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# Safe Water Adaptability for Salinity, Arsenic and Drought Risks in Southwest of Bangladesh

**Md. Anwarul Abedin and