single XY co-ordinate pair. These are mostly commonly defined on maps using X, Y Cartesian co-ordinates such as longitudes, latitudes. The Cartesian co-ordinates are then transferred to X, Y co-ordinates of GIS file.

4.1 Set up of a geographical information system

GIS has mainly three important components which are to be in balance for effective and satisfactory utilization of GIS. The set up of GIS comprises (A) computer hardware, (B) set of application software modules, and (C) proper organizational context.

(A) Computer Hardware : The computer hardware of GIS comprises central processing unit, disc drive storage unit, visual display unit, plotters, printers, digitisers, scanners etc. Now-a-days, work station based GIS (IBM AIX 3.2) is also available in many working places. The computer or central processing unit (CPU) is linked to a disk drive storage unit, which provides space for storing data from maps and documents into digital form and send them to the computer. A plotter or any other kind of display device is used to present the results of the data processing, and tape drive is used for storing the data or programmes on magnetic tape, or for communicating with other systems.

(B) Software Modules : Every GIS software package consists of different basic technical modules for data base management, GIS coverage creation, transformation, display of results and ultimately for action plan development. These basic modules are mainly used for five functions like, (i) preparation of digital data base and data input creation which is done by digitizing, scanning, file format conversion or co-ordinate geometry methods; (ii) data storage and database management in which editing, cleaning, building the spatial relations and projection etc. operation have been done; (iii) data transformation and analysis: this step is carried out using a projective transformation function based on control points (real world co-ordinates); (iv) map composition and output : for reporting to users or ultimate target groups, the suitable colour symbol and class names are added to the polygon attribute table. The final maps are then composed with the elements like text information, north arrow mark, scale bar, outer box, legen, etc; and (v) action plan generation: this is the most important module of GIS where the individual thematic maps as well as integrated maps are studied for development of site specific action plan. Keeping existing one theme as a reference, on other factors, the action plan map is generated.

Some of the GIS packages presently available are ARC/INFO, ARC GIS, ARCVIEW, GEOMETICA, DELTAMAP, INFOMAP, INTEGRAPH, SICAD, SYSSCAN, GEBASED, SYSTEM 600, SPANS, ERDAS, ILWIS, PAMP, IDRIS etc. These are available either in mini and main frame computers of PC/micro computers.

(c) Organizational aspect of GIS : the ultimate aim of the GIS technology is to utilize it for some developmental programmes like management of natural resources, watershed management, environment impact assessment, natural disaster management etc. So for effective utilization of GIS technology, it needs to be placed at proper organization. The draft action of different activities should be verified keeping in view the socio-economy and local environments of a particular region. For any organization, simply the purchase of hardware and software will not serve the purpose. The derived action plan is to be implemented properly. The trained manpower and effective cooperation from every sphere of society like government, autonomus organization, NGO's, local panchayats, scientists, ferments students and so on are needed for effective utilization of this modern tool.

4.2 Source of data for GIS and data base collection

The data collection approach consists of the acquisition of geographic information sources such as land use map, soil map, slope map, drainage map, settlements, climatic data, hydro-geomorphology map, climatic suitability maps, administrative maps etc. The type of data needs to be interpreted may vary according to the objectives of study. For example, climatic data, water requirement of crops, irrigation conveyance and other approaches are necessary for water management. While for development of site specific, alternative land use system in watershed, we need the information on existing land use, soil map, slope map, drainage pattern hydrogemorphology map, climatic and socio-economic data base. While for the studies of soil erosion hazards assessment, information on soil map, slope map, soil erodibility index map, existing land use-land cover map are required for interpretation. Books, reports (census reports, statistical report of government, socioeconomic report), satellite imagery, aerial photographs and related documents on various themes are the main source of data for problem identification and policy making. Each data set on various themes can be collected, reviewed, evaluated and classified to establish its usefulness and appropriateness for inclusion in the GIS.

4.4 Data types and presentation of geographical data in GIS

Data in GIS are of two types i.e. spatial data and non-spatial or attribute data. Spatial data represent the location within geographic space where the features reside. Geographic features like village location, drainage, and forest are represented by point, line and area, respectively. Non-spatial or attribute data provide descriptive information like class of land use/land cover, name of the geographic unit etc. The information for geographic features has four major components *viz.,* (i) its geographic position, (ii) its attributes, (iii) its spatial relationships, and (iv) time. At present there are two fundamental ways of representing geographical/topological data in the form of digital data base.

(a) **Vector form :** Vector form is suitable when real world objects can be accurately defined. In this case points are stored as co-ordinates. Lines are stored as combination of points and areas by the lines surrounding its. Vector data structures use discrete points and lines to define location of geographical features. Discrete features (boundaries, streams canals, cities etc.) are formed by connecting line segments. In the vector representation of data, topology (mathematical study of the relationships and transformations of geometric configurations) among entities is explicitly recorded; **(b) Raster form :** In the raster form of representation, areas are presented in the form of regular network of grid cells in specific sequence. The conventional sequence is row by row from top left corner of the map. Each cell is independently addressed with a single value or an attribute. Each location in the study area must correspond to a cell in raster data structure. The grid cell size is fundamental in respect of accuracy and presentation of maps. The cell size should be defined in relation to the objectives of the study of applications.

5.0 Improving traditional watershed management with modern technologies

Alternative sustainable land use/ cropping system and crop management strategies over large agricultural area on watershed basis require generation and gathering of precise information on a number of spatial natural resources parameters. With the advent of modern tools like remote sensing and GIS, appraisal and interaction of natural resources data and depicting their spatial distribution are much easier now, which otherwise through manual methods are time consuming and tedious. GIS is useful tool to design and organize an error free digital data base for natural resources and useful for spatial natural resources analysis. Some of the watershed development and management plans are described below where remote sensing and GIS can really aid value for natural resources management.

5.1 Morphometirc analysis using remote sensing and GIS

The mapping of drainage pattern of watershed for morphometric analysis can be done by using satellite data or from topographical map. Earlier many researchers performed quantitative analysis of drainage network using manual methods like area measurement using grid method or using planimeter and length measurement using thread length, Opsiometer, Ruler and Digital Curvimeter etc. But these methods are very tedious and time consuming. It is more difficult if the map is on higher scale like 1:50,000 0r 1:25,000. To overcome the problem, GIS technique was used for watershed morphometric analysis.

5.2 Estimation of soil loss using remote sensing and GIS

Estimation of soil loss from the watershed to identify priority area for establishment of soil and water conservation measures.
The widely adopted USLE model (RKLSCP) is used to estimate soil erosion. From the average annual rainfall and maximum 30-miniute intensity of rainfall, the R is calculated. The erodibility factor (K), topographic factor (LS), and cover management factor (C) are extracted form different sources.
Detailed methodology for estimating soil loss and watershed prioritization using USLE model in conjunction with remote sensing and GIS has been given in flow chart.

5.3 Estimation of runoff from remote sensing imagery

The SCS run-off curve number method is used for computing runoff depth to assess water harvesting potential of the region.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad , P \geq 0.2S$$

Where, P= total storm rainfall, Q= actual direct run-off, S= potential maximum retention

P, Q and S are expressed in the same units, e.g. centimeters or inches or millimeters.

$$S = \frac{2540}{CN} - 25.4$$

In which CN is the run-off curve number (dimensionless) and S is in centimeters.

5.4 Estimation of sediment yield index using remote sensing and GIS

Quantitative estimate of sediment yield index (SYI) is carried out after computing two derived parameters; firstly the erosivity (measure of erosion intensity units) and secondly a delivery ratio indicating transportability of sediment to the dam reservoir. Area weightage value of each erosion intensity unit and sediment yield index of the watersheds were calculated using the following formulae;

$$E = \frac{\sum \left(A_{ei} \times W_{ei} \right)}{A_w}$$

$SYI = E \times Dr \times 100$

where,

E = the erosivity of mapping unit

A_{ei} = the area if the i^{th} erosion mapping unit

W_{ei} = the weightage assigned to i^{th} mapping unit

A_w = the area of the watershed

SYI = the sediment yield index, and

Dr = the delivery ratio.

5.5 Land use planning in watershed with remote sensing and GIS tools

Site-specific rainfed crop diversification and land use plan in different rainfed rice ecologies, requires integrated information on existing topography, land use, soil resources, hydrology, climate etc. Survey techniques and manual methods for appraising these natural resources in an integrated way over a large rainfed agricultural area may be time consuming and tedious. The action plan on alternative management practices may not be available to planners in time. With the availability of high-resolution satellite data (IRS-ID, RESOURCESAT-1), geographic information system (GIS) and computer based models the natural resources appraisal and planning become easier, faster and accurate, which increases the scope of applicability of satellite remote sensing data and GIS for regional level planning, to improve productivity of rainfed area.

Proper inventory of natural resources data like land use, soil, slope hydrogeomorphology, groundwater resources, climate, etc. can be made using GIS in the form of separate layers. With the help of integrated GIS coverage of different thematic maps and based on some decision rules, alternative site specific land and water resources development can be suggested on watershed or block basis. Keeping existing land use and land cover as a base and considering the limitation and potential of other factors for development, alternative site-specific landuse system like agro-forestry, silvipasture, multiple cropping, agro-horticulture, plantation crops, fodder plantation etc. may be recommended. Water harvesting and soil-water conservation measures can also be suggested on the basis of soil, slope, hydrogeomorphological information. GIS helps in planning and development of the region through supply of regional maps (1:25,000 scale), localities maps (1:50,000) to 1 :25,000 scale) and large scale (1:12,500) scale or larger scale plans/maps for on site construction activities. GIS is useful in decision making through the visualization of spatial spread of the events with speed so that relief and mitigation measures are quickly channelised from different sources to the affected area.

5.6 Remote sensing applications in water resources

Remote sensing techniques, complementing the ground based data collection methods, can provide adequate, reliable and time effective information on water resources.

Water availability includes inventory of surface and ground water resources. High altitude aerial photography and satellite remote sensing are have been used for mapping surface water bodies such as reservoirs, lakes and tanks over large areas.

Investigation for ground water requires comprehensive information on soil, vegetation, geology etc.

The hydrological application of Remote Sensing can be divided into 2 groups :

(i) Direct indicator – refer to the detection of physical properties directly associated with ground water or the ground water environment. Persistence of green vegetation during the dry season may indicate shallow water table conditions. The excessive soil moisture in a given region could be an indicator of shallow aquifers. The detection of recharges and discharge zones in also directly linked with the movement of the ground water.

(ii) Indirect indictor: other than the climatological factors the movement of surface and subsurface water is controlled by the geomorphology (landforms) and geology (lithology and structures) of the region. The indirect indicators essentially refer to the interpretation of these hydrogeological factors.

5.7 Remote sensing applications in aquifer characterization

The presence of broad shallow valleys, alluvial cores, alluvial fans etc. suggest the availability of fluvial deposits, which form good shallow aquifers. The information extracted about the lineaments, the dykes, outcrop pattern like circular and accurate will be of great hydro-geological significance and will help in locating deep aquifers.

5.8 Microwave remote sensing for soil moisture determination

The dielectric properties of a medium determine the propagation characteristics for electromagnetic waves in the medium, and as a result they affect the emissive and reflective properties at the surface. Thus these latter two quantities for a soil will depend on its moisture content, and they can be measured in the microwave region of the spectrum by radiometric (passive) and radar (active) techniques. This physical relationship between microwave response and soil moisture plus the ability of the microwave sensors to penetrate clouds, make them very attractive for use as soil moisture sensors.

5.9 Generation of Digital Elevation Model

The DEM represents a data base from which various secondary products are derived e.g., contours, profiles, volumes, slope, hill shading, 3D scenes, perspective view, etc. A special class of application relates to the intersection of DEMs with other spatial or planiertric data like cadastral properties, land use, vegetation cover, traffic lines, etc. DEM also forms a base of technical modeling for many natural and induced processes of our environment such as climate, water, floods, disaster monitoring, etc. DEM data can be extracted from terrain directly or from images of the terrain (photographs or remote sensing). There are mainly three techniques for acquiring DEM data:

- Field survey techniques - Tacheometry, leveling, Airborne survey
- Photogrammetric techniques - Digitizing stereo images, Correlation of stereo images
- Cartographic techniques - Digitizing existing topographic, maps (manual or automatic)

DEM data has been utilized for determining many catchment properties:

- Incidence angle, volume, area and shaded area.
- Storage of elevation data for watershed digital topographic database
- Drainage network, overflow path and watershed boundaries.
- To model soil erosion/sediment yield of a basin
- Slope, aspect, convexity/concavity and area-altitude plots
- Line of sight maps, perspective views
- Automatic landform delineation form DEM
- Calculation of pour point table and overland flow paths

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Table-1: Electromagnetic spectrum

Spectral region	Main interaction mechanism	Examples of remote sensing application
γ - rays X - rays	Atomic processes	Mapping of radio active materials
Ultraviolet(UV)	Electronic processes	Presence of H and He in atmospheres
Visible(VIS),Near infrared(NIR)	Electronic and vibrational molecular processes	Surface chemical composition, vegetation cover, biological properties
Mid infrared (MIR)	Vibrational, Vibration rotational processes	Surface chemical composition, atmospheric chemical composition
Thermal IR	Thermal emission, Vibrational and rotational processes	Surface heat capacity, surface temperature, atmospheric temperature, atmospheric and surface constituents
Microwave	Rotational processes, thermal emission, scattering, conduction	Atmospheric constituents, surface temperature, surface physical properties, atmospheric precipitation.
Radio frequency	Scattering, conduction ionospheric effect	Surface physical properties surface sounding, ionospheric sounding.

Table-2: Some of the sensors data available with IRS and other missions

Satellite	Launch date	Sensor complement	Spectral Bands (µm)	Spatial resolution (m)	Swath width (km)	Repeat cycle (days)
IRS-1A	17.03.1988	LISS-I, and LISS-II A/B (3 sensors)	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	72.5 m LISS-I 36 m LISS-II	148 74 x 2 (swath of 148 km)	22
IRS-1B	29.08.1991	LISS-I and LISS-II A/B	same as for IRS-1A		148 74 x 2	22
IRS-P2	15.10.1994	LISS-II M	0.45-0.52 0.52-0.59 0.62-0.68 0.77-0.86	32 m x 37 m	66 x 2 (131 km for combined swaths)	24
IRS-1C	28.12.1995	LISS-III	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	23.5 23.5 23.5 70	142 142 142 148	24
		PAN	0.50-0.75	5.8	70	24 (5)
		WiFS	0.62-0.68 0.77-0.86	188	804	5
IRS-P3	21.03.1996	WiFS	0.62-0.68 0.77-0.86 1.55-1.70	188	804	5

		MOS-A MOS-B MOS-C	0.75-0.77 0.41-1.01 1.595-1.605	1500 520 550	195 200 192	Ocean surface
		IXAE	Indian X-ray Astronomy Experiment			
1D	29.09.1997	Satellite and instruments are identical to those of IRS-1C				
IRS-P4 (OceanSat-1)	26.05.1999	OCM MSMR	0.4-0.9 6.6, 10.65, 18, 21 GHz (frequencies)	360 x 236 105x68, 66x43, 40x26, 34x22 (km for frequency sequence)	1420 1360	2 2
IRS-P6 Resource Sat-1	17.10.2003	LISS-IV	0.52-0.59 0.62-0.68 0.77-0.86	5.8 5.8 5.8	70	24 (5)
		LISS-III*	0.52-0.59 0.62-0.68 0.77-0.86 1.55-1.70	23.5 23.5 23.5 23.5	140	24
		AWiFS	0.62-0.68 0.77-0.86 1.55-1.70	70 70 70	740	5
IRS-P5 CartoSat-1	05.05.2005	PAN-F PAN-A	0.50-0.75 0.50-0.75	2.5 2.5	30 30	2-line stereo camera
CartoSat-2	10.01.2007	PAN camera	0.50-0.85	< 1	9.6	
OceanSat-2	23.09.2009	OCM SCAT ROSA	0.40-0.90 8 bands 13.515 GHz GPS occultation	360 x 236 25 km x 25 km	1420 1400	2
RISAT	2011	SAR instrument	5.350 GHz (C-band)	< 2 m to 50 m	100 - 600	
Megha Tropiques (ISRO/CNES)	2011	MADRAS SAPHIR ScaRaB GPS-ROS	5 channel radiometer Atmos sounder Radiation budget Occultations	40 km x 60 km	1700	2
SARAL (ISRO/CNES)	2011	AltiKa DORIS Argos-3 LRA	35.75 GHz Ka-band altimeter S/C tracking for POD services			

Table 1 (a): Some of the important spectral indices for natural resources management

S.No.	Spectral Index	Formula
1.	Simple subtraction	Infrared (IR) – Red (R)
2.	Simple division (infrared/red ratio)	Infrared (IR)/Red(R)
3.	Complex division	$\frac{IR}{R + \text{other wavelengths}}$
4.	Normalized difference Vegetation index	$NDVI = \frac{IR - R}{IR + R}$
5.	Transformed vegetation index	$TVI = \sqrt{VI + 0.5}$
6.	Difference– difference Index	DD=(2xMSS7-MSS6) -(MSS5-MSS4)
7.	Perpendicular vegetation Index	$PVI=\sqrt{(R_{soil} - R^{veg})^2 + (IR_{soil} - IR_{veg})^2}$
8.	Green-red ratio vegetation index	GRVI = Green/Red
9.	Soil adjusted vegetation index	SAVI = (NIR-R) ×1.5/(NIR+Red+0.5)
10.	4 – space tasseled cap	
	(i) Soil brightness index (BR)	BR = 0.43 MSS 4 + 0.63 MSS 5 +0.59 MSS6 + 0.26 MSS 7
	(ii) Greenness index (Gn)	Gn = -0.29 MSS4 – 0.56 MSS 5 +0.60 MSS6 + 0.49 MSS 7

Table 1 (b): Some of the important spectral indices for drought management

1. Normalized difference vegetation Index (NDVI)	$NDVI = (\gamma_{NIR} - \gamma_{red}) / (\gamma_{NIR} + \gamma_{red})$ Where γ_{NIR}&γ_{red} are the reflectance in the near infra-red & red bands respectively NDVI ranges from –1 to 1.	Drought seventy = $NDVI_i - NDVI_{mean.m}$ Where $NDVI_i$ is the current NDVI for month I and $NDVI_{mean.m}$ is the long-term mean NDVI for a calendar month m(m=1,2,…..12).
2. Enhanced vegetation index (EVI)	Unlike NDVI, enhanced vegetation index (EVI) takes the advantage of multiple bands. The EVI is calculated as : $EVI = G \times \frac{P_{NIR} - P_{Red}}{P_{NIR} + C_1 \times P_{Red} - C_2 \times P_{Blue} + L}$	The Coefficients adopted in the EVI algorithm are, L = 1, C1 = 6, c2 = 7.5. and G (gain factor = 2.5. EVI is more sensitive in high biomass regions and ensures the improved monitoring through a reduction in atmosphere influences.

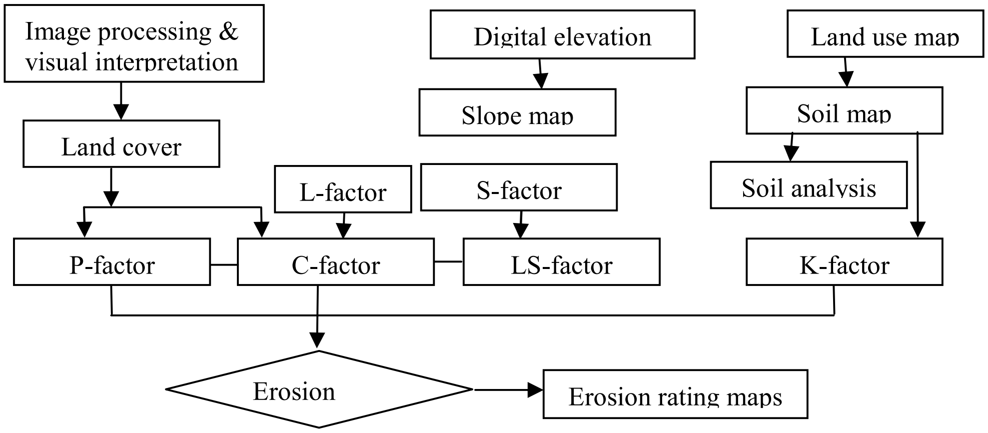
	Where, G = Gain Factor P_{NIR} = NIR Reflectance, P_{Red} = Red Refletance, P_{Blue} = Blue Reflectance C_1 = Atmosphere Resistance Red Correction Coefficient C_2 = Atmosphere Resistance Blue Correction Coefficient L = Canopy Background Brightness correction Factory	
3. Vegetation condition index (VCI)	The VCI shows, effectively, how close is the current months NDVI to the minimum NDVI calculated from the long-term record of remote sensing images. $$VCL_j = \frac{(NDVI_j - NDVI_{min})}{(NDVI_j - NDVI_{min})} \text{ X } 100$$	Where, $NDVI_{max}$ and $NDVI_{min}$ are calculated from the long-term record (e.g. 20 years) for that month (or week), and j is the index of the current month (week). In dry month when the vegetation condition is poor and the VCI is close or equal to zero. On the other hand, with optimal condition of vegetation, the VCI is close to 100%. The VCI of 50% reflects a fair vegetation condition.
4. Temperature condition index (TCI)	Unlike VCI, the TCI includes the deviation of the current months (weeks) value from the recorde maximum. $$TCI_j = \frac{(BT_{max} - BT_j)}{(BT_{max} - BT_{min})} \text{ X } 100$$	Where BT is the brightness temperature (e.g. AVHRR band 4). Under the atmospheric conditions, objects emit heat in this thermal band. The maximum and minimum values of BT are calculated from the long term (e.g. 20 years) record of remote sensing images for each calendar week of month j. The low TCI value (close to 0%) indicates the very high temperature in that month or week.

Table 1 (c): Some of the thermal indices for soil and crop characterization of watershed.

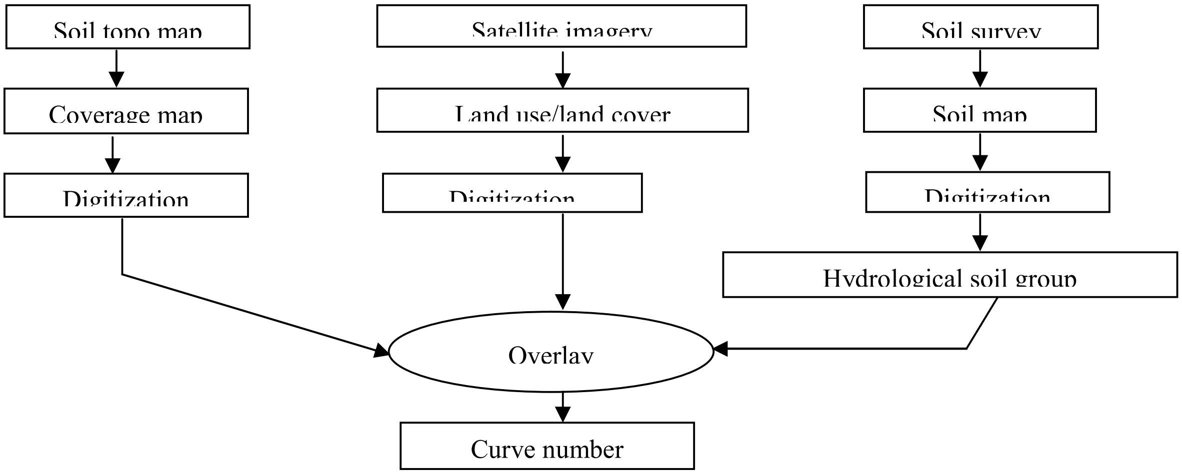
1. Canopy-air temperature difference (CATD) :	CATD is an indicator of crop water stress. This index has been used by several workers for monitoring water stress in different crops.
2. Stress degree day	SDD is the cumulative difference between the canopy and the air

(SDD) :	temperatures accumulated over a given period of time, as given below: SDD = $\sum_{t=x}^{y}(Tc-Ta)_i$ Where Tc and Ta are the canopy and air temperatures measured one hour after solar noon on day I accumulated for x – y day growth stage of the crop.
3. Canopy temperature variability (CTV):	It is the variability of temperature encountered in a field during a particular measurement period. It is expressed as the standard deviation of mid-day canopy temperature within a field. Gardner *et.al* (1981) reported a standard deviation of midday canopy temperature of about ± 0.3° C in fully irrigated plots of corn. In non-irrigated plots it was as great as ± 4.2° C.
4. Temperature-stress day (TSD) :	It is defined as the temperature differences between a stressed plot and a nonstressed reference plot. Use of well watered plot as reference compensates for environmental effects. It needs to be in the vicinity of the field to be irrigated. Clawson and Blad (1982) tested irrigation in corn plots when the average of all canopy temperatures measured in stressed plot during a particular time period were 1°C warmer than the average canopy temperatures of the well watered plot. Their experiments indicated that both CTV and TSD methods could be used to evaluate water stress.
5. Crop water stress index (CWSI) :	The crop water stress index (CSWI) is based on the fact that the canopy air temperature difference is linearly related to the air vapour pressure deficit (VPD). This relation derived from energy balance consideration can be expressed as below (Monteith & Szeicz, 1962; Jackson et.al. 1981) : $T_c - T_s = \frac{\gamma_a R_n}{pCp} . \frac{\gamma(1+r_c/r_a)}{\Delta+\gamma(1+r_c/r_a)} \frac{VPD}{\Delta+\gamma(1+r_c/r_a)}$ Where, r_a and r_c are the aerodynamic and canopy resistances ($s.m^{-1}$), R_n is the net radiation ($W.m^{-2}$). C_p is the volumetric heat capacity of air ($J.\ m^{-3}\ c^{-1}$). γis the psychrometric constant ($P_a.\ c^{-1}$) and Δ is the slope of the temperature saturated vapour pressure relation ($P_a.C^{-1}$). Jackson et.al. (1981) developed the mathematical equivalent of the proposed equation and later used to derive crop water stress index as: CWSI = $1-\frac{ETa}{ETp} = \frac{r[1+(rc/ra)-\gamma^*}{\Delta+\gamma\{1+(\gamma_c/\gamma_a)]}$ Where ETa is actual evapo-transpieration. ETp is potential evapo-transpiration, γ is psychro metric constant (paC^{-1}, r_c is the canopy resistance ($sec\ m^{-1}$)., r_a is the aerodynamic resistance ($sec\ m^{-1}$) and Δ is the slope of saturated vapour pressure temperature relation ($Pa°C^{-1}$).

Flow chart for estimating soil loss using remote sensing technique.



The methodology for determining curve number with remote sending and conventional technologies are given in flow chart below.



Watershed management and water harvesting using rubber dam as a measure for climate change adaptation

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Introduction

In climate change scenario we experience more extreme events of cyclone, flood, drought, long dry spells etc. The intensity, amount and distribution of rainfall are also not as per the crop requirement. Secondly land and water are the two most vital natural resources of the world and these resources must be conserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite, non-renewable over the human time frame, and prone to degradation through misuse and mismanagement. Total global land degradation is estimated at 1964.4 M ha, of which 38% is classified as light, 46% as moderate, 15% as strong and the remaining 0.5% as extremely degraded, where as present arable land is only 1463 M ha which is less than the land under degradation (Koohafkan 2000). The annual rate of loss of productive land in the whole world is 5 to 7 M ha, which is alarming. In India, out of 328 M ha of geographical area, 182.03 M ha is affected by various degradation problems out of which 68 M ha are critically degraded and 114.03 M ha are severely eroded whereas total arable land is only 156.15 M ha (Velayutham 2000). It was reported that in India 0.97% of total geographical area is under very severe erosion (> 80 t ha^{-1} yr^{-1}), 2.53% area under severe erosion (40-80 t ha^{-1} yr^{-1}), 4.86% area under very high erosion (20-40 t ha^{-1} yr^{-1}), 24.42% area under high erosion (10-20 t ha^{-1} yr^{-1}), 42.64% area under moderate erosion (5-10 t ha^{-1} yr^{-1}) and rest 24.58% area under slight erosion (0-5 t ha^{-1} yr^{-1}) (Singh et al. 1992). Therefore the problem of land degradation due to soil erosion is very serious and with increasing population pressure, exploitation of natural resources, faulty land and water management practices, it will further aggravate. Land degradation also reduces the world's fresh water reserves. It has a direct impact on river flow rates and the level of groundwater tables. The reduction of river flow rates and the lowering of groundwater levels lead to the silting up of estuaries, the encroachment of salt water into groundwater, the pollution of water by suspended particles and salinization, which in turn reduces the biodiversity in fresh and brackish water and consequently fish catches. Lower river flows also interfere with the operation of reservoirs and irrigation channels, increasing coastal erosion and adversely affecting human and animal health.

Proper watershed management, which is a comprehensive term meaning the rational utilization of land and water resources for optimal production and minimum hazard to natural resources could be the solutions to all these problems (Jena 2002). There are several measures such as mechanical (engineering) and biological (agricultural) which are used for soil and water conservation in watershed management. Check dams are engineering measures which are mainly used for soil and water conservation in watersheds. In India, several types of check dams are being used for regulating runoff in watersheds which in turn help in assured water supply to crops. Generally, most of the check dams in watersheds are made of steel, concrete, soil, rock (permanent) or with vegetation (temporary). The use of rubber as a construction material is a technological innovation in materials application. At the same time, the check dams are rigid one and they cannot allow more water to pass over it at times of heavy flood/runoff or store sufficient runoff at lean season of rainfall for use in Rabi season by farmer for different Rabi crops like pulses, oilseeds and vegetable. To give more flexibility in release and control of water flow across the streams, research efforts were made at Indian Institute of Water Management (ICAR-IIWM), Bhubaneswar in collaboration with Indian Rubber Manufacturers Research Association (IRMRA), Central Institute for Research on Cotton Technology (ICAR-CIRCOT), and Kusumgar corporate Pvt. Ltd. (KCPL), Mumbai to fabricate and install rubber sheets instead of cement concrete/ stone material for check dams and to study their impact on crop performance.

What is rubber dam?

A rubber dam is an inflatable and deflatable structure used for regulating water flow and store water. Rubber dams are installed to function as weirs or barrages which are relatively low-level dams constructed across a river for the raising of river level for the diversion of flow in full, or a part, into a supply canal or conduit for irrigation, domestic, industrial use (Tam 1998). The rubber dam is also known as inflatable dam or Fabridam. Most of the civil engineering structures constructed in the history of humankind are made of steel, concrete, soil, or, rock. The use of rubber as a construction material is a technological innovation in materials application (Tam and Zhang 2002).

When it is inflated, it serves as a check dam and when it is deflated it functions as a flood mitigation device. The head or height of the rubber dam is variable. According to the requirement its height can be increased or decreased. This variable head also regulate the depth of flow in the diversion channel for irrigation present in the upstream side of the check dam.

Components of rubber dam

As an innovative hydraulic structure, the rubber dam mainly consists of four parts: (i) a concrete foundation with head wall extension, side wall and wing wall of a normal check dam; (ii) the head wall replaced by rubberized fabric dam body; (iii) Anchoring mechanism (anchoring of rubber sheet with bottom and side of the check dam); (iv) an inlet/ out let piping system for inflation and deflation by water; and (v) a pump for filling water for inflation.

Advantages of rubber dam

The main advantages of the rubber dam are its ability for better soil erosion control (stream bed as well as stream banks or side of channel) and flood control during excess runoff water flow. Rubber dam can be occasionally deflated during flood to flush out all the sediment to the downstream side. During dry period/ lean season the head wall can be easily inflated to store more water. Due to flexibility of the head wall, during extreme events of high intensity rainfall and extreme flood situation, the structure can be easily deflated, so there is no damage to the structure and there is no breaching of stream bank/ levees and no scouring or erosion of stream bed. Earth quake, land slide cannot damage the head wall as it is made of rubber and repair to the side and wing walls can be easily done without dismantling the structure. There will be no conflict of interest of farmers and other beneficiaries as desirable amount of water can be easily delivered to downstream side by storing desirable quantity in the upstream side and maintaining environmental flow in the downstream side.

Installation and field evaluation

The different steps followed in successful design and installation of rubber dam by Indian Institute of Water management, Bhubaneswar and its impact on agricultural productions are given below.

a) Selection of sites for check dam, impounding structure and loose boulder structure to install rubber dam.
b) Socio-economic survey of the location where rubber dams were to be installed.
c) Hydrological data collection and analysis
d) Design, estimation and execution of base structure
e) Fabrication, installation and testing of rubber dam
f) Development of inflation, deflation mechanism of the rubber dam.
g) Observation of crop yield data of the farmers who got benefit from rubber dam.

Five rubber dams were initially installed as different hydraulic structures for various uses in watersheds at different locations of Khurda district, Odisha i.e. Mendhasal, Baghamari, Badapokharia and Chandeswar with innovative manufacturing, fabrication and installation technology. These are the first indigenous rubber dams which were been fabricated and installed in our country by Indian scientists.

The dimensions of different important components of the rubber dams installed in five different sites are given in the following table 1.

Table 1 Dimension of different components of installed rubber dams

Sl. No.	Sites	Dimensions(m)		
		Crest length (≈width of stream)	Spacing between anchoring bolts	Height of head wall
1.	Baghamari	5.00	1.20	1.00
2.	Badapokharia	2.00	1.50	1.00
3.	Mendhasal	2.00	0.50	0.50
4.	Chandeswar-1	4.15	1.50	1.50
5.	Chandeswar-2	4.15	1.50	1.35

Installation of rubber dam

Enough care has been taken during development of the rubber composite along with nylon reinforcement that when installed across streams it does not have any adverse effect on water quality (may be due to oozing out of chemicals or any extracts from the rubber composite) and also on crop productivity. It does not have any adverse impact on environment.

Rubber composite sheet manufactured by IRMRA was fixed with concrete base structure through double rows anchoring mechanism. The angle of inclination of side anchoring to the base has been optimized by IIWM to minimize wrinkles and easiness to inflate and deflate. The angle varied within 105^0 to 150^0 to the base. The spacing between bolts and also the dimension and structural strength of different bolts were tried. The dimension and strength of different anchoring bots were optimized by IIWM for different dimensions of rubber dam. The structure was made leak proof (no water flow between top of the base of the concrete foundation structure and the rubber sheet) using different proportions of adhesives like Sillica gel, M-Seal, Araldite and were tested by filling with water through inlet pipe using 1.5 hp kerosene operated petrol start centrifugal pump. Two of the installed rubber dams at Channdeswar are presented through plate 1.

Plate1. Rubber dams installed in watersheds of Odisha by IIWM, Bhubaneswar

Impact of rubber dam on crop performance

Uneven rainfall in the *Kharif* season results in lower rice productivity. Rubber dam helped in providing irrigation in critical stage of paddy i.e. in flowering stage and hence it has saved the crop. Also the water stored above the rubber dam was used for rice nursery raising which helped in transplanting during the recommended period. The stored water in rubber dam was diverted to the right side of dam through diversion irrigation channel to around 40 ha of paddy field at Baghamari. From 15th July' 2010 to 13th Aug'2010, there were no rainfall in the rubber dam project site i.e. Baghamari in Khurda district of Orissa. There was water scarcity and paddy fields became dry. Therefore nineteen farmers from village Baghamari got benefit by irrigating their fields with stored water by diverting the water through the diversion irrigation channel present just adjacent to the upstream side of rubber dam. Farmers also utilized water from this rubber dam in the flowering stage of rice which is very crucial period (critical growth stage) for crop. After harvesting rice, the average productivity of the above farmers in *kharif* 2010, was found to be 4.67 t/ha where as it was only 2.87 t/ha in *kharif* 2009 i.e. before installation of rubber dam in this area. The increase in average productivity is around 62%. The rainfall occurred during 2nd week of December 2010 has been stored in rubber dam and has been used by the farmers for *rabi* pulses, oilseeds and vegetable cultivation.

The average productivity of green gram in *rabi* season at Baghamari enhanced from 0.63 t/ha to 0.92 t/ha and the productivity of sunflower and cucumber in *rabi* season is 0.84 t/ha and 4.3 t/ha respectively. The increase in cropping intensity at Baghamari is 31% due to cultivation of green gram, sunflower and cucumber.

The economic analysis indicated that the intervention of rubber dam has potential to enhance the gross returns of the farmers by 62% from Rs. 28,700 ha^{-1} to Rs. 46,700 ha^{-1} if farmers grow only rice crop. At the same time, the total gross returns of the farmers may increase from Rs. 45184 ha^{-1} to Rs. 70792 ha^{-1} if farmer practices rice-green gram cropping system with the additional water available through rubber dam and the total gross returns may increase to Rs. 72500 ha^{-1} and Rs. 75135 ha^{-1} if farmers practice rice-cucumber and rice-sunflower cropping system. Similarly, the net returns of the farmers will increase from Rs. 12400 ha^{-1} to Rs. 27600 ha^{-1}, Rs. 43942 ha^{-1}, Rs. 43200 ha^{-1} and Rs. 47935 ha^{-1} under sole rice cropping, rice-green gram, rice-cucumber and rice-sunflower cropping systems respectively.

The productivity, percentage increase in yield of different crops grown close to the rubber dam installed at Chandeswar prior to the installation of rubber dam and after installation is presented in table 2.

Table 2. Yield enhancement of different crops after the installation of rubber dam at Chandeswar

Crop	Pre project condition (productivity; t/ha)	Yield (t/ha) after installation of rubber dam	% Yield enhancement
Pumpkin	6.3	8.5	34.9
Ridge gourd	5.5	8.1	47.2

Cowpea	5.2	6.6	26.9
Brinjal	4.8	6.7	39.6

The yield of pumpkin, ridge gourd, cowpea and brinjal was enhancement from 6.3 t/ha, 5.5 t/ha, 5.2 t/ha, 4.8t/ha during pre-project condition to 8.5 t/ha, 8.1 t/ha, 6.6 t/ha, 6.7 t/ha respectively after installation of rubber dam. The percentage yield enhancement was 34.9%, 47.2%, 26.9% and 39.6% respectively for pumpkin, ridge gourd, cowpea and brinjal. Thus the productivity of summer vegetables at Chandeswar enhanced significantly due to assured water supply from installed rubber dams. Similarly, 30 ha of rice fields were irrigated at critical stages through stored water from rubber dams at Chandeswar during kharif 2011. The paddy grain yield recorded a jump of 23% from 4.14 t/ha during pre project period to 5.09 t/ha after installation of rubber dam in Chandeswar 1 and a jump of 19 % from 4.48 t/ha during per project period to 5.33 t/ha after installation of rubber dam in Chandeswar 2.

Testing of rubber dams in different agro-ecological regions of the country

After successful installation of rubber dams in Odisha, the technology was implemented in states of Maharashtra, Gujarat, Uttarakahnd, Himachal Pradesh, Tamil Nadu, Meghalaya, Jharkhand, Odisha and West Bengal. Many of them are already installed and working well and few of them will be installed after the monsoon is over. This rubber dam (ICAR Flexi Check dam) technology has been commercialized and a MoU has been signed between the ICAR and Zenith Industrial Rubber Products Pvt. Ltd., Mumbai. This industry can fabricate and provide rubber composite sheets with requisite strength and dimension to any site in India. The installation technology is available with ICAR-Indian Institute of Water Management, Bhubaneswar. The technology was developed in a consortium mode. This technology has no adverse impact on environment.

Conclusions

From the preliminary agricultural and hydrologic data observation it is apparent that, rubber check dams can be well utilized for achieving sustainable crop production and could be instrumental for enhancing crop and water productivity in watersheds. It does not have adverse impact on environment. It can be easily installed, operated by farmers of the watersheds. There is almost no maintenance except the running cost of filling (inflating) with water at the time of need. This can be used as a good measure for climate change adaptation.

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Climate Resilient Agriculture through Common Property Resource Management

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Introduction

Common property resource (CPR) management has become focal point in community based management of natural resources under various development schemes for villages. The economic benefit to the community from the access to the common property is substantial. Absence of regulatory mechanism at the village level for use of common properties has led to free access and over exploitation of these resources beyond sustainable limit. The traditional water bodies like village ponds, wetlands and the drainage lines have been issues for conflicts due to clash of interest of users at different points which arises because of competitive exploitation of CPR to maximize private profit. The traditional management mechanism and property right issues got blurred under commercial interest linked to these resources. The emerging scenario of participatory irrigation management in minor irrigation sector along with watershed development programmes put the issues of common property management and community action at the centre stage.

Description

CPR refers to those natural resources to which no individual has exclusive property rights as the resource is accessible to whole community with equal access rights. Like village pond, wastelands, pasture lands, wet lands, drainage lines, rivers, rivulets, irrigation canals and village forests etc. Most common property natural resources are land and water bodies within and around local bodies with easy access. There has been a gradual transfer of ownership from kings, local lords, zamindars to private rights/panchyat rights. Reforms measures for land and other community use common resources have come through in last century rapidly for a change in rights of ownership, size and status of holdings. After independence, a host of central and state legislations have come in for better management of resources, revenue earnings for local self governments. Panchyats exploit their common property land and water resources to earn taxes, duties, tolls and fees

An estimate by finance commission reveals that about 60% of annual revenue of the Panchayats comes from leasing of the common property. The total market valuation of produce from CPRs in India was estimated to be more than Rs. 9400 crores during the year 1998. Dharia committee (1994) emphasized the quantification of the benefits accruing to different class of people over time and space from CPRs and policy enforcement for their optimal use and management. Little study has been done in India on the actual benefit accruing to the community through use of CPRs especially CPWRs (common property water resources). Chopra et al. (1999) attempted one study for forest regeneration under watershed development programme and Selvarajan etal (2002) for Bhopal lake. Palanisami etal. (2001) attempted for valuation of tank resources under multiple use in South India. These CPRs has economic benefits to the community/individual HH in the form of increase in productivity and production, recreational value, income augmenting values in the private property based farming system and equity impacts (free access irrespective of class and caste if enforced by decree of panchyats). It is estimated that (NSSO 54th round) about half of the rural HH seemed to collect some material or the other from the CPRs. The resource/proceeds are either used for HH consumption or marketed. The magnitude of accrual of benefits varies in time and space. Some users manipulate its control to their advantage and benefits get skewed though ideally it should be equi-proportional. Indiscriminate/ conspicuous use leads to physical degradation, lessening of benefits to the poor thereby reducing equity impact and ultimately environment degradation.

Management and Governance of Common Property

There are three components for management and governance of CPRs to which a state looks into. These are benevolence (b) revenue maximization (c) policing. Benevolence and policing are having more non tangible benefits where as "revenue maximization" is tangible on which the community/HH is immediately interested for benefit maximisation. The following issues concerning CPRs are of immediate interest to influence state policy domain with respect to natural resource management

1. Tenure systems and access to CPRs
2. Use, management and production of CPRs
3. Community organization and collective action
4. Conflict and conflict management

5. Pressures, challenges and threats to CPRs
6. Innovations

In the absence of clearly defined property rights, the sustainable use is never in the minds of the present consumers of the CPRs. Absence of regulatory mechanism like commonly agreed price mechanism, regulation on conspicuous consumption, wasteful uses degrade common properties over the years. In a developed watershed, the developed common properties like WHS, community miscellaneous tree plantations, orchards and drainage lines are listed under user's name who might have contributed to their development. But a clear mechanism of usufruct sharing is absent in most of the cases. The watershed development fund is generated for post project maintenance of assets created/developed during project period. However, a clear cut community driven guideline is not found in the project villages for its use. Rights and collective actions affect decision on investments in most of the village development work where natural resources like water and soil form the basis of interventions

In the case of water resources, the ownership and use rights vary across water sources, usage and states. The water use is guided by multiple property regimes viz. common property, common pool resource, private resource and state owned regime. There is difference in ownership and use of the CPRs. The user of water resources have their own assessment about the resource and accordingly the use pattern is governed which most of the time is based on utility maximisation. The typical use pattern in a drought prone area of the ground water through excessive withdrawals is an example of the short run private profit maximisation using the public investment. In the case of a village pond, while water is considered a common pool resource and there are unwritten customs of sharing it, the water going to recharge the well from the pond becomes a private property. The owner of such a well even in a period of scarcity may not agree to share water with the community. Efforts of a community in conserving water, which help in recharging individual wells, result in building the private poverty which may not be equitably shared with the other members of the community. Recharging of wells under various employment generation and poverty eradication programmes in drought prone areas comes through public investment and augments private profit. Watershed development programmes, is a good example of public investment becoming a private property. Under the watershed development programme and other employment generation programmes where emphasis is given on durable asset creation through public spending in the form of irrigation sources, plantations etc, the benefit sharing mechanism is weak as usufruct rights are ill defined. This leads to non maintenance of the assets and gradual deterioration of the capital base. The creation of WDF under watershed programme though has potential in taking care of the maintenance of assets after project period, due to absence of operational mechanism; the huge sums deposited in the accounts remain idle.

The analysis of the estimate of NSSO 54th round (Table. 1) reveals that common property land resources constitute about 15% of the total land resources of the country. The land resources are mostly classified under un-cultivable wastelands, village forests wood lots, and pasture lands etc which are mostly marginal land with no or little irrigation facilities. Per household availability of CPR is estimated to be 0.31 ha and per capita CPR to be 0.06 ha. The households reporting collection of materials from CPRs are estimated to be about 48% (Table .2) and average annual value of collection was Rs. 693 which formed about 3.03 % of total consumption expenditure of the hous holds reporting. The house holds reporting use of CPR water resources for livestock rearing was about 30% and for irrigation purposes was estimated to be 23%.

Common Property Water Resource Management- A Case Study

A case study of use of CPR water resources like tanks and wells for different economic activities was carried out by WTCER in Keonjhar, a plateau district of Orissa, reveals that (Table 3 and Chart 3), the majority of relatively poor HH (having land holdings < 0.5 ha) constituting about 75% of the population under the command of the sources completely depended on the system for agricultural purpose. It was estimated that about 33% relatively better off HH (having land holding > 0.5 ha) depended completely on the tank and well system for sustenance of agriculture. It was also estimated that 85% of relatively poor HH used the sources for livestock rearing where as for relatively better off HH it was estimated to be 78%. There was a stark difference among the two group of HH with respect to sanitation dependence which revealed that about 79% of poor HH completely depended on the system (tank and well) where as for relatively better off HH it was only 46% indicating importance of the CPWRs (common property water resources) for the livelihoods of the poor people in tribal districts.

With respect to use of CPRs for economic activities, it is revealed that agricultural income constituted about 67% of total income (Chart 1) of relatively poor HH and the agricultural income obtained from the use of CPWRs was about 78% where as for relatively better off HH, the agricultural income was estimated to be 58% and the tank cum well based agricultural income was 65%. It is inferred that for economic use also, the poor HH depend more on the CPWRS in comparison to relatively better off households. The contribution of CPWRs towards generation of on farm employment was estimated to by about 342 mandays (Chart 2) and 148 man days respectively for two different groups of HH.

Conclusion

The common property land resources constitute about 15% of total geographical area of the country accruing an annual income of about Rs 693 per house hold forming 3.03% of total consumer expenditure. About 23% of households used common property water resources for irrigation in India during the year 1998. The case study in Keonjhar reveals that the agricultural income from common property constituted about 78% income of poor households in comparison to 65% of income for non poor households. The on farm employment generation for poor households through use of CPRs was estimated to be 342 man days per year as against 178 mandays for non poor households. For better management of common property resources, resource sharing and voluntary contribution towards maintenance will go a long way in ensuring sustainability.

Table.1. Availability of common property land resources in rural India

Sl No	Items	Estimate
1	Percentage of common property land resources in total geographical area	15
2	Common property land resources (ha) per HH	0.31
3	Average HH size	5.04
4	Common property land resources per capita	0.06
5	Distribution of common property land resources (% of total)	Estimate
	Common pasture and grazing land	23 or 3.45% of TGA
	Village forest and woodlots	16 or 2.40% TGA
	others	61 or 9.15% TGA

Source: Estimate from NSSO 54th round

Table.2. Use of Common Property Resources

Sl No	Item	Estimate
1	HH reporting collection of any material from CPRs (%)	48
2	Average value of annual collection per HH (Rs)	693
3	Average value of collection to average value of consumption expenditure (%)	3.02
4	HH reporting to grazing in CPRs (%)	20
5	HH reporting use of common water resources	(%)
	Irrigation	23
	Livestock rearing	30
	HH enterprise	2.8

Source: Estimate from NSSO 54th round

Table.3. Use types of CPRs under tank and well system in a project village in Orissa

	Relatively poor HH (%) LH <0.5 ha	Relatively better HH (%) LH >0.5 ha
Complete dependence on tanks and wells for agriculture	75	33
Complete dependence on tanks and wells for sanitation purpose	79	46
Complete dependence on tank and wells for livestock purpose	85	78
Water lifting devices (Mechanical/Manual)	Manual	Manual, Mechanical

Source wise income distribution in a project villag

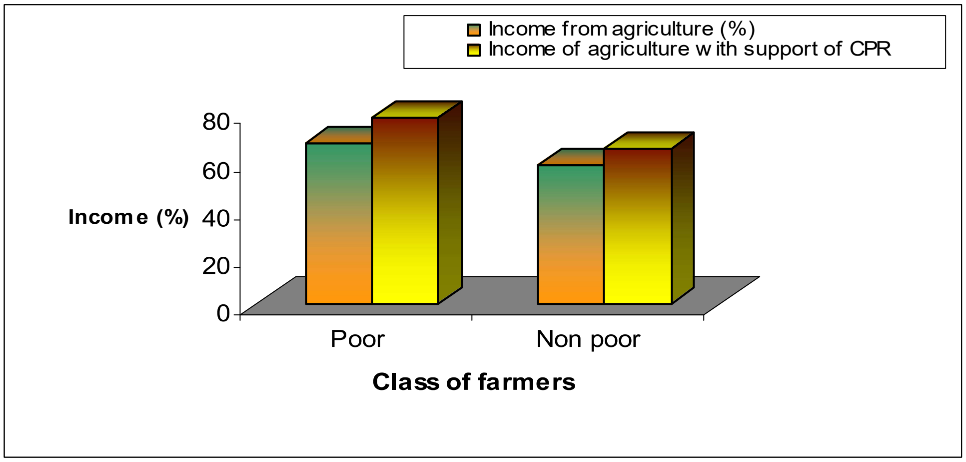

Chart 1

On farm employment generation through use of CPR in a village

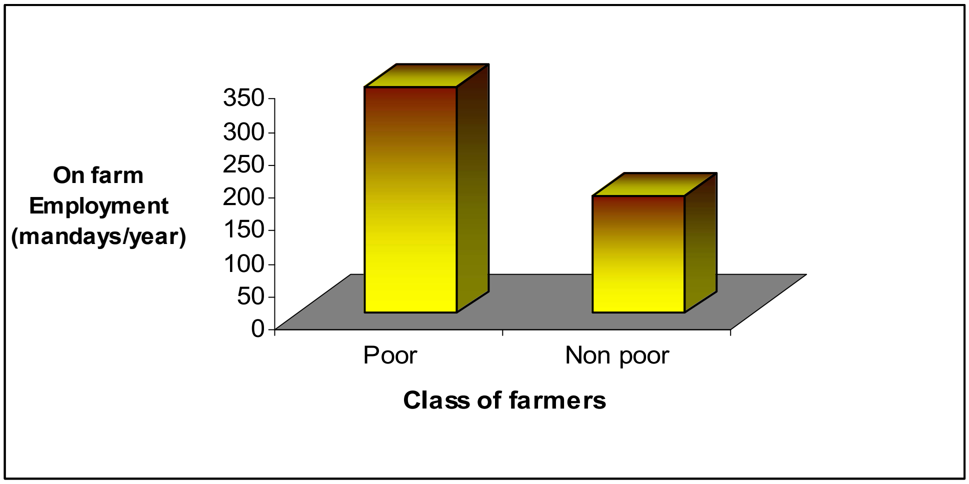

Chart 2

CPR use of tanks and wells

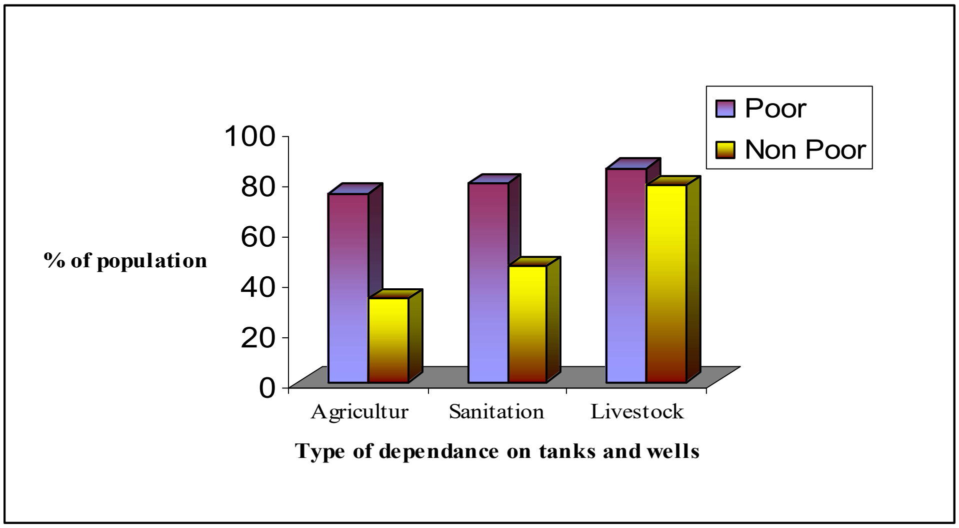

Chart 3

Agricultural diversification and land shaping for higher water productivity and climate resilient agriculture

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Introduction

In the past India has witnessed a phenomenal rise in population from 361 millions in 1951 to 1340 millions in 2016(Anonymous, 2016). To cater their needs, natural resources were transformed to various usable products at a rapid rate. As a result our food production jumped to 264.77 million tonnes in 2013-14 compared to meager 50.82 million tonnes in 1950-51 (Anonymous, 2014). Though we could able to prove Malthiew's theory wrong by adopting green revolution technologies, yet the attainment of food grain self sufficiency invited lot many problems which further threatened our future sustainability. The productive capacity of our soils got reduced, irrigated ecosystem saw yield stagnation, change of pest dynamics to alarming situation, enhancement of cost of cultivation and reduction of total factor productivity. When our entire strategies were relooked in holistic manner, it indicated a major change for ensuring future sustainability. Presently we are accounting for 17 per cent of global population, 15 per cent of global livestock and 7 per cent of global fisheries (Ababouch and Karunasagar, 2013). However, to meet their requirements we are relying on 2.4 per cent of land resources, 4.2 per cent water resources, 1 per cent forest and 0.5 per cent pasture on global basis(Jadav and Sarkar,2009).

Continuous practice of monoculture or repeated cultivation of same crop rotation year after year have given rise to many problems among which ecological and economic are the major ones. This can only be addressed through crop diversification. Similarly to address the reduced per capita land availability, production enhancement through vertical expansion approach has to be followed i. e. production enhancement through time and space dimensions. Land shaping concepts would be a befitting answer in this direction. Low water productivity is another area of concern. Agriculture (including animal husbandry and fishery) being the major consumer of water, we need to adopt " more production per drop" concept for our future water sustainability. The influence of global climate change on the out put of agricultural commodities has been felt in various parts of the world in recent past and it is going to affect Indian agriculture in a big way in the coming years. Farmers should be conversant with various adaptation and mitigation technologies for climate change to make our agriculture climate resilient agriculture.

1. Agricultural diversification

Agricultural diversification is intended to give a wider choice in the production of a variety of crops with livestock and fishery in a given area so as to expand production related activities on various products and also to lessen risk. Agriculture diversification in India is generally viewed as a shift from traditionally grown less remunerative system to more remunerative systems. The shift (diversification) also takes place due to governmental policies and thrust on some commodities over a given time, for example creation of the Technology Mission on Oilseeds (TMO) to give thrust on oilseeds production as a national need for the country's requirement for less dependency on imports. Market infrastructure development and certain other price related supports also induce shift. Often low volume high-value crops like spices also aid in diversification. Higher profitability and also the resilience/stability in production also induce diversification, for example sugar cane replacing rice and wheat.With the advent of modern agricultural technology, especially during the period of the Green Revolution in the late sixties and early seventies, there is a continuous surge for diversified agriculture in terms of crops, livestock and fishery primarily on economic considerations. Selection of enterprise combination, however, are the outcome of the interactive effect of many factors which can be broadly categorized into the following five groups (Hazra, 2016).

a) Resource related factors covering irrigation, rainfall and soil fertility.

b) Technology related factors and those related to marketing, storage and processing.

c) Household related factors covering food and fodder self-sufficiency requirement as well as investment capacity.

d) Price related factors covering output and input prices as well as trade policies and other economic policies that affect these prices either directly or indirectly.

e) Institutional and infrastructure related factors covering farm size and tenancy arrangements, research, extension and marketing systems and government regulatory policies.

2. Land shaping

Burgeoning population and their requirements have forced diversion ofagricultural lands to non agricultural purposes. In this process, per capita availability of agricultural land has reduced drastically. For ensuring food security of the people, more food to be produced from less land. The productivity of the land in terms of agricultural produce cannot be increased infinitely by growing one or two crops in a year. Hence production enhancement should be in time and space dimension. In recent years, there has been a shift in food pattern. Consumption of non cereal food items like fruits, vegetables, milk, meat, egg and their derivatives have increased many fold creating a huge demand- supply gap. Hellin and Schrader, 2003 have suggested alternative approaches for better land management in central America. Cao and Paniconi, 2007 worked on assessment of alternative land management practices using hydrological simulation and decision support tool in Arborea agricultural region and demonstrated how both qualitative and quantitative methods and informations can assist in decision making in complex settings. Lasanta*et. al*, 2006 reported increase in bio- diversity and annual pasture resources by 16.7% using landscape ecology to evaluate an alternative management scenario in abandoned Mediterranean mountain areas.

3.Water productivity

Water resources are becoming more precious day by day due to population pressure. Agriculture including animal husbandry and fisheries is one of the major consumers of fresh water. The per capita per annum water availability has been reduced from 5177m^3 in 1951 to 1869 m^3 in 2001. It is further estimated to be reduced to 1341 m^3 in 2025 and 1140 m^3 in 2050(Vision 2030, 2011). By 2050, our total water demand would be 1447 BCM(Vision 2050, 2013) which will be 324 BCM higher than our total utilizable water resources(1123 BCM). Out of which agriculture sector only will require about 1074 BCM. This will create very alarming situation if timely adequate attention is not paid by all the concerned stake holders. The slogan should be more production per drop. The integration of low water requiring variety/breed/fishery, proper management practices, application of water saving technologies like drip & sprinkler, reduction of wastage of water, harvesting & recycling of more rain water, integrated watershed management programmes and developing & adopting multiple use of water models can definitely enhance the water use efficiency of our production system and conserve water.

4. Climate resilient agriculture

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events, delayed onset of monsoon, early with drawl and long dry spell in a number of regions. Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise(IPCC,2014).There are a list of **v**illage level interventions which can ensure climate resilient agriculture(NICRA, 2012)

a)Building resilience in soil

Soil health is the key property that determines the resilience of crop production under changing climate. A number of interventions are made to build soil carbon, control soil loss due to erosion and enhance water holding capacity of soils, all of which build resilience in soil. Soil testing should be done in all villages to ensure balanced use of chemical fertilizers. Improved methods of fertilizer application, matching with crop requirement to reduce nitrous oxide emission.

b)Adapted cultivars and cropping systems

Farmers in the villages traditionally grow local varieties of different crops resulting in poor crop productivity due to heat, droughts or floods. Hence, improved, early duration drought, heat and flood tolerant varieties are introduced for achieving optimum yields despite climatic stresses. This varietal shift was carefully promoted by encouraging village level seed production and linking farmers decision-making to weather based agro advisories and contingency planning.

c) Rainwater harvesting and recycling

Rainwater harvesting and recycling through farm ponds, restoration of old rainwater harvesting structures in dryland/rainfed areas, percolation ponds for recharging of open wells, bore wells and injection wells for recharging ground water are taken up for enhancing farm level water storage.

d) Water saving technologies

Since climate variability manifests in terms of deficit or excess water, major emphasis was laid on introduction of water saving technologies like direct seeded rice, zero tillage, drip & sprinkler irrigation and other resource conservation practices, which also reduce GHG emissions besides saving of water.

e) Farm machinery (custom hiring) centers

Community managed custom hiring centers are setup in each village to access farm machinery for timely sowing/planting. This is an important intervention to deal with variable climate like delay in monsoon, inadequate rains needing replanting of crops.

f) Crop contingency plans To cope with climate variability, ICAR has developed district level contingency plans for more than 400 rural districts in country. Operationalization of these plans during aberrant monsoon years through the district/ block level extension staff helps farmers cope with climate variability.

g) Livestock and fishery interventions

Use of community lands for fodder production during droughts/floods, improved fodder/feed storage methods, feed supplements, micronutrient use to enhance adaptation to heat stress, preventive vaccination, improved shelters for reducing heat/cold stress in livestock, management of fish ponds/tanks during water scarcity and excess water are some key interventions in livestock/fishery sector.

h) Weather based agro advisories

Automatic weather stations at KVK experimental farms and mini-weather observatories in project villages are established to record real time weather parameters such as rainfall, temperature and wind speed etc. both to issue customized agro advisories and improve weather literacy among farmers.

i) Institutional interventions

Institutional interventions either by strengthening the existing ones or initiating new ones relating to seed bank, fodder bank, commodity groups, custom hiring centre, collective marketing, and introduction of weather index based insurance and climate literacy through a village level weatherstation are introduced to ensure effective adoption of all other interventions and promote community ownership of the entire programme.

j)Village Climate Risk Management Committee (VCRMC)

A village committee representing all categories of farmers including women and the land less is formed with the approval of Gram Sabha to take all decisions regarding interventions, promote farmers participation and convergence with ongoing Government schemes relevant to climate change adaptation.

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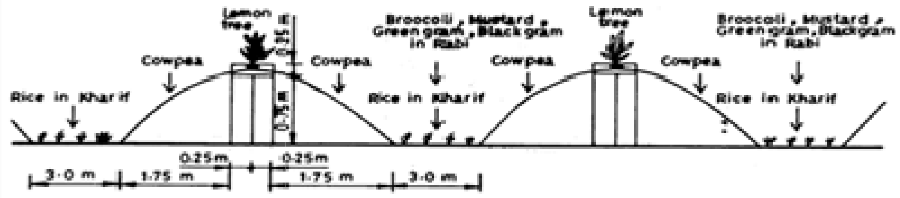

Fig 1: Schematic diagram of multiple cropping through land shaping

Fig. 2 Rice in land shaping field

Fig. 3 Lemon+cowpea+rice in land shaping field

System of Rice Intensification (SRI): Adaptation Strategy and Mitigation Opportunity for Food Security under Climate Change

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1. Introduction

During the Green Revolution, the yields of rice and major grain crops was increased through the introduction of higher-yielding varieties (HYVs), application of mineral fertilizers, and use of herbicides and pesticides to control various weeds, insect pests, and pathogens (Swaminathan, 2007). It has been widely believed that the more water, plants (seed) and agrochemicals used, the better. More inputs are considered necessary to achieve higher output of food. However, these practices are encountering rising economic, social and environmental costs. There is growing evidence that using more water, new seeds and chemical fertilizers as a strategy to improve crop production is counterproductive, or at least subject to what economists understand as 'diminishing returns'.

The maintenance of food security now and in the years ahead is challenged by population growth, declining arable land per capita, and water scarcity for agriculture (Fedoroff et al., 2010). Climate change adds further constraints to these challenges (Wheeler and Braun, 2013). According to FAO, food production will need to rise by 60% between now and 2050 to satisfy the demand of a population expected to reach or surpass 10 billion people (FAO, 2012). Yields in rice breeders' trials at the International Rice Research Institute have not significantly increased over the past 30 years (Sheehy et al., 2007). The question arises to what extent biotechnology and input-driven agriculture can ensure food security in the future? Or whether there are other strategies which should be given equal if not greater attention? There is increasing agreement that policies and investments should examine and give opportunities for approaches broadly grouped under the rubric of agroecology, relying on and utilizing productive potentials that exist within crop plants and within the soil and above-ground ecosystems that they depend on.

Over the past 15 years, it has been demonstrated that there are more efficient ways to grow irrigated rice than with the currently-favored practices. Simple changes in cultivation methods can enable farmers to raise the productivity of the land, labor, water, seeds, nutrients and capital that they presently invest in growing rice, this method discussed here are known as the System of Rice Intensification (SRI), developed at Madagascar in 1980s. The plants that result from these modified cultivation practices are better able to adapt to and resist the multiple stresses of climate change. These practices which raise production can also contribute to diminished net emissions of greenhouse gases (GHGs) from paddy fields, lowering the global warming potential (GWP) of irrigated rice production.

2. System of Rice Intensification (SRI): A strategy under changing climate

The recommended changes in managing rice plants, soil, water and nutrients under SRI, as previously described by Stoop et al. (2002). SRI principles include:

- Early, careful, and quick establishment of healthy plants
- Reduced plant density to lessen competition between plants
- Improved soil conditions for root growth and soil life
- Reduced and controlled water applications
- Active soil aeration

Its methods are reported to (i) enhance the growth of rice plants' root systems, and (ii) support a more abundant, biodiverse soil biota, summarily referred to as 'the life in the soil.' These methods can help farmers to grow more productive and robust rice plants (phenotypes) from both modern and traditional rice varieties (genotypes), by eliciting fuller expression of plants' existing genetic potentials rather than by modifying genes and increasing material production inputs. With larger, better-functioning root systems and with enhancement of beneficial biological resources in both soil and plants, SRI phenotypes produce more tillers and larger panicles, have more grain filling and often heavier grains, and thus achieve greater production of both grain and biomass Along with giving higher yields, SRI cropping offers water savings, and its plant phenotypes are better able to tolerate the stresses of pests and disease, also withstanding various extremes in weather: drought and heat, flooding, and cold snaps.

The practices that are recommended for SRI crop management reflect certain agronomic principles for sustainable production intensification, each valid in its own right. For example, rice seedlings planted singly produce larger roots and synthesize more plant hormones (cytokinins) than do three or more seedlings of the same variety planted together in one hill (San-oh et al., 2006). When seedlings are transplanted at a younger age, they experience lesser competition in the nursery and minimal transplanting shock, and their tillering starts earlier, with the result of increased tillering and greater root growth (Pasuquin et al., 2008).

Wider spacing between plants also promotes more profuse growth of roots and tillers by giving the plants more access to nutrients, water and light (Thakur et al., 2010b). Organic fertilization and keeping paddy fields unflooded improve soil health, nutrient uptake, and the rhizosphere environment (Zhang et al., 2009). Each of these practices directly or indirectly enhances roots' growth and functioning, resulting in improved growth and functioning of shoots, and giving farmers more output per unit of input as well as crop climate-resilience.

SRI management is characterized as a systems approach because it continues to evolve, adapted to location-specific circumstances. It is expected that farmers will adjust SRI ideas and methods to their own conditions rather than simply adopt them as a blueprint. Farmers should be helped to understand the reasons why changing their practices is beneficial, rather than being simply told what they should do.

The efficacy of SRI principles and practices has been seen in more than 50 countries of Asia, Africa and Latin America, and extensive information is now available on different institutional websites. Benefits from SRI management have been seen in a wide variety of agro-ecological systems, ranging from mountain conditions in Afghanistan (Thomas and Ramzi, 2011) to desert conditions in Mali (Styger et al., 2011), to the tropical environment of Panama (Turmel et al., 2011), to temperate climate in Japan (Chapagain and Yamaji, 2010).

The scientific foundations of SRI principles and practices are becoming better known and elaborated (Mishra et al., 2006; Stoop, 2011; Toriyama and Ando, 2011; Thakur et al., 2016). SRI have shown that given rice genotypes can be made significantly more productive by modifying the conditions under which they grow. Comparison research at the ICAR-Indian Institute of Water Management in Bhubaneswar (Thakur et al., 2010a, 2010b, 2011, 2013, and 2016) has found that rice plants grown with SRI methods have:

- Increased tillering and panicle-bearing tillers; more grains per panicle; greater grain filling; and heavier grains;
- Larger, deeper and better distributed root systems, with greater xylem exudation rates;
- A more open plant architecture above ground, with more erect and larger leaves, and with a higher leaf area index that results in more light interception: 14% more at panicle initiation, even though there are only 1/6th as many plants m^{-2};
- Greater chlorophyll content in the leaves, correspondingly higher rates of photosynthesis and delayed senescence.

With SRI management, the same varieties planted on the same soil can usually give 20-50% higher yield, but sometimes increases of 100% or more, the percentage being affected by what were the previous usual yields (FAO, 2016). The basis for such increases is easily seen in the larger root systems, the greater number of tillers, the more numerous and longer panicles, and less senescence of rice plants' roots and leaves (Thakur et al., 2010a; Zheng et al., 2013). Improvements in yield components are consistent with the measured increases in yield and reported in several hundred journal articles (SRI-Rice, 2015).

3. Adaptations to climate change through SRI

a. Increased water productivity with water saving

With water for agricultural production becoming more limited and less reliable, water productivity and water saving are urgent considerations. When paddy fields are not kept continuously flooded -- the standard practice for growing rice wherever water supplies permit - this is known to substantially reduce water consumption with little or no yield penalty (Bouman et al., 2007). However, when SRI methods of crop management are used along with alternate wetting and drying (AWD) or keeping rice field moist, not only is less water required, but yields can be increased. This gives farmers incentive to adopt new methods that conserve water because these methods become profitable, with net benefits rather than just costs.

Greater water productivity with SRI methods was seen across all agro-climatic zones, with different soil textures and soil pH, in both wet vs. dry seasons, and with short, medium and long duration varieties, showing the robustness of the overall findings (Jagannath et al., 2013). Water saving and greater water productivity with SRI has been confirmed by studies in countries as varied as

Afghanistan (Thomas and Ramzi, 2011), China (Zheng et al., 2013), India (Thakur et al., 2011), Indonesia (Sato and Uphoff, 2007), Iraq (Hameed et al., 2011), Kenya (Ndiiri et al., 2013), and Sri Lanka (Namara et al., 2008).

b. Drought resistance

Rice plants with deeper roots that do not senesce (die back), as rice roots commonly do under hypoxic flooded conditions, are better able to tolerate water stress. This effect is reinforced when there is abundant life in the soil, since the soil biota represents a reservoir of water in the soil in addition to its making the soil better-structured and more porous, thus better able to absorb and retain water.

Direct data on drought resistance are reported from an IWMI evaluation of SRI in Sri Lanka. The paddy crop in the 2003/04 *maha* season was subjected to 75 days of severe drought. Eighty percent of the tillers on SRI-grown plants formed panicles, whereas only 70% of the plants under usual management did so; and even though the farmer-practice fields had 10 times more rice plants m^{-2}, the number of panicle-bearing tillers m^{-2} in the SRI fields was 30% higher in this drought-stressed season. The number of grains $panicle^{-1}$ on SRI plants was also higher, and their harvested yield was 38% greater (Namara et al., 2008). This shows better translocation of photosynthates towards the grain under drought conditions with SRI management. A similar advantage was documented in rainfed SRI trials in eastern India, comparing rice production results from drought-stressed vs. more climatically-normal seasons (Thakur et al., 2015).

As climatic hazards become more severe and constraining, more emphasis should be given to reducing farmers' risks of crop loss due to the effects of climate change, rather than focus so much on the production advantages of certain practices or cropping systems under 'normal' conditions. Inducing morphological and physiological improvements in crop phenotypes to withstand drought stress will become more needed in the years ahead.

c. Resistance to storm damage

When rice plants have larger, deeper, non-senescing root systems and stronger, thicker shoots anchored onto a unified base, they are better able to withstand the pounding of rain and wind during storms, which become more frequent and more severe with climate change. Along with deeper, more robust root systems of an SRI crop, Thakur et al. (2011) found its average tiller circumference to be 38% greater than with conventionally-flooded rice of the same variety. Chapagain and Yamaji (2010) reported from comparison trials that 93% of the rice plants under conventional management lodged under wind stress compared to only 9-10% of those grown with SRI methods. They also found that the lodged plants under SRI were only partially lodged, whereas nearly half of the lodged plants under conventional management were completely lodged (Chapagain et al., 2011). Apart from deeper and greater root anchorage and more tiller strength, wider spacing between hills under SRI may also be allowing winds to pass through without damaging the plants.

d. Stress avoidance with shorter growth cycle

With weather becoming more variable and with associated pest and disease problems becoming more severe, farmers can benefit from having a shorter crop cycle between seeding and harvest so that they can get their crops out of the field sooner, especially if the harvests themselves are larger. Farmers often report that with SRI management, their rice crops can be harvested 5 to 10 days earlier, sometimes even 15 days earlier, than with conventional transplanting methods.

In Nepal, data on planting and harvest dates, as well as yield and other statistics, were gathered from 413 farmers who had used SRI methods with 8 varieties in Morang district by that district's Agricultural Development Office in the 2005 main season. The varieties' advertised time to maturity ranged from 120 to 155 days (ave. 141 days). However, the SRI crops were harvested at 115-133 days (ave. 126 days). The SRI paddy yields averaged 6.3 tons ha^{-1}, while the yield with usual rice production methods was 3.1 tons ha^{-1} (Uphoff, 2011). In Bangladesh, Uzzamann et al. (2015) evaluated 16 rice varieties under SRI, and all varieties showed earlier maturity under SRI management, ranging from 3 to 23 days. SRI crops were thus substantially less exposed to biotic and abiotic stresses while giving farmers higher yield.

e. Resistance to insect pests and diseases

Phenotypical advantages of SRI-grown rice crops are seen also in terms of their reduced susceptibility to infestation and damage by insect pests and diseases. This constraint on agriculture is heightened by the changes in precipitation and temperature that occur with climate change. Most studies of this effect have shown SRI plants to be less vulnerable to insect pests and to bacterial and fungal diseases, although not to all, e.g., Chapagain et al. (2011); Pathak et al. (2012); Visalakshmi et al. (2014).

These various manifestations of resistance to climate-related stresses -- water shortage and drought, wind and rain damage from storms, temperature extremes, and pest and disease incidence -- can be ascribed to the effects induced by SRI management practices on rice plants' growing environments both below- and above-ground. It is easy to see and measure the greater growth and health of SRI plants' root systems. Less visible are the influences that SRI practices have in enhancing the life in the soil, which have been documented in a number of studies (Zhao et al., 2010; Anas et al., 2011; Lin et al., 2011; Gopalakrishnan et al., 2013), Still, much remains to be known about how the soil-plant microbiome performs its various services for rice and other plants.

4. Mitigation of climate change through SRI

The emission of methane gas (CH_4) from rice paddies is one of the major impacts that the agricultural sector has on the greenhouse gas emissions (GHG) that drive global warming and climate disruption. Irrigated rice is responsible for about 10% of human-induced CH_4 emissions, or 20% of total agricultural CH_4 emissions (Kumaraswamy et al., 2000). Methane is about 25-times more potent in terms of its global warming potential (GWP) than carbon dioxide (CO_2), the most ubiquitous GHG which results from a variety of sources, including the production and transportation of synthetic fertilizers and other uses of hydrocarbon products. Even more potent than CH_4 in terms of GWP is nitrous oxide (N_2O), which is emitted in small amounts from aerobic soils through bacterial activity. Its GWP is about 12-times that of CH_4.

In flooded-rice production, increased methane emissions derive from the availability of organic substrates from root exudation plus stocks of inorganic N from applying synthetic fertilizers under anaerobic soil conditions. Under SRI management, where soils are intermittently wetted and dried and a soil-aerating mechanical weeder is used to control weeds, the partially aerobic soil conditions have lower rates of methane emission because the populations of methanogens, anaerobic microorganisms synthesizing CH_4 are reduced. Also, there are more aerobic soil microbes (methanotrophs) that consume the CH_4 produced by methanogens. It has been shown that intermittent irrigation and drainage by itself reduces GHG emission from paddy fields in Japan and Indonesia (Hadi et al., 2010). Various reports have shown lower methane emissions from SRI practice (Suryavanshi et al., 2013; Choi et al., 2015).

On the other hand, there is a possibility of having greater N_2O emissions from SRI fields because aerobic soils have a greater supply of NO_3-N through nitrification as compared to a saturated soil-moisture regime. NO_3-N serves as a substrate for denitrification by microbial denitrifiers which results in N_2O emission. Under flooded (anaerobic) conditions, most of the N_2O formed during the processes of nitrification and denitrification gets further reduced to N_2. Jain et al. (2014) found that with SRI management with the soil and climate conditions prevailing at their research site at the IARI in New Delhi, there was a 62% reduction in CH_4 emission accompanied by a 23% increase in N_2O emission, resulting in a net overall reduction of 28% in GWP ha^{-1}. A similar results were reported by researchers from Vietnam (Dill et al., 2013) and Korea (Choi et al., 2015).

Most studies of GHG emissions from SRI fields have indicated that when SRI methods reduce CH_4, there is some increase but not a large one in N_2O emission; occasionally there is a small reduction in N_2O. But in either case, N_2O emissions do not offset the reduction in GWP that can be achieved by lowering methane emissions with SRI management. This creates no superfluity of nitrogen in the soil supplied by synthetic N fertilizers. The microbes that synthesize N_2O do not have much substrate to work with, and there is little excess N to be volatilized into the air and less to get leached into water systems.

Gathorne-Hardy et al. (2016) found that overall, SRI offered substantial economic and environmental benefits: yield increases of 60%; GHG emissions reduction of 40%; ground-water depletion reduced by 60%; and use of fossil energy reduced by 74% kg^{-1}. As SRI methods reduced farmers' costs of production ha^{-1}, their economic returns ha^{-1} were raised by over 400%.

Reducing farmers' applications of inorganic fertilizers should in itself diminish CO_2 emissions as the production of such fertilizers has been estimated to create GHG emissions equal to 5-10% as much GWP as from all the direct emissions of GHG that result from food production (Vermeulen et al., 2012).

To this should be added the CO_2 emissions that derive from the far-flung distribution and on-farm application of N fertilizers. Reducing farmers' reliance on inorganic fertilizer as well as on agrochemicals for the control of weeds, insect pests and diseases could make a non-trivial contribution to the mitigation of climate change since the agricultural sector as a whole contributes about 30% of anthropogenic GHG emissions, and rice is one of its major crops. Overall, SRI should be contributing to net reductions in GHG emission.

5. Conclusions

The modifications in production methodology of SRI have been repeatedly documented as enhancing crops' root growth and functioning plus promoting the abundance, diversity and activity of beneficial soil organisms so as to make soil systems more fertile and sustainable. The resulting production increases are in the first instance direct, attributable to the more productive phenotypes evoked by these practices. But there are also indirect effects, producing phenotypes that are better able to adapt to adverse climatic conditions; and beyond this there are more indirect and long-term effects, diminishing the net emission of greenhouse gases from rice paddies so as to help abate global warming. The science and practice of SRI are still evolving as it is a work in progress, but there is now substantial scientific evidence to support earlier claims that altering crop and water management can produce more robust as well as more productive phenotypes.

Adaptations to climate stress, like mitigation of the forces that are driving climate change, are matters of degree. As biotic and abiotic stresses become greater, nobody can know where and when tipping points may occur and plant-microbial defenses may implode. Agricultural production systems on which individual and collective human life depend will need to be modified in many ways to sustain and increase food production to meet human needs over the next 50 years.

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Wastewater Recycling through Filter in agriculture in the regime of climate change

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Introduction

The impact of climate change on natural resources especially on water resources is multifarious and wide. Changes in annual mean temperature and rainfall directly influence the availability of water resources. The fifth IPCC Assessment Report (AR5) projected changes in weather patterns and extreme weather events. There will be increase in net annual temperatures from 1.7 -2.2 ^{0}C and the maximum temperatures may increase by 1 - 4 ^{0}C mostly in the coastal regions. There may be increase in average precipitation during summer monsoon, with increase in extreme rainfall events varying in different parts of the country. With variation in rainfall there will be flood and drought but the number of extreme events may decrease from 2030s with increase in the intensity. Due to lack of infrastructural facilities and increase in population and rapid urbanisation the eastern coast will be vulnerable to the impact of extreme events with frequent flood and drought events. Indian agriculture is largely dependent on rainfall and irrigation, thus any negative impact of climate change on water availability and supply will experience major impact on food production, livelihood and agricultural incomes in the rural areas.

As per IPCC analysis India could suffer from outright water stress – annual availability of less than 1,000 cubic meters per capita – by 2025, and gross water availability could fall as much as 37 percent by mid-century. Eight river basins viz. Cauvery, Pennar, Mahi, Sabarmati, Tapi east flowing rivers between Mahanadi and Pennar, east Flowing Rivers between Pennar and Kanyakumari and West Flowing rivers of Kutch and Saurashtra, including Luni are already water scarce. i.e. having per capita water availability less than 1000m^3 per year. By 2025 three more river basins viz. Ganga, Krishna and Subarnarekha may add to the list of water scarce basins taking the total water scarce basins to eleven by 2025. By 2025 Indus basin may also become water scarce while Godavari basin may be close to water scarce level. At present agriculture sector is the largest consumer of water (82.8%) and continued to be the major consumer with an increased demand of 910 km^3 by 2025 against the total demand of water of 1093 km^3 (CWC, 2010). The stress on water resources in terms of quantity and quality is increasing and efficient water management is one of the important key to achieve climate smart agriculture in India.

Water availability

India receives about 4000 BCM of rain water annually but the water resources potential as natural runoff in the rivers is estimated at about 1869 BCM. About 1121.3 BCM of the total potential with 690 BCM through surface water resources and 431.3 BCM by groundwater can be utilized. The total annual fresh water requirement in India by 2025 and 2050 is estimated to be 1093 and 1447 BCM respectively where domestic requirement will be 30 to 40 percent more than present requirement with concomitant increase in domestic wastewater generation to the tune of 58 and 82 BCM (Table 1). By 2050 there is a rapid decline in future availability of so-far-unused water resources. Under such circumstances untreated wastewater becomes an alternative source for irrigation and food production. The urban conglomerations which are hub of multifarious activities will produce huge quantity of wastewater with channelized discharges from domestic, service, industrial sectors (mainly small and medium sector units in urban centres) etc will be a huge resources to address water scarcity issues if managed scientifically otherwise may have serious environmental repercussions.

Table 1 Sector wise water requirement in India

Annual Requirement of Water in India (in BCM)			
	Standing Sub-Committee of MoWR		
Water uses	**2010**	**2025**	**2050**
Domestic	56	73	102
Irrigation	688	910	1072
Industry	12	23	63
Energy	5	15	130
Others	52	72	80
Total	813	1093	1447

Wastewater production and treatment

The Central Pollution Control Board has carried out an inventorization of Sewage Treatment Plants (STPs) located in India in the year 2014 - 15 which is quite disturbing and of concern. The estimated sewage generation from Class I cities and Class II towns together in India is 62000 mld , and sewage treatment capacity developed so far is only 23277 MLD from 816 STPs out of which only 522 STPs are operational with a capacity of 18883.2 MLD. It is projected by Ministry of Environment & Forests, Govt. of India that by 2051 gross wastewater generation will be 1,32,253 mld. The huge installation (approximately 80 – 120 lakh per MLD of average pollution load), maintenance and operational costs (approximately 172 lakhs per annum per MLD excluding the cost of electricity) of conventional biological treatment (Kodarkar and Joshi 2009) coupled with land scarcity and technological difficulty are the limitations and makes it unrealistic proposition and yet unsustainable, to treat all generated wastewater (sewage) in any growing city on sustainable basis.

Wastewater use in agriculture (Indian Scenario)

In India wastewater is generally used for irrigating crops in periurban areas and as aquaculture stabilization ponds. Strauss and Blumenthal (1990) estimated the area under wastewater irrigation to be over 73000 ha although no official estimates are available but actual figures seems to be much higher.Wastewater is used for irrigation along rivers which flow through rapidly growing cities as Delhi, Kolkata, Coimbatore, Hyderabad, Indore, Kanpur, Patna, Vadodara, Varanasi, Dharward, Bhubaneswar etc. Along the rivers' the water is diverted via anicuts (weirs) to canals and often to tanks and then channeled to the fields for irrigation. If such uses were included, a much higher figure than 73000 ha would be obtained as in Musi river, Hyderabad alone approximately 40500 ha is irrigated with wastewater (van der Hoek, 2004). Kolkata (formerly Calcutta) has a long history of using wastewater stabilisation tanks for aquaculture. An estimated 2.4 t/ha (Gopal *et al.,* 1991*)* of fish is produced annually in Kolkata from about 3200 ha of ponds with inflow of about 3 m^3/sec. Table 2 shows the area under wastewater use reported upon. Another estimation says that wastewater contributes to irrigating 600,000 hectares in India (http://www.iwmi.cgiar.org/assessment/files_new/research_projects/Urban%20Wastewater Full_Report.pdf).

A variety of food and non-food crops are irrigated with urban wastewater water supporting the livelihoods of the households of millions of farmers in India. Wastewater is a rich source of macro nutrients (nitrogen, N; phosphorous, P; and potassium, K) and micro nutrients (iron, Fe; copper, Cu; zinc, Zn; and manganese, Mn;) with varied concentration (Table 2).

Table 2. Macronutrients (N, P and K) and micronutrients (Fe, Zn and Mn) content in wastewater generated from some cities in India

Location	N (mg l^{-1})	P (mg l^{-1})	K (mg l^{-1})	Fe (mg l^{-1})	Zn (mg l^{-1})	Mn (mg l^{-1})	Reference
Nagpur	55–68	9–11	31–37	1.41–1.57	0.9–1.2	0.14–0.20	Kaul et al. (2002)
Calcutta	14–17	1–2	16	449–656	0.3–0.4	0.65–0.66	Mitra and Gupta (1999)
Haryana	32–70	15–30	250–500	6–25	1.6–28.0	0.8–2.8	Gupta et al. (1998)
Haryana	25–98	4–13	28–152	0.6–21.8	0.13–0.90	0.25–0.60	Baddesha et al. (1986)
Indore	11–64	1	20–54	0.14–0.21	0.01–0.11	0.19–2.14	CSSRI (2004)

Impact of Wastewater Use

Wastewater use in agriculture especially sewage water use has been beneficial to the farming community in comparison to fresh water use due to higher crop productivity resulting from high nutrient value of sewage and consequent lower use of fertilizer (Minhas and Samra 2004). A comparative study on wastewater and fresh water irrigation in 5 cities by IWMI showed in most cases sewage-fed farming is more profitable (Amerasinghe et al 2013).

Raychaudhuri et al 2014 reported overall increase in fertility status of soils in terms of major nutrients (N, P and K) along with increase in organic matter when Ganguanala wastewater irrigation was practised in vegetables at Bhubaneswar. They reported increase in Fe, Mn, Cr and Pb concentration by 13, 94, 72 and 21 percent respectively in surface soils. They reported transfer of heavy metals from soil to plant for different vegetables were in the order, Amaranths Red= Tomato> Amaranths green> Water melon> Malabar Climbing> Bitter gourd> Ladies Einger> Ridge gourd. This shows that consumption of leafy vegetables grown with wastewater irrigation is risky due to higher accumulation of metals in leaves.

Studies conducted (Raychaudhuri et al 2013, Singh et al 2016) in the Patna bye-pass area where farmers grow a variety of vegetables and field crops viz., red spinach, cowpea, okra, radish, bittergourd, sugarbeet, cabbage, turnip, spongegourd and pumpkin by lifting sewage water through pumps and open wells. Over the last 50 years the area receives a continuous disposal of sewage sludge from the city. Soils, plants and groundwater samples were collected from wastewater irrigated sites and analysed to estimate the heavy metal content. The soils nearest to the discharge point of sewage treatment plant contained appreciably higher amount than other sampling sites away from the discharge point. Theyalso reported that leafy vegetables contain more amounts of heavy metals which are of concern.

The relative accumulation of these metals in different plant species were as follows.

i) Sugar beet > Radish > Potato> Amaranthus> Cabbage> Spinach> Onion> Cowpea> Bittergourd >Cauliflower >Mustard> Bakla >Lady's finger> Maize.(Zn)
ii) Amaranthus>Spinach>Cowpea>Sugar beet>Potato>Lady's finger>Bakla> Radiosh=Cabbage>Cauliflower >Bittergourd> Mustard> Bakla> Maize>Onion. (Cu)
iii) Sugar beet> Spinach> Amaranthus> Bittergourd>Onion> Cowpea>Maize> Radish >Potato> Mustard.> Lady's finger>Cauliflower. (Fe)
iv) Sugar beet> Spinach> Amaranthus> Maize>Potato> Cauliflower>Cabbage> Bittergourd> Cowpea>Radish> Lady's finger > Mustard> Onion. (Mn)
v) Sugar beet> Spinach> Amaranthus> Potato>Radish>Bittergourd> Bakla> Cauliflower> Mustard> Onion> Maize> Cabbage> Lady's finger > Cowpea. (Cd)
vi) Sugar beet >Spinach> Amaranthus> Potato> Radish> Bittergourd> Bakla>Cauliflower>

Mustard>Onion>Maize> Cabbage>Lady's finger> Cowpea. (Cr)

vii) Sugar beet> Cabbage> Spinach> Amaranthus>Mustard>Bakla> Cauliflower> Bittergourd =Lady's fingerCowpea> Potato> Onion> Maize>Radish. (Ni)

viii) Amaranthus>Spinach> Sugar beet> Cabbage> Cow pea> Bittergourd> Lady's finger and Maize. (Pb)

It has been reported by Anita Singh et al 2010 that in certain areas of Varanasi city, waste water from Dinapur sewage treatment plant is used for irrigating vegetable plots. They revealed that waste water used for irrigation had the highest concentration of Zn followed by Pb, Cr, Ni, Cu and Cd. Continuous application of waste water for more than 20 years has led to accumulation of heavy metals in the soil. Consequently, concentrations of Cd, Pb and Ni have crossed the safe limits for human consumption in all the vegetables. Percent contribution of fruit vegetables to daily human intake for Cu, Ni, Pb and Cr was higher than that of leafy vegetables, while the reverse was true for Cd and Zn. Target hazard quotient showed health risk to the local population associated with Cd, Pb and Ni contamination of vegetables.

In another study of heavy metal contamination in Musi River and its environs at Hyderabad, Sridhara Chary et al 2008 assessed heavy metals in soils, forage, grass, milk from cattle, leafy and non leafy vegetables. They found high content of Pb, Zn, Cr and Ni as compared to permissible limits and also reported high hazard quotient (HQ) for Zn, Cr and Pb particularly in leafy vegetables like spinach and amaranthus.

Industrial effluents those are relatively less toxic such as food/beverage sector, for example breweries, sugar mills and fruit processing units are being used in agriculture. The SABMiller brewery in Andhra Pradesh has been distributing treated wastewater free of charge to local farmers; Ugar Sugar Works in Karnataka has been selling treated effluent from its sugar mill at Rs. 3,000/ha to local farmers. However, since industrial wastewater is typically more toxic, agricultural reuse efforts are likely to be concentrated mainly on municipal sewage for the foreseeable future.

Recycling of wastewater

One of the challenges to meet the target of crop water requirement in near future and to adapt the climatic variability is to explore the feasibility of use of treated municipal wastewater for irrigation in peri-urban areas. Strategies were developed to assess the suitability of wastewater for irrigation based on available standards and management practices. Methodologies as suggested by FAO (Ayers and Westcot 1984), conjunctive use of wastewater with fresh water (Raychaudhuri, S. et al 2014, AICRP GWU 2011), Water Quality Index (WQI) (Raychaudhuri, Mausumi et al 2014), wetland systems, etc. require infrastructural facilities and expertise. A device at the farmers' level to reduce the content of undesirable materials like sediments, microbial loads and heavy metals in-situ from the wastewater for safe use of wastewater use in agriculture is the need of the hour.

Small scale Filter

A four chambered small scale on-line hybrid filter has been designed and developed by the Institute to reduce sediments, microbial load and heavy metals from the wastewater at the point of application and evaluated at farmers' field condition under surface and drip irrigation system. With a discharge of 0.25 l/s under an inlet pressure of 2.1 kg/cm^3 the filter could irrigate 1000 to 1200 m^2 area matching the water requirement of the horticultural crops. It has been observed that the efficiency of the filter in removing turbidity and heavy metals is more than 50 per cent whereas microbial loads reduced by 10 folds (Fig 1).

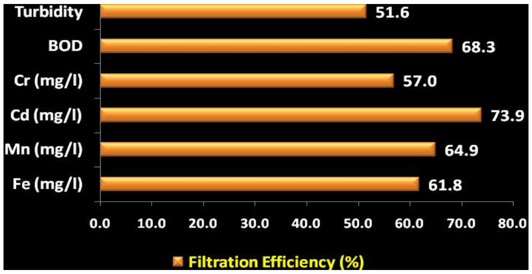

Fig 1. Efficiency of Filter evaluated at farmers field in reducing contaminants

Plate 1. Small scale filter developed is being used by farmers at Jaypur Patna using Gangua Nala water for safe irrigation.

The filtered water was found highly effective under drip irrigation system. The average discharge of the dripper varied from 1.38 to 1.43 lph with an average uniformity coefficient varying from 97.7 to 98.5 percent. Clogging of drippers is the usual phenomenon with drip system when wastewater is being used for irrigation. The filter was demonstrated to the farmers of peri-urban areas using municipal wastewater for cultivation of horticultural crops. The technology was also extended to the line departments for safe use of municipal wastewater use in agriculture.

Conclusion

In the face of hydrological changes and scarcity of freshwater, vulnerability, and risks due to climate change, treated wastewater is a reliable source for adaptation if managed scientifically. Wastewater generation will increase vehemently and large centralized treatment systems appear to be unsustainable and require huge expenses due to requirement of large tracts of land, high energy and skilled labour for maintenance. Cumulatively, the total wastewater generated (treated/untreated) can irrigate around 1.1 million ha of land in urban and peri-urban areas, if released to water ways. In 30 cities with over 1 million population, the wastewater generated ranged from 108 –3520 mld. Assuming that 50 percent of the generated wastewater will be used for farming, about 1.6 lakh ha could be irrigated. Barring the coastal cities where most of the wastewater enters the ocean, still about 1.21 lakh ha could be used in agriculture. Thus, an inclusive management system needs to be adopted for urban wastewater where intervention should start from the point of generation followed by exploring reuse options within the urban area and safe use in agriculture in the downstream. The small scale filter developed could reduce the risk factor to a significant level at the point of application providing an option for safe use of wastewater in agriculture. This could save fresh water for high value potable or non-potable use and enable farmers to manage water stress in the regime of climate change.

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Climate resilient agriculture to mitigate problems of waterlogged areas

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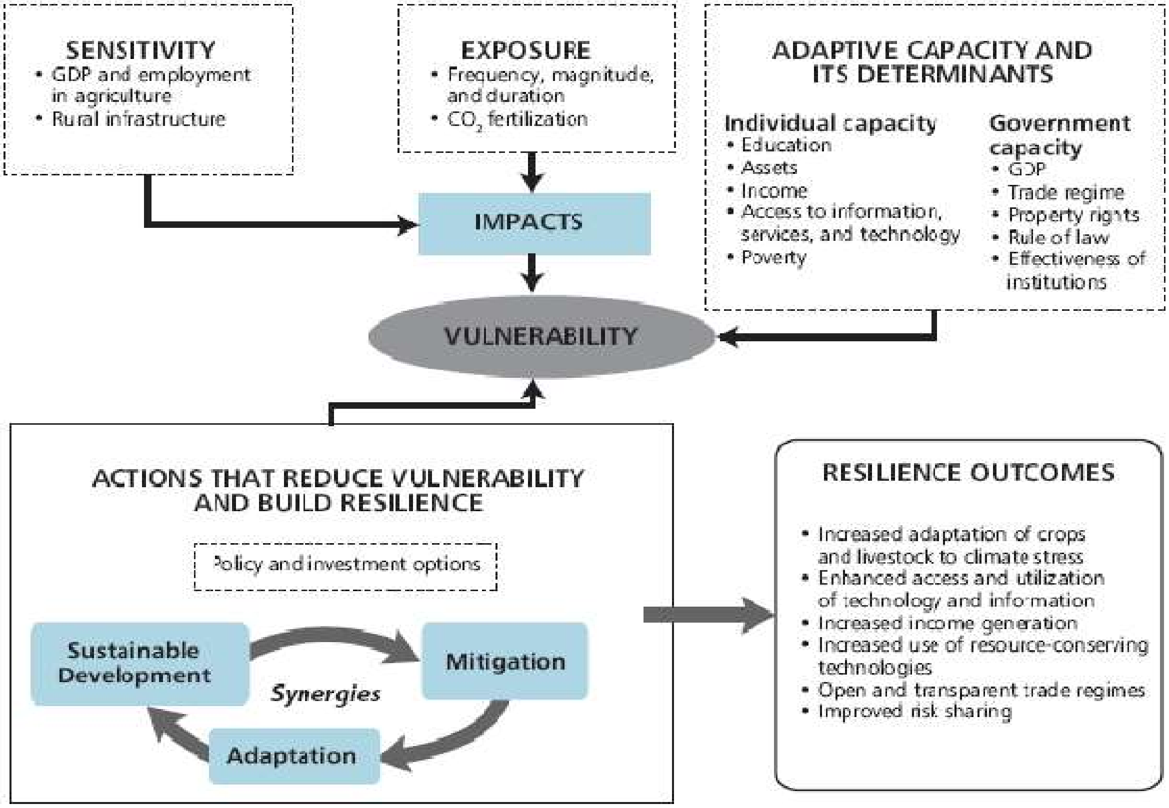
Introduction

The climate change effects are clearly perceived through more frequent visit of extreme weather events like drought, flood, cyclones, etc. If we categorize world into developing and developed nations, the impact of global climate change is expected to be more severe on developing world compared to developed world due mainly due to their poor capability to adapt to variability to changed climate scenario (IFPRI,ADB report 2009). The general impact of climate change on water resources which was brought out by Intergovernmental Panel on Climate Change (IPCC) in their third assessment report suggested intensification of global hydrological cycle influencing both surface and ground water supply (IPCC 2000). In recent past world experienced a global level food crisis when prices of major agricultural comodities, food grains increased significantly, bringing a sense of food insecurity and affecting access to food grain of millions of people. Adverse impact of changed climate on agriculture might make situation still acute, affecting food grain production. The direct linkage between climate and agricultural production have made situation urgent, where we have to look forward to strategies to reduce impact of adverse climate on agriculture ans a whole and on food production in particular especially for developing nations where majority of the people are directly or indirectly depend on agriculture for their livelihood. The concept of climate 'resilient' agriculture emerges from such background. The term resilience suggested "The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization,
and the capacity to adapt to stress and change" (IPCC 2007).

As agricultural production depends on management and usage of natural resources, for its achievements it relies significantly on services of both social as well as ecological sectors. Moreover long term sustenance of such production system will deterministically depend on resilience of both the system. The resilience of social system is influenced by several factors like individual house hold, communities and region depending on capacity of farmer to utilize assets or knowledge as well as different institutional services extended by government and other agencies. Income from farm is also a major determinant of social resilience especially in agrarian economy. Whereas the resilience of agricultural sector is determined by slowly changing parameters like farming system size, different parameters of changing climate, changed nutrient availability scenario, different land use pattern etc. Therefore road mapping of different steps for introduction of resilience to agriculture involves development of strategies to reduce vulnerability as well as to generate farm income for poverty reduction and improved livelihood. A schematic representation of stepwise development of strategies for resilience is presented below (IFPRI, ADB 2009).



The above conceptual framework schematically identifies influencing factors of climate change which are likely to affect agricultural production, their impact on societal sensitivity, and the concomitant adaptive strategies adopted for negotiating the impact of nature by the society both at individual level as well as at institutional level of government .Therefore the vulnerability or degree of susceptibility of a system to adverse effect of climate change including climate variability and extremes (IPCC2007) is influenced by three factors namely- Exposure, nature and duration of changed climate variables, sensitivity of the system in response to such exposures and adaptive capacity of the system both at individual as well as at government level. Hence it is important to parameterize different sources for vulnerability as well as their measurement in order to build resilience in agricultural sector. The different indicators for vulnerability in agriculture is given table below.

Table 1.Different vulnerability indicators for developing climate resilient agriculture.

Vulnerability Parameters	Indicator Source	Measurement Class
Exposure the biophysical impacts of climate change on agroecological systems	Biophysical indicators	Soil & Climate (temperatue, precipitation) Crop Calender Water availability & storage Biomass yield
Sensitivity (the degree to which a system is either beneficially or adversely affected by climate variability)	Agricultural system characteristics	Land resources Input & technology Irrigation share Production scale
Adaptive capacity (the ability of individual or institution to avoid potential damage, to take advantage of opportunities or to cope with consequent changes)	Socioeconomic data	Rural welfare Povety and nutrition Protection and trade Crop Insurance

After Tubiello and Rosenzweig 2008, adapted from IFPRI,ADB 2009.

Therefore the vulnerability has three dimensions i.e. (1) exposure or biophysical impact of climate change on agroecological systems (Tubiello and Resenzweig 2008). The exposure includes both spatial and temporal variation of events like drought, rain , higher temperature regime and also magnitude and duration of these events. On the beneficial side the increased biomass production mainly by C_3 species under enhanced CO_2 concentration scenario suggested positive biophysical impact due to exposure to changed climate scenario.

(2) The second dimension of vulnerability is sensitivity and suggests the degree to which system is affected due to climate variability either adversely or beneficially. It is complex concept as response of a system is dependent on both intrinsic factors and also the factors beyond it e.g. unprotected low lying coastal area will be more sensitive to flood than a walled area in same zone. Similarly a drought affected area with irrigation facility is likely to insensitive to impact of drought than a drought prone area without any irrigation infrastructure. Greater dependence on agriculture, rural population density, irrigated land and agricultural employment are other indicators for sensitivity of agriculture to climate change. (3) The third dimension of vulnerability is adaptive capacity or the capacity to avoid damage, taking advantage of opportunities and coping with consequent changes. Several socioeconomic variables determine the adaptive capacity like poverty rate, access to credit, farm income are monitorable parameters to determine adaptive capacity

The steps taken for reduction of vulnerability can be envisaged as either strategies for adaptation or strategies for mitigation. One of the important key adaptation and mitigation strategy is to develop a resilient agro-ecological system which actually determines the productivity of an agricultural system. When changed climate scenario is likely to interfere with the normal ecological services e.g. excess water situation in agricultural land, the resilient ecosystem will be in a position to take on such climate induced shock and resurrect after damage. The implementation of various technologies involving land modifications like raised and sunken bed (Singh et al 2005), pond based integrated farming system in deep waterlogged areas , adoption of ecologically suited crops like aquatic crop cultivation in waterlogged areas (Roy Chowdhury et al 2006), strategic cropping systems involving biological drainage (Roy Chowdhury et al 2011) use of submergence tolerant paddy cultivars like swarna sub-1 or deep water cultivars like ‘hanseswari’ has potential to sustain agricultural productivity in waterlogged or low lying flood prone areas (Roy Chowdhury *et al* 2016) integrated rice-fish culture (Mohanty *et al* 2008) and improve livelihood of the farmers in waterlogged areas (Ghosh *et al* 2011). Introduction of water chestnut based cropping system (Sahoo *et al* 2009, Brahmanand et al 2015) medicinal plants (Brahmanand et al 2011) , development of micro water resources waterlogged areas (Jena *et al* 2006) or pond based farming system in deep waterlogged areas (Kar *et al* 2010) are few successful options depending upon location specific requirement for improvement of productivity in low lying areas prone to submergence.

Raised and Sunken bed for Higher Productivity in Canal Command

Description of the technology: Alternate sunken and raised beds, each of 30 m length and 5 m width and 60 cm higher than the adjacent sunken beds are to be raised by putting the dugout soil over the adjacent strip. The top 20-30 cm. soil of the raised beds remains in unsaturated condition and allows cultivation of different vegetable crops. Brinjal-Okra, okra-brinjal or tomato-cowpea, pointed gourd+ snake gourd or pointed gourd+ bitter gourd, cabbage + snake gourd or pointed gourd + papaya were observed to be remunerative cropping systems for the raised beds. The rice or crops like taro (*Colocasia*) can be grown simultaneously in adjacent sunken beds where soil remains submerged. Fish spawn can also be raised up to fingerling stage in the sunken beds together with rice within 90 days. Application of FYM or compost @10 t/ha or growing *Sesbania* in sunken beds during dry season in the initial 1-2 years increases the fertility of the system.

Output and scalability: The technology is suitable for growing vegetable crops and rice or other crops like *Colocasia* in medium and low lands of eastern India. The cost of intervention per unit area is Rs. 50,000 ha. The adoption of the technology increased kharif paddy and pointed gourd yield from 4.2 to 5.2 t/ha and 4.24 to 4.74 t/ha, respectively along with fish yield of 1 t/ha. The technology can generate additional benefit of Rs. 70,000/ha/year compared to conventional technologies. The highest net return of Rs. 153,634 ha/yr. with a benefit cost ratio of 4.01 can be achieved from the system. The technology has been adopted by farmers of Balipatna village of Khurda district, Odisha. The technology has been developed and demonstrated in the farmers' field and is already in public domain.

Biological Drainage of Waterlogged Lands in High Rainfall Areas

Description of the technology: *Eucalyptus* was planted at inland sites and *Casuarina* at coastal areas due to their salt tolerance ability. The 30 cm tall saplings were planted at 4mx4m spacing on raised mound to avoid submergence of roots during monsoon six month before onset of monsoon. The space in between the biodrainage trees were utilized for cultivation of other crops *i.e.* paddy during *kharif* and watermelon, green gram, black gram, cow pea and groundnut during *rabi*season. In topographically depressed areas plantations tolerated both surface waterlogging during monsoon and subsurface waterlogging during rest of the season. In coastal areas, *Casuarina* vegetation tolerated waterlogged condition during monsoon and also showed resilience against cyclones in coastal areas.

Output and scalability: In *kharif* season paddy intercrop in side *Casuarina* or *Eucalyptus* vegetation produced upto 3.51 t/hagrain. In *rabi* season, intercrops like ground nut (yield upto 1.4 t/ha), watermelon (24.16 t/ha) showed better yieldt han non-biodrained areas. Accelerated drainage through biodrainage advanced watermelon cultivationin *rabi* season by 15-20 days with additional benefit of Rs.15,000 /hadue to better market price and avoiding market glut. The aquaculture intervention in the refuge at lowest point in the field gave yield of 1.35 t Indian major carp, grass carp and air breathing fish. From watermelon cultivation under *Casuarina* plantation profit was Rs.45, 500 /ha with B:C ratio of 3.67 (2009 prices). Under *Eucalyptus* groundnut cultivation gave Rs. 10,000/ha profit with B:C ratio of 2.0. *Casuarina* plantation gave an additional yield of upto 2.3 t/haof twig biomass through pruning of trees as fuel wood worth Rs.5500/ha as annual income to the farmer. Developed in collaboration with CADA, Govt. of Orissa, the technology is being popularized through line departments of State Government.

Fitting medicinal plants in rice based cropping system in waterlogged areas in post rainy season

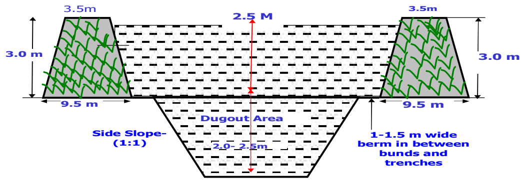
Description of the technology: In post rainy season, the land will be prepared for planting of stem cuttings of medicinal plants like *Coleus forskholii* and *Eclipta alba*. Fertilizer N, P_2O_5 and K_2O of 60 kg/ha, 50 kg/ha and 50 kg/ha are required for *Coleus forskholii*. Cuttings may be planted at a spacing of 60x45 cm and the cost of cuttings is Rs.8000/ha. Two irrigations may be given at crop critical growth stages like tuber initiation and tuber development.

Output and scalability: The yield potential of *Coleus forskholii* in post rainy is found to be 900 kg/ha to 1200 kg /ha. The cultivation of coleus in post rainy season in waterlogged ecosystem results in the gross water productivity (Rs. 13.3/ m^3) and net water productivity (Rs. 5.42 /m^3) and provides additional net returns about Rs.32,000/- to Rs.44,000/ha (2009 prices).

Pond Based Farming System for Deep Waterlogged Areas

Description of the technology: In such areas pond based farming technology (deep water rice in *kharif* + salt tolerant vegetables like watermelon, ladies finger, spinach, chili in winter + on-dyke vegetables-fruits + fish inside pond) was developed in deep waterlogged areas (1-2.5 m water depth) of Puri district, Odisha. micro-water harvesting system was designed (in Fig) and implemented pond based farming system in the coastal areas of Puri district, Odisha. During rainy season waterlogging tolerant rice varieties were grown in command areas of each pond to mitigate deep waterlogged ecosystem. After harvesting rice during dry season, second crops were grown on the same land utilizing supplemental irrigations from the harvested rainwater on the pond. The cost of intervention is Rs. 65,000/ haof net command area (2011 prices).

Output and scalability: The technology can generate additional net return of Rs. 25,000-30,000 /ha/year with increased water productivity of Rs. 7.2 /m^3 from the system. In a pond based farming area of 0.63 to 0.82 ha, net returns of Rs. 19807 to Rs. 24571 were obtained in 2008-09. In the 2009-10, the productivity was still higher which varied from Rs. 28317 to Rs. 31392 per ha from same size of ponds because of additional returns from medicinal plants. From deep water rice farmers are getting 2.4 – 2.8 t/ha yield but success of getting rice crop depends on distribution of monsoon rainfall. The technology has potential to generate higher income due to intensive cropping with harvested water along with fisheries, and on-dyke horticulture. Farmers will have also access to water for timely transplanting of rice during post flood period. Thus the non-productive waterlogged area can be converted into a productive and profitable system. The deep water rice represents 4.9 Mha areas of Eastern India and the technology has potential for adoption in the area.



Design of a pond for deep waterlogged area

Use of suitable paddy cultivars in seasonal deep waterlogged areas

Description of the technology: The deep water rice cultivars like 'Hangseswari', 'Saraswati', 'Ambika', 'Sabita' were cultivated in seasonal deep waterlogged areas in Puri district in*kharif* season. The aquaculture was taken up in the adjacent pond.

Output and scalability: Improved deep water rice cultivar 'Hanseswari' produced 2.4-2.5 t ha^{1} yield in *kharif* season in deep waterlogged situation which was about 200% higher than of local cultivars. The State Government of Orissa released 'Hanseswari' to put under State Seed Chain and adopted for seed production in State Farm . By *kharif*2009 it was revealed that about 180 farmers in 105 ha of land adopted deep water rice production technology. The technology can be replicated in 3.4 Mha deep water areas of eastern India. Package of practices for cultivation of aquatic medicinal plants, Bach (*Acorus calamas*) was standardized and implemented in farmers' field of seasonal waterlogged areas with deep water rice.

Integrated Water Chestnut Cultivation and Aquaculture Technology

Description of the technology: Depth of water between 0.5- 1.5 m is favorable for water chestnut cultivation and planting is done from early June to 1st week of July. Before planting seedlings from nursery is given a combined treatment of fungicide and insecticide *i.e.* captan or carbandazime @0.1% with chloropyriphos @0.2% by dipping overnight (12 hour). Three to four young seedlings are loosely tied at the bottom in a knot. The knot is planted in the muddy bottom of the water body with gentle push with toe. At a spacing of 1.5m x 1.5m about 4400 bundles/ha of seedlings (each containing 3-4 seedlings) are required.

In fish-water chestnut integration, Indian Major Carp (IMCs), fingerlings of 35±5 g MBW size can be released during 2nd week of July at stocking density of 3000/ha, whereas cat fish (like Magur;*Clarius batrachus*) of 15 g MBW can be released with 5000-7500/ha stocking density during 1st week of August. In this co-production system fish gets natural food even in presence of supplemental feed. About 25-30% feed can be reduced during each meal. It also results an increase in gross and net water productivity and net water productivity.

Output and scalability: The assessment of impact of the technology on farming situation and livelihood of farmers was on 35 farmers adopting integration of water chestnut (WCN) cultivation and aquaculture in Balasore district The integration of aquaculture with water chestnut increased the average income of farmers by about Rs. 76000 /ha/year. The total average income of the farmers from the farming has increased by more than 50% after adoption of integrated water chestnut cultivation with aquaculture technology. The technology of integrated cultivation of fish and water chestnut was demonstrated to farmers of Balasore, Bhadrakh and Jagatsinghpur district in coastal Odisha. The shallow low land ecosystem provides ideal environment for cultivation of this crop during *kharif* season.

Conclusion

Therefore milestones for achieving goals for building resilience in agriculture would be apparent through following monitorable indicators

1. Increased adaptation of crops and livestocks to climate stress
2. Greater access and better utilization of state of the art technologies
3. Increased generation of income for better livelihood
4. Use of resource conservation technologies
5. Open and transparent trade regime
6. Better risk taking ability

However present knowledge status for building resilience in agriculture has to give more emphasis on changes in pest and disease incidence (Rosegrant et al 2007) and attack pattern on crop and live stocks under changed climate scenario.

The impact of degraded land and impact of changed climate on pastures and their implication on livestock production, the impact of water quality parameters due to changed climate scenarios and its impact on aquaculture are areas which warrants further attention. Generation of information in these areas and their subsequent integration in the models would further consolidate robustness to the framework to build up resilience in agriculture.

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Characterization of Soil Physical Property

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1.0 Introduction

In the past, the focus was on increasing food production to attain self-sufficiency. But, indiscriminate use of resources has led to unsustainable production, environmental pollution, decreasing factor productivity, decreasing soil organic matter (OM) storage, degradation of soil health etc. especially under high intensity agriculture of the post green revolution era (Bandyopadhyay et al., 2009). So, in the present condition, sustaining agricultural productivity at higher level is the key issue in Indian agriculture to meet the increasing demands of food and fiber for the growing population. Maintaining soil health/quality is indispensable for sustaining the agricultural productivity at higher level (Bandyopadhyay et al., 2009). Though, both soil health and soil quality are synonymous, soil health is a qualitative term and often used by producers, whereas soil quality is a quantitative term and mainly used by scientists Soil quality is defined as the capacity of soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain the environmental quality and promote plant, animal and human health (Doran and Parkin, 1994). Soil quality includes three groups of mutually interactive attributes, *i.e.*, soil physical, chemical and biological quality, which must be restored at its optimum to sustain productivity at higher levels in the long run. Soil Physical Quality/Health is the ability of a given soil to meet plant and ecosystem requirements for water, aeration, and strength over time and to resist and recover from processes that might diminish that ability (Doran and Parkin, 1994). Concepts of soil physical quality/health can be applied to individual soil horizons, profiles, or areas classified to a common soil type.

It is well known fact that unless the soil physical properties are maintained at its optimum level, the genetic yield potential of a crop cannot be realized even when all the other requirements are fulfilled. The characteristics like supporting power and bearing capacity, tillage practices, moisture storage capacity and its availability to plants, drainage, ease of penetration by roots, aeration, retention of plant nutrients and its availability to plants are all intimately connected with the physical properties of soil. Hence, for satisfactory plant growth, it is essential that the soil provides a favourable soil physical environment for root development that can exploit the soil sufficiently to provide the plant's needs for water, nutrients and anchorage.

The different soil physical properties which significantly influence the crop growth are texture, structure, density, porosity, water content, strength (consistency),colour, temperature and aeration etc. Characterization of soil physical properties are essential for better management of soil physical environment and hence sustainability of food production.

2.0 Soil texture

The relative proportions of soil separates (sands, silts, and clays) in a particular soil determines its soil texture. Since the proportion of each size group in a given soil (the texture) cannot be easily altered, it is considered a basic property of a soil.

2.1 Particle size classification

Many particle size classification schemes exist, each of which having different class limits for each size fraction. The classifications of the International Union of Soil Science (IUSS) and United States Department of Agriculture (USDA) are widely followed (Table 1).

Table 1: Classification of soil particles according to size

Soil separate name	USDA diameter range (mm)	Soil separate name	IUSS diameter range (mm)
Gravel	>2.0	Gravel	>2.0
Very coarse sand	2.0-1.0		
Coarse sand	1.0-0.5	Coarse sand	2.0-0.2
Medium sand	0.5-0.25		
Fine sand	0.25-0.10	Fine sand	0.2-0.02
Very fine sand	0.10-0.05		
Silt	0.05-0.002	Silt	0.02-0.002
Clay	<0.002		<0.002

2.2 Influence of soil separates on soil properties and behavior of soils

In general, sandy soils are have low water and nutrient holding capacity, low OM content, little or no swelling and shrinkage, poor sealing properties for ponds and dams, high leaching of nutrients and pollutants. The fine sands are easily blown by wind, while coarse sands resist erosion by water. The silty soils have medium to high water and nutrient holding capacity, moderate aeration, slow to medium drainage, medium to high OM content, usually good supply of plant nutrients, moderate leaching of pollutants and nutrients. These soils are easily blown by wind and are susceptible to water erosion, easily compacted, have little swelling and shrinkage and are moderately difficult to till after rain. The clayey soils have high water and nutrient holding capacity, are poorly aerated, have very slow drainage unless cracked, high to medium OM content, medium to excellent supply of plant nutrients and high swelling and shrinkage. These soils resist wind erosion; aggregated clays also resist water erosion. They are easily compacted and retard leaching of nutrients and pollutants. A loam soil contains a balanced mix of coarse and fine particles with properties intermediate among those of sand, silt, and clay. A loam soil is often considered to be the optimal soil for plant growth and agriculture.

2.3 Soil textural classes

The textural class is determined on the basis of different proportions of sand, silt and clay by using the textural triangle (IUSS). Within each of the three broad groups so soil textural classes, i.e., sandy soils, loamy soils and clayey soils, specific classes had been devised based on the relative proportion of sand, silt and clay particles. In sandy soils, the sand separates make up at least 70 % and the clay separates 15 % or less of the material by weight. Two specific classes are recognized – sand and loamy sand. The loamy soil group contains many subdivisions. An ideal loam is defined as a mixture of sand, silt and clay particles that exhibit the properties of these separates in about equal proportions. The various subdivisions are: sandy loam, loam, silt loam, silt, sandy clay loam, silty clay loam and clay loam. In clayey soils, the characteristics of clay separate are distinctly dominant. Three distinct classes exist, viz., sandy clay (at least 35 % clay), silty clay (at least 40 % clay and 40 % silt) and clay (at least 40 % clay and less than 40 % silt).

2.4 Determination of soil texture

Soil texture can be determined by (i) Feel method and (ii) Mechanical analysis method.The common field method of determining the textural class of a soil is by its feel (Brady, 1990).

This is done by rubbing a sample of soil, usually in a moist to wet condition, between the thumb and fingers. The “feel” method is used in soil survey and land classification. The accuracy in determination of soil texture by feel method depends largely on experience. Soil texture determination in laboratory is referred as Particle size analysis or mechanical analysis. The procedure used to separate a soil into various size groups from the coarsest sand, through silt, to the finest clay, is particle-size analysis (mechanical analysis). Particle size analysis (PSA) is done by using sieves to mechanically separate out the very fine sand and larger separates from the finer particles. Sedimentation method is employed for separating out the finer particles. After complete dispersion of the soil sample in an aqueous solution, the settling velocity of the particles or the density of the suspension from which the particles are settling is measured based on the principles of Stokes’ law. The international pipette method and the hydrometer method are usually used for mechanical analysis of soils.

3.0 Soil structure

The term “soil structure” refers to the grouping or arrangement of primary (sand, silt, clay fraction) and secondary particles (aggregates or peds) into a certain structural pattern. Soil structure greatly influences many soil physical processes such as water retention and movement, porosity and aeration, transport of heat, etc. The various soil management practices such as tillage, cultivation, application of fertilizer and manures, amendments (liming, gypsum) and irrigation, bring about changes in soil structures that influence other soil properties, thereby affecting root growth, water and nutrient uptake, crop growth and yield.

3.1 Classification of soil structure

The soil structure is classified into (i) the types (shape and arrangement of peds); (ii) the classes (size of the peds) and (iii) the grades (distinctiveness and durability of the peds).

3.1.2 Types of soil structure

Based on the shape and arrangement of peds or aggregates, soil structure is classified into four principal types - plate-like, prism-like, block-like and spheroidal with a few subtypes in each category (Fig. 2).

3.1.2.1 Plate-like (platy): In this structural type the aggregates (peds) are arranged in relatively thin horizontal plats, leaflets, or lenses. It may occur in any part of the profile.

3.1.2.2 Prism-like (columnar and prismatic subtypes): These subtypes are vertically oriented aggregates occurring commonly in subsurface horizons of semi-arid and arid regions. When the tops of the prisms are rounded, the term columnar is used. When the tops of the prism are plane, level, and clean cut, the structural pattern is designated prismatic.

3.1.2.3 Block-like (blocky and subangular blocky subtypes): These aggregates look like blocks, irregularly six-faced and having their three dimensions more or less equal. When the edges of the cubes are sharp and the rectangular faces distinct, the subtype is designated blocky. When subrounding has occurred, the aggregates are referred to as subangular blocky. Formation of these types of structures is influenced by root penetration, soil drainage, and aeration. They mostly occur in the subsoil.

3.1.2.4. Spheroidal (granular and crumb subtypes): Rounded peds or aggregates are placed in this category. They usually lie loosely and are separated from each other. Relatively nonporous aggregates are called granules and the pattern granular. However, when the granules are especially porous, the term crumb is applied. These two types of structures occur in surface soils high in OM, in grasslands and are greatly influenced by farming practices.

3.1.3 Class of soil structure

The various sizes of peds are designated by class of soil structure as very fine, fine, medium, coarse and very coarse. The size classes for different shapes of structure are presented in Table 2.

3.1.4 Grade of soil structure

The grade of the soil structure are evaluated by the distinctness, stability, or strength of the peds. Three structural grades are used, (i) weak: peds are barely distinguishable in part of the moist soil; only a few distinct peds can be separated from the soil mass, (ii) moderate: peds are visible in place; many can be handled without their breaking, and (iii) strong: most of the soil mass is visible as peds, most of which can be handled with ease without their breaking.

The soil is structureless when there is no observable aggregation or there is no line of cleavage indicating the presence of peds, e.g. single grain soil particles in sand dune areas and massive structure in puddled soil from a rice field.

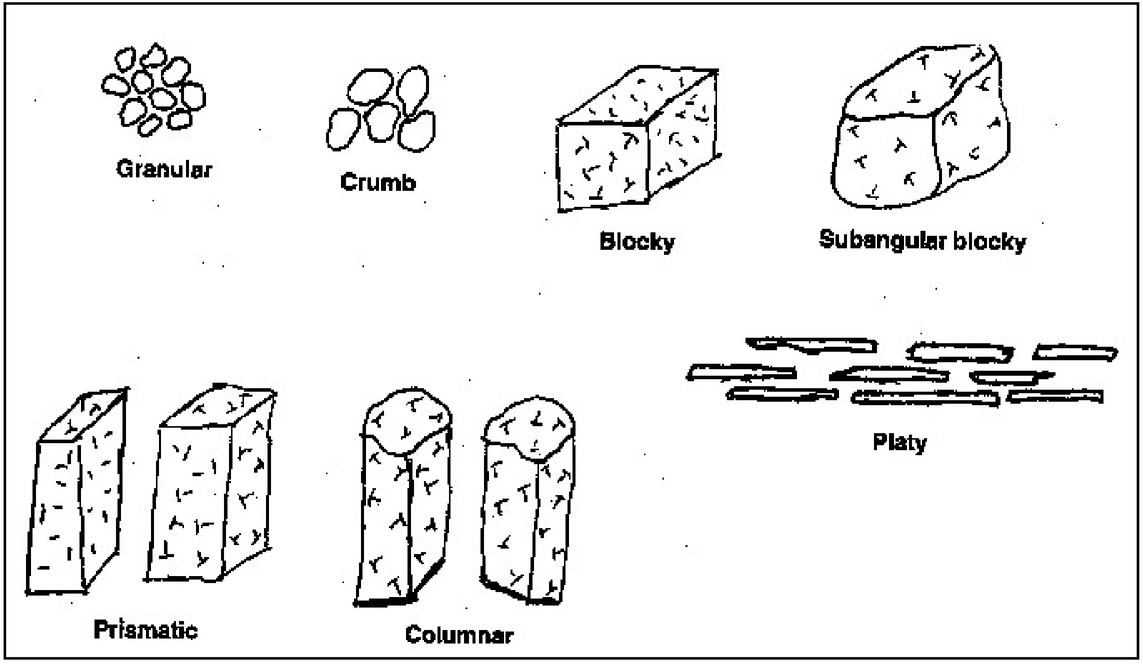

Fig. 2: Various structural types found in soils

Table 2: Shapes and size classes of soil structure

Size class	Shape of structure						
	Platy	Prismatic	Columnar	Angular blocky	Subangular blocky	Granular	Crumb
Very fine	<1	<10	<10	<5	<5	<1	<1
Fine	1-2	10-20	10-20	5-10	5-10	1-2	1-2
Medium	2-5	20-50	20-50	10-20	10-20	2-5	2-5
Coarse	5-10	50-100	50-100	20-50	20-50	5-10	NA
Very coarse	>10	>100	>100	>50	>50	>10	NA

3.2 Evaluation of soil structure

Soil structure can be evaluated by direct and indirect methods. The direct methods involve the microscopic evaluation in the laboratory and the macroscopic or field observation. It characterizes shape, size and arrangement of soil aggregates. The indirect methods of soil structure evaluation involve measurement of (i) size distribution of stable aggregates, (ii) stability of aggregates, and (iii) soil property which is a function of soil structure.

3.2.1 Size distribution of stable aggregates: This is done either by dry or by wet sieving techniques. Dry sieving technique determines the proportion of aggregates which is stable against vibrating action simulating the scouring effect of wind is determined. The wet sieving technique (van Bavel, 1953) is generally used for determining the size distribution of water stable aggregates. The different indices used for characterizing the size distribution of stable aggragates are Mean Weight Diameter (MWD), Change in Mean Weight Diameter (CMWD), and Geometric Mean Diameter (GMD). Also, the percentage of aggregates greater than 0.25 mm diameter is a widely used index. The MWD gives an estimate of weighted percentage of average size of all the aggregates. The proportion by weight of a given size fraction of aggragates to the total sample weight is multiplied by the mean diameter of that fraction. The sum of these products for all size fractions is called the MWD. The CMWD is the difference in MWD of dry and wet sieving of aggregates. Within certain limits, the lower is the CMWD, the better is the soil structure. In GWD, the weight of the aggregates in a given size fraction is multiplied by the logarithm of the mean diameter of that fraction. The sum of these products for all the size fractions is divided by the total weight of the sample.

3.2.2 Measurement of stability of the aggregates: This is evaluated by the degree to which soil aggregates resist dispersion. The different indices used for stability of the aggregates are stability index (SI), structural coefficient (SC), dispersion coefficient (DC) and water drop method. SI is the difference between per cent clay and silt as determined by the mechanical analysis and that obtained by suspension of soil sample in water. The greater the difference, the better is the soil structure. SC is given by (D-S)/S, where, D is the percentage of particles of <0.25 mm diameter, as determined by the mechanical analysis and S is the percentage of aggregates smaller than 0.25 mm diameter, as determined by wet sieving technique. The higher is this value, the better is the soil structure. DC is the ratio of clay dispersed in water to that dispersed as in mechanical analysis, multiplied by 100. The lower the value, the higher is the structural stability. In the water drop method, stability is measured by the number of drops (4.7 mm), falling from a height of 30 cm on aggregates, that are required to completely disrupt the aggregates. The greater the number of drops required, the better is the stability.

3.2.3 Measurement of soil properties: A number of soil properties such as bulk density, infiltration rate, hydraulic conductivity, rate of aeration and aeration porosity, available soil water and degree of soil compaction are used as indicators of the suitability of soil structure for plant growth.

4.0 Density

Density is the mass of an object per unit volume. Two density measurements- particle and bulk density- are common for soils.

4.1 Particle density (PD): Particle density is the ratio of total mass of soil solids to the total volume of soil solids. The measurement doesn't include water weight or pore (air) space. It is expressed as g/cm^3 or Mg/m^3. Particle density depends on the chemical composition and crystal structure of the mineral particles and is not affected by pore space. Although there is considerable range in the density of the individual soil minerals, the figures for most mineral soils usually vary between 2.60 and 2.75 Mg/m^3.

4.2 Bulk density (BD): BD is defined as the mass (weight) of a unit volume of dry soil. This volume includes both solids and pores. The BD is expressed as g/cm3 or Mg/m3. BD of soil is influenced by soil texture, structure, OM content and land management practices. The BD of the coarse textured soils varies from 1.40 to 1.80 g/cm^3 and of fine textured soils normally ranges from 1.10 to 1.40 Mg/cm^3. Increase in OM content lowers the BD of soil. High BD indicates compactness of the soil.

Particle density is determined using Archimedes principle using a pycnometer whereas soil core method is most widely used for the determination of bulk density in the field.

5.0 Soil porosity

Pore spaces (voids) in a soil consists of that portion of the soil volume not occupied by solids, either mineral or organic. Pores in soil are the result of irregular shapes of primary particles and their aggregation; the forces of penetrating roots, worms, and insects; and of expanding gases entrapped by water. Under field conditions, pore spaces are occupied at all times by air and/or water. The total pore space in sandy surface soils show a range of 35-50 % whereas medium- to fine-textured soils vary from 40-60 % and even more in cases of high OM and marked granulation. Two types of pore spaces- macro and micro-occur in soils. Although there is no clear-cut demarcation, pores less than about 0.06 mm in diameter are considered micropores and those larger, macropores. The macropores allow ready movement of air and percolating water. In contrast, the micropores are mostly filled with water in a moist field soil and don't permit much air movement into or out of the soil. The water movement is also slow.

5.1 Characterization of porosity:

Porosity (f) is the ratio of total volume of pore space to the total volume of soil. Porosity is related to the BD and PD of the soil and is given below by the equation:

$$f = \frac{PD-BD}{PD} \ldots\ldots\ldots\ldots\ldots (1)$$

The pore spaces in a soil contain both capillary and non-capillary pores which remain filled with water when the soil is saturated. As the soil dries, the non-capillary pores are emptied first. Thus, capillary porosity is determined by finding the volume of water retained in soil at 50 cm tension. The non-capillary porosity is determined by substracting the value of capillary porosity from the total porosity value. Capillary porosity are important since water retained in these pore spaces are used by the plants for their growth. Pore size distribution can be characterized by soil water characteristics curve.

6.0 Soil water

Water is essential constituent of the terrestrial ecosystems. In soil, water is held on the surfaces of its particles as adsorbed water and in the intervening voids as pore water. Water is requird to meet the evapo-transpiration demand of the plants. Water acts as solvent that together with the dissolved nutrients makes up the soil solution from which plants absorb essential elements. Soil moisture controls two other important factors essential to normal plant growth- soil air and soil temperature. Water is also important for various activities of the soil microorganisms leading to the decomposition of organic matter and fixation as well as release of soil nutrients. The soil properties like consistency, compactability, strength, swelling and shrinkage are strongly influenced by its water content. So, in order to understand the availability of soil water as well as its role in controlling various soil properties and processes, it is very essential to study the water status of the soil.

The amount of water present in soil at a particular point of time is called soil water content. When it is expressed on mass basis, it is called water content by weight and is equal to the mass of water divided by the dry mass of the soil expressed as per cent. It is also expressed on volume basis as volume of water divided by the total volume of soil multiplied by 100.

Soil water content is measured directly by the gravimetric method. The other commonly used indirect instruments are neutron moisture meter and TDR.

7.0 Soil aeration

The aerobic respiration in roots of plants and soil microorganisms involves continuous consumption of O_2 and evolution of CO_2. An inadequate gas exchange may decrease the growth and yield of crops due to decreased metabolic processes of roots. Soil aeration refers to the exchange of O_2 and CO_2 between soil pore spaces and atmospheric air. This process controls the deficiency of O_2 consumed during respiration of plant roots and soil microorganisms and prevents toxicity of CO_2 evolved during respiration in the soil air. The composition of soil air is more or less similar to that of the atmospheric air except the CO_2 concentartion which is 10 times higher than that of atmospheric air. Soil characteristics, crop, tillage, OM, biological activity, season, etc. greatly affect composition of soil air.

7.1 Characterisation of soil aeration

Soil aeration is quantified by redox poteential method and Oxygen diffusion rate meter method.

The oxidized or reduced state of chemical elements in the soil gives an idea about its aeration status. If Eh value is positive and high, strong oxidizing conditions exist. If it is low and even negative, elements are found in reduced forms. In a well-drained soil, the Eh is in the 0.4-0.7 V range. As aeration is reduced, the Eh declines to a level of about 0.30-0.35 V when gaseous oxygen is depleted.

The Oxygen diffusion rate (ODR) largely determines the rate at which O_2 can be replenished when it is used by respiring plant roots or by microorganisms or when it is forced out of the soil pores by water. It is measured by ODR meter. In general, the critical ODR value of soils in which roots of many plants will not grow is of the order 20×10^{-8} g/cm^2/min.

8.0 Soil temperature

Soil temperature greatly affects the physical, biological, and chemical processes occurring in that soil. In cold soils, biological decomposition can come to a near standstill, thereby limiting the rate at which nutrients such as nitrogen, phosphorus, sulfur, and calcium are made available. Also absorption and transport of water and nutrient ions by higher plants are adversely affected by low temperature. Similarly, seed germination, emergence, root and shoot growth are slow under unfavorable temperature conditions. Seeds of most of the crop species germinate within a reasonable time period between 10 to 35 ^{0}C. The temperature optima for root growth of most crop species is between 20 to 25 ^{0}C. The plant growth is initiated only when the minimum temperature is reached and rate of growth increases up to the optimum temperature, followed by a decline at the maximum tolerable temperature. Soil temperature is basically controlled by the factors which affect energy balance on and within the soil. Incoming and outgoing solar radiations, albedo, soil colour, slope, soil composition, mulches and vegetation, irrigation and drainage, and evaporation affect the soil temperature.

Soil temperature can be measured by both contact and non-contact methods. The contact type method includes measurement using thermometers in which thermal expansion of a solid (eg. bimetallic strip thermometers), liquid (eg. mercury or alcohol in glass thermometers) or gas (eg. constant pressure or constant volume thermometers) is measured. Other common contact type thermometer are based on the change in electrical properties of the material with change in temperature (eg. thermistors and thermocouple thermometers). In most of the commonly used contact methods, changes in temperature are recorded using mercury in glass thermometers, thermistors and thermocouple thermometers. The non-contact type methods include optical pyrometers, total intensity radiometers, and infrared thermometers.

9.0 Soil consistency

Soil consistency is a term used to describe the resistance of a soil at various moisture contents to mechanical stresses or manipulations. It is a composite expression of those forces of mutual attraction among soil particles that determine the ease with which a soil can be reshaped or ruptured. It is commonly measured by feeling and manipulating the soil by hand or by pulling a tillage instrument through it. The consistence of soils is generally described at three soil moisture levels: wet, moist, and dry. Terms used to describe soil consistence at these three moisture levels are shown in Table 3.

Table 3: Terms used to describe the consistencies of the soil

Wet soils			
Stickiness	**Plasticity**	**Moist soils**	**Dry soils**
Non-sticky	Non-plastic	Loose	Loose
Slightly sticky	Slightly plastic	Very friable	Soft
Sticky	Plastic	Friable	Slightly hard
Very sticky	Very plastic	Firm	Hard
		Very firm	Very hard
		Extremely firm	Extremely hard

Source: Brady, 1990

10.0 Soil colour

Soil colour often gives a ready clue to its condition and some important properties. Soil colour varies from place to place in the landscape. Within a soil profile, the colour may change with depth through the different horizons. Even within a single horizon, colour may vary from spot to spot. Most important factors influencing the soil colour are mineralogy and chemical constituents, OM content, soil moisture, soil structure and particle size.

For determination of soil colour, standard system using Munsell colour chart is used. The three variables that combine to give colour are hue, value and chroma. Hue is the dominant spectral colour and is related to wavelength of light. Value refers to the relative brightness (lightness or darkness) of the colour and is a function of total amount of light reflected. Chroma is the relative purity or strength (intensity) of the dominant spectral colour.

11.0 Conclusion

Characterization of soil physical properties is required for assessment of soil physical health. Management of soil physical health is essential for continuously increasing and sustaining high crop productivity level. This can be achieved by adoption of site specific technologies *viz*., optimum tillage practices and mulching, use of suitable cropping system, amendment of acid soils and salt affected soils and amelioration of soil physical constraints, efficient use of organic manures and fertilizers, which can improve the soil physical health. The improvement of soil health, in turn, will lead to efficient use of inputs and help in sustaining agricultural production at the desired levels. As the physical indicators of soil quality also influence the chemical and biological properties of soil, these three are not mutually exclusive, rather these are interactive. This demands wider recognition to soil physical properties than what it has received so far. Some of the crucial soil physical properties along with soil biological properties should be included in the ambitious soil health card mission of the Govt. of India to make it holistic and effective

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Freshwater carp polyculture: enhancing water productivity under changing climate scenario

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Introduction

Global aqua-food and nutritional security must be achieved through increased production, improved nutritional quality of food produced. An increase in aqua-food production must take place in a context where resources necessary for aquaculture, such as land and water, are even scarcer in a more crowded world, while the world is required to change the ways it conducts economic activities in the face of global climate change. The rapid expansion of global aquaculture production has continued with no sign of reaching its peak: during the past three decades, global aquaculture production expanded at an average annual rate of over 8%, from 5.2 million tons in 1981 to 70.3 million tons in 2014. Global fish production has grown steadily in the last five decades, with food fish supply increasing at an average annual rate of 3.2 percent, outpacing world population growth at 1.6%. The dynamism of Indian aquaculture and capture fisheries sector has been marked by 12-fold increase in fish production in just six decades, i.e. 9.57 million tons in 2013-14. This resulted in an average annual growth rate of 4.5% over the years, thus putting India on the forefront of the global fish production scenario, only after China.

The three Indian major carps, *Catla catla*, *Labeo rohita* and *Cirrhinus mrigala* contribute to the extent of 70 to 75 percent of the total fresh water fish production, while silver carp, grass carp, common carp, and catfishes contribute the rest. Currently, only about 40 percent of the available potentially suitable area of 2.36 million hectares of ponds and tanks has been utilized under freshwater aquaculture. The national mean production levels from ponds has gone up from 600 kg/ha/year in 1974 to 2900 kg/ ha/ year at present, although there are examples of higher production levels up to 8–12 tons/ ha/ year.

However, under the changing climate scenario of recent years, water scarcity has posed serious challenges to aquaculture and ecosystem sustenance, along with the threat from the population growth expected to reach 9.6 billion by 2050. In fact, uncertainty in monsoon rain due to climate change and limited availability of freshwater resources necessitate wise-use of water resources in aquaculture and warrants a more holistic approach to water management. Since, aquaculture has been criticized widely for wasteful use of water resources, efforts to enhance productivity with less water are critical to averting a crisis in future. Competition over freshwater resources has been increasing due to increased demand for agriculture to feed the growing population, along with industrial demands and the growing economy. The estimated global water withdrawal will grow from 4500 billion m^3 $year^{-1}$ presently to 6900 billion m^3 $year^{-1}$ by 2030 and the estimated total water withdrawal in freshwater aquaculture is 16.9 m^3/kg production, representing, 3.6% (429 km^3/yr) of flowing water globally. In India, estimated utilizable water resources is 668 billion cubic metre (BCM). The consequence will be alarming as the projected demand of even 897 BCM, corresponding to low demand scenario, cannot be met even after full development of utilizable water resources. Furthermore, in aquaculture sector, carp aquaculture is water-intensive and its future growth would be constrained by the freshwater availability.

However, as in agriculture, there is considerable scope for better integration of fisheries and aquaculture with water management systems to improve water productivity. A range of technical options is available to increase aquacultural water productivity for a particular situation or hydro-ecological condition. The two major requirements in improving aquacultural water productivity are the blue water required for culture and the input management. Presently, on-farm water use in aquaculture can be as low as 500–700 l in super-intensive re-circulation systems and as high as 45,000 l of water per kilogram of produce in extensive pond system. The technology developed for composite fish culture in ponds/ tanks in which more than one type of compatible fishes are cultured together, is the most advanced and popular now a days in the country. Any perennial fresh water pond/ tank retaining water depth of more than 1.5 metres can be used for composite fish culture purpose. Even seasonal ponds/ water bodies/ WHSs can also be utilized for short duration fish culture.

Composite fish culture-based agriculture and integrated fish farming not only accommodates crop diversification, enhance productivity, generate employment opportunity, increase income and provide nutritional security to resource poor farming community but also distribute the risk (both biological and economic), since two or more subsystems are involved instead of a single-commodity farming system. However, water productivity in this system can further be improved with scientific manipulation/ adjustment in stocking density, feed and water quality management, periodic growth and health monitoring, and finally input management. Practices not directly related to water management also impact water productivity because of interactive effects such as those derived from improvements in soil fertility, pest and disease control, species/ crop selection or access to better markets.

Composite fish culture/Polyculture

The most successful system of inland aquaculture is the polyculture (composite fish culture) of three Indian major carp species – *C. catla, L. rohita and C.mrigala* along with three Chinese carps (non-predatory, fast growing and compatible with IMCs) viz. silver carp (*H. molitrix*), grass carp (*C. idella*) and common carp (*C. carpio*). Indian carps such as *Catla catla, Labeo rohita, Cirrhinusmrigala,* and *Labeo calbasu* are cultured in the northern belt whereas *Labeo fimbriatus, L. kontius, Cirrhinus cirrhosa,* etc. in the southern belt of the country. Their farming is widespread and thus the systems differ according to the availability of the species, market demand, local consumer preferences etc. In general, in a pond, the surface is occupied by floating organisms like plankton, the column region with live and dead organic matter sunk from the surface and the bottom with detritus or dead organic matter. The different trophic levels of the pond can be utilized for increasing the water productivity and profitability of fish culture. Therefore, composite fish culture is a polyculture system in which compatible fishes of different species having different feeding habits are selected and grown under one aquatic environment in the pond to exploit all types of food available in the different regions of the pond for maximizing fish production.

The aquatic vegetation, plankton, decayed organisms and other debris available in the surface, middle and bottom water layers are utilized as feed by the stocked surface, column and bottom feeder fishes. The best results in terms of fish production in this system results not only through a judicious combination of species, but also due to appropriate management techniques including pond fertilization, supplementary feeding and health care. On the basis of growth performance of different species, modifications are often made in stocking density, species ratio, fertilization schedule and supplementary feeding programme in different agro-climatic conditions.

The carp culture system as a whole is operated as a three-tier culture system where the practices are adopted for rearing fish during their different stages till they are harvested. Spawn (post larvae) are reared up to fry (2–3 cm) stage in nursery ponds, fry to fingerlings (8–12 cm) in rearing ponds and finally fingerlings to table-size fish (> 700g) in composite fish culture ponds or stocking ponds. Relatively smaller, seasonal ponds are mainly used for rearing spawn to fry stage and harvested after 2–3 weeks. Several crops (3–4) of fry are usually taken during the season. Pond fertilization by cattle manure and feeding with 1:1 mixture of oil cakes and rice bran is the usual practice. Fry raised in nurseries are reared up to fingerlings in slightly bigger ponds (0.05 – 0.1 ha) of seasonal or perennial in nature. Fingerlings are removed after 3 months and stocked in composite fish culture grow-out ponds.

Initially, under this system, average productions were around 1000 kg/ha/year. After extensive experimentations, the average production rate has been increased by 2-3 times. However, much higher production than this (10-12 t/ha/year) is also reported from commercial farmers of Andhra Pradesh and Punjab. Though possible, productions at this level not only deteriorate the pond productivity but also enhance the associated risk factor many fold. Therefore, a moderate production target with out any significant environmental degradation is advisable. A production as high as 3000 - 3500kg/ha/5-6 months (two crops a year, i.e., 6-7 t/ha/yr) at farmer's field (with technical intervention of DWM, Bhubaneswar) has recently been obtained by stocking Indian major carps @ 7,500 fingerlings (70-85g size)/ha in the ratio of 30:30:40::SF:CF:BF.

Rearing fish for 5-6 months instead of one year (market price of harvested fish in both case is almost same) not only minimizes the risk factor but also prevent pond's early environmental deterioration. Usually, to produce 500g-sized fish, the requirements are - one cubic meter water, one fingerling/2-3 advanced fry, 750g manure, 50-75g inorganic fertilizer, 1kg supplementary feed and 5-6 months time. However, these requirements vary from site to site and largely dependent upon the degree of management. The technology of polyculture or composite culture of Indian major carps includes mainly the pond preparation, removal of predatory fishes by using suitable ichthyocide, fertilizing the pond with both organic and inorganic fertilizers, manipulation of stocking density, feeding the fishes with supplementary feed and periodic water quality and health monitoring.

Pond preparation: Perennial ponds that retain water throughout the year to a minimum depth of 1.5m are suitable. For fish culture, the waterweeds had to be removed from the ponds/tanks either with weedicides or manually. After removal of the weeds, the pond should be free from predator fished by dissolving Mohua Oil Cake @ 200 kg/Ac. After this, the pond is fertilized with both organic and inorganic fertilizers. Raw Cow Dung @ 3500 kg/Ac. is to be applied in the Pond/Tank. This is followed by application of inorganic fertilizers like Single Super Phosphate @ 120 kg/Ac. Add Ammonium Sulphate @ 100-120 kg/Ac. Generally the inorganic fertilizers are added to tank in installments throughout the culture period. When the tank is fertilized in this manner, it develops proper natural food of the fish i.e. Plankton. The inorganic fertilizers are to be applied after 3 or 4 days of application of Raw Cow Dung. For good production, the pond water should have pH ranging between 7.5 – 8.00. In order to have this, lime will be applied in the pond as a basal @ 200 kg/Ac. per annum. The lime should be applied after 15 days of application of Mohua Oil Cake. Periodic liming @ 50 kg/ha and bi-monthly manuring with RCD @ 500kg/ha is essential in maintaining bloom. The lime also helps in the eradication of any fish parasites existing in the pond and enables proper reaction of fertilizers. Now the pond is ready for stocking.

Stocking pattern: After 15 days of application of inorganic fertilizers, the seed should be stocked. As far as possible, pond should be stocked with surface feeders and their density should not exceed more than 30 %. Growth is normally affected if their proportion in the stock is more than 35%. Rohu feeds in the underwater are called a column feeder and do grow well in deeper water. Therefore, ponds having more than 2 meter depth of water need to be stocked with maximum 30% of rohu. In shallow ponds the stocking density of rohu should not increase more than 20% of the total stocking density. Bottom feeders such as mrigal and common carp are stocked at a higher ratio which may together account to about 40–50%. Freshwater prawn, *M. rosenbergii* can also be stocked as bottom feeder instead of mrigal and common carp, or with 50:50 combination, which is highly profitable. Availability of aquatic weeds in the pond or in the vicinity decides the stocking density of grass carp. It is always desirable to keep 5 to 10% grass carp, and manages to feed it with aquatic weeds, green vegetables or even with land grasses. It is seen that in aquaculture, as the number of fish is increased production of fish increases to a maximum and then decreases again. Under crowded conditions fish compete for the food supply, and they also suffer stress due to aggressive interaction. Under stress fish are found to eat less and grow more slowly, while in static ponds there is reason to believe that the excretory products of the fish may themselves tend to suppress their growth. Thus there is an optimum-stocking rate, which gives the highest production and the largest fish. Overcrowding may lead to biological crowding resulting in waste build up, decreased availability of feed and dissolved oxygen, deterioration of water quality etc., and hence it is advisable to stock 5000 - 7500 nos. of fingerlings per hectare of water spread area.

Feeding management: The fish seed i.e. fry/ fingerling start feeding on the natural food in the water by occupying different ecological zones of the tank. However, natural food alone is not sufficient to achieve the expected production. Hence, supplementary feeds like floating feed or pellets with 26-28% protein content or groundnut oil cake + rice bran + 3-5% fishmeal combination is always preferable and fed to the fishes during the culture. The supplementary feed is to be fed twice a day. Supplementary feeding @ 4-3% of body weight in the initial 2 months of stocking and 3–2% of body weight from 3rd month onwards on daily basis is necessary for proper health and faster growth of the fish.

Restricted feeding protocol and compensatory growth:

The success of aquaculture depends heavily on maximizing cost effective manner during the production process. It is well known that inappropriate feeding management may lead to over feeding, higher production cost and contamination of aquatic environment, while insufficient feeding lead to poor growth that make losses in aquaculture business. Therefore, an important approach to reduce feed cost in commercial aquaculture is to develop proper feed management and husbandry strategy. One potential way of reducing feed cost is to take advantage of the phenomenon of compensatory growth (CG). Compensatory growth offers the possibility of improving the growth rates of fish by a careful choice of feeding schedules/ protocol, in which periods of feed deprivation are followed by periods of satiation feeding. If CG can completely make up for growth lost during starvation, there could be an opportunity to save on fish feed by starving the fish and making up for lost growth when feeding resumes.

Disease and health management: Outbreaks of communicable diseases are result of interactions between the three factors - the pathogen, a susceptible host the fish and the pre-disposing environmental condition prevailing in such ponds. Under high level of intensification the risk increases. In order to achieve optimum production, the fish must be kept as healthy as possible throughout the culture period which can be achieved through proper fish health management involving three sequential steps, viz., (i) prophylactic measures, (ii) fish health monitoring and (iii) treatment. Prophylactic measures include sanitation of ponds using disinfectant like bleaching powder or quicklime prior to stocking. Prophylactic therapeutic treatments against parasites and other microbial pathogens are done prior to stocking as well as during trial netting and subsequent handling.

Apart from adopting prophylactic measures it is essential to check the health status of cultured fish quite frequently. This helps in timely detection and diagnosis so that immediate treatment measures can be adopted depending upon the nature of the disease. Significant differences in growth rate among population of the same age may often be a sign of some chronic internal diseases. Diseased fish exhibit either or both physical and behavioral signs among which most common are (a) slowing down or a complete stoppage of feeding (b) loss of equilibrium, abnormal swimming pattern and (c) surfacing and scrapping against the bottom, sides or some objects in the pond. Common clinical symptoms shown by the fish are: (i) excess mucous secretions, (ii) change in normal coloration, (iii) erosion of scales, fins, part of skin etc., (iv) erosion of gill lamellae, discoloration of gills, (v) formation of cysts, patches over the gills, body etc. and (vi) abdominal swelling and bulging of eyes etc. These necessitate immediate diagnosis of the disease and the proper treatment.

Water quality monitoring: Proper management of rearing environment offers optimum environmental conditions for the growth and better health of the cultivated fishes. It also strengthens the defense mechanism of the fish body to fight against invading disease producing organisms. Eradication of predatory and weed fishes, disinfecting the pond, selection of quality and healthy seed for stocking, maintaining proper species ratio and stocking density, water quality regulation, proper feeding and proper handling are the various steps of this management measure. Though water exchange has no significant impact on growth, survival and yield, it is essential to maintain a cleaner aquatic environment. Therefore, water exchange criteria should be based on emergency basis ‘as and when required’, thus will have an significant impact on water productivity.

Some of the physico-chemical parameters of water have their direct influence upon the fish health. Any abrupt and wider fluctuations of such values often cause state of stress in fish resulting sometimes in widespread disease outbreaks. Dissolved oxygen content, pH, turbidity, temperature, introduction of some chemicals, detergents, pesticides and naturally produced toxic products like hydrogen sulfide, ammonia, dinoflagellate toxins etc., are most potential stress related parameters. Excessive application of inorganic fertilizers and accumulation of organic matter in older ponds may cause over production of phytoplankton, appearance of algal and bacterial bloom etc., leading to dissolved oxygen (DO) depletion to lethal level. For health and optimum growth, the D.O. level should not drop below 4 mg/l.

Carbon dioxide concentration upto 20–30 mg/l can be tolerated by fish provided oxygen is near saturation. At lower levels of DO the toxicity of carbon dioxide increases. The optimum pH range is between 7.3 and 8.5 and liming agents may be applied to correct low pH. Ammonia concentration above 1 mg/l indicates organic pollution. Hydrogen sulfide toxicity increases with decreasing pH and it is harmful even at 1 mg/l concentration level. Making the pond environment more congenial and hygienic eliminates the risk of stress and provides safety to fish. Proper and timely management of soil and water by manipulating feeding, fertilization, liming, addition of water, aeration, bottom recking, etc., eliminates most of the environmental stressors and provides better and healthy environment for the healthy growth of fish. If possible the pond may be dewatered as it eliminates all the unwanted species of fish and other animals such as insects, molluscs, tadpoles and frogs at the same time sun drying of the bottom is an effective disinfection method. For making it more effectives freshly dewatered pond bottom should be treated with bleaching powder @ 500 kg/ha and then left to react for 7–10 days before refilling it. An interval of 5–7 days between the end of filling the unit with water and the stocking eliminates most of the obligatory pathogens from the environment.

Crop water requirement & water productivity: In its broadest sense, water productivity aims at producing more food, income, better livelihoods and ecosystem services with less water. Water productivity is the net return for a unit of water used or the ratio of the net benefits from aquaculture systems to the amount of water used to produce those benefits. Physical water productivity is therefore defined as the ratio of aquacultural output to the amount of water consumed – 'more crop per drop' –, and economic water productivity is defined as the value derived per unit of water used. The term 'increasing or improving water productivity' implies how best we can effectively improve the yield of a crop with the water currently in use.

In this backdrop, an innovative research work was carried out at Balasore, since 2009, by a team of scientists from Directorate of Water Management (ICAR), Bhubaneswar. The aim of the project was to estimate the water requirement and water productivity along with feeding management for improving water quality and triggering compensatory growth performance of Indian major carps, giant freshwater prawn and black tiger shrimp in grow-out culture system. The approach of cyclic feed restriction and refeeding that triggers compensatory growth ultimately enhanced the yield by 16-18% and maintained water quality, thus minimizes the water requirement for exchange. This also helps in enhancing water productivity by 34%, preventing wastage of water and operational cost by 20-25% in grow-out aquaculture. Under BWMP, regulated water exchange has significantly higher net water productivity over periodic water exchange while, periodic water exchange has no significant impact on growth and biomass gain, but essential on demand basis to maintain a cleaner aquatic environment. Further, the team has estimated the water requirement (without hampering the growth, yield and water quality) of 5.2-6.5 m^3/kg biomass in composite freshwater fish and prawn culture at a stocking density of 5000-8000 fingerlings/ha. This will give a new dimension to aquaculture industries and would help in minimizing the wasteful use of water in grow-out aquaculture

Water balance study and water budgeting: To make precise estimates of water budget (water use) in ponds, hydrological water balance equation, inflow = outflow ± change in volume (ΔV), can be used. Water use in aquaculture may be categorized as either total water use (TWU) or consumptive water use (CWU). TWU is the sum of all probable inflows to ponds such as management additions or regulated inflows (I), precipitation (P), runoff (R), and groundwater seepage (S_i) whereas, CWU includes the possible outflows such as intentional discharge or regulated discharge (D), overflow (O_f), evaporation (E), seepage (S_o), transpiration, and water content in the harvested biomass which is a negligible amount (about 0.75 m^3/t) that can be ignored. Aquaculture ponds rarely receive direct inflow from streams/ creeks. Further, aquatic weeds are disallowed from growing in and around edges of ponds and water is rarely used for activities other than aquaculture. Therefore, stream inflow, and transpiration are seldom major factors. As embankment ponds are small watersheds, runoff is therefore, negligible and groundwater inflow is also seldom a factor. Thus the appropriate equation is:

$$P+I = E + S_o + O_f + D \pm \Delta V$$

Options for improving water quality and production: Conventional earthen ponds, where fish are fed with supplemental feeds and without aeration, generate annual yields of 2000 to 3500 kg/ha. On a global scale, even in India, most ponds produce on an average closer to the lower end of this range. The challenge is to raise pond production by exploring the limits of fish production based on creating congenial water quality, natural pond productivity, and to increase feed efficiency.

Large-scale expansion of extensive pond aquaculture is not possible because of constraints associated with the availability of suitable land. Assuming an annual production of 2000 kg/ha, 5m^2 of pond area is needed to produce 1 kg fish. Raising the annual fish supply by 14 kg/capita, even if we conservatively assume that only 50% of this increase will be produced in extensive ponds, requires an additional 30 m^2/capita. Thus, a world population of 10 billion people would require an additional 300,000 km^2 of ponds. This analysis is conservative because it considers only productive water surface area, and not the additional area required for dikes, channels, roads and farm buildings, which would increase the need for land by an additional 20–30%. Considering growing population pressure and competitive uses of land in areas suitable for aquaculture development, such large-scale expansion of pond area is highly unlikely. Consequently, increased aquaculture production will have to come primarily from increased intensity rather than from added area and greater water consumption, while decreasing the quantity of fish caught for feed. The challenge is to raise productivity while maintaining environmental sustainability. Considering the current contribution of small-scale farmers to global production, a large fraction of the production increase must be realized through low-cost technologies.

Restricted feeding protocol and compensatory growth (CG): Introduction of floating feed can change the feed and water management scenario in aquaculture. Feed comprises about 65% of the production cost. In addition to extra expense, water quality can deteriorate unnecessarily due to over feeding. Extruded, vacuum coated floating feeds offer the advantage of watching the feeding response as opposed to a sinking, steam -pelleted feed. Floating feed has many advantages over sinking feeds such as minimal wastage of feed, minimal deterioration of water quality, low FCR, easy to digest, faster growth, higher yield and water productivity. Further, one potential way of reducing operational cost/feed cost is to take advantage of the phenomenon of compensatory growth (CG). Compensatory growth offers the possibility of improving the growth rates of fish/prawn by a careful choice of feeding schedules/ protocol, in which periods of feed deprivation are followed by periods of satiation feeding. If CG can completely make up for growth lost during starvation, there could be an opportunity to save on fish feed by starving the fish and making up for lost growth when feeding resumes.Using CG is therefore, perceived as a way to increase water quality, water productivity and profits of aquaculture operations. Usually, compensation is improved when the duration of growth restriction is short and is not too severe. Otherwise, severely stressed fish and very young animals often fail to express CG.

Biofloc technology (BFT): In aquaculture production systems where fish are fed a concentrated feed, nutrient recovery in harvested fish represents typically 25% of applied nutrients. Aquaculture can improve nutrient utilization efficiency by considering waste nutrients as resources and designing systems to promote recovery. Integrated agriculture–aquaculture farming is such an approach. Besides integration, intensification also enhances nutrient recovery. Biofloc technology (BFT), based on microbial control of water quality within the pond, is an approach toward intensification. Water exchange in BFT ponds is very low, with some systems operating with no water exchange for extended periods. Metabolic wastes from production animals stimulate the development of high-density microbial communities. From the perspective of microbial growth, metabolic wastes in aquaculture production systems are relatively rich in nitrogen compared to carbon. By adding carbonaceous substrates (e.g., molasses, cassava meal, bagasse, etc.) microbial production is enhanced while inorganic nitrogen, including potentially toxic ammonia and nitrite, are immobilized and hence controlled. In addition, many aquatic species obtain nutritional benefit from the microbial biomass. Protein utilization in BFT systems can be twice as high as in conventional ponds. Microbial flocs utilized by fish or shrimp contain significant levels of vitamins and minerals. These systems are considered to be environmentally benign because few nutrients are released to the outside environment.

Manipulation of the Carbon:Nitrogen ratio: A minor fraction of the nutrients applied to semi-intensive ponds is retained in harvested production: 5–25% N, 20% organic carbon (OC) and 5–18% P. A large fraction of the input nutrients ends up in the sediment: 66–70% N, 38–46% OC and 35–86%P. The harvested animal production from ponds on a dry weight basis represents only a minor fraction (0.85–1.7%) of the primary production. Assuming that half of the production realized in ponds receiving supplemental feeds is based on natural foods available in the pond, only 0.4–0.8% of the primary production is harvested. After careful preparation of the pond bottom prior to stocking, removing accumulated organic matter through drying and scraping, the role of microbial flocs in BFT systems is replaced by a dense aerobic microbial community that develops on the pond bottom, and which contributes to shrimp nutrition.

Deploying submerged surfaces in ponds to stimulate the development of attached microbial communities (periphyton), increases pond production by 50–180%. Periphyton communities consist of bacteria, algae and other micro-organisms that utilize suspended and dissolved organic matter, reducing accumulation of organic matter at the pond bottom. Within these communities, autotrophic or heterotrophic biomass dominates, depending on light, dissolved oxygen, and nutrient availability. Compared to organic matter at the bottom, the organic matter trapped by substrates in the water column is decomposed in more oxygen-rich water, thus contributing to a beneficial microbial food web. Manipulating the Carbon:Nitrogen ratio of the water increases the production of both bio-flocs in the pond water and of bio-films on submerged surfaces. A further increase can be reached by increasing the submerged surfaces and by stocking the ponds with species using different niches in the aquatic food-web thus creating synergies. Carp polyculture systems are designed to exploit multiple spatial and feeding niches in aquaculture ponds. In pond systems, C:N ratio manipulation doubles protein input efficiency, substrate addition increases production 2–3 fold, and using the right mix of species in polyculture doubles production.

Conclusion: Aquaculture is under growing pressure to make production more resource efficient. The 'Blue Revolution' referring to the rapid growth of aquaculture must go 'green' with the 'ecological aquaculture' integrating aquacultural water management principle. The future development of Aqua- farming requires responsible practices to improve operational efficiency and help prevent wasteful use of water and environmental degradation through water cutback approach. Water budgeting and density-dependent water use are two major requirements in improving aquaculture performance. Further, farming systems with low water exchange, serves to keep the water quality suitable for the fish growth, improves water use efficiency and helps in minimizing the quantity of pollutant outputs. Minimization of unnecessary water exchange/ replenishment and taking advantage of the compensatory growth response, also perceived as a way to increase water productivity and profits in aquaculture operations. Addition of duckery to the pond system and utilization of nutrient rich pond water for life-saving irrigation to on-dyke horticulture and low-duty *rabi* crop in the adjacent field would further help in enhancing the system's overall water productivity.

Water Productivity Improvement through Integrated Farming Systems in a Canal Command

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Introduction

India accounts for only about 2.4% of the world's geographical area and 4% of world's renewable water resources, but the country has to support about 18% of the world's human population and 15% of livestock (DES, 2013). The net sown area has remained about 140 M ha since 40 years (DES, 2015). Per capita availability of water per year is steadily declining from 5177 m^3 in 1951 to 1820 m^3 in 2001, 1588 m^3 per year in 2010 (CWC, 2010, 2013) due to increase in population, rapid industrialization, urbanization, cropping intensity and declining groundwater table; and it is expected to decline further to 1341 and 1140 m^3 by the years 2025 and 2050, respectively; the problems are likely to aggravate in future if suitable measures are not adopted. Average rainfall in the country is 1183 mm, 75% of it occurs in about 100-120 days; 68% of the sown area is subjected to drought with varying degrees (DAC, 2014). Increased climate variability has made rainfall patterns more inconsistent and unpredictable. There is an increase in the recurrence of drought or draught like situations. Though there has been a significant achievement in water resources development, a wide gap still exists between irrigation potential created (123.3 M ha) and irrigation potential utilized (91.5 M ha) (CWC, 2013); hence, it has become the great challenge to bridge the gap by evolving innovative as well as adopting existing technologies. The gross irrigated area in the country increased from 23 M ha in 1950-51 to 88 M ha in 2008-09 and the gross water demand by irrigation sector alone contributes 71% of the gross water demand by all users by 2025 (DES, 2015). It was also reported that net irrigated area in India is 63 M ha which accounts for 44.5% of total net sown area. Major irrigation source in India is through tube wells and other wells (60%) followed by canal irrigation (26%). Tank irrigation is confined to few pockets accounting for less than 5% (DES, 2015). Further, depletion of groundwater and limitation of surface water imply that not all of the net sown area is amenable to irrigation.

Most of the canal projects suffer from inadequate supply and poor reliability of water, especially at the tail end during lean season. Similar situation exists in many irrigation schemes in eastern India. This situation can be changed by proper utilization and conservation of runoff and rainwater in storage tank during rainy season and by recycling the same for life saving irrigation during post rainy season. To ensure water availability and dependability to all the farmers, it is necessary that some storage tanks (to harvest runoff and subsurface water) and shallow wells (to utilize ground water) are introduced in command area as per needs. The eastern region of India has one of the most favourable ecosystems for agriculture, yet the agricultural production from this area is much lower than its potential. In fact, agricultural growth in eastern states is low. Odisha, an eastern Indian state, is mainly an agrarian state where about 70% of the population is engaged in agricultural activities and 50% of the state's economy comes from agricultural sector. Even though several factors are responsible for poor growth of agricultural productivity, lack of irrigation water availability and its reliability are the major constraints in realizing the production potential. Water availability during post-monsoon season from the major state irrigation projects is either low, or the cost of water is quite high. In Odisha, rice-fallow is the most common practice in major command areas. Farmers keep their fields fallow after kharif season because water availability is very unreliable and undependable. It is, therefore, essential to develop and create a dependable and reliable water supply system in the canal command through conjunctive use of rainwater, canal water and groundwater.

Tank irrigation is an age-old practice. Most of them have independent source of water supply. Many of these tanks located in the commands could be made adjunct to the existing canal system, and deciding water harvesting structures for providing round the year full irrigation. The economic analysis shows that the increased crop yields, resulting from improved temporal distribution of water supply to match the crop water requirement at critical growth stages, more than compensate the cost of providing the auxiliary reservoir storage. It is essential that every farm entity to have a service reservoir so that the farmer can use his allocation at his convenience, both in time and size of stream/canal. Attempts have been made to study and examine the technical, economic and other feasibility of a canal irrigation system supplemented by water availability through rainwater harvesting in water storage tanks and dug wells for irrigation to crops during dry spells and post-monsoon seasons; and development of integrated farming systems including components viz. crop, fish culture, on-dyke horticulture etc. in the canal command, i.e., Kuanria medium irrigation project in Odisha, India.

The study site, rainfall and runoff characteristics

The study has been carried out under the Kuanria Medium Irrigation Project (KIP) at Daspalla, Nayagarh district of Odisha. The project area is located at $20^0 21'$ N latitude and $84^0 51'$ E longitude at an elevation of 122 m above mean sea level. The district is in the higher altitude than the sea level and above the flood level. The site is about 135 km from Bhubaneswar, the state capital via Khurda and Nayagarh.

The total rainfall in the Kuanria canal command area ranged from 1304 to 1895. The variation in rainfall was less during pre-monsoon period (Mar-May) for every year. Rainfall is quite low during the period, November to May. Maximum rainfall occurred during monsoon months i.e., June-September i.e., 75, 81.4, 74.5 and 53.5, 75% in the year 2010, 2011, 2012, 2013 and 2014, respectively; the least or no rainfall occurred during the months of December to March every year. Winter season (Jan-Feb) contributed negligible to only 5.4% of the total annual rainfall received in the command area (Table 1).

Table 1. Rainfall, effective rainfall, runoff in Daspalla, Nayagarh district of Odisha

Seasons	Average rainfall (mm)	Percentage of total rainfall	Average effective rainfall (mm)	Effective rainfall (% of rainfall)	Average Runoff (mm)
Pre-monsoon (March-May)	163.3	10.6	42.9	89.2	58.8
Monsoon (June-September)	1134.5	75.8	124.2	82.6	271.8
Post-monsoon (October-December)	162.6	10.4	572.1	51.5	50.1
Winter (January-February)	48.6	3.2	114.0	82.0	6.4

On an average, the area receives 1532 mm of rainfall annually; out of this 386 mm (25%) is lost due to runoff (Table 1). Runoff during post-monsoon and summer season was nearly 12% and 14% of rainfall received during that season respectively.

Water productivity estimation

Water productivity is estimated for fish and crop production to assess the efficiency of water management. The gross water productivity (GWP) and net water productivity (NWP) was calculated (Rs. m^{-3}) keeping the total volume of water used into account as: GWP = total economic value of produce (Rs.) / total volume of water used (m^3); NWP = {total economic value of produce (Rs.) - production cost (Rs.)} / total volume of water used (m^3). Total volume of water use (precipitation + management additions or regulated inflows) and consumptive water use (evaporation + seepage + intentional discharge or regulated discharge + water in harvest biomass) was estimated for fish culture in water storage tanks. Average water in harvest biomass was about 0.75 m^3 per tonne of fish biomass, was taken into account. Further, to separate the evaporation from the total loss, evaporation was estimated using the following equation:

Pond evaporation (mm) = pond-pan coefficient x Class-A pan evaporation (mm)

Pond pan coefficient of 0.8, most appropriate for ponds, was used in the above equation. The pond seepage was quantified by subtracting the evaporation loss from the total loss.

Economic water productivity of crops was estimated as: total economic value of produce (Rs.) / total volume of water used (m^3) to irrigate different crops under the pond-command.

Participation of water users' association (WUA) & farmers

A total of 10 numbers Pani Panchayats (water users' associations) have been operational under the command area. The jurisdiction area of the Pani Panchayats varies from 274.95 ha to 501.70 ha. The elected bodies under the Pani Panchayat are involved in operation and management. Distribuatries having less than 150 cusec capacity, all minors and sub-minors will be maintained through participatory irrigation management (PIM) by the apex body of the Pani Panchayats. There are 10 water users' association (WUA) distributed over the entire area of the Kuanria Medium Irrigation Project (KIP). WUA 1 and 6 are situated towards head end, WUA 2, 3, 7 and 8 are in the mid end and similarly WUA 4, 5, 9 and 10 are situated at tail end under KIP. The composition of WUAs is well represented by both male and female farmers with dominance of former which is due to the association of membership right with the land ownership and in the patriarchal society male members of the family are mostly owners of the land.

Farmers' participation was assessed through analyses of WUA's composition including its executive committee members, matrix of members by location of their land at head/ middle/ tail reach and productivity, review of WUA formation process (awareness of WUA, individual farmer's role: active/ passive, who elect members of WUA, what is the process of election), functionality and powers of WUA and farmers-members' involvement in activities of WUA. Farmers-members' participation in different activities undertaken by WUA was studied with the help of farmers' participation index

Pond-based integrated farming systems and improving water productivity

In the region, most of the farmers keep their fields fallow after harvesting of rainy season rice because of lack of irrigation to entire land during post-monsoon season. Rainfall is quite low during winter and pre-monsoon season. Therefore, it is essential that every farm entity to have a service reservoir for effective and efficient use of water, so that the farmer can use his allocation at his convenience. Thus, in order to conserve the rainfall, seepage and excess canal water ponds were constructed within the command area under beneficiary farmers (photo plates).


A view of the water storage tank under Soroda sub-minor (II) that facilitates fish culture, on-dyke horticulture and irrigation


A view of the open well constructed under Mangalpur sub-minor which facilitates conjunctive use of water for irrigation to crops


On-dyke horticultural crops on constructed pond and fish culture


In an event of fish catching for IMC- *rohu, catla and mrigal*


On-dyke horticultural crops like papaya, banana and other vegetable crops with a beneficiary farmer


On-dyke horticultural crops like papaya with a beneficiary farmer


Brinjal-maize intercropping with conjunctive use of water from storage tank and open wells done by a beneficiary farmer


Sole maize crop including sweet corn with conjunctive use of water from storage tank and open wells done by a beneficiary farmer

There has been a significant impact on the crop and fish production due to intervention through the project activities. The integrated farming systems were developed under different sites (head-, mid-and tail end) of the canal command. The sites belong to the Odasar S/M, Mangalpur S/M, Khamarasahi S/M, Khairapankalsahi S/M, Madhyakhand S/M, Madhyakhand S/M (2nd site), Lunisara S/M and Soroda S/M-II. The site villages and location etc. are mentioned in previous sections. The crops were grown under the command with the recommended package of practices. For every site, rice was the primary crop during kharif season in the pond command as well as in the non-command area. Fish culture was made in the constructed pond. Rabi crops were grown with conjunctive use of water. On-dyke horticultural crops were grown for improving farm income.

Fish production was successful in the constructed ponds. The production and performance index, and fish water productivity were studied for water storage tanks. Indian major carps i.e., IMCs (*Catla catla, Labeo rohita and C. mrigala*)were stocked @ 5,000/ha with a stocking composition of 30:30:40 in each pond. After 210 days of rearing, harvesting was carried out. Fish production ranged between 1.32-5.20t ha^{-1} $210d^{-1}$. Species-wise production-size index ranged between 540.7-609.6, 241.1-279.2, and 338.6-382.4 for *Catla catla, Labeo rohita* and *C. mrigala,* respectively.

Table 2. Fish and crop water productivity due to interventions in different canal commands under head, mid- and tail ends indicated with different jurisdictions of water users association

Sl. No.	Name of sub-minor canal	WUA No.	Canal reach	Gross return (Rs/ha)	Fish water productivity (Rs/m^3)	Crop water productivity (Rs/m^3)
1	Odasar S/M	6	Head reach	2,23,270	17.40	39.91
2	Mangalpur S/M	2	Mid- reach	1,74,330	8.74	39.32
3	Khamarasahi S/M	8	Mid- reach	1,63,675	21.48	34.74
4	Khairapankalsahi S/M	4	Tail- end	77,940	5.29	53.46
5	Madhyakhand S/M	5	Tail- end	2,00,600	9.70	20.50
6	Madhyakhand S/M-2	9	Tail- end	1,84,800	9.36	42.71
7	Lunisara S/M	10	Tail- end	34,663	6.84	25.00
8	Soroda S/M-II	10	Tail- end	1,12,515	8.05	48.77

Conjunctive use of water facilitated development of integrated farming systems viz. rice + (fish in pond)-maize, rice + (fish in pond)-vegetables (bhindi/ tomato/ cauliflower/ onion/ pointed gourd/ brinjal/ pumpkin etc.), rice + (fish in pond) + on-dyke vegetables/ papaya/ banana/ arhar - green gram/ black gram/ ragi etc., rice + (fish in pond)-green gram, rice + (fish in pond)-black gram, rice + (fish in pond)-arhar, rice + (fish in pond)-sesame and rice + (fish in pond)-ragi. The excess canal water and rain water stored in tanks and dug wells provided irrigation to post-monsoon crops, and thereby enhanced productivity of dry season crops and improved livelihood of farmers. Gross economic return ranged from Rs 34,663 to 2,23,270 per ha, fish water productivity ranged from 5.29 to 21.48 Rs/m^3 and crop water productivity varied between 20.50 and 53.46 Rs/m^3 (Table 2).

The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command viz. Odasar S/M, Mangalpur S/M, Khamarasahi S/M, Khairapankalsahi S/M, Madhyakhanda S/M, Madhyakhanda S/M (second site), Lunisara S/M and Soroda S/M-II. Fish production was 1.32-5.20 t ha^{-1} with gross water productivity of 5.29-21.48 Rs m^{-3} and net water productivity of 3.52-15.66 Rs m^{-3}. Water productivity of crops and overall water productivity was improved due to intervention through construction of rain/ runoff water storage tanks and open wells with total return of Rs 34,663 to Rs 2,23,270. Multiple use of harvested water was meant for on-dyke horticultural crops, fish culture (rohu, catla and mrigal) and life saving irrigation to field crops in the command area especially during dry/ lean period. The life saving irrigation was found beneficial to rice nursery in the command area during the drought period prior to late onset of monsoon in 2014.

It can be concluded that infrastructure development under the canal command in a participatory mode and adopting appropriate integrated farming system will improve both land and water productivity through augmented water resources. There will be definite social and economic impact of the beneficiary farmers through the integration of multi-enterprise components viz. fish culture, high value horticulture crops and remunerative diversified field crops. This will improve livelihood of farmers without affecting the environment. Participatory development of integrated crop & fish culture systems accrue greater economic return to the farmers and improvement in water productivity; greater success depends on financial support to the farmers, economic condition of the farmer, extent of farmers' participation, functioning of WUA, liaison with Government departments, and capacity development of the farmers. Hence, there is need for participatory integrated water management (PIWM) in canal commands in future along with capacity building of farmers through training and demonstration for enhancing agricultural productivity.

Agronomic management of soil and water conservation for climate change adaptation

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Introduction

Climate variability with more frequent and severe droughts, floods, storm damage, cold snaps, untimely rains, and hot spells is a major threat to agriculture. To achieve a more productive and resilient agriculture requires major shifts in the way that land, water, soil, nutrients, and genetic resources are managed to ensure their efficient and sustainable use (FAO, 2013). Agriculture in India primarily depends on the monsoon. Distribution pattern and intra-annual variation in rainfall amount is a major challenge while planning for future adaptation strategies, especially in the context of climate change. National Action Plan on Climate Change (GOI, 2008) consists of 8 missions and two of these are important for agriculture and food security. National Mission for sustainable Agriculture aims to transform agriculture to adapt Climate Change, while National Water Mission aims to improve WUE and manage water resources sustainably. Technical programme NICRA (National Initiative on Climate Resilient Agriculture) was initiated in the year 2011 for dealing with the adaptation measures against climate change effects. Climate Smart Agriculture is defined as an approach that ‘sustainably increases productivity’, enhances resilience (‘adaptation’), reduces greenhouse gas emissions (‘mitigation’), promotes carbon sequestration, and increases food security and development goals (FAO, 2010). Integrated use of soil and water conservation practices with balanced plant nutrition can sustain increased productivity and soil quality. Natural resource management practices that conserve soil and water also help to maintain surface and groundwater quality (Sahrawat et al., 2010). Fertile soil and good quality water are precious natural resources; hence, the foremost action is to conserve them for their efficient and economic use. Agronomic practices for soil and water conservation help to intercept rain drops and reduce the splash effect; help to obtain a better intake of water rate by the soil by improving the content of organic matter and soil structure; and, help to retard and reduce the overland run-off through the use of contour cultivation, mulches, dense-growing crops, strip-cropping and mixed cropping. These measures can also be applied in congruence with the engineering measures for soil and water conservation. In some systems they may be more effective than structural measures although sometimes difficulty arises in implementation (Heathcote 1998). Agronomic management is the cheapest way of soil and water conservation (Wimmer, 2002). Conservation of water and soil goes hand in hand, and often inseparable. Agronomic management for conservation of soil often helps in conservation of water and vice-versa. These management practices are described in subsequent sections.

A) Soil and Water Conservation measures under climate change

1. Contour farming

Frequency of high intensity rainfall events is expected to increase under climate change effects. During intense rain storms, the soil cannot absorb all the rain that falls and the excess water flows down the slope under the influence of gravity. If land preparation and planting of crops is done up and down the slope (along the slope), the flow of water is accelerated, because each furrow serves as a rill for easy carrying of soil and water. Farmingpractices when performed across the slope, keeping the same level as far as possible (contour-farming), has many beneficial effects. The ridges and the furrows created across the slope due to tilling, planting, hoeing and earthing up under contour farming act as a continual series of miniature barriers against the flowing water over the soil surface. The barriers are small individually, but as they are large in number, their total effect is great in reducing run-off, soil erosion and loss of plant nutrients. Contour farming is effective on mild slopes. On greater slopes, it must be supported with engineering measures. Establishing Glyricidia, subabul, Sesbania, Tasmania plants along key lines helps in identifying and undertaking agricultural operations on contour.

Experimental results in Alluvial soils, black soils and deep lateritic soils proved that contour-farming reduces run-off and prevents soil erosion as compared with the up-and-down cultivation. Apart from conserving the water and soil, contour-farming conserved soil fertility and increased crop yields. Results of contour-farming experiment at Kanpur in alluvial soil with 2.2 per cent slope have revealed that 490 kg of *jowar* grain and 273 kg of *jowar* stalks were produced more under the contour practice than the up-and-down cultivation. Also, each mm of rain-water conserved by contour-farming produced 22.5 kg of *jowar* grain and 12.5 kg of *jowar* stover more. Contour farming conserved 11.3 kg of N, 11.7 kg of P_2O_5, 44.4 kg of K_2O, 398.1 kg of CaO, 118.1.kg of MgO embedded within soil in one season alone.

Table 1. Effect of contour cultivation on run-off and soil erosion

Treatment	Rainfall causing run-off (mm)	Run-off (mm)	Soil loss (tonnes/ha)
Alluvial soils-8 % slope - Dehra Dun			
Maize (up-and-down cultivation)	1,223	670	28.5
Maize + cowpeas (contour cultivation)	1,223	511	19.3
Deep lateritic soil-25 % slope- Ootacamund			
Potato (up-and-down cultivation)	1,295	52	39.3
Potato (contour cultivation)	1,295	29	14.9

http://beta.krishiworld.com/html/soil_water_con5.html

Practising contour-farming: On long slopes, bunding is usually done to reduce the length of the slope. These bunds serve as a good guide for contour-farming. All the cultural operations are to be done parallel to these bunds. Bunding may not be essential on gentle slopes (between 0.5 to 2.0 per cent). Contour (the line passing through the points having the same level) guidelines can be marked with the help of a hand level. On uniform slopes, these lines are to be marked about 50 m apart. Farming is done parallel to these lines. The establishing of contour-farming on undulating land (having many depressions and ridges) is difficult. The water from each furrow collects in the depressions and results in breaches. The depressions are required to be filled up by levelling or may be left under grass. Farmers must be educated/convinced before making contour lines. Burundian Govt in 2009 constructed contour lines in Gitega province, but destroyed by farmers as they did not know why these structures were made.

2. Cover crops (Dense growing crops)

Canopy covers and protects the land by reducing splashing effects of rain drops and/or reducing the wind speed. In general legume crops (cowpea, sesbania, green gram, black gram, horse gram) provide better soil cover using close and dense canopy as compared to the clean cultivated crops. Sowing time of these crops should be adjusted so that maximum vegetative growth stage coincides with peak period of erosion.

Table 2. Suitable cover crops for different locations

Location	Suitable cover crops
Dehra Dun	Cowpea followed by green gram, black gram, sesbania
Vasad	Cowpea and sunnhemp followed by green gram groundnut
Kota	Velvet bean followed by cowpea
Kanpur	Green gram followed by black gram, guar
Rehmankhera	Cowpea followed by styzolobium*,* green gram, groundnut, black gram, moth

http://beta.krishiworld.com/html/soil_water_con5.html

3. Mulching

It is a practice to cover the soil with dead vegetation so that it may allow rain water to enter in the soil by increased infiltration. It reduces evaporation losses from the soil surface and break down upward movement of capillary water. It prevents soil from being blown and washed away, controls weeds, improves soil structure, buffers soil temperature, and eventually increases crop yields. Inter-culture may produce 5-7 cm thick soil mulch, which helps to reduce evaporation from the top soil. It also breaks the surface crust formed after each downpour. Stubble mulch is produced from the crop residues. Vertical mulch is practised in low permeable vertisols. In this practice, locally available crop residues like jowar and bajra stalks are embedded in trenches across the slope allowing it to protrude 30 to 40 cm above the ground level. Series of such barriers arrest run-off and conserve water *in-situ*. At Dehra Dun, mulching with maize residues did not significantly influence the yield of the following crop possibly due to very high C:N ratio of the mulching material. At Kota, mulching resulted in higher yield of wheat grain and straw than no mulching. At Bellary, mulching with different materials (paddy husk, Encap Esso, grass mulch, *jowar* stubble) did not increase the yields of cotton and *jowar* crops. On eroded soils at Ranchi, mulching with straw or Encap Esso increased the infiltration rate, soil moisture and crop yields of wheat, barley, gram and linseed grown after the maize crop.

4. Strip cropping

It is a combination of contour farming and crop arrangement in which alternate strips of clean crops (erosion permitting crops) and soil conserving crops (erosion resisting crops) are grown following the natural contours of the terrain to prevent soil erosion. In areas prone to wind erosion, the crop strips are planted at 90° to the wind direction. When soil is detached from the row crops by the forces of wind or water, the dense soil-conserving crops traps some of the soil particles and reduces wind translation and/or runoff. There are 4 types of strip cropping. In contour strip cropping, tillage operations and planting of crops are practised along the contour. Width of strip varies according to the horizontal spacing of the contour lines. Field strip cropping is practised, when the land topography is very irregular and complex and the width between contour lines vary. Strips of almost uniform width are constructed across the general slope of the land. They do not follow any contour lines. Buffer strips consists of planting some grass or legume species that completely cover the ground between contour strips. These strips are generally planted in steep slopes or highly erodible areas. Sometimes, buffer strips are used as correction or filler strips, when widths of strips vary much due to irregular topography. Wind strip cropping consists of growing tall growing crops (jowar, maize, bajra) and dwarf crops in alternately arranged straight, long relatively narrow, and parallel strips across the direction of wind.

5. Mixed/inter cropping

It is the practice of growing more than one crop in the same field at the same time. There is one main crop and one or more subsidiary crops. This system gives better cover of land, protection from beating action of rain, and production security/stability. Crops with different pattern of root and/or shoot growth helps in efficient harvesting of sunlight, soil water and nutrient. Some examples include: Ragi + pigeon pea/black gram/green gram/ground nut, Upland paddy + pigeon pea/black gram/green gram, Maize + cow pea/French bean/ pigeon pea/black gram/green gram/ground nut/potato or Pigeon pea + black gram/green gram/ground nut/ French bean/vegetables.

6. Crop Rotations

Crop rotations are beneficial to all agricultural production systems because they help control soil erosion and pests such as insects, plant diseases, and weeds. When crops with different rooting depth and pattern are used, water and nutrients from different soil depth are utilized. When legume cover crops are used, essential nitrogen is added to the soil for the use of succeeding crops.

7. Tillage

Tillage is the practice of loosening the soil, killing weeds and increasing porosity with the help of tools or implements. It affects soil-water-air status, thermal characters and root growth. Tillage encourages water loss from surface layers, but cumulative loss from soil profile is less. This practice is suitable for medium textured soils. Off season tillage is useful in increased rain water infiltration and decreasing weed intensity. This helps in early sowing and so, longer growing season. Deep tillage helps in breaking sub-soil crust/hard pan and encourages deep infiltration. Deep tillage is effective after each 2-3 years. Furrows are useful in harvesting rain water. Tillage helps uniform distribution of soil moisture in profile and longer period of availability.

8. Land configuration

(a) Land levelling within the inter-bund area helps uniform spread of soil moisture in the profile. This is practised before or during the onset of monsoon. (b) Furrows may be provided during the early cropping period to facilitate higher infiltration. (c) Tied ridging: The ridges and furrows are opened after harrowing the field and the ridges are “tied” to allow rain water collection in the furrows which slowly percolates into the soil profile. This water stored in soil profile is useful for crops in post-rainy season. (d) Scooping: Small basins are formed by scooping the soil. This helps in retaining rain water on the surface for longer periods. It is reported that run-off under this practise can be reduced by 50% and soil loss by 3-8 t/ha. (e) Bedding system: This system requires furrows at every 3-6 m intervals across the slope on a grade of 0.2 to 0.4%. The bed width depends on the crop, soil type and rainfall. This layout acts as a disposal system during intense rains, but as a conservation measure when rainfall is low.

9. Contour/graded border strips

Levelled strips (10-12 m wide) are formed across the slope either on contour or on grade depending on annual rainfall of the area. The system is efficient in ensuring uniform moisture distribution in the profile and enhancing yield. But initial investment is high. Also, drastic poor growth occurs if the cutting depth of soil in elevated points is more than 15 cm (as surface soil is removed).

10. Compartmental bunds

The field is divided into compartments by making bunds around. The size of compartments varies from 6m x 6m to 10m x 10m. The harvested water in these compartments facilitates high infiltration due to longer opportunity period. The thoroughly saturated soil profile in rainy season helps to grow a crop in post-rainy season. This is usually suitable in deep black soils where infiltration rate is very slow and rainfall amount is medium to low.

B) Water Conservation measures under climate change

1. Growing of low water requiring crops

A hectare of high-yielding rice requires approximately 12 million liters/ha of water considering 120 days field duration and 1 cm requirement (6 mm ET and 4 mm percolation). Well managed rice will yield of 7 t/ha. In contrast, wheat, which produces less plant biomass than either corn or rice, requires only about 2.4 million liters/ha of water for a yield of 2.7 t/ha (Pimentel, 2006). Yield, water use and water use efficiency of some *rabi* crops in farmers field are given in Table 3.

Table 3. Yield, water use and water use efficiency of some *rabi* crops in farmers field

Crop	Yield (t/ha)	Water use (mm)	Gross return (INR)	Expenditure (INR)	Net return (INR)	Water productivity (kg yield/ mm)
Bhendi	2.59	365.8	26500	12542	13958	6.9
Bittergourd	1.85	352.8	26102	10291	15811	5.5
Ridge gourd	4.75	386.4	38686	12359	26327	12.3
Brinjal	6.33	387.8	48170	13458	34712	15.7
Spinach	4.22	237.3	39063	14800	24262.5	19.9
Cucumber	7.03	472.0	35930	14312	21618	15.6
Cowpea	2.34	177.1	23083	11733	11350	13.6
Sunflower	1.48	336.6	22187	9083	13104	4.4
poi	18.75	468.7	46875	20125	26750	40.0
pumpkin	12.45	266.2	49800	11831	37969	46.7
Tomato	8.77	362.8	37094	13689	23406	24.0
patato	4.80	303.9	26071	10902	15170	16.3
chilli	7.45	247.7	26271	9348	17346	15.2
cabbage	5	220.5	25000	6100	18900	22.6
cauliflower	5.5	272.3	27500	8400	19100	20.2
Garlic	3.44	324.9	33888	14150	19737	12.7
onion	3.09	313.0	23169	9878	13291	9.8

2. Manure application

Cow, buffalo, pig, rabbit, goat, sheep and chicken husbandry generate enough animal manures. The collection and application of this manure to crop field over years help in raising organic matter level. Organic agriculture and other systems that stress "feeding the soil" can, depending on soil type, increase the amount of organic matter up to as much as 6 percent compared with only about 1 to 2 percent in conventional soil. Soil organic matter promotes the formation of aggregates, which acts in regulating air and water infiltration. It reduces runoff during intense storms, conserve water, and increase the crop yields. In one study, organic corn and soybeans with levels of soil organic matter of nearly 6 percent, had corn yields 33 percent higher than those of conventional corn, and soybean yields 50 percent higher than those of conventional soybeans (Pimentel, *et al.*, 2005). As compared to conventional growing practices, the greater crop yields in well-managed organic systems are especially noticeable during drought years.

3. Cropping/Farming system

On average, the amount of soil organic matter is significantly higher in organic production systems than in conventional systems. In a comparison of three cropping systems, increase in soil carbon was highest in an organic system that included an animal enterprise (Table 4), medium in the organic system using legumes but not using animal manures, but only 9 percent in the conventional farming system(Pimentel *et al.,* 2005). The large amount of soil organic matter and water present in the organic systems is considered the major factor in making these systems more drought resistant. Furthermore, the 110,000 kg/ha of soil organic matter in an organic corn system could sequester 190,000 kg/ha of carbon dioxide. This is 67,000 kg/ha more carbon dioxide sequestered than in the conventional corn system. The added carbon sequestration benefits of organic systems have beneficial implications for reducing global warming.

Table 4. Increase in soil organic carbon under different farming systems

System	% increase in Organic Carbon
Organic system with an animal enterprise	28
Organic system using legumes but no animal manure	15
Conventional farming system	09

4. Paired row bed planting

It involves closing the row spacing between two adjacent rows and making a bed for these two rows by puling soil from furrow vicinity to the bed. Integration of bed planting to such paired row alters the land configuration in addition to crop geometry. A study was conducted during 2010 and 2011 on okra (*Abelmoschus esculenta*) during summer season. In paired row bed planting, two rows of the crop were planted at a closer row spacing of 40 cm on a raised bed. A wider furrow of 60 cm was maintained between two adjacent raised beds. In triple row bed planting, closer row spacing of 40 cm and wider furrow of 60 cm was maintained but three adjacent rows on a raised bed. These two modified row arrangement and planting techniques were compared with the normal practice of 50 cm row spacing. The results revealed that paired row planting on bed produced similar yield with the normal planting but with the less irrigation requirement by 18% (Table 5). Triple row bed planting resulted in lower yield (12.8%) and less irrigation requirement (27.4%). Yield per unit water under the paired row planting were 14.5 and 23.3 kg/mm water, in the first and second year, respectively. The results suggest that farmers should adopt paired row bed planting to save water without sacrificing yield. However, under water scarcity situation farmers may opt for triple row planting to get higher yield per unit water.

Table 5. Effect of planting techniques on irrigation requirement and yield of okra (Mean of 2010 and 2011)

Planting techniques	Yield (t/ha)	Irrigation use (mm)	Irrigation productivity (kg yield/mm)
Normal Planting (50 x 25 cm)	10.1	615.5	16.5
Paired Row bed (40/60 X 25 cm)	9.6	507.5	18.9
Three row bed (40-40/60 x 25 cm)	8.7	447	19.5
CD (0.05)	0.76	-	-

5. Opportunistic cropping

Rainfall behavior of monsoon is difficult to predict with accuracy. This behavior is further complicated with climate change effects. So farmers should adapt themselves to changed rainfall situations like late onset of monsoon or early onset of monsoon being prepared for new crop or variety. Efficiency of fertilizer application, weeding, and pesticide application are associated with soil moisture content and this may be adjusted with the rainfall situations.

6. Crop specific water saving technologies

Sprinkler irrigation for closely spaced crops like upland rice, wheat and pulses are promising. Drip irrigation in fruits and high value vegetable enhances water productivity. Pitcher irrigation in arid and semi-arid climate with water stress situations is feasible. Widely spaced creeper crops like water melon, bottle gourd, cucumber, bitter gourd, pumpkin should be irrigated under ring basin method. Impact of climate change and identification of adaptation strategies for agricultural water management was studied by Kakumanu et al., 2016 using optimization model. They reported that adaptation practices such as systems of rice intensification, machine transplantation, alternate wetting and drying (AWD) and direct seeding could reduce the water and labour use by 10-15% and stabilize rice production.

AWD is considered as climate smart practice as it provides multiple benefits like enhanced tiller number and encourages stronger root growth (Dong et al, 2008, Bouman et al, 2007, Liu et al., 2013, Richards and Sander, 2014); mitigating GHGs emissions especially, CH_4 (Jain et al., 2013) and enhancing adaptation to water scarcity by consuming less irrigation water (Table 6). Increased yield and yield components are reported under AWD as compared to continuous flooding (Liu et al., 2013). However, other authors have reported yield penalty associated with AWD (Borrell et al, 1997; Tabbal et al, 2002, Towprayoon et al, 2005, Dong et al, 2012).

Table 6: Water consumption and saving under AWD

Country (site)	Continuous flooding (mm)	AWD (mm)	Water saving (mm)	Water saving (%)	Author
Philippines (Guimba)	2352	905	1447	62	Tabbal et al., 2002
India (Andhra Pradesh)	2248	1245	1003	45	Reddy et al., 2016
India (New Delhi)	1750	980	770	44	Jain et al., 2013
Bangladesh (Mymensingh)	1172	897	275	23	Oliver et al, 2008
Philippines (Canarem)	750	590	160	21	Tuong 2007
China (Jhangbang)	876	780	96	11	Yao et al., 2012
Australia (Dry season)	1351	764	587	43	Borrell et al, 1997
Australia (wet season)	1286	873	413	32	Borrell et al, 1997

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Topographic Survey Technique for Water Management Planning

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Topographic surveys are used to identify and map the contours of the ground and existing features on the surface of the earth. Surveying, in general is the art of making such measurements as will determine the relative positions of points on the surface of the earth in order that the shape and extent of any portion of earth's surface may be ascertained and delineated on a map or plan. It is essentially a process of determining positions of points in a horizontal plane. Topographic surveys are useful for water management or watershed management planning as they help in identifying the position and elevation of different points on the map. They help in preparation of contour maps and identifying the suitable sites for construction of water harvesting structures.

Surveying can be divided into 3 categories.

a) Land survey
b) Marine or, navigation survey
c) Astronomical survey

Land surveys may be further subdivided into the following classes.

a) Topographic surveys for determining natural as well as artificial features of a country such as hills, valleys, rivers, nallas, railways, canals, towns, villages etc.
b) Cadastral surveys involve additional details such as boundaries of fields, houses and other properties.
c) City surveys involve laying out plots and constructing streets, water supply systems and sewers.
d) Engineering surveys for determining quantities, and for collecting data for the design of engineering works.

Topographic survey

Topographic surveying is the process of determining the positions both in plan and elevation of the natural and artificial features of a region and delineating them by means of conventional symbols upon a map called a topographic map. The distinguishing feature of a topographic survey is the location and sketching of contours. A topographic map shows (1) relief including hills and valleys, (2) the natural features such as streams, lakes, rivers and plantations, (3) the artificial features such as roads, railways, canals and houses etc. In topographic survey, methods of surveying are combined with methods of leveling and therefore every surveying instrument used to advantage in topographic work.

In topographic maps, reliefs may be represented on a map by hauchers, contours, shading or form lines. There are two general systems of representing the relief on a map i.e by hauchers and contours. In the first system, short lines called hauchers are always drawn in the direction of steepest slope. This system gives the relative idea of the form of the ground. On the other hands, contour lines not only give the relative idea of the topography, but also the actual elevation of the ground surface. The system of representing the relief by contours is the best and is in the most general use.

A topographic survey consists in locating a sufficient number of representative points by means of three co-ordinates so as to enable the intervening surface of the ground to be known. The field work may be done in following steps (1) Establishing control, (2) locating contours and (3) locating the details such as streams, roads and rivers etc. When the area of survey is small, the entire work may be done simultaneously and by one party. But in case of extensive survey it is usually done in correct sequence by several parties, one party establishing horizontal control, another party establishing vertical control, while other parties locating contours and filling in details.

Based on the instrument employed, surveying can be of following types.

a) Chain surveys
b) Plane table surveys
c) Compass surveys
d) Theodilite surveys
e) Photographic and aerial surveys.

Chain Survey

The chain is composed of 100 or, 150 pieces of galvanized mild steel wire called links. The ends of each link are bent into a loop and connected together by means of three oval rings which afford flexibility to the chain. Tapes can also be used instead of chains. Tapes can be of cloth, metallic, steel or synthetic material.

Ranging survey lines

In measuring the length of a survey line, it is necessary that the chain should be laid out straight on the ground between the end stations. If the end station is clearly visible or the line is short, it is easy to put the chain in true alignment. But if the end station is not clearly visible, it is necessary to place intermediate ranging rods to maintain the direction. When the chain line crosses a valley from which the ranging rod at forward station is not visible, or undulating ground, it is advisable to establish a number of intermediate points. The operation of establishing intermediate points on a straight line between the terminal point is known as ranging, which should be done prior to chaining.

Ranging can be either direct or indirect. It is called direct when intermediate ranging rods are placed in line by direct observation from either end, while it is called indirect when they are interpolated by reciprocal ranging or running an auxiliary line.

Chain Triangulation

The term triangulation when used without qualification, denotes a system of surveying in which the sides of the various triangles are completed from (1) A single line measured diversely called base line (ii) Three angles of each triangle. Chain triangulation is the system of surveying in which the sides of the various triangles are measured directly in the field and no angular measurements are taken. It consists of the arrangement of framework of triangles. Since triangle is the only simple plane figure which can be plotted from the lengths of it's sides alone. The arrangement of triangles to be adopted depends upon the shape and configuration of the ground. An equilateral triangle can be more accurately plotted than an obtuse angled triangle. A triangle is called well conditioned or, well proportioned when it contains no angle smaller than 30^0 and no angle bigger than 120^0. The main principle of chain surveying is working from the whole to the part and not from part to the whole. It reduces the error in surveying.

Base line: The longest of the chain lines used in making a survey is generally regarded as the base line. It fixes up the direction of all other lines as the framework of the survey is built upon the base line.

Check line: A cheek line is a line joining the apex of a triangle to some fixed point on the side opposite or a line joining some fixed points on any two sides of a triangle. A check line is measured to check the accuracy of the framework.

Tie line: A tie line is a line joining some fixed points termed as tie stations on the main line. A tie line checks the accuracy at the framework and enables the surveyer to locate the interior details.

Offsets: In a survey, the positions of details are located with respect to survey lines by means of lateral measurements to such objects right or, left of the chain lines. These lateral measurements are called offsets. They can be either perpendicular offsets or, oblique offsets.

Levelling

Leveling is the art of determining the relative height or elevation of points or objects on the earth's surface. It deals with measurements in a vertical plane. To determine the elevation of points, an instrument is used which is called a level. Dumpy level is one at the most commonly used instrument for determination of levels. It is a simple compact and stable instrument. A telescope is attached to furnish the horizontal line of sight.

Reduction of levels

There are two systems of working out the reduced levels of points from the staff reading taken on the field. They are

1. The collimation system
2. The rise and fall system

Collimation system

In this system, elevation of the plane of collimation is found for every set up of the instrument. Then reduced levels of points are obtained with reference to the respective plane of collimation. At the beginning, the elevation of the plane of collimation for the first position of the level is determined by adding the back sight to the reduced level of the benchmark. The reduced levels of the intermediate points and the fist change point are then obtained by subtracting the staff reading taken on these points (intermediate sight and fore sight) from the elevation of the plane of collimation. When the instrument is shifted to the second position, a new plane of cllimation is set up. The levels of two planes of cllimation are correlated by means of the back sight and foresight taken as the change point. The elevation of this plane is obtained by adding the new back sight taken on the change point from the second position of the level to the reduced level of the first change point. The reduced levels of the successive points and the second change point are found by subtracting their staff readings from the elevation of the plane of collimation. This process is repeated until all the reduced levels are worked out.

Rise and fall system

In this system, the difference of level between consecutive points is determined by comparing each point after the first with that immediate preceding it. The difference between their staff readings indicates a rise or a fall depending on whether the staff reading at the point is smaller or greater than that at the preceding point. The reduced level of each point is then found by adding the rise to or subtracting the fall from the reduced level of the preceding point.

Theodilite Survey

Theodilite is the most accurate and precise instrument used for measurement of horizontal and vertical angles in surveying. It consists of a telescope which can sight the distant objects. The telescope has two distinct motions, one in horizontal plane and the other in vertical plane. The angles in the horizontal and vertical direction are measured by asset of verniers. Theodilite can also be used for various other purposes such as laying of horizontal angles, locating points on a line, prolonging survey lines, establishing grades, determining differences in elevation etc.

Theodilites are primarily classified as (i) transit and (ii) non-transit. A theodilite is called transit theodilite, when it's telescope can be revolved through a complete revolution about it's horizontal axis in a vertical plane. The non-transit theodilites have now become obsolete. Theodilites are made of various sizes varying from 8 cm to 25 cm, the diameter of the graduated circle on the lower plate defining the size. 8 cm to 12 cm instruments are used for general survey and engineering work, while 14 cm to 25 cm instruments are used for triangulation work.

A transit theodilite consists of the following parts. (1) the leveling head (2) two spindles (3) lower plate (4) Upper plate (5) level tubes (6) the standards (7) the compass (8) the telescope (9) the vertical circle (10) Index bar.

Total station

Total station is an optical instrument used in modern surveying works. It is a combination of an electronic theodilite, an electronic distance measuring device and software running on an external computer.With a total station one can determine angles and distances from the instrument to points to be surveyed. With the aid of trigonometry, the angles and distances are used to calculate the co-ordinates of actual positions of surveyed points, or the position of the instrument from known points, in absolute terms. The data can be downloaded from the theodolite to a computer and application software will generate a map of the surveyed area.

Measurement of distance is accomplished with a modulated microwave or infrared carrier signal, generated by a small solid-state emitter within the instrument's optical path, and bounced off of the object to be measured.The modulation pattern in the returning signal is read and interpreted by the onboard computer in the total station, and the speed-of-light lag between the outbound and return signal is translated into distance. Most total stations use a purpose-built glass prism as the reflector for the EDM signal, and can measure distances out to a few kilometers, but some instruments are "reflectorless", and can measure distances to any object that is reasonably light in color, out to a few hundred meters. The typical Total Station EDM can measure distances accurate to about 0.1 millimeter or 1/1000-foot, but most land surveying applications only take distance measurements to 1.0 mm or 1/100-foot. Some modern total stations are 'robotic' allowing the operator to control the instrument from a distance via remote control. This eliminates the need for an assistant staff member to hold the reflector prism over the point to be measured. The operator holds the reflector him/herself and controls the total station instrument from the observed point.

Global positioning system

Global positioning system uses the services of satellites to identify the latitude, longitude and altitude of a desired location. Utilizing a constellation of at least 24 earth orbit satelites that transmit precise microwave signals, the system enables a GPS receiver to determine its location, speed, direction, and time. A typical GPS receiver calculates its position using the signals from four or more GPS satelites Four satellites are needed since the process needs a very accurate local time, more accurate than any normal clock can provide. The receiver internally solves for time as well as position. In other words, the receiver uses four measurements to solve for 4 variables - x, y, z, and t. These values are then turned into more user-friendly forms, such as latitude/longitude or location on a map, then displayed to the user.

Each GPS satellite has an atomic clock and continually transmits messages containing the current time at the start of the message and parameters to calculate the location of the satellite.

The signals travel at a known speed - the speed of light through outer space, and slightly slower through atmosphere. The receiver uses the arrival time to compute the distance to each satellite, from which it determines the position of the receiver using geometry and trigonometry. GPS receivers come in a variety of formats, from devices integrated into cars, phones, and watches, to dedicated devices. The user's GPS receiver is the user segment (US) of the GPS system. In general, GPS receivers are composed of an antenna, tuned to the frequencies transmitted by the satellites. They also include a display for providing location and speed information to the user. A receiver is often described by its number of channels which signifies how many satellites it can monitor simultaneously.

Contouring

Contour is a line joining points of equal elevation. The elevations and depressions at the surface of the ground are shown on the map by means of contour lines A contour may be defined as the line of intersection of a level surface with the surface of the ground. The vertical distance between two consecutive contours is known as contour interval.

Characteristics of contour lines

1. Contour lines run close together near the top of the hills representing very steep ground and wide apart at the foot of a hill indicating flat ground.

2. A uniform slope is indicated by uniformly spaced contour lines.

3. Contour lines cross ridge lines or valley lines at right angles.
4. Contour lines can not merge or cross one another except in case of overhanging cliff.
5. Contour lines can not end anywhere, but close on themselves either within or without the limits of the map.
6. A series of closed contours on the map indicate a depression or summit depending on the higher or lower values that are inside them.

Uses of contours

1. Idea about the topography of the land can be obtained from contour lines.
2. The most economical and suitable sites for engineering works may be approximately selected.
3. Quantities of earthwork may be computed from the contour maps.
4. Contours may be used to determine the area of the drainage basin and the capacity of the reservoir.
5. A route of a given grade line can be traced on the map.

Locating contours: The various methods of locating contours may be classified as

1. Direct method
2. Indirect method

Direct method: In this method the contours to be plotted are actually located on the ground with a level by marking various points an each contour. These points are then surveyed and plotted on plan. This method is very slow and tedious, but most accurate and is used for contouring small areas and where great accuracy is required.

Indirect method: The indirect methods are cheaper, quicker and less laborious than the direct method. The reduced level of a point on the surface of the ground is called the spot level or spot height. In these methods, the spot levels are taken along a series of lines laid out over the area or the spot levels at several representative points, representing ridge and valley lines, summits, depressions and important changes in slope scattered over the area are observed. Their positions are then plotted on the map and the contours are then drawn by interpolation.

Survey of India Toposheet

The survey of India is the National Survey and Mapping Organization of our country under the Ministry of Science and Technology, and is the oldest scientific department of government of India set up in 1767. Survey of India toposheets have been prepared for all over the country by extensive survey by the above organization. For development of any water management or watershed management plan or any other developmental activities, Survey of India toposheets act as a base map. The Survey of India has following features:

1. SOI doesn’t have maps on 1:5000 scale, and covering a watershed area of 500 hector with coding.

2. Topographical maps on 1: 250,000 (toposheet with 2nd order no.) 1:50,000 (toposheet with 3rd order no. having contour interval of 20 m) and 1:25,000 (toposheet with 4th order no. having contour interval of 20 m) scales are available.

3. Both analogue and digital data on 1:250,000 and 1:50,000 scale toposheets for the whole country and on 1:25,000 scale topo maps for some parts of the

country are available on WGS 84 Datum and UTM protection on payment basis.

3. Various other general maps such as those displaying political boundaries, physical features, states, railways, and roads are available on smaller scales as well as larger scales for developmental activities in the country.

4. DEM for the above products are also generated on demand and payment basis.

Digital Products

1. Digital cartographic data Base (DCDB) on scales of 1:1,000,000, 1:2,50,000, 1:50,000 and 1:25,000 cater to the needs of various GIS applications and quick updating of topographic maps.
2. Digital elevation model (DEM) form 1:2, 50,000 scale maps with an accuracy of about ± 100 mts. In DTED-1 format i.e. with a resolution of 3” x3”, higher resolution DEMs from 1:50,000 /1:25,000 scale maps or from stereo aerial photographs / satellite imageries are also available.
3. Digital terrain analysis using Digital Terrain Model
4. Large scale digital city maps for utility mapping.
5. Maps in raster format of all topographic maps on 1:250:,000 and 1:50,000 scales (will be scanned at 2000 dpi) and warped in geographic system so that they can be joined seamlessly (without any limit)

The area covered per square centimeter over the map and in hectors over the ground with toposheets of various scales available with SOI is provided in Table 4. the enlarged map on 1:25,000 and 1:5000 scales represents 6.25 and 0.25 ha area, respectively.

The SOI has topographical maps for whole of the country on a scale of 1:50:,000. They are also developing these maps on a scale of 1:25,000 which are now available for many parts of the country. These maps contains streams, roads, contours and other details like water bodies and land use, railway lines, post offices etc. The topographical maps are available at a cost of about Rs. 30/- per sheet covering 15 x 15 minutes of latitude and longitude with a contour interval of 20 m on a scale of 1:50,000 and 7.5 x 5 minutes or 5x5 minute of latitude and longitude and with a contour interval of 10m.

Management of soil hydro-physical and chemical properties for sustainable production under climate change scenario

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Introduction

The major challenge for the coming decades is that the production environments are unstable and rapidly degrading despite bearing the responsibility for improving production to meet the demand of expanding population and its related services. In reality *it will become even harder to produce enough food and fuel to meet demands without further depleting natural resources.* About a third of the world's soil has already been degraded owing to deforestation, shifting cultivation on hills, excess application of fertilizers and chemicals and other heavy farming techniques. "Soils are the basis of life" unless new approaches are adopted, the global amount of arable and productive land per person in 2050 will be only a quarter of the level in 1960 as per one of the estimates of FAO. S*oil degradation is however closely interlinked with increasing population pressure, rise of earth temperature and carbon – di – oxide concentration, altered rainfall and Nitrogen deposition and other atmospheric impediments under climate change process. Considering all, there is a need to formulate strategies to make the best use of soil which could sustain food productivity and increase resilience to climate change.* Soil response to climate change is complicated because of 1) the presence of an intricate network of chemical, biological and hydrological reactions and processes; 2) chemical elements, nutrients, and contaminants involved in these reactions and processes are distributed in the soil solid, liquid, and gas phases; 3) the scale-dependent effects related to mineralogical, chemical, and physical heterogeneities; and 4) climate extremes (e.g., heat waves and dry spells) induce interconnected short- and long-lasting effects in soils that currently are not well understood. To address these and other related issues mentioned above, studies should be conducted at different levels and spatial scales.

Soils mostly not having that much intrinsic resilience against degradation processes to compensate the impact by restoring its actual properties, for example in humid climates, it is the complete soil cover near ground level combined with the perforating activity of the soil fauna that makes the soil-vegetation system resilient against physical degradation (FAO). Researches to increase resilience of soils against any adverse effects of climate change could be done in conjunction with that on soil resilience against direct adverse human impacts. Until site-specific management procedures have been elaborated, soil and crop (including trees and pasture) management should aim to maintain soil cover and organic matter supply to soil biota, while minimizing mechanical disturbance by heavy traffic, cultivation or excessive grazing intensity. Such kind of management may also help to conserve plant nutrients (in soils not flooded for wetland cultivation) since the stable, heterogeneous system of biopores produced by the soil fauna would favour bypass flow of any excess moisture and thus decrease leaching through the soil mass. But a single management recipe would not be generally applicable in different conditions. All factors which influence soil health and affect food production should be taken into account in designing an optimum management strategy for any specific natural and cultural environment.

Impact of climate change

An important aspect of climate-change is accelerated weathering of the rocks and minerals induced by higher atmospheric CO_2 concentrations ($\geq$400 ppm) and temperature, intensive rainfall and heat waves and extended periods of drought, which subsequently effect soil properties. The spatial patterns of the impact, its temporal trends and controlling factors of the impacts at different scales, especially regional, continental, and global scales are difficult to explain. However, for planning of precise and adequate management practices, a sound understanding is required for prediction of the interaction between climate pattern and soil properties under climate change scenarios and land use systems.

Soil forming factors

The climate-change induced weathering in mountainous terrestrial systems is positively correlated with erosion as observed across diverse landscapes, although there are limits to this relationship that remain largely untested (Dixon and von Blanckenburg 2012). Using new global data compilations of soil production and weathering rates it has been indicated that a soil production speed limit of between 320 to 450 t /km^2 / yr^1 and an associated weathering rate speed limit of roughly 150 t /km^2 / yr^1. According to the authors, these limits are valid for a range of lithologies and also extend to mountain belts, where soil cover is not continuous and erosion rates outpace soil production rates. The influence of climate on the formation rates of regolith (i.e., the mantle of physically, chemically, and biologically altered material overlying bedrock), which covers much of earth's continents, was also investigated and reported by Dere et al. 2013. Dissolution of CO_2 resulting in acidification vis-à-vis chemical weathering of carbonate and silicate minerals have also been promoted by changing climate.

Climate change and its hydrological consequences may result in the significant modification of soil conditions. The quantification of potential future changes is complex due to the uncertainties involved in forecasting global and long-term temperature and precipitation patterns including their spatial and temporal variability combined with changing hydrological cycle and integrated with the influences of natural vegetation and land use patterns. Consequently the long-term effect of soil forming processes would be a rough estimate, only help to draw some general conclusions. In the natural soil formation processes the pedogenic inertia will cause different time-lags and response rates for different soil types developed in various regions of our globe.

Soil moisture

The amount of water stored in the soil is having fundamental importance in agriculture, it is the result of the influence on the rate of actual evaporation, groundwater recharge, and generation of runoff. The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate change. Climate change may also affect soil characteristics, perhaps through changes in water-logging or cracking, which in turn affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing. Boix-Fayos et al. (1998) showed that infiltration and water-holding capacity of soils on limestone were greater with increased frost activity and inferred that increased temperatures could lead to increased surface or shallow runoff. Soil moisture is a key component of the hydrological cycle, controlling the partitioning of precipitation between runoff, evapotranspiration and deep infiltration. It links between the biosphere and the edaphic zone, soil water plays a crucial role for terrestrial ecosystems by determining plant growth. If the soil water level falls below a species-specific threshold, plants experience water stress, and decreased soil moisture under warmer conditions can inhibit photosynthesis (Lindroth et al., 1998). Vegetation however can influence the soil water regime by offsetting drier conditions through decreased transpiration, a phenomenon which is expected to occur more frequently in summer months under a warmer climate (Etchevers et al., 2002; Seneviratne et al., 2002; Yang et al., 2003) while dry soils can cause a negative feedback by amplifying the impact and duration of heat waves (Brabson et al., 2005) and prolonging the effects of meteorological droughts (Nicholson, 2000). The exceptionally hot summer of 2003 in Europe led to large scale soil moisture depletion and associated ecosystem impacts (Reichstein et al., 2007). Several soil formation processes including organic matter turnover, structure formation, weathering, podzolization, clay translocation, gleying ar strongly influenced by soil moisture.

Soil Structure

Soil structure is responsible for movement of gasses, water, nutrients and other elements. The change on soil structure (type, spatial arrangement and stability of soil aggregates) is a complex process. The most important direct impact is the aggregate-destructing role of raindrops, surface runoff and filtrating water, especially during heavy rains, thunderstorms and even 'rain bombs', the increasing hazard, frequency and intensity of which are characteristic features of climate change. The rate of structure damage depends on the intensity of the destroying factor and the stability of soil aggregates against these actions. The nature and quality of structure is strongly influenced by the amount and quality of organic matter present, inorganic constituents of soil matrix, cultivation methods and natural physical processes. A decline in soil organic matter levels lead to dispersion of soil aggregates and structures, inhibit soil water transmission and resulting to soil compaction and susceptible to erosion. In some areas there could be an increase of flash flooding due to cracking and disruption of soil structure. Increased droughts will increase the likelihood of shrink-swell in clay soils, and disturbance to building foundations and need for underpinning/repair. Increased soil temperature may also exacerbate chemical attack to foundations. There is a potential risk to engineered structures based on clay caps (e.g. in contaminated landfills), with likelihood of increased leachate generation and release of landfill gases.

The indirect consequence of changes of vegetation pattern on soil structure can be both favourable and unfavourable. The impact of over-grazing, unreasonable land use, misguided agricultural utilization (cropping pattern, crop rotation) and improper agro-techniques (heavy machinery, over-tillage, over-irrigation) is unfavourable, practically non-reversible and hardly correctable. On the contrary, rational land use, proper agro-techniques and amelioration practices may help the maintenance or restoration of good soil structure (Várallyay, 2003).

Soil Temperature

It is closely associated with air temperature. Warmer soil accelerates soil functions like rapid decomposition of organic matter, increase microbiological activity, quick release of nutrients, increase infiltration rate and accentuate chemical weathering of minerals. Soil temperature will also be influenced by the vegetation existing on its surface which may change itself as a result of climate change and adaptation management.

Soil acidity

The dissolution of atmospheric CO_2 gas in soil water and the subsequent formation of carbonic acid cause a decrease in soil water pH as a result of hydrogen enrichment. Experimental and modeling studies conducted with soil and subsoil materials have shown a decrease in pH of 1 to 3 units in soil pore water as a result of excess exposure to CO_2 gas (Quafoku 2014). A decrease in pH on the lower end of this range is typical of well-buffered systems in which CO_2-induced dissolution of reactive carbonates, silicates, and clay minerals provides enough buffering capacity (via HCO_3- alkalinity) to resist changes in pH. Poorly buffered systems (e.g., sandy soils) have low abundance or are devoid of alkalinity-producing minerals and, therefore, lack the ability to resist changes in pH. In such systems, the decrease in pH is generally more pronounced and may have long-term consequences, and the risk for pH-induced perturbation of these systems is more significant compared to well-buffered systems (Quafoku 2014).

Climate determines the dominant vegetation types, their productivity, the chemical character and decomposition of their litter deposits, and influences the development of soil reaction. Brinkman and Sombroek (1999) suggested that most soils would not be subjected to rapid pH changes resulting from drivers of climate change e.g. elevated temperatures, CO_2 fertilisation, variable precipitation and atmospheric N deposition (DeVries and Breeuwsma 1987; McCarthy et al. 2001), it is likely, however, that these drivers of climate change will affect organic matter status, C and nutrient cycling, plant available water and hence plant productivity, which in turn will affect soil pH.

Soil salinity and sodicity

One of the well-pronounced consequences of global warming is the rise of eustatic sea level in combination with low precipitation and high temperature intensify salinization /sodification processes through increasing upward capillary transport of water and water-soluble salts from the groundwater to the root zone, and high rate of evapotranspiration with low or negligible leaching. Pariente (2001) examined that the dynamics of soluble salts concentration in soils from four climatic regions (Mediterranean, semi-arid, mildly arid and arid) and found a non-linear relationship between the soluble salts content and rainfall, with sites that received <200 mm rainfall contained significantly high soluble contents and vice versa. Clearly, there is a need for comprehensive assessment of the influence of drivers of climate change on soil salinity as an important soil parameter in different ecosystems.

Cation exchange capacity

The cation exchange capacity (CEC) is considered an important determinant of soil chemical quality, particularly the retention of major nutrient cations Ca, Mg and K, and immobilization of potentially toxic cations Al and Mn; the property is thus be useful to determine a soil's capacity to absorb nutrients, as well as pesticides and chemicals (Dalal and Moloney 2000; Ross et al. 2008). Since CEC of coarse-textured soils and low-activity clay soils is attributed to that of SOM (Weil and Magdoff 2004), the increasing decomposition and loss of SOM due to elevated temperatures (Davidson and Janssens 2006) may lead to the loss of CEC of these soils. Low CEC of soil may result in increased leaching of base cations in response to high and intense rainfall events, thus transporting alkalinity from soil to waterways.

Soil Organic matter

The soil organic matter (SOM) is a critical component of ecosystem, improves cation exchange and water holding capacity and acts as a major control on pH and nutrient holding capacity of soil. It also promotes soil aggregation, porosity and water transmission characteristics. Soil C accumulation and turnover are important global processes: soils contain about 1527 gm C, which is 2-3 times bigger than the total amount of C in the vegetation. The C flux between soils and the atmosphere is huge, with soil respiration surpassing about 10 times of the C flux due to fossil fuel combustion. Thus, any change in rates of soil C turnover has a remarkable effect to the global C cycle. The litter input quantity and quality are taken into account under most scenarios of global climate change, but the resulting effects on SOM stability and turnover can not be accurately predicted. The level of SOM is influenced by litter production and added soluble organic material as input, and decomposition and leaching as output. Climate change affects on the input and output too through effects on net primary production (NPP) as well as through changes in rates of decomposition and leaching.

Soil organic matter monitoring programmess, long term experiments and modeling studies all indicate that changes in land use significantly affect soil organic matter levels. It declines when grasslands, forests and natural vegetation are converted to cropland. The reverse is true if croplands are converted to grasslands, forests and natural vegetation. The soil organic matter or carbon cycle is based on continually supplying carbon in the form of organic matter as a food source for microorganisms, the loss of some carbon as carbon dioxide, and the build-up of stable carbon in the soil that contributes to soil aggregation and other physical properties. Carbon assimilation is a dynamic process necessary for nutrient availability and cycling. Different sources of organic matter have different assimilation and decomposition characteristics, and result in different soil organic matter fractions. If the rate of assimilation is less than the rate of decomposition, soil organic matter will decline and, conversely if the rate of assimilation is greater than the rate of decomposition, soil organic matter will increase. Both the assimilation and decomposition processes occur concurrently, but are of a different order of magnitude. Like for land use changes, organic matter can be lost instantaneously, whereas its build up is spread over several decades.

SOM has been used as indicator for the assessment of climate change in long-term soil experiments (Richter et al. 2007; Rinnan et al. 2007), although the response of SOM to elevated temperature remains logically controversial and without consensus. In general, increase in temperature has been reported to enhance decomposition of SOM, but rising temperature and precipitation, CO_2 fertilisation and atmospheric N deposition may support high plant productivity and organic matter input to soil and consequently increase SOM. According to Davidson and Janssens (2006) and Kuzyakov and Gavrichkova (2010), it is the accessibility and availability of SOM to microorganisms that govern SOM losses rather than the rate-modifying climate factor (i.e. temperature), the labile soil organic C is rapidly depleted as the temperature rises (Davidson and Janssens 2006; Knorr et al. 2005). In addition, elevated CO_2 in the future may reduce sequestration of root-derived soil C, a major source of labile, light fraction C (Heath et al. 2005).

Soil Nitrogen

Carbon and nitrogen are the major components of soil organic matter. Nitrogen limitations may negatively affect plant growth (Hungate et al. 2003), and modeling of C dynamics as influenced by N indicates less C sequestration by soil than originally expected under CO_2 fertilization (Zaehle et al 2001). A long-term elevated CO_2 experiment in a grasslands ecosystem indicated that N and P became limiting within two years, again limiting plant biomass response to elevated CO_2 (Niklaus and Körner, 2005). When CO_2 enrichment increases the soil C:N ratio, decomposing organisms in the soil need more N, which can reduce N mineralization (Gill et al., 2002; Reich et al., 2006), which is an essential step for supplying N to plants (Pierzynski et al., 2009; Mullen 2011). Therefore, if N mineralization is reduced, it would be expected that plant-available N levels in the soil would also be reduced and plant productivity would be negatively affected. Increased temperature stimulates N availability in the soil leading to more terrestrial C uptake as observed in the results of Hungate et al. (2003). However, the stimulated C uptake is not enough to offset the N limitation and the net result is still an increase in atmospheric CO_2 and an overall reduction in soil C levels (Holland 2011). Some researchers have reported that increasing temperatures increase N mineralization (Norby & Luo, 2004, Reich et al., 2006; Joshi et al., 2005), which could have a positive effect on plant growth. However, a warning study by An et al.

(2005) showed that N mineralization was stimulated in the first year but depressed afterward.

Management options for sustainable production

Strategies for offset the impact of changing climate on soil properties is widely diverse depending on land use, soil types, prevailing agro-climate, socio-economic background in a particular context for upholding sustainable production. Nevertheless reduced tillage, incorporation of crop residues, changing crop sequence, use of organics and practice of soil conservation measures are some of the guidelines to eliminate the impact of green house gasses, global warming and other climate change impediments.

Soil management techniques such as no-till systems may result in lower CO_2 emissions from and greater C sequestration in the soil as compared to management systems based on intensive tillage, although some recent studies have indicated that no-till systems may simply result in higher C accumulations in the upper 15–20 cm of the soil with no increase in C when the entire soil profile is considered (Bakker et al., 2007; Blanco-Canqui &Lal 2008; Christopher et al., 2009). Other management changes such as using cover crops, crop rotations instead of monocropping, and reducing or eliminating fallow periods can lead to C sequestration in soil. Sequestration of C tends to be rapid initially with declining rates over time (Brevik 2013). Most agricultural soils will only sequester C for about 50–150 years following management changes before they reach C saturation (Lal, 2010).

The best management practices (BMPs) result in augmentation of soil carbon and enhanced productivity due to better soil structure and soil moisture conservation. The relevant practices include precise and timely applications of fertilizers, use of slow-release fertilizers (to minimize leaching or volatilization), prevention of erosion, shortening or elimination of fallow periods, use of high-residue cover crops, and minimization of mechanical disturbance of the soil. Benefits of all such practices never be continued indefinitely thus a combination of those agricultural practices fitting to location specific soil problems will be applied to cope with climate change for sustainable production and food security.

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Pressurized Irrigation System to Reduce Crop Water Demand in the Regime of Climate Change

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Introduction

In almost all regions of the world, water supply is the major constraint to crop production due to water demand for rapid industrialization and high population growth. In present climate change scenario, the further scarcity of irrigation water for crop production should be checked for sustaining the food supply through efficient water conservation and management practices even in high rainfall areas. Moreover, the financial return per every drop of irrigation water should be enhanced while considering the best water use efficiency (WUE) associated with any crop.

Pressurized irrigation, otherwise known as micro-irrigation (MI) in India is a way of water supply to crop fields through net work of pipes creating pressure or hydraulic head at the source of irrigation. Pressure may be generated by using either mechanical energy through devices like diesel or electrical motor and pump, and/ any unconventional (renewable) energy sources like solar pump, wind mill etc. or gravitational head. The MI system under gravitational head, known as gravity-fed MI is very much successful in sloppy and hilly areas.

There are different types of pressurized or MI system such as drip, sprinkler, micro-sprinkler, micro-jet, etc. used in crop production. The optimum irrigation scheduling under pressurized irrigation system is vital for higher water productivity (WP). The application of fertilizers through pressurized irrigation, called fertigation is also important for enhanceing fertilizer use efficiency (FUE) in crops. The use of water and nutrients through pressurized irrigation in concurrence with plant demand therefore, could be one of the potential options for sustainable crop production. In recent years, pressurized irrigation or MI is gradually gaining popularity among the farmers. However, the area under MI is around 5.0 Mha, in spite of 70.0 Mha potential for the system in our country. The poor awareness of farmers regarding the impact of this irrigation system on crop productivity, water saving and profitability is one of the reasons of low area coverage under the system.

2. Pressurized Irrigation Systems

Pressurized irrigation or MI has a many advantages over surface irrigation methods, mainly in terms of more uniform and partial wetting of the soil surface and equally effective on sloppy lands. The selection and adoption of suitable MI system in the crops grown in the areas is vital for successful farming. When drip irrigation (DI) is selected for fruit, vegetable and other crops grown with wider spacing, overhead sprinkler irrigation (SI) is selected for the crops like cereals, pulses etc. grown with narrow spacing. Microsprinkler irrigation (MSI) and microjet irrigation (MJI) systems are normally preferred for vegetables (onion, garlic etc.) grown with narrow spacing and for under tree irrigation purposes. However, the knowledge regarding different components as well as their maintenance is utmost essential for successful operation of MI system.

2.1. Merits of micro-irrigation systems: Micro-irrigation systems hold following

advantages over conventional method of irrigation:

- Water saving of 40-50 % and fertilizer saving up to 30% over surface irrigation method.
- Yield enhancement around 55-60% with improved profit up to 2 times over surface irrigation method
- Weed reduction by 40-50 %, thereby reduce the labor cost on weeding
- Saline water for irrigation can be safely used
- Equally effective on undulating land used for citrus cultivation
- Enhances better crop growth
- Prevents soil erosion and runoff under surface irrigation

2.2.Essential components micro-irrigation system: Following are the essential components of micro-irrigation system:

- Water source: well, tube well, canals, river, pond, etc.

- Electrical pump: mono-block or sub-mercible
- Filters: sand, screen and by - pass arrangement
- Back wash arrangement and pressure gauges
- Fertilizer tank/injection tank/venturi
- Main pipe line and control valves
- Laterals (12, 16, 20, 25 mm)
- Drippers (2, 4, 8, 16 lph) and micro-jets (180^0, 300^0, 360^0) for DI system; riser, sprinkler nozzles for SI system and micro-jets/micro-sprinkler nozzles and stakes for MSI and MJI systems

2.3.Drip irrigation system

Drip irrigation (DI) is a method, which optimizes the effective use of irrigation water through uniform distribution and applies water into the root zone of the plants through a closed network of plastic pipes and drippers of different water discharging capacities. The basic principle involved in drip irrigation is frequent application of water as per the plant requirement to meet its evapo-transpiration requirement at low discharge rate (drop by drop) directly to root zone. The soil moisture held under the drippers is at optimum level that favors better nutrient and water uptake. The advantages under this system include saving in water and power, labor, better uniformity in plant canopy development, soil-water continuum to enhance fruit yield and quality.

2.3.1. Design of drip irrigation system: The proper design of the irrigation system is essential for success of the system in any crop. The foremost step of designing irrigation system is knowledge of crop water requirement (ET_C) which is normally calculated using following formula:

ET_c (lit/day) = $\{K_c \times K_p \times (E_p\text{-}ER) \times A \times W_p\} / E_i$.

where, K_c – Crop coefficient (0.4-0.7 for fruit crops and 0.6-0.8 for vegetables); K_p – Pan evaporation factor (0.6 in winter and 0.8 in summer); E_p– Pan-evaporation (mm/day); ER-effective rainfall; A – Area of the plant canopy or crop area (m^2), W_p –Wetting factor (0.5 for fruit crop and 1.0 for vegetables) and E_i- efficiency of irrigation system (for drip $E_i = 90\%$)

After quantifying the crop water requirement, the size of main pipe, sub-main pipe and lateral pipe is decided, using area-velocity approach. Normally, the diameter of main pipe is taken as 90 mm or 75 mm whereas, the sub-main pipe with 63 mm or 50 mm diameter is taken for DI. Lateral pipe of diameter of 12 mm and 16 mm with black colour is used in DI.

For tree crops, on-line DI system is generally used, whereas for close spacing crops (vegetables, field crops, etc), in-line DI system is used. The number of drippers and dripper distance from tree trunk are important in DI design in tree crops. Following the details about the number of drippers per plant to be placed at a distance from tree trunk in relation to plant age:

Plant Age (year)	No. of Dripper (4 l/h)	Distance of Dripper from Tree Trunk (m)
1-2	1	0.3
3-4	2	0.45
5-10, > 10	4, >4	0.75

Pump capacity is one of the important design parameter in DI. The formula used in estimating the pump capacity (HP) = Q (discharge required in litre per second) x Total head (m) / (75 x efficiency of pumping), whereas the efficiency of pluming is 70%. In thumb rule, if the land is near to source of irrigation and land topography is flat, the land area in acre is recommended for HP of the pump.

2.3.2. Precautions before/during drip irrigation) installation: Before installation of micro irrigation systems, the following points should be considered for smooth installation and operation of the system

- Soil physico-chemical analysis of orchard and water analysis of watersource.
- Sand and screen filters for water containing debris, algae etc.
- Main and sub-mains of PVC to be installed at 1.5 to 2.00 feet below ground.
- If the land has slope, then sub-main should be laid along with slope and lateral across the slope.
- Design should be done as per the slope, orchard land topography and plant requirement.
- In drip system for 12 mm diameter lateral, 40-50 m long lateral and for 16 mm diameter, 60-70 m long lateral in field should be usually used.
- Drippers should be installed on upper side of the slope and at the convenient distance as per the plant age.

2.3.3. Maintenance of drip irrigation system: After successful installation of the micro irrigation system, maintenance of the system is a vital component, which requires sufficient technical knowledge to cope up. The following points should be kept in mind for better maintenance of the system:

- Laterals and sub-main pipelines should be flushed at least once in a week keeping the system at 1.5 to 2.0 kg/cm^2 operating pressure.
- Regular checking of the drippers for operation, breakups or some leakages.
- Clogged drippers should be treated in acid (12N HCl) at least once in six months.
- Laterals of the drip system should be rolled and kept inside the safe place during the rainy period.
- Chlorination (calcium hypo chloride solution at 45 g/l) should be done as per requirement or once in 6 months.
- Cleaning of screen filter and sand filter once in a week or as and when required.

2.3.4. Performance of drip irrigation in different crops: Drip irrigation research in different crops indicates that the system enhances the yield of the crops to different extent with differential amount of water savings. The yield improvement with water saving in different crops under DI is given below.

Crop	Yield improvement over surface irrigation (%)	Water saving compared with surface irrigation (%)	Improvement in water productivity (%)
Okra	35	60	55
Cabbage	40	50	70
Cauliflower	60	50	60
Tomato	45	40	90
Citrus	40	55	120
Banana	50	70	135
Pomegranate	30	40	85
Sugarcane	60	40	95
Cotton	50	60	110

2.4. Sprinkler irrigation system

Sprinkler irrigation is normally recommended for closely growing crops like wheat, pulses, etc. This system requires higher pressure to operate the sprinkler heads. The system consists of Pump, high density polyethylene (HDPE) pipe, riser pipe and sprinkler head with nozzles. The HDPE pipe of size 63 mm and/ 75 mm diameter are normally used through couplers for conveying irrigation water from source. The water through diameter of sprinkler varies from 10 m to 18 m, depending upon the size of sprinkler head. However, the normal through diameter of sprinkler used is 12 m, therefore, the spacing of sprinkler head is generally kept at 12 m. The pump capacity required for sprinkler irrigation system is calculated using the same formula that used for DI. Sprinker irrigation yield of the crops from 30% to 60% with 40–60% water saving compared with surface irrigation in different crops,

Sprinkler irrigation in wheat crop

2. 5. Micro-sprinkler and Micro-jet irrigation system

Micro-sprinkler and/ micro-jet irrigation systems are normally used for under tree irrigation and closely grown vegetables. The system requires more pressure/energy for operation. The capacity of pump is calculated using the same procedure used in DI. The water throwing diameter in case of micro-sprinkler and micro-jet systems varies from 3 m to 6 m, depending upon the size of nozzles and pressure of operation.

3. Irrigation Scheduling

The amount of water to be applied on daily basis (water requirement) is an integral part of an efficient micro-irrigation scheduling. Due to seasonal annual rainfall in crop grown areas of the country, determining the irrigation scheduling in post-monsoon period is a necessary part of proper irrigation guidance. Thus, maintaining soil moisture at optimum level during the critical growth period through proper irrigation scheduling is essential for sustainable crop production.

3.1. Quantity of Irrigation water

3.1.1 Soil water potential based scheduling: Irrigation scheduling at different level of soil moisture depletion viz., 10%, 20%, 30% and 40% indicated the best growth, fruit yield and quality under drip irrigation at 20% depletion of soil moisture in vegetables and 30% of depletion of soil moisture in fruits.

3.1.2. Open pan evaporation based scheduling: Response ofIrrigation scheduling based on open pan evaporation (0.6, 0.7, 0.8 and 0.9 Epan) through drip irrigation system showed the substantial improvement in growth, yield and fruit quality with irrigation at 0.8 of open pan evaporation and 0.7 of open pan evaporation in vegetables and fruit crops, respectively.

3.2. Frequency of Irrigation

Frequency of irrigation assumes greater significance in maintaining the plant growth and orchard productivity on sustained basis. The interval may vary 10 to15 days in winter and 7 to 10 days in summer days. During the hot periods, the topsoil dries up quickly and light irrigation is advisable. Bearing trees should be irrigated at shorter intervals than non-bearing trees. Irrigation during harvest period should be avoided because it reduces TSS and acid.

• On clay soils	2 to 3 days
• On clay loam soils	1 to 2 days
• On sandy soils	daily

4. Fertigation

Fertigation is application of water soluble as well as liquid fertilizers through irrigation on weekly/monthly basis, so as to reach both water and fertilizers each and every plant, regularly and uniformly. Use of proper quantity of fertilizer at appropriate time can be achieved through fertigation. With the adoption of the trickle irrigation system, the fertilization schedule in citrus orchards can be adjusted to precise fertilizer application using fertigation technology.

4.1 Advantages of Fertigation : Following are the advantages of fertigation:

- Accurate amount of fertilizer through micro-irrigation saves time, labor, and energy
- Required amount of fertilizer are applied in the effective root zone of the plants. Thus it saves 25 to 30% fertilizers, besides increasing the fruit yield by 15-20 %.
- Fertilizers are applied in diluted form hence it eliminates the danger of burning the plants root system due to dilution effect.
- Other chemicals such as insecticides and weedicides may also be applied along with fertilizers. Thus saving the time and labor further.
- It is possible to apply fertilizer according to crop growth stage and climatic conditions

4.2. Fertigation Methods:

Fertilizer application through micro-irrigation method can be done by any of the following methods:

- Through fertilizer tank
- Through venturi
- Through injection pump (dispenser)

5. Automation in Micro-irrigation System

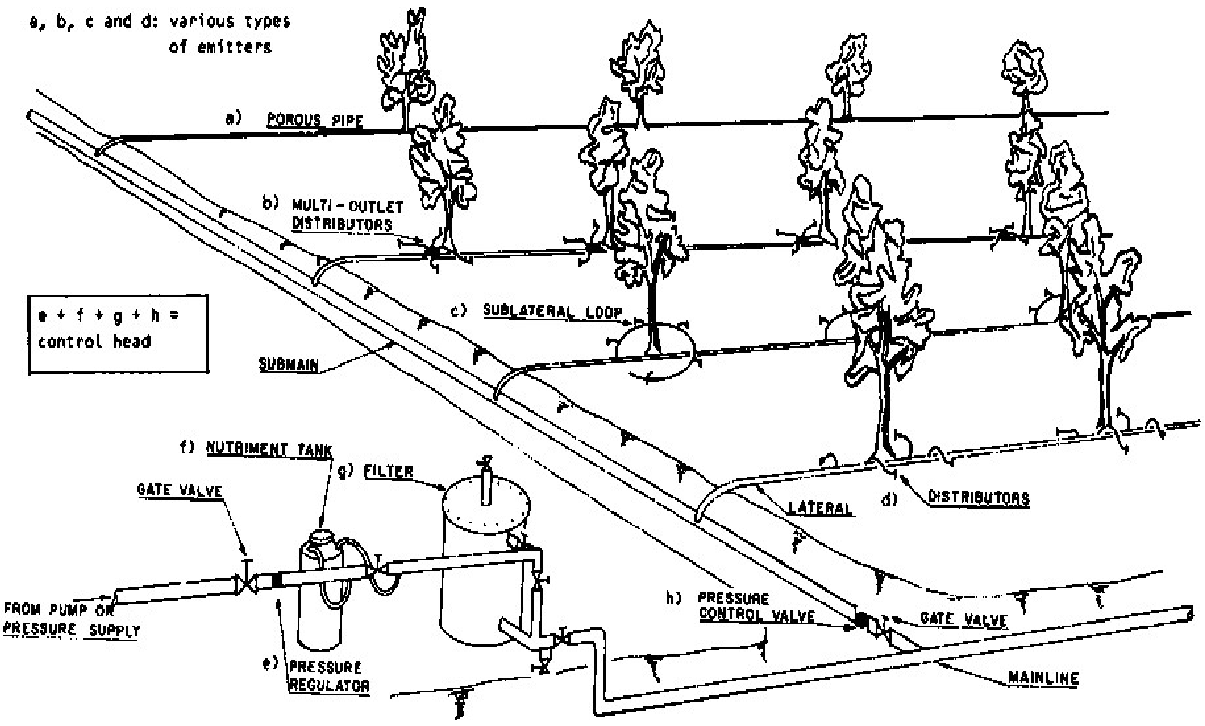
Using automation in micro-irrigation, one can control the irrigation valves, pump, fertilizer injectors automatically with minimum or even no manual interventions. Different types of automations like time-based system, volume based system and real time feedback system are available.

For automation of drip and micro-jet irrigation system, hybrid station controller and solenoid valves are needed in addition to existing micro-irrigation systems. The advantages of automation are:

- Automated drip/ micro-jet system can be operated 2-3 times daily maintaining the optimum soil moisture within plant’s rhizosphere and saves 10-14.5% water over manually operated system.
- The response on plant growth, fruit development, yield and quality is excellent.
- Offers a better alternative to labor shortage and electric load shading.

6. Micro-irrigation Integrated with Rainwater Harvesting in Watersheds

The rainwater from the crop area should be conserved in micro-scale by constructing inter-row harvesting measures.It is desirable to cover the basins with straws or dry leaves or weeds, which not only conserve the soil moisture but also will check the growth of weeds. Mulching by organic mulches and decomposition of the same increases the soil nutrients and organic carbon contents of soil and resultantly enhances the yield and fruit quality. Except organic mulches, black polythene sheet has been reported to give better results in respect of moisture conservation and regulation of temperature. As the rainwater harvesting in pond is cost effective, the water should be used precisely using MI system in the crops. In sloppy or hilly areas, gravity-fed MI is necessary, which can operate without any electrical energy.



Drip irrigation system with different components

Role of Information Communication Technology to Disseminate Climate Resilient Water Management Technologies

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Introduction

Information and Communication Technology is a wide term that refers to all computer based advanced technologies for managing the data and communicating information. Usually, ICT is employed for three major actions: (1) to store data and information, (2) to transform the data and information into knowledge which can be shared, (3) to communicate the data, information and knowledge to the end user. The framework and role of information communication technologies are described in Fig.1. In order to tackle climate change, three main strategies are available: mitigation, adaptation or both. The application of information technologies in this sector follows the approach of applying it to mitigate climate changes as well as to adapt to changes.

Adaptation strategies in climate change have been employed throughout all of history, while mitigation initiatives have been designed only when the scientific community determined a possible interaction between human actions and climate. Therefore, adaptation processes can also begin from the application of techniques already used and handled in various ways from all human communities.

Mitigation is connected mainly to the energetic sector, while adaptation actions are necessary for all the associate-economic fields (health, agriculture, water management etc.). These fields have their own specific role and their own series of institutional, economic and normative barriers (FAO, 2010; Zanamwe and Okunoye, 2013).

ICT for mitigation

ICTs are important carriers to reduce greenhouse gas emissions. Several associations demonstrated that it is possible to reduce the emissions of CO_2 in a substantial way through ICTs, replacing transfers with data transmissions and making our economic system more sustainable.

Technologies for adaptation

Technologies are commonly considered one of the key elements to develop, plan, implement and manage adaptation strategies to climate change. It is useful to highlight the main categories of advanced technologies because they will probably be involved in the adaptation processes; information systems & communication technologies, and other advanced technologies. It is important to remember that biotechnologies, nanotechnologies and geo-engineering, among the others, are likely to play a big role in the next future.

Regarding information and communication technologies, it must be noted that the possible solutions developed within the field of ICT for Climate Change Adaptation (ICT4CCA) vary significantly, depending on the nature of the local context, due to the wide range of impacts that climate change can have on different sectors at different levels. A real ICT4CCA sector does not even exist yet, as to date the contributions of ICTs in the climate adaptation arena have come from different branches of its domain. For example, remote sensing techniques have been employed for environmental monitoring purposes and decision support tools have been designed to guide users in the planning and implementing adaptation processes (Ghorbani and Moradi, 2014).

ICT for climate change within agricultural sector

There are several tools available for climate change and agriculture as number of crops and the complexity of replicating the same conditions across different regions are high. Every tool allows one to analyze different processes of the agricultural sector, from local crop modelling under climate change conditions to the management of economic impacts of climate change on agriculture (variations in land value, production demand and supply etc. Some of the tools allow simulating the growth of specific crops, verifying their variations under different climate change scenarios. Usually these tools are site-specific, but they can be applied at a national or regional level through a link to an appropriate Geographic Information System (GIS).

The first step of the application process happens with the definition of boundary conditions which include data on crop calendar, soil status, etc. and input climate parameters and data such as temperature, precipitations, wind speed, global radiation, soil moisture etc. Some of the tools include data related to crop management conditions. The general output of this kind of software is the assessment of crop production under given scenarios, facilitating decision making at a farm level up to a whole crop system. For example, APSIM (Agricultural Production Systems SIMulator), developed by a consortium of universities and departments of the Australian state of Queensland named Agricultural Production Systems Research Unit (APSRU): it can be applied on more than twenty crops and plants, such as wheat, barley, chickpea, cotton, eucalyptus, lupine, maize, peanuts, sugarcane, sunflower, tomato etc. (FAO, 2010).

Apart from the climate change mitigation strategies, the World Economic Forum put forward seven contributions of ICT to mitigating climate change grouped into following three thematic areas. The first category is infrastructure innovation which focuses on reducing energy consumption and Green House gases (GHGs). The second category is behavioural change and green enablement. This category focuses on the need for global measurement and tracking of carbon reduction, as well as tools that impact positive behavioural change including software tools for measuring carbon footprint and the use of innovative technologies and opportunities that reduce travel and transportation, such as those for virtual meetings, telecommuting, and on-line services (*viz.* e-learning, e-Health, e-Tourism and e-Agriculture etc.). The third category is energy efficiency of ICT products and solutions. This category includes adopting green computing which is basically environmentally sustainable computing. This contribution must be monitored because the public will judge the whole sector as environmentally unfriendly if the sector does not address its own carbon footprint. First, this would impact ICT's credibility, making it difficult to deliver on the points above. Second, the rapid increase and penetration of ICT products can, if no action is taken, result in increased energy demand (World Economic Forum).

The Intergovernmental Panel on Climate Change (IPCC, 2007) in its report on climate change tackles the priorities of developing countries through adaptation (i.e. recovery and adjustment in the face of climate change). IPCC (2007) further asserts that the potential of ICTs in adapting to climate change is now evident in use of devices like mobile phones and other applications used in adapting to climate change.

Dissemination of climate resilient information through web portal

Using the information communication technology application, a web based information system namely agriculture water management portal (http://www.iiwm.res.in/awmp) was developed. The web pages were prepared on open source PHP language (Holzner, 2007) on web 2.0 standards with different modules such as research, extension, farmers, general information, e-learning and climatic information for use of different group of stakeholders as shown in Fig.2. The information of All India Coordinate Research Project on Water Management Centres regarding their general information and information related to their research activities were collected and compiled in the web pages. Webpage format has been prepared for researches carried out by AICRP Centres across the country to share the related information to the public. The background information, centre information, theme of research, location map, soil type, alongwith the major accomplishments done by the centre so far was uploaded on the website (Fig. 3). The Information Technology is used in development of a portal mainly for collecting, storing, processing and communicating information to the end users. Information and Communication Technology delineates how these various forms of digital mediums interact with each other through web based applications to meet a specific objective (Nayak, 2015).

An e-learning module of the web portal was developed similar to RKMP (2015) for the use of farmers and other researchers based on the literature on research carried out and extension activities specific to agriculture water management. The webpage format for e-learning is shown in Fig.4. The published literature, bulletins and leaflets for agriculture water management in Hindi and Odia language were made available on the webpages as e-books. The bulletins published by the Institute and e-books already available in the Institute website were linked with the web portal.

The success stories on agricultural water management by different coordinating centres of All India Coordinate Research Project (AICRP) on Water Management have also been incorporated in the portal. The success stories and technologies are categorized on the basis of different agro-ecological regions, irrigation methods for easy interpretation of the data by end users as shown in Fig. 5. A user after entering to the website can get the information about the major technologies available across the country and their application in agriculture. The web pages are also prepared on various technologies developed under different research aspects at this Institute viz. rainwater conservation, micro level water resource development, farm pond based agriculture, crop diversification, rubber check dam for watersheds, raised and sunken bed, system of rice intensification, sub-surface water harvesting structure and waterlogged area management as depicted in Fig.6. The information has also been created in Hindi language. The list of progressive farmers who were awarded by the Institute are also made available in the portal alongwith their adopted technologies.

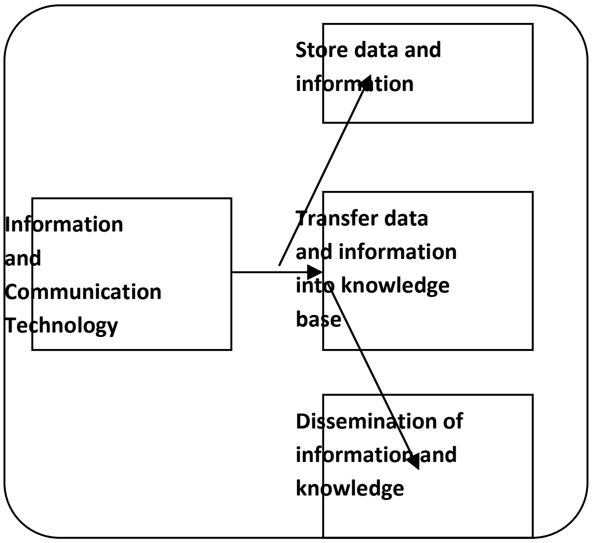

Fig.1. Role of Information communication technology

Agriculture Water Management Portal

Water is a natural resource which is a fundamental to life, livelihood, food security and sustainable development. India has more than 17 percent of the world's population, but has only 4% of world's renewable water resources with 2.6% of world's land area. There are further limits on utilizable quantities of water owing to uneven distribution over time and space.

With a growing population and rising needs of a fast developing nation as well as the given indications of the impact of climate change, availability of utilizable water will be under further strain in future with the possibility of deepening water conflicts among different user groups. Low consciousness about the scarcity of water and its life sustaining and economic value, results in its mismanagement, wastage and inefficient use.

In addition, there are inequities in distribution and lack of a unified perspective in planning, management and use of water resources. Rapid industrialisation and urbanization coupled with continuous decline in per capita water availability is putting a lot of pressure on the available water resources in the country. As per report

Fig. 2. Homepage of the Agriculture Water Management Portal

All India Coordinated Research Project on Irrigation Water Management

Background

The cost effective irrigation water management technologies have been developed through All India Coordinated Research Projects on Water Management and Groundwater Utilization sites spread over fourteen agro-ecological regions across the country. The achievements and technologies are ready for implementation and adoption with viable bankable criteria. Technology demonstration programs were held in different centres in the country. During XII plan, AICRP on Water Management and AICRP on Groundwater Utilization were merged together and operated with revised themes within the existing staff positions. The merged scheme to be renamed as AICRP on Irrigation Water Management (IWM) with adequate emphasis on surface water, groundwater and wastewater management. In order to cater to the future research needs on agricultural water management, it is essential to strengthen research facilities, information sharing facilities etc. at ICAR-IIWM and cooperating centres of the AICRP on Irrigation Water Management located in different parts of the country. This would provide the solutions to different problems concerning irrigation water management in different agro-ecological regions and geo-hydrological situations of the country.

Model Themes of Research

- Assessment of water availability at regional level and to devise interventions for matching water supply with the agricultural system demand.

Fig. 3. Webpage depicting the AICRP information

E-PUBLICATIONS

| Hindi language | Odia language (ଓଡ଼ିଆ) | English Language |

The ICAR-Indian Institute of Water Management, Bhubaneswar published various Research Bulletins, Books, folders, leaflets etc. in English, Hindi and also in regional languages (Odia) on various water management issues. The free publications are available in the Institute website for downloading....

Research Publications in Odia

Fig. 4. Webpage showing the e-publication module

Success Stories on Water Management

Rainwater Management | Waterlogged Area Management | Waste water use in farming

Success Stories classified on Agriculture Water Management

Agro Ecological Region/Centre-wise | Irrigation method-wise

Agro Ecological Region 2

Centre	Success Stories
Bhatinda Centre	Diversification with hi-value crops and adoption of water saving techniques Canal water harvesting and use of micro irrigation for higher productivity

Fig. 5. Webpage for success stories categorization

Technology developed by ICAR-IIWM

Water the critical resource is being affected by deforestation, industrialization, urbanization, increasing population and all developmental activities. The ICAR-Indian Institute of Water Management (formerly known as DWM) has been addressing the issues of on-farm water management through basic, applied and strategic research activities under rainwater, canal water, groundwater, and waterlogged area management programmes. The Institute developed various technological packages suiting to the need of different agro-ecological regions across the country. These are compiled and described the nitty gritty of the technologies in simple language in this booklet, which help the farming community to go through, understand it and reap the benefits of various technologies wherever possible at their own context.

ICAR-Indian Institute of Water Management (ICAR) has developed many promising technologies for (i) management and conservation of on-farm water resources for sustainable agricultural production, (ii) significant reduction in the use of irrigation water per unit irrigated area, (iii) excess water management in agricultural lands, (iv) development of sustainable cropping systems in relation to the availability of water, (v) strategies for multiple uses of water to enhance water productivity, (vi) reuse of poor quality groundwater and industrial and municipal wastewaters, and (vii) avoiding the contaminations and further degradation of soil and water resources.

These technologies are tested in the farmers' field and being demonstrated / exhibited through the programmes such as Farmers' Participatory Action Research Programme (FPARP) and Scaling-up of Water Productivity in Agriculture for Livelihoods (SWPA) in different locations. Some of the most promising and bankable technologies to enhance the water

Fig. 6. Webpage showing the technologies available in the portal

Conclusion

ICTs play a major role in monitoring climate change through serving in data collection, storage, collaboration, processing and dissemination. The growth of ICT in developing countries offers a new technological aspect and new opportunities for sharing useful information for farmers and other stakeholders. The mechanism of sharing the information on agricultural water management through web portal for farming community, which has long been plagued with problems related to climate resilient technologies for soil, water and its management. In this connection, the developed web based information system on agriculture water management will be useful for better utilization of water resources and technologies in agriculture. The information available in the web portal are useful for researchers, farmers and other stakeholder to know the agricultural technologies developed across the country. The published literature, bulletins and leaflets for agriculture water management in English, Hindi and regional language are made available on the webpage in the form of easily accessible e-books which can be viewed by general public. The success stories available in the portal on agricultural water management by different coordinating Centres of AICRP on Water Management in the country are useful for the farming communities. The success stories and technologies are categorized on different agro-ecological region-wise, irrigation method-wise for easy interpretation of the data by end users.

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Water quality analyses for determining irrigation suitability

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Water resource and demand

Water is getting increasingly limited with increasing demand of growing population coupled with domestic, industrial, agricultural and other requirement. Per capita annual availability of fresh water less than 1000 m^3 is called water scarcity. The availability to a level of less than 500 m^3 per capita per annum, a condition called ‘Absolute scarcity’ may prevail upon many countries by the end of 2025.Out of all water on the earth, only 2.5–2.75% is fresh water. Fresh water can be defined as water with less than 500 parts per million (ppm) of dissolved salts. India has 2.42% of the total land on earth, 17% (2011 census) of the world population and only 4% of total available freshwater. The total annual fresh water requirement in India by 2025 and 2050 is estimated to be 1093 and 1447 BCM respectively where domestic requirement will be 30 to 40 percent more than the present requirement. The industrial requirement will be around 23 and 60 BCM by 2025 and 2050 respectively. To meet the food demand of growing population in India agricultural sector will also require about 910 and 1072 BCM. In the face of higher demands of fresh water from domestic and industrial sectors, the allocation of fresh water to agriculture sector is bound to decrease in future. Therefore, agriculture sector needs to exploit other marginal water resources like wastewater, naturally occurring non-potable water, such as sea water, brackish water, saline and sodic water, unpotable groundwater, rainwater and fog harvesting. Albeit, use of marginal quality water has it’s associated risks. In fact, India produces about 62000 million litre daily (mld) of urban wastewater in which about 80% is disposed untreated. Many peri-urban farmers use the untreated wastewater to grow a variety of crop risking the health of consumers, soils and themselves oblivion of the water quality, driven mainly by perpetual availability, nutrient richness and non-availability of alternative source of fresh water.

Water quality

Good quality water helps to maintain agricultural productivity and sustain soil fertility. In general, water quality refers to the chemical, physical, biological, and radiological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose (Nancy 2009). Specific uses have different quality needs and one water supply is considered more acceptable (of better quality) if it produces better results or causes fewer problems than an alternative water supply. The water quality used for irrigation is essential for the yield and quantity of crops, maintenance of soil productivity, and protection of the environment.

Suitability of water for irrigation

The suitability of an irrigation water depends upon several factors, such as, water quality, soil type, plant characteristics, irrigation method, drainage, climate and the local conditions. The integrated effect of these factors on the suitability of irrigation water (*SI*) can be expressed by the relationship given below:

$$SI = \int QSPCD$$

Where

Q = quality of irrigation water, that is, total salt concentration, relative proportion of cations, etc;

S = soil type, texture, structure, permeability, fertility, calcium carbonate content, type of clay minerals and initial level of salinity and alkalinity before irrigation;

P = salt tolerance characteristics of the crop to be grown, its variety and growth stage;

C = climate, that is, total rainfall, its distribution and evaporation characteristics; and

D = drainage conditions, depth of water table, nature of soil profile, presence of hard pan or lime concentration and management practices.

These factors act interactively such that a single suitable criteria is hard to be adopted for widely varying conditions

The chemical parameters of irrigation water refer to the content of salts in the water as well as to parameters derived from the composition of salts in the water; parameters such as pH, EC/TDS Electrical Conductivity (EC)/ Total Dissolved Solids (TDS), SAR (Sodium Adsorption Ratio) alkalinity and hardness.

Problems Related to Irrigation Water Quality

Quality of water used for irrigation may differ significantly depending upon the nature and magnitude of dissolved salts. Salts may be present in irrigation water in relatively small but are significant. Salts come from dissolution or weathering of the rocks and soil, including dissolution of lime, gypsum and other slowly dissolved soil minerals. These salts are transported with the water to the place of application. In the case of irrigation, the salts are accumulated through evaporation with time. The suitability of water for irrigation is not only governed by the quantity but the type of salts as well. Many types of soil and cropping problems may be developed with the increase in total salt concentration in soil, thus, different management practices are required to sustain desired crop yields. Water quality or suitability for use is judged on the probable severity of problems that can be expected to escalate through long-term use.The problems may vary equally in kind and degree, and are altered by soil, climate and crop, as well as by the expertise of the water user. The suitability for use is driven by the conditions which affect the buildup of the water constituents and which may limit crop yield. The most commonly met soil problems are those related to salinity, water infiltration rate, toxicity and a group of other miscellaneous problems and are used as a basis to evaluate water quality

Salinity : Salts in soil or water reduce water availability to the crop to such an extent that yield is affected.

Water infiltration rate : Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately from one irrigation to the next.

Specific ion toxicity : Certain ions (sodium, chloride, or boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields.

Miscellaneous : Excessive nutrients reduce yield or quality; unsightly deposits on fruit or foliage reduce marketability; excessive corrosion of equipment increases maintenance and repairs.

Alkalinity and pH : Alkalinity is the resultant sum of the quantities of bicarbonates (HCO^{3-}), carbonates (CO_3^{2-}) and hydroxide (OH^-) in water. The unit of alkalinity is mg/l or meq/l $CaCO_3$. Alkalinity buffers the water against sudden variations in pH. If the alkalinity is too low, any addition of acidic materials will quickly and significantly lower the pH. In container plants and hydroponics, root exudates may alter the pH of rhizosphere pH rapidly if alkalinity is low**.**

Salinity – Salinity in water is one of the main problem related to irrigation water quality.Water salinity speaks about how much salts are dissolved in water and is expressed in general as mg/litre.

However, salinity does not give information of the kind of salts or their relative amounts dissolved in the water. High level of salts in the irrigation water reduces water availability to the crop (because of osmotic pressure) and causes yield reduction. Beyond a certain threshold, reduction in crop yield is proportional to the increase in salinity level. Different crops vary in their sensitivity to salinity and therefore have different thresholds and yield reduction rates.

The most common parameters used for determining the irrigation water quality, in relation with its salinity, are EC and TDS. Total Salt Concentration—It is expressed as the electrical conductivity (EC). In relation to hazardous effects of the total salt concentration, the irrigation water can be classified into four major groups as given in Table below.In case the irrigation water salinity exceeds the threshold for the crop, yield reduction occurs. Equations were developed to estimate the yield potential, based on the irrigation water salinity.

$$\% \text{ Yield (of maximum)} = 100 - b\,(ECe - a)$$

Where (b), is the percent loss in relative yield per unit increase in salinity, (a) the EC threshold the crop can tolerate and ECe is the electrical conductivity of the saturated soil paste, which is measured in the laboratory.

ECe is proportional to the electrical conductivity of the irrigation water, depending on the percentage of irrigation water leached below the root zone. (http://www.smart-fertilizer.com/articles/irrigation-water-quality)

Sodium hazard and irrigation water infiltration - The parameter used to determine the sodium hazard is SAR - Sodium Adsorption Ratio. This parameter indicates the amount of sodium in the irrigation water, in relation to calcium and magnesium. Calcium and magnesium tend to counter the negative effect of sodium.

$$SAR = \frac{Na\ (meq/l)}{\sqrt{\frac{Ca\ (meq/l) + Mg\ (meq/l)}{2}}}$$

High SAR levels might result in a breakdown of soil structure and water infiltration problems. Soil tends to seal and to become hard and compact when dry.

Atypically, higher salinity reduces the harmful effect of sodium on soil structure. So, when sodium levels in the soil are high in relation with calcium and magnesium, i.e SAR is high, flushing the soil with good irrigation water quality will only worsen the problem. Numerous references refer to sodicity problems associated with irrigation water as permeability. Complicating the issue of sodicity is the fact that at very low salinity levels (even though the ratio of sodium to calcium plus magnesium may be high), soil flocculation and aggregation (which occurs with any high salt concentration) is lost and permeability decreases. Thus, irrigation water which is very low in salt concentration (< 0.2 dS/m) accentuates poor permeability resulting from high SAR (Rhoads et al 1992).

Toxicity of specific ions

The quantity of specific ions is also a driver of the irrigation water quality. The quality can be also ascertained by the presence and the quantity of specific ions. However, difference between salinity and toxicity problems is that ion toxicity mostly occurs within the plant itself, as a result of accumulation of a specific ion in the leaves. The most common ions which might be the reason for toxicity problem are chloride, sodium and boron. The same as with salinity, different crops show difference in their sensitivity or tolerance to these ions. Special attention is needed for boron because boron toxicity occurs in very low concentrations, even though it is an essential plant nutrient. Similarly in case of sewage irrigation risk of heavy metals accumulation in soil and plant is high.

Toxic levels of even a single ion in the irrigation water might make the water unsuitable for irrigation. Individual ions in irrigation water may have toxic effects on plant growth or may have excess accumulation in edible parts beyond permissible limits. Table 3 below lists some of the known toxic elements and their permissible concentration in irrigation water where continuously applied on all soils and also when used on fine textured soils for short terms. Many of these are also essential for plants growth.

Salt tolerance of crops

There are intra-generic and inter-generic differences in salt tolerance of crops and this character of crops and crop varieties could be exploited to use saline/alkali water. The data presented in Table 4 and 5 below the relative tolerance of salts to soil salinity and soil alkali. These tables could be used to select crops depending upon the kind and degree of the problem with water.

Wastewater irrigation and water quality guidelines

Apart from physico-chemical parameters microbiological aspects assumes greater significance when it comes to wastewater irrigation. Often it is accepted that microbiological quality is the most important criterion to determine the suitability of wastewater for irrigation. The past twenty years have seen considerable research carried out to evaluate the microbiological risks to health associated with the use of wastewater for crop irrigation, particularly with a view to developing design guidelines for the treatment of wastewater. In defining a “safe” microbiological water quality three different approaches may be used:

1. The absence of faecal indicator bacteria
2. No measurable excess risk of infection attributable to wastewater use
3. A modelled risk of infection which falls below a predefined level (Blumenthal *et al*. 2000).

Major review of epidemiological studies that were available (Shuval *et al* 1986), supported by evidence from microbiological studies, microbiological quality guidelines were defined that it was considered would not lead to any measurable increase in infection risk. These set the level of faecal coliform for unrestricted irrigation at ≤ 1000 /100 ml, with an additional guide of ≤ 1 nematode egg / litre. These guidelines have been criticised by some as being too lax, (Blumenthal *et al*. op cit), but despite that they have been adopted by a number of countries. Blumenthal *et al* (op cit) who set out recommendations for revising the WHO 1989 guidelines in accordance with the values in Table 6. In reaching their conclusions Blumenthal *et al* used both epidemiological studies and quantitative microbial risk assessment models, the third approach suggested above. They retain the value of 1,000 faecal coliform /100 ml for unrestricted irrigation but suggest a more restrictive limit of 0.1 (rather than 1) nematode egg / litre. For

irrigation of cereal, fibre or fodder crops, pasture or trees, they now suggest limits for faecal coliform which vary depending on the irrigation method and the age of those exposed. There was previously no faecal coliform guideline for this category. (www.ruaf.org/sites/default/files/econf)
Westcot (1997) provided a useful points to monitor and interpret water quality parameters for irrigation. These are summarised in Table 7.

Concluding remarks

Successful management of agricultural production systems irrigated with poor quality water can be achieved by understanding potential damaging factors and accounting for their influences in determining production inputs (nutrients, soil amendments, cultivation, and irrigation). There are some management practices that can help in reducing the damage. These practices include proper leaching, increased frequency of irrigations, avoidance of overhead irrigation and use of fertilizers having chloride or boron, using suitable soil amendments, selecting the right crops, etc. Water quality assessment is imperative for safe irrigation and is an important tool to exploit marginal quality water that may bring more area under irrigated agriculture.

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Table 1 Guidelines for interpretations of water quality for irrigation							
Potential Irrigation Problem				**Units**	**Degree of Restriction on Use**		
					None	**Slight to Moderate**	**Severe**
Salinity*(affects crop water availability)*							
	EC$_w$			dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)						
	TDS			mg/l	< 450	450 – 2000	> 2000
Infiltration*(affects infiltration rate of water into the soil. Evaluate using EC$_w$ and SAR together)*							
SAR	= 0 – 3	**and EC$_w$**	=		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6		=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12		=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20		=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40		=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)						
	surface irrigation			SAR	< 3	3 – 9	> 9
	sprinkler irrigation			me/l	< 3	> 3	
	Chloride (Cl)						
	surface irrigation			me/l	< 4	4 – 10	> 10
	sprinkler irrigation			me/l	< 3	> 3	
	Boron (B)			mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements (see Table 21)						
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)			mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/l	< 1.5	1.5 – 8.5	> 8.5
	pH				**Normal Range 6.5 – 8.4**		

Table 2 Laboratory determinations needed to evaluate common irrigation water quality problems				
Water parameter	**Symbol**	**Unit**	**Usual range in irrigation water**	
Salinity				
Salt Content				
Electrical Conductivity	EC$_w$	dS/m	0 – 3	dS/m
(or)				

Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{--}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
Nutrients				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
Miscellaneous				
Boron	B	mg/l	0 – 2	mg/l

TDS ppm or mg/L	EC µS/cm	Salinity hazard
<500	8	Low
500 - 1000	0.8 - 1.6	Medium
1000 - 2000	1.6 - 3	High
> 2000	> 3	Very high
(http://www.smart-fertilizer.com/articles/irrigation-water-quality)		

Table 3 Upper permissible concentrations of trace elements in irrigation water

Element	Recommended Max. Conc. (mg/l	Remarks
Al (aluminium)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.10	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1.0[3]	Inactivated by neutral and alkaline soils.
Fe (iron)	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn (manganese)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni (nickel)	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pd (lead)	5.0	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
V (vanadium)	0.10	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] Adapted from National Academy of Sciences (1972) and Pratt (1972).

Table 4. Crop groups based on response to soil salinity

Sensitive Group		Resistant Group	
Highly sensitive	**Medium sensitive**	**Medium tolerant**	**Highly tolerant**
Lentil	Radish	Spinach	Barley
Mash	Cow pea	Sugarcane	Cotton
Chickpea	Broad bean	Indian mustard	Sugar beet
Beans	Vetch	Rice (transplanted)	Turnip
Peas	Cabbage	Wheat	Tobacco
Carrot	Cauliflower	Pearl millet	Safflower
Onion	Cucumber	Oats	Rapeseed
Lemon	Gourds	Alfalfa	Karnal grass
Orange	Tomato	Blue panic grass	Date palm
Grape	Sweet potato	Para grass	Ber
Peach	Sorghum	Rhodes grass	*Mesquite*
Plum	Minor millets	Sudan grass	*Casuarina*
Pear	Maize	Guava	*Tamarix*
Apple	Clover, *berseem*	Pomegranate	*Salvadora*
		Acacia	

Table 5 Relative tolerance of crops to alkali stress

Characteristics	ESP range*	Crops
Sensitive	10-15	Safflower, mash, peas, lentil, pigeon pea, urd bean
	16-20	Chickpea, soybean
	20-25	Groundnut, cowpea, onion, pearl millet
Semi-tolerant	25-30	Linseed, garlic, *guar*
	30-50	Indian mustard, wheat, sunflower
Tolerant	50-60	Barley, S*esbania*
	60-70	Rice (Transplanted)

*Relative yields are only 50% of the potential in respective alkali range

Table 6 Recommended revised guidelines for treated wastewater use in agriculture. (After Blumenthal *et al*, 2000)

Category	Reuse conditions	*Exposed group*	Irrigation method	Intestinal nematodes. mean no. eggs/ litre	Faecal coliform mean no. / 100 ml
A	Unrestricted irrigation. Vegetables and salad crops eaten raw. Sports fields	Workers, consumers, public	Any	≤ 0.1	≤1,000
B	Restricted irrigation. Cereal, fibre or fodder crops, pasture or trees.	B1: Workers, but no children <15yrs, nearby communities.	Spray or sprinkler	≤ 1	≤ 100,000
		B2: as B1	Surface	≤ 1	≤ 1,000
		B3: Workers, including children <15yrs, nearby communities.	Any	≤ 0.1	≤ 1,000
C	Localised irrigation of crops in category B, if exposure of workers and the public does not occur.		Drip/trickle	Not applicable	Not applicable

Source : www.ruaf.org/sites/default/files/econf retrieved on 27th August 2016

Table 7 Ranges of Contamination and Recommendations (after Westcot, 1997)

Mean number of faecal coliform / 100 ml	Recommendation
< 1,000	Appropriate for irrigation of vegetables
1,000 – 10,000	Potentially safe if the source of contamination (presumed to be localised) can be eliminated
10,000 – 100,000	Heavy contamination requiring treatment before the water can be used for unrestricted cropping
> 100,000	Extensive heavy contamination – highly unsuited for irrigation.

Management and reclamation of waterlogged, saline and alkali water areas in the regime of climate change

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Introduction

Agricultural production in India faces severe threat from excess water stress situation prevailing in about 11 M ha of land area. With the considerable changes in climate over a period of time, the situation with respect to crop production is expected to be worse in future. Waterlogging and flood occurrence are highly correlated and climate change will further enhance the frequency and extent of the both events. Most importantly, the climate change has resulted in erratic distribution of rainfall which is a big concern for agriculture. The waterlogging causes severe damage to agriculture in several ways. The crops get affected both in terms of establishment and productivity. The stagnation of water inside the crop fields result in crop damage. The pulses and oil seeds and vegetable crops are highly susceptible to flood and the flood will result in their complete crop loss. In case of paddy, the duration of flood will decide the extent of damage to crop.

For achieving the target of 400 million tonnes of food grain production to feed the evergrowing population of the country by 2025, utilization of waterlogged areas, saline and alkali areas for crop production is highly essential. Excess water stress affects plant establishment and severely restricts the plant growth. This requires us to employ surface or subsurface drainage to remove the excess water. Wherever surface drainage is feasible, providing drainage at optimum growth stages like tillering would enhance the productivity of rice (Brahmanand *et al.,* 2000 & 2009). Crop management interventions that provide better resilience under waterlogged condition have to be developed and implemented on large scale. In some of the conditions where slope is not there, engineering drainage measures will not work and we have to think for better alternatives like bio-drainage. Moreover, bio-drainage with *Casuarina sp.* proves to be ideal measure for reclaiming waterlogged condition in coastal / saline tracts of the country.

In some patches in coastal tracts and canal command areas in semi arid zone, salinity and alkali condition accompany waterlogging situation. Cultivation of salinity tolerant crop varieties and reclamation measures would be highly essential to minimize the crop loss and to ensure sustainable crop production. The resilience capacity of the community has to be increased for reducing the vulnerability of the community (UNESCO-IHE, 2009). The role of both mitigation and adaptation of climate change impacts in minimizing the yield losses is significant under such situation (Adger, N., & Kelly, M. (1999). An integrated approach is required to provide a long term solution to these problematic soils. Some prominent techniques for reclamation of waterlogged, saline and alkali soils are discussed here.

Over-aged rice seedlings

The level of submergence at the time of transplanting is found to be higher than the seedling age in flood prone waterlogged areas which makes the establishment of seedlings difficult. To overcome this constraint, Directorate of Water Management, Bhubaneswar has developed a flood resilient mechanism in the form of over aged seedlings of 60 days old. This has provided an yield advantage of about 32% over the normal seedlings (30 days old) and most importantly this practice has helped successful establishment of seedlings in flood prone areas (Roy Chowdhury *et al.,* 2011).

Waterlogging / Flood tolerant rice varieties

Waterlogging tolerant varieties of rice such as Durga, Hangseswari, Varshadhan are being suggested for areas of the deep waterlogged and flood prone areas which have resulted in additional rice yield and economic returns of the farmers. The agro-economic analysis of improved crop management interventions conducted by ICAR-Indian Institute of Water Management, Bhubaneswar revealed that the pod yield of green gram variety SML-668 (0.680 t/ha) was found to be superior compared to that of local greengram variety (0.586 t/ha) under post flood situation in Garadpur block of Kendrapada district. It recorded about 16% higher pod yield compared to traditionally grown greengram variety. As a result, the economic net returns obtained from the cultivation of SML-668 variety of greengram was found to be higher by Rs. 5,600/- per ha compared to the local variety. Similarly, flash floods are frequently witnessed due to heavy rains with in short period resulting in huge crop loss. The flash flood tolerant rice varieties such as Swarna Sub-1 should be used by the farmers to reduce the yield loss under such conditions. Farmers in coastal Odisha which is flood prone area have taken the benefit of this variety, but there is a need to generate more awareness among the farmers and to supply adequate quantity of the seed.

Drainage at tillering stage of rice crop

The studies were conducted at Central research farm of ICAR-Indian Institute of Water Management (ICAR), Bhubaneswar during 1998 to 2001 for assessing the impact of drainage at different growth stages i.e. tillering, panicle initiation, dough stage and tillering cum panicle initiation stages on the productivity and water and nutrient savings of scented rice. The results revealed that the highest grain yield (2.86 t ha^{-1}) was recorded when drainage is given at tillering stage which accounted for 22 % increase over the grain yield recorded at continuous submergence (2.35 t ha^{-1}) (Table 1) (Brahmanand *et al.* 2005). Drainage at tillering stage leads to loss of excess soluble salts, which are harmful to rice crop and it gets aeration for the proper growth and development resulting in favorable grain yield. Moreover, irrigation water was saved by 16% when drainage was given at tillering stage for 10 days duration compared to that of continuous submergence as drainage acted as an alternate wetting and drying measure.

Table 1.Grain and straw yield of scented rice as influenced by drainage, ICAR-IIWM research farm, Mendhasal, India.

Treatments	**Grain yield (t ha^{-1})**	**Straw yield (t ha^{-1})**
Drainage at tillering stage	2.86	3.32
Drainage at panicle initiation stage	2.29	2.78
Drainage at dough stage	2.44	2.93
Drainage at tillering and panicle initiation stage	2.55	3.20
No drainage	2.35	2.84
Drainage throughout the growing season	1.98	2.47
LSD (0.05)	0.17	0.11

Highest nitrogen use efficiency was also recorded when drainage was provided at tillering stage when nitrogen was applied @ 60 kg ha^{-1} (Table 2.). The superior performance of rice under drainage at tillering stage (4.31 t ha^{-1}) compared to continuous submergence was also demonstrated in farmers' fields at Biswanathpur, Khurdha district, Odisha during 2001-2003 and the farmers have adopted this water saving practice in large scale.

Table 2. Nitrogen use efficiency (agronomic efficiency) of scented rice as influenced by drainage, ICAR-IIWM research farm, Mendhasal, India.

Drainage treatment	**NUE0–30 (kg grain produced/kg nitrogen applied)**	**NUE0–60 (kg grain produced/kg nitrogen applied)**
Drainage at tillering stage	20.7	15.7
Drainage at panicle initiation stage	16.0	11.5
Drainage at dough stage	17.0	11.0
Drainage at tillering and panicle initiation stage	22.0	15.0
No drainage	20.3	14.8
Drainage throughout the growing season	14.3	10.3

Contingency crop planning and post flood management

Contingency crop planning helps in providing better resilience in post flood period resulting in lesser extent of crop damage. The contingent crop plans were prepared for Kendrapara, Puri, Cuttack, Bhadrak, Jagatsinghpur and Balasore districts of Odisha. The practice of zero tillage as crop management intervention helped in better crop establishment and productivity of sunflower, okra and bittergourd under post flood situation.

Waterlogging resistant aquatic crops with economic importance

In areas of perennial waterlogging where even rice cultivation is difficult, ICAR-Indian Institute of Water Management, Bhubaneswar has standardized a technique for cultivation of aquatic crops with economic importance such as water chestnut. It was revealed that water chestnut either as sole crop or with fish which has potential to enhance the water chestnut yield by 1.22 t/ha and fish yield by 0.36 t/ha with an additional net income of famers by Rs.33,000/ha. The package of practices for cultivation of other aquatic crops such as Typha sp. And Colocasia sp. were also standardized for flood prone waterlogged areas.

Bio-drainage options for better waterlogging and salinity resilience

Bio-drainage is a process of removal of water from the agricultural fields through cultivation of plant species. It may also be defined as a process of pumping of excess soil water by deep rooted plants using their bio energy (Ram *et al.,* 2008). The combined processes of absorption of water from the soil through roots, translocation of water through xylem tissue and transpiration of water in to environment through stomata in leaves would play vital role in draining the excess water under bio-drainage concept. Some plants have higher rate of absorption and transpiration and hence suit well under bio-drainage. In flood prone and waterlogged areas, the practice of bio-drainage using *Casuarina and Eucalyptus* plantations would act as a viable flood resilient system as they improve soil drainage and operates better micro climate. This allows intercrop cultivation and helps in advanced planting of rabi crop resulting in higher water and land productivity. The farmers will get higher economic net returns due to fuel wood, intercrop and rabi crop produce.

For example, Eucalyptus sp. and Casuarinas sp. transpire water at very higher rates and hence suit well as bio-drainage species. The water transpiring ability of Eucalyptus sp. makes it most suitable species for bio-drainage vegetation (Hatton et al., 1998; Morris et al., 1998). In case of salt affected areas, some bio-drainage species have been identified as most suitable due to their salt resistance and hence they can be given preference (Table 3)

Table 3: Salt tolerant trees suitable for bio-drainage in saline and alkaline water areas

Name of the tree	Tolerance to
Eucalyptus camaldulensis (Saphaida)	Salinity, waterlogging and drought
Eucalyptus rudis (Saphaida)	-do-
Eucalyptus microtheca (Saphaida)	-do-
Eucalyptus tereticornis (Saphaida)	-do-
Tamarix aphylla (Frash)	Salinity
Terminala arjuna (Arjan)	Salinity and Waterlogging
Salix babylonica (Baid)	Salinity
Pongamia pinnata (Sukhchain)	Salinity
Acacia nilotica (Kikar)	Salinity and Sodicity
Acacia tortilis (Kikar)	-do-
Acacia ampliceps (Kikar)	-do-
Albizia bebbeck (Siris)	Salinity
Eugenia jambolana (Jaman)	-do-
Ziziphus jujuba (Ber)	-do-
Pridium guajava (Guava)	-do-
Prosopis juliflora (Jangli Kikar)	Salinity and Sodicity
Prosopis chilensis (Jangli Kikar)	-do-
Prosopis alba (Jangli Kikar)	-do-
Leucaena leucocephala (Ipil Ipil)	Salinity
Salvadora oleiodes (Van)	-do-
Phoenix dactylifera (Date palm)	-do-

Prosopis spicigera (Jand)	-do-
Capparis aphylla (Karir)	-do-
Azadirachta indica (Neem)	-do-
Grewia asiatica (Falsa)	-do-

Source: Ahmad (1988)

Another factor that plays important role here is that the survival ability of the plants at the time of their establishment under waterlogged condition. Eucalyptus and Casuarina species have higher survival rate and hence have great prospect for fitting under bio-drainage system. The inter tree spaces under bio-drainage vegetation have to be properly utilized for growing field crops for attaining the maximum water productivity and economic net returns to the farmers. In Kharif season when water stagnates for more than three months period, rice can be grown as an intercrop in bio-drainage vegetation. Waterlogging resistant rice varieties like durga, hangseswari, varshadhan may be grown under this situation. In rabi season, crops like groundnut, blackgram, water melon can be grown to utilize the residual soil moisture in optimum manner. Even in salt affected areas, some field crops which have reasonable tolerance may be grown as inter crops to derive the maximum benefit (Table 4).

Table 4: Salt tolerance of crops (Land Reclamation Directorate Studies, Pakistan)

Crop	**EC_e threshold (dS/m at 25°C)**	**EC_e (dS/m) at which yield decreased by**		
		10%	**25%**	**50%**
Wheat	5.0	5.9	7.2	9.9
Cotton	5.9	8.7	12.7	17.1
Sugar cane	1.8	3.0	5.5	9.9
Rice	4.0	4.6	5.8	7.4
Barley	7.0	8.9	11.6	15.7
Oilseeds	4.0	5.2	6.8	9.7
Berseem	1.2	2.4	5.4	12.0
Lucerne	1.5	2.9	5.0	9.0
Oats	4.2	5.5	7.6	11.7
Mash	4.0	5.2	7.1	10.0
Lentil	1.6	3.0	5.7	12.0
Garden cress	7.5	9.2	12.2	17.0
Jantar	6.0	8.0	12.0	15.4
Kallar grass	9.0	12.4	14.0	16.0

Source: Ahmad (1988)

The identification of suitable intercrops and their cultivation in bio-drainage system would be highly beneficial in optimizing the resource utilization and maximizing the economic net returns for the farming community in waterlogged ecosystem.

Fitting high value medicinal plants under post rainy season in waterlogged ecosystem

The experiment was laid out in split plot design with two main plot treatments (irrigation scheduling : M1:Irrigations at two critical stages and M2: Irrigation at one critical stage) and 11 sub plot treatments (medicinal crop or inter cropping combination: S1: Coleus forskholii S2: Eclipta alba S3: Eupatorium S4: Centela asiatica S5: Marselia quadrifolia S6: Black gram S7: S1+S6 intercropping S8: S2+S6 intercropping S9: S3+S6 intercropping S10: S4+S6 intercropping and S11: S5+S6 intercropping). The Coleus + blackgram intercropping and Eclipta + blackgram intercropping resulted in significantly higher yield attributes compared to other treatments. Two stage irrigation enhanced the crop productivity by 12 – 13 % relative to that of single stage irrigation. Two stage irrigation resulted in significantly higher dry matter production (15%) and leaf area index (16%) than that of single stage irrigation. Single stage irrigation resulted in average crop yield of 6.17 q/ha compared to 6.96 q/ha recorded in two stage irrigation.

Among all the five medicinal plants, *Coleus forskholii* proves to be the best performer in terms of dry matter accumulation, crop growth rate, and economic yield. It recorded an economic yield of 7.3 - 8.98 q/ha with a net return of Rs. 15,860 to Rs. 27,050/-.Bring raj *(Eclipta alba*) has resulted in the highest leaf yield of 13.5 – 14.6 q/ha with a net profit of Rs. 8,600/- to Rs. 13,840/-. The highest gross water productivity (Rs.13.3 /m^3) and net water productivity (Rs. 5.42m^3) were noticed with coleus followed by that of bringraj in sole cropping.

Overall, *Coleus forskholii* + blackgram intercropping resulted in the highest economic returns than that of other treatments. Bringraj (Eclipta alba) recorded significantly superior leaf yield (15.7 q ha^{-1}), dry matter accumulation (624 g m^{-2}) and leaf area index (2.08) compared to that of other medicinal plants like Coleus forskholii, Centela asiatica, Marselia quadrifolia and Eupatorium sp. The performance of *Eupatorium*, *Centela asiatica* and *Marselia quadrifolia* was not found to be satisfactory compared to their average expected yields. This might be due to the heavy weed infestation in the initial stages of crop growth. Hence, it is concluded that Coleus as sole crop, bringraj as sole crop and their intercropping with blackgram are found to be the viable options for seasonal waterlogged areas.

Conclusion

The agricultural crops experience huge yield loss when they are subjected to excess water stress or waterlogging and the extent of yield loss is quite high under unfavorable soil reaction. The development of reclamation measures such as surface drainage, biological drainage, cultivation of over aged rice seedlings and waterlogging and salinity tolerant rice varieties would certainly reduce the crop yield loss and ensure the better crop survival rate leading to higher economic net returns to the farmers.

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Interactive management of fertilizer and water for sustainable crop and soil management in the context of climate change

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Introduction

Water and nutrient use within plants are closely interrelated under different agro ecosystems. A plant with adequate nutrition can generally better withstand water stress (Gonzalez-Dugo et al., 2010; Waraich et al., 2011). Under rain-fed situations, farmers gain yield by applying nitrogen in conjunction with rainfall. Phosphorus applied at early stages of plant development can promote root growth, which is helpful in accommodating water stress. Potassium plays a key role in stomata and osmotic regulation. Plant nutrients and water are complementary inputs, and plant growth response to any nutrient or to water is a function of the availability of other inputs. Thus, the incremental return to fertilizer inputs is larger when water is not limiting, just as the incremental return to irrigation generally is larger when nutrients are not limiting. If rainfall is inadequate or late in arriving, the investment in fertilizer might generate no return. Thus, to be meaningful, the metrics used to express the performance of agricultural inputs, such as fertilizer use efficiency and water productivity, should be analyzed together and in combination with complementary indicators reflecting the overall effectiveness of the farming system, including crop yield and soil nutrient levels.

Wise management of water, fertilizer, and soil is critical in sustainable food production. Such management can increase food production and enhance environmental quality if ecosystems and their services receive sufficient attention. Unfortunately, the long term benefits of an integrated approach may not be immediately obvious for farmers or businesses making short-term decisions. While farmers may have a shorter time horizon, extension systems lack capacity, and markets often do not properly account for long-term implications of current management decisions. As a result, some appropriate technologies that could increase yields and conserve soil, water, and nutrients are not being implemented on agricultural fields. Additional understanding regarding adoption constraints and incentives to alleviate these constraints will enhance efforts to promote farm-level use of integrated innovative crop production methods. Improvements in crop genetics, the spread of irrigation, and the increase in plant nutrient use will contribute to efforts to feed, cloth, and provide fuel and building materials for an increasing and wealthier global population. Yet, we must continue to integrate these factors into viable strategies and policies.

Measurement of water use efficiency and water productivity

Crop scientists express and measure water use efficiency as the ratio of total biomass or grain yield to water supply or evapotranspiration or transpiration on a daily or seasonal basis (Sinclair et al., 1984).The irrigation system perspective of water use efficiency depends upon the water accounting where losses occur at each stage as water moves from the reservoir (storage losses), conveyed and delivered at the farm gate (conveyance losses), applied to the farm (distribution losses), stored in the soil (application losses) and finally consumed by the crops (crop management losses) for crop production. Depending upon the area of interest, it is possible to measure the water conveyance efficiency, application efficiency, water input efficiency, irrigation water use efficiency and crop WUE. Whereas, crop water use efficiency compares an output from the system (such as yield or economic return) to crop evapotranspiration the irrigation efficiency often compares an output or amount of water retained in the root zone to an input such as some measure of water applied. The term ‘water productivity’ was an attempt to mediate the prevailing complexity and other inherent limitations of the existing concept (Table 1).The concept of water productivity (WP) was offered by Kijne et al. (2003) as a robust measure of the ability of agricultural systems to convert water into food. So, the basic expression of agricultural water productivity is a measure of output of a given system in relation to the water it consumes, and may be measured for the whole system or parts of it, defined in time and space.

Water productivity= Agricultural benefit/Water use

Nutrient use and nutrient use efficiency

The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other components of soil quality. NUE is a critically important concept for evaluating crop production systems and can be greatly impacted by fertilizer management as well as soil- and plant-water relationships. NUE indicates the potential for nutrient losses to the environment from cropping systems as managers strive to meet the increasing societal demand for food, fiber and fuel. NUE measures are not measures of nutrient loss since nutrients can be retained in soil, and systems with relatively low NUE may not necessarily be harmful to the environment, while those with high NUE may not be harmless. NUE addresses some, but not all, aspects of that performance (Mikkelsen et al., 2012).

Therefore, management practices that improve NUE without reducing productivity or the potential for future productivity increases are likely to be most valuable. If the pursuit of improved NUE impairs current or future productivity, the need for cropping fragile lands will likely increase. Fragile lands usually support systems with lower NUE that also use water less efficiently. At the same time, as nutrient rates increase towards an optimum, productivity continues to increase but at a decreasing rate, and NUE typically declines (Barbieri et al., 2008). The extent of the decline will be determined by source, time, and place factors, other cultural practices, as well as by soil and climatic conditions.

Water and fertilizer interactions at the field and farm level

In crop production, water availability, water use and nutrient supply to plants are closely interacting factors influencing plant growth and yield. Generally, it is reported that application of fertilizers enhances water use efficiency by causing greater increase in yield relative to that in evapotranspiration (Ritchie, 1983). Evapotranspirational and transpirational WUE can be improved by raising soil nutrient levels. Adequately fertilized soils promote rapid leaf area expansion, thereby increasing transpiration, and more rapid ground cover, as a result reducing evaporation and increasing evapotranspirational water use efficiency. Raised soil nutrient levels seem to exert additive effects on water use efficiency, and increasing or optimizing yields by adequate application of fertilizers will increase transpiration efficiency of the crop plants. Plants which have adequately used fertilizers may also show higher drought tolerance (Lahiri, 1980). Water use efficiency also increases with increase in water supply up to a certain level. Water supply has been observed to increase fertilizer use efficiency by increasing the availability of applied nutrients. In fact, water and nutrients have been shown to exhibit interactions in respect of yield. Combined effects of nitrogen (N) and irrigation are generally more than the sum of their individual effects. Gajri etal. (1993) very conclusively show that in deeply wetted coarse-textured soils with low organic matter, N application and early-post seeding irrigation in wheat enhance profile water use by increasing depth and density of rooting as well as leaf area index and leaf area duration. While better rooting increases capacity of the plant to extract water by increasing the size of the water reservoir, extensive canopy with longer duration increases the plant demand for water.

Increased canopy also increases the transpiration component of evapotranspiration. Thus N application, apart from increasing evapotranspiration and transpiration/evapotranspiration ratios, also increases water use efficiency (Table 2). A strong interaction between N and water for yield, dependence of water use efficiency on N rate, and N use efficiency on water supply have important management implications. Similarly, water use efficiency was 119% and 150% higher when only pre-sowing irrigation and pre-sowing irrigation plus phosphorus application were made, respectively, to the wheat crop, as compared to control (Li et al., 2004). Fertilizer rates, over which farmers usually have better control, need to be adjusted properly in relation to the available water supplies.

In several studies, soil N level was positively related to WUE. Similarly, applying phosphorus fertilizers increases root density and rooting depth and the amount of water available to plants is increased. Phosphorus, in a balanced soil fertility program, increases WUE and helps crops achieve optimal performance under limited moisture conditions (Wang et al., 2011). The uptake of water by the plant roots and the transport of the water to other parts of the plant are significantly determined by potassium. Potash fertilizers are directly involved in the water management of the plant since it reduces water loss through transpiration. In sandy soils, water use efficiency for total dry matter production is increased by potassium application (Prasad et al., 2000). With integrated soil and water management, focusing on mitigation of dry spells and improved soil fertility can potentially more than double on-farm yields. In most cases, increasing or optimizing yields by the use of adequate fertilizers will increase water use efficiency. Thus, for the high productivity fields, balanced use of fertilizers should be encouraged to ensure sustainable productivity in the intensive cropping system as its lack could lead to significant decline in yields and water use efficiency with lapse of time. Additions of organic materials to soil increases soil water-holding capacity, which in turn improves water availability to plants.

Sustainable water management in agriculture

Sustainable water management in agriculture aims to match water availability and water needs in quantity and quality, in space and time, at reasonable cost and with acceptable environmental impact. Its adoption involves technological problems, social behaviour of rural communities, economic constraints, legal and institutional framework and agricultural practices. Under water demand management most attention has been given to irrigation scheduling (when to irrigate and how much water to apply) giving minor role to irrigation methods (how to apply the water in the field). Many parameters like crop growth stage and its sensitivity to water stress, climatic conditions and water availability in the soil determine when to irrigate or the so-called irrigation frequency. However, this frequency depends upon the irrigation method and therefore, both irrigation scheduling and the irrigation method are inter-related.

Localized irrigation

Localized irrigation is widely recognized as one of the most efficient methods of watering crops Localized irrigation systems (trickle or drip irrigation, micro-sprayers) apply the water to individual plants by means of plastic pipes, usually laid on the ground surface. With drip irrigation water is slowly applied through small emitter openings from plastic pipes with discharge rate ≤ 12 l/h. With micro-sprayer (micro-sprinkler) irrigation water is sprayed over the part of the soil surface occupied by the plant with a discharge rate of 12 to 200 l/h. Studies in diverse countries as India, Israel, Spain and United States have consistently shown that drip irrigation reduces water use by 30 to 70% and raises crop yields by 20 to 90%. Drip irrigation's combination of water savings and higher yields typically increases at least by 50% the water use efficiency and yield/ unit water and makes it a leading technology in the global challenge of boosting crop production in the face of serious water constraints. The main barriers to its expansion are the high investment cost, ranging from 1,500 to 2,500 € per hectare, and the high sensitivity to clogging.

Irrigation scheduling

Irrigation scheduling is the decision making process for determining when to irrigate the crops and how much water to apply. It forms the sole means for optimizing agricultural production and for conserving water and it is the key to improving performance and sustainability of the irrigation systems. It requires good knowledge of the crops' water requirements and of the soil water characteristics that determine when to irrigate, while the adequacy of the irrigation method determines the accuracy of how much water to apply (Fig. 1). With appropriate irrigation scheduling deep percolation and transport of fertilizers and agro-chemicals out of the root-zone is controlled, water-logging is avoided, less water is used (water and energy saving), optimum soil water conditions are created for plant growth, higher yields and better quality are obtained and rising of saline water table is avoided. In water scarce regions, irrigation scheduling is more important than under conditions of abundant water, since any excess in water use is a potential cause for deficit for other users or uses.

Fertigation

The application of fertilizers through the irrigation system (fertigation) became a common practice in modern irrigated agriculture. Thus, the soluble fertilizers at concentrations required by crops are applied through the irrigation system to the wetted volume of the soil. Possible disadvantages include the non-uniform chemical distribution when irrigation design or operation are inadequate, the over-fertilization in case that irrigation is not based on actual crop requirements and the excessive use of soluble fertilizers.

Deficit irrigation practices

In the past, crop irrigation requirements did not consider limitations of the available water supplies. The irrigation scheduling was then based on covering the full crop water requirements. However, in arid and semi-arid regions increasing municipal and industrial demands for water reduce steadily water allocation to agriculture. Thus, water availability is usually limited, and certainly not enough to achieve maximum yields. Then, irrigation strategies not based on full crop water requirements should be adopted for more effective and rational use of water. Such management practices include deficit irrigation, partial root drying and subsurface irrigation.

Subsurface Drip Irrigation

Subsurface drip irrigation (SDI) is a low-pressure, low volume irrigation system that uses buried tubes to apply water. The applied water moves out of the tubes by soil matrix suction. Wetting occurs around the tube and water moves out in the soil all directions. The potential advantages of SDI are: a) water conservation, b) enhanced fertilizer efficiency, c) uniform and highly efficient water application, d) elimination of surface infiltration problems and evaporation losses, e) flexibility in providing frequent and light irrigations, f) Reduced problems of disease and weeds, g) lower pressure required for operation. The main disadvantages are the high cost of initial installation and the increased possibility for clogging, especially when poor quality water is used. Subsurface irrigation is suitable for almost all crops, especially for high value fruit and vegetables, turfs and landscapes.

Agricultural Practices

Agricultural practices, such as soil management, fertilizer application, and disease and pest control are related with the sustainable water management in agriculture and the protection of the environment. Agricultural practice today is characterized by the abuse of fertilizers. Farmers very rarely carry out soil and leaf analyses in order to clarify the proper quantity and type of fertilizer needed for each crop and they apply them empirically. This practice increases considerably the cost of agricultural production and is potentially critical for the deterioration of the groundwater quality and the environment. Agrochemicals (herbicides and pesticides) are also excessively used, endangering the quality of the surface water and negatively affecting the environment. There is a large variety of traditional and modern soil and crop management practices for water conservation (runoff control, improvement of soil infiltration rate, increase soil water capacity, control of soil water evaporation) and erosion control in agriculture, some of which apply also for weed control. The soil management consists of:

Soil surface tillage, which concerns shallow tillage, practices to produce an increased roughness on the soil surface permitting short time storage in small depressions of the rainfall in excess to the infiltration.

Contour tillage, where soil cultivation is made along the land contour and the soil is left with small furrows and ridges that prevent runoff. This technique is also effective to control erosion and may be applied to row crops and small grains provided that field slopes are low.

Bed surface profile, which concerns cultivation of wide beds and is typically used for horticultural row crops.

Conservation tillage, including no-tillage and reduced tillage, where residuals of the previous crop are kept on the soil at planting. Mulches protect the soil from direct impact of raindrops, thus controlling crusting and sealing processes. Conservation tillage helps to maintain high levels of organic matter in the soil thus it is highly effective in improving soil infiltration and controlling erosion.

Mulching with crop residues on soil surface which shades the soil, slows water overland flow, improves infiltration conditions, reduces evaporation losses and also contributes to control of weeds and therefore of non beneficial water use.

Increasing or maintaining the amount of organic matter in the upper soil layers, since it provides for better soil aggregation, reduced crusting or sealing on soil surface and increased water retention capacity of the soil.

Addition of fine material or hydrophilic chemicals to sand/coarse soils. This technique increases the water retention capacity of the soil and controls deep percolation. Thus, water availability in soils with low water holding capacity is increased.

Control of acidity by liming, similarly to gypsum application to soils with high pH. This treatment favours more intensive and deep rooting, better crop development and contributes to improved soil aggregation, thus producing some increase in soil water availability.

Adoption of appropriate weed control techniques to alleviate competition for water and transpiration losses by weed.

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Table 1. Possible forms of agricultural production used for estimating water productivity

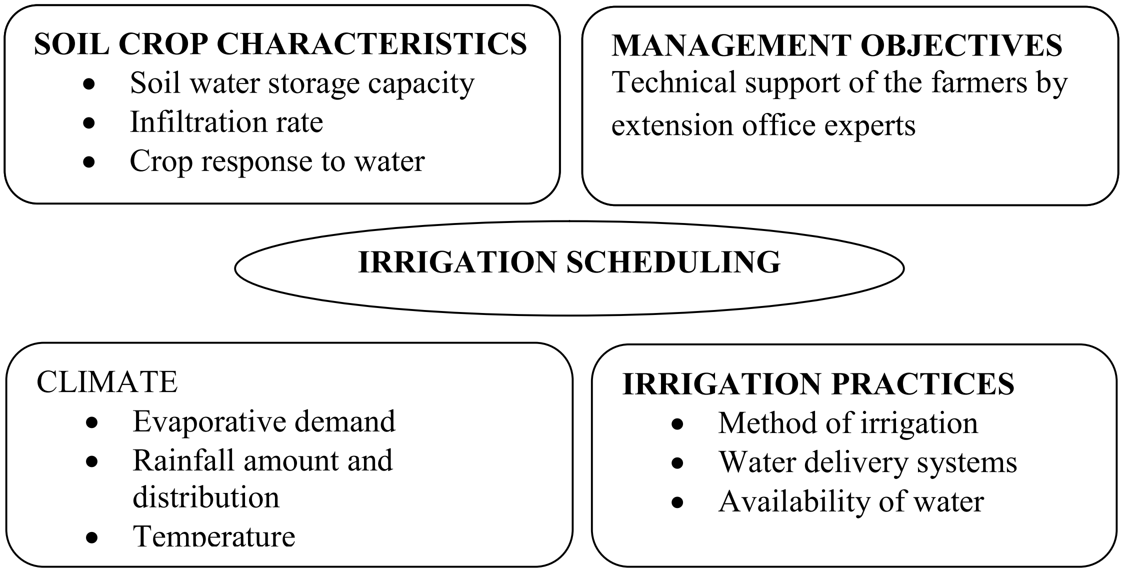
Parameter	**Agricultural production**
Physical water productivity at field, farm or system level	Yield (kg) of biomass, or fruit or grain
Economic water productivity at farm level	Gross or net value of product, or net benefits of production (monetary or energy units)
Economic water productivity at basin scale	Any of the above valuations including those derived from livestock, fishery, agro forestry, pastures and plantations.
Macroeconomic water productivity at regional or national scale	Monetary values of all direct and indirect economic benefits minus the associated costs, for all the uses of water in the domain of interest.

Table 2. Common NUE terms and their application

Term	Calculation*	Question addressed	Typical use
Partial factor Productivity	PFP = Y/F	How productive is this cropping system in comparison to its nutrient input?	As a long-term indicator of trends
Agronomic efficiency	AE = (Y-Y0)/F	How much productivity improvement was gained by	As a short-term indicator of the impact of applied nutrients on productivity. Also used

		use of nutrient input?	as input data for nutrient recommendations based on omission plot yields.
Partial nutrient balance	PNB = UH/F	How much nutrient is being taken out of the system in relation to how much is applied?	As a long-term indicator of trends; most useful when combined with soil fertility information
Apparent recovery efficiency by difference	RE = (U-U0)/F	How much of the nutrient applied did the plant take up?	As an indicator of the potential for nutrient loss from the cropping system and to access the efficiency of management practices.
Internal utilization efficiency	IE = Y/U	What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.)?	To evaluate genotypes in breeding programs; values of 30-90 are common for N in cereals and 55-65 considered optimal
Physiological efficiency	PE = (Y-Y0)/ (U-U0)	What is the ability of the plant to transform nutrients acquired from the source applied into economic yield?	Research evaluating NUE among cultivars and other cultural practices; values of 40-60 are common.

Fig 1.Schematic Diagram of Irrigation scheduling components



Conjunctive use of water for climate change adaptation

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Climate change has direct impacts on regional and global water resources. According to IPCC (2007a), climate change result in increased temperature, rising sea level, widespread changes in rainfall and evaporation patterns and increased frequency and magnitude of extreme weather events such as flood, droughts, and heat waves. These changes can substantially affect present water resources management practices. During wet season, there is excess river/canal water flow resulting flood and low/no flows occur during dry season resulting water deficit in many parts of India. This also results in conflicts between upstream and downstream users in river/canal command areas. Under climate change conditions, there will be imbalance in supply-demand scenario to a greater extent, hence best approach to manage water resources in such condition is upstream storage of excess wet-season river flow for use during dry season. This requires regional conjunctive-use management strategies. Effective conjunctive use of surface water and groundwater results in a total annual system yield that exceeds the sum of the yields of the separate components (Bredehoeft and Young 1983). Traditionally, dams and reservoirs are used for surface water storage, but these are very costly, prone to high evaporative loss, and also have adverse environmental effects. In contrast, sub surface aquifers can act as efficient water reservoirs with minimum evaporative loss and no surface area for inundation (Bouwer 2000). Hence it is desirable to develop effective management strategies for mitigating or reducing the negative impacts of climate change on water resources. Conjunctive use of surface water and groundwater refers planned and coordinated management to maximize the efficient use of total water resources. As there is interrelationship between surface and groundwater resources, it is possible to store excess surface water and utilize it during the deficit period or both the resources can be utilized effectively to address the climate change issues. Conjunctive use of surface water and groundwater has been extensively studied and a number of methods/techniques have been reported for supporting conjunctive water use planning and management (Matrosov et al., 2011; Shi et al., 2012; Bejranonda et al., 2013; Khan et al., 2014).

One of the major characteristic of conjunctive use is to use surface water resources (canal, creeks, and water bodies) and groundwater resources making it especially important for the mitigation of climate changes impacts. It is often the best way to confront some of the serious problems of groundwater salinization and soil waterlogging on alluvial plains. It is necessary to manage the conjunctive development of water resources such that there should be balance between local recharge and groundwater use. Fig. 1 shows the different component of conjunctive use of water with respect to climate change adaptation. Other issues which are related to conjunctive use of groundwater and surface water sources are

- Greater water supply security – by taking advantage of natural groundwater storage in aquifers
- Better timing of irrigation water delivery – since groundwater can be used during any shortfall in canal water availability at critical times in the crop-growth cycle
- Reduced environmental impact – by counteracting land waterlogging and salinization

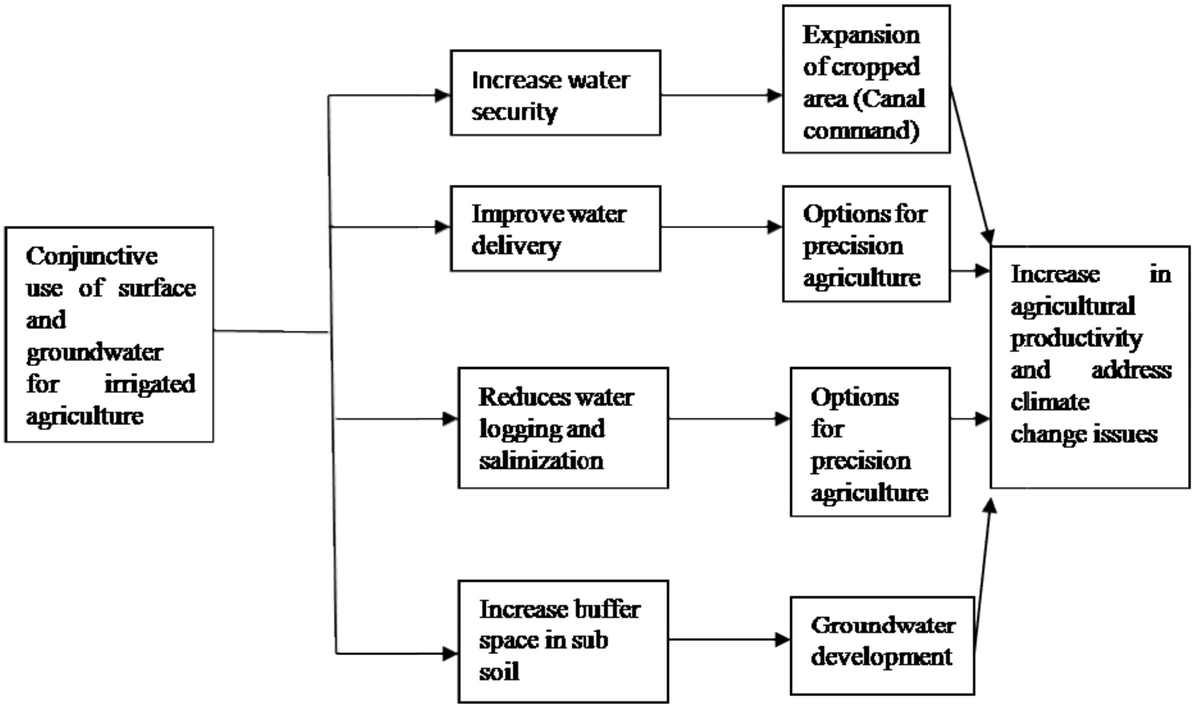

Fig. 1: Conjunctive use planning components in addressing climate change issues

Management of waterlogged area

Waterlogging can be prevented by (i) Effective drainage (ii) Conjunctive Use for surface and ground water (iii) Efficient Irrigation Water Management. Out of different options recommended for anti-waterlogging measures, conjunctive use is the best option. Waterlogging problem emerged mainly as a direct affect of seepage from applied irrigation and from the large scale canal systems. But it can also be caused by excess soil moisture due to periodic flooding, overflow of run-off, seepage, artesian water and obstructed sub surface drainage. Following are few studies in different canal command areas, where water logging problems have been reduced due to conjunctive use planning.

Management of saline water

Saline water use for irrigation is a challenge to agricultural sustainability and food security, through which there is chance of increasing salt buildup in the root zone. Hence conjunctive use allows the utilization of poor quality surface water and/or groundwater resources with freshwater for irrigation. This helps to maintain the salinity level in irrigation water and thus crop production is not hampered.

- Conjunctive water management in saline groundwater area can be standardized to assess and combat long term impacts of various combinations of saline water applications in different cropping systems.
- Use of desalinated water for increasing crop yields, which can also reduce the negative environmental consequences

Management of rising water table

- The conjunctive use of surface water and groundwater resources can control the rising water tables by increasing the groundwater utilization. The reduction in percolation of irrigation water is a major challenge in rice-dominated cropping systems, as more than half of the total water applied to a rice field gets percolated, and thus contributes to the rise in water table. A reduction in rice area against other crops could reduce the percolation rates significantly (Singh et al., 2010).
- Reduction of canal water release into the non-rice areas also reduces net recharge to the aquifer. Thus, the conjunctive use of two water sources along with changed cropping pattern could be of great help in solving the waterlogging problem.
- The conjunctive use of saline drainage water with fresh water allows the expansion of

irrigated agriculture and also solves the disposal problem of saline drainage (Sharma et al., 1989, 1991).

- In India the poor quality water utilization in different States range between 32% and 84% of total surface water development (Tyagi and Minhas, 2002). While implementing poor quality groundwater for controlling the rising watertable, the adoptation of salt tolerant crops is also suggested as it reduces the harmful effects of salts on plant growth. Though, the increased use of poor quality groundwater can control the waterlogging problem up to some extent, its excessive use can lead to higher concentrations of salts in the soil and thus to salinity.
- In coastal areas, the lowering of water tables can lead to seawater intrusion and can degrade groundwater quality, making it unsuitable for irrigation. The lower water tables also increase pumping costs, and the depletion of aquifers raises questions about the sustainability of irrigated agriculture (Qureshi et al., 2008). Also the ultimate aim of any water management project is to maintain the water table at a depth, which is neither too shallow nor too deep. It helps to avoid the adverse effects of waterlogging and at the same time would not lead to over-exploitation.

Mathematical modeling in conjunctive use planning

- The optimal allocation of water resources is achieved by different optimization technique i.e. linear, non linear, dynamics and genetic algorithms
- Deterministic LP model for allocation of two water sources for irrigation in order to determine optimal water use in alkali soils under reclamation.
- Water allocation model, which incorporates deficit irrigation for optimizing the use of water for irrigation.
- Conjunctive use management strategies involving subsurface water storage evaluated. Ganges Water Machine (GWM), Pumping Along Canals (PAC), and Distributed Pumping and Recharge (DPR) numerical models are used to determine the efficacy of different strategies. Results for the Indian State of Uttar Pradesh (UP) indicate that these strategies create seasonal subsurface storage from 6 to 37 % of the yearly average monsoonal flow in the Ganges exiting UP over the considered range of conditions. This has clear implications for flood reduction, and each strategy has the potential to provide irrigation water and to reduce soil waterlogging (Khan et al, 2014).
- A conjunctive use linear programming (LP), deterministic LP model model was developed by Tyagi and Narayana (1981, 1984) to allocate surface water and groundwater for irrigation of agricultural crops in a semiarid area of India where alkalization was a problem. LP-based optimization models have been extensively used in water resources system analysis and planning (Suryavanshi and Reddy, 1986; Vedula and Kumar, 1996; Md. Azamathulla et al., 2008; Lu et al., 2011). These models compare various combinations of different water sources and select an optimal combination based on economic, hydrological or allocation criteria; for example, least cost, minimum conveyance, acceptable water quality or resource conservation (Duckstein and Kisiel, 1968; Maknoon and Burges, 1978; Lingen and Buras, 1987; O'Mara, 1988; Vincent and Dempsey, 1991; Peralta et al., 1995; Philbrick and Kitanidis, 1998).

Challenges and perspectives in conjunctive water management under climate change

1. Mismatch between large-scale global or regional climate models and small-or medium-scale hydrological processes (Arora and Boer, 2001; Merritt et al., 2006;Young et al., 2009). This can limit the effectiveness of climate models in supporting conjunctive water management. In order to transform the coarser outputs of GCMs to match the smaller scales of hydrological systems, effective downscaling techniques and methods are desirable (Hanson and Dettinger, 2005; Mileham et al., 2009).
2. Uncertainty associated with GCM structure and its initial conditions, greenhouse gas emission scenarios, downscaling methods, hydrological model structures and parameters, and conjunctive water use optimization management (Serrat-Capdevila et al., 2007; Kay et al., 2009; Chen et al., 2011; Kienzle et al., 2012). Uncertainty can significantly affect the accuracies of forecasting hydrological responses to climate change and consequently the effectiveness of conjunctive water management strategies (Candela et al., 2012). Effective reflection

and quantification of these uncertainties are critical for making appropriate climate-change mitigation strategies for conjunctive water management (Brekke et al., 2004).

3. Limited availability of long-term groundwater data and information impaired our abilities to investigate the responses of groundwater systems to climate variability and change (Taylor et al., 2013).
4. The integrated water resources management strategies should be capable of dealing with not only local-scale but also basin-sale issues (López-Moreno et al., 2014). In addition, the activities related to enhancement of social awareness and public attitudes to water resources and their management, capacity building, community involvement should be promoted (Vargas-Amelin and Pindado, 2014).
5. Understanding and incorporation of these non-climatic factors into climate change scenarios will be beneficial to decision makers and planners for development of more realistic and feasible water management policies and climate-change mitigation measures (Woldeamlak et al., 2007; Tong et al., 2012). More detailed studies are desired to address the abovementioned issues in development of imperative conjunctive water management strategies under climate change.

A case study in canal command area of Odisha

A study was conducted in a canal distributory (Pattmundai canal in Mahanga block of Cuttack district) of Odisha. During the *kharif* season, 71% to 87% of the area is covered with paddy and rest with Jute, vegetable and spices. After harvesting *kharif* crops, farmers grow vegetable, pulses, and groundnut and oil seeds. But the major crops are green gram and black gram either on residual soil moisture or with heavy pre sowing irrigation through canal which is released for short period during January–February month every year. Preliminary survey was carried out to quantify water availability during *kharif* and *rabi* seasons. Details about the canal release pattern, availability of canal water to the farmers of head, middle and tail reach, cropping pattern, crop yield were collected from different sources. Head reach areas faces waterlogging problem due to canal seepage, where as middle and tail reach areas faces water deficit during *rabi* and summer season. Hence conjunctive use planning was prepared and required water resources (dug well, bore well and water harvesting structures) were developed in a farmer's participatory approach (Sethi et al, 2015). Selection of sites for construction of these structures, were based on Electrical Resistivity Survey (VES) and availability of water bearing zones. Finally impact of these structures was assessed based on change in cropping pattern, groundwater table depth, crop yield and water productivity of the entire areas. Total amount of water available through canal+ rainfall was 317.07 ha-m as against 36.30 ha- m crop water demand. The water harvesting structures were designed for capacity of 1500 m^3 each. The dug well depth was decided based on the availability of top layer aquifer and it was constructed upto 6.65 m depth with 3 meter diameter of the well. The depth of bore well was 15 meter and it was constructed near to the water harvesting structures. Conjunctive use planning of irrigation through bore well, dug wells and ponds on farmers' participatory approach in tail reach of the canal command areas could increase cropping intensity from 151% to 300% with high value and less water requirement crops. Interventions showed that during long dry spell period in *kharif* season and non availability of canal water, use of groundwater up to 20 % of the crop water demand could enhance crop yield up to 21 %. Utilizing water from dug well, for three crops (short duration rice- potato/ radish- bitter gourd) in a year recorded highest net return of Rs 87368/ha without depletion of groundwater level. Further, highest water productivity (kg fruit yield/$m^3$of water used) was observed in potato (6.67-8.41) followed by brinjal (4.06-4.42). The groundwater table fluctuation showed that during pre-monsoon period, it the ranged within 2.0 m to 3.18 m, during post monsoon period it ranged from 2.0 m to 3.2 m and it remained about 2 m during monsoon season. Waterlogging problem in head reach areas were reduced through these interventions.

Table 1: Over view of the results of conjunctive use studies in different irrigation canal command areas (Chadha, 2013)

Sl. No	Canal name	Study area, ha	Waterlogged area, ha	Conjunctive use planning
1	IGNP-1	5530	1150	Groundwater development increased from 7% to 18% of Canal releases; cropping intensity increase to 120 % the water logged area will reduce to 785 sq. Km
2	Hirakud	1570.18	Pre-monsoon (174); post monsoon (1494)	The irrigation intensity can be increased from 170% to 200 % by using surface water 90% and groundwater 10%. Cost benefit ratio is 1.66.
3	Sarada Sahayak	8978	4874	Under the conjunctive use plan, to control spreading of water logging it is proposed to reduce surface water utilization from the present 1481.8 MCM to 1015.9 MCM and the groundwater utilization to be increased from 906.32 MCM to 1356.23 MCM; this will increase the cropping intensity from 153 % to 200%; cost benefit ratio 1.56.
4	Tangabhadra	6354	Pre-monsoon (98.75), Post-Monsoon (229.00)	The conjunctive use study indicates two possible scenarios or development plans. By implementing an integrated groundwater development by these two plans 85.8% of the canal water shortage areas can be irrigated. By adopting water saving methods rest areas can be brought under irrigation. Cropping intensity can be increased from 61.43 % to 116%. Cost benefit ratio 3.45.
5	Ghatprabha	10370	July(143) Aug (344) Nov(580)	The present cropping intensity which is 84% in left bank can be increase to 200% by utilizing 84% of surface water and 16% of groundwater. In the right bank cropping intensity of 140% by using 69% surface water and 31% groundwater. Cost benefit ratio varies 1.25 to 5.34 for irrigated dry crops and oil seeds.
6	Mahi Kadana	3717	Pre-monsoon (33.70); post monsoon (160.8)	From the study it has been observed that out of 12 zones, in five zones already maximum possible irrigation intensity is achieved, in one zone, because of existing shallow water condition and saline groundwater, no further increases in irrigation has been considered. In the rest six zones spreading over are area of 33000 ha, only the irrigation intensity has to be maximized. The results of ground water simulation studies indicate that the present utilization of surface water and groundwater in the proportion of 65:35 is optimal situation of conjunctive use, without creating any adverse effect.

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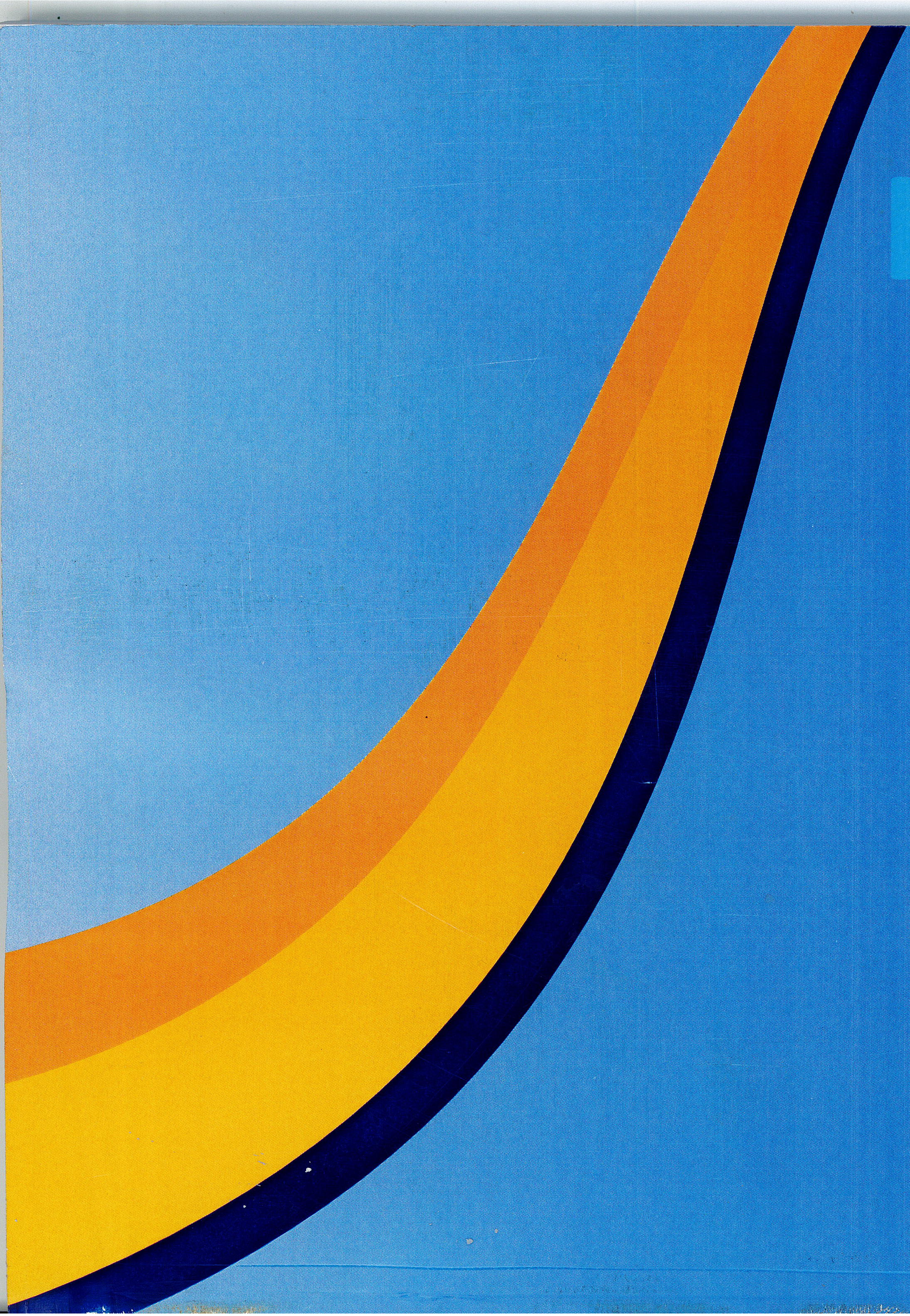

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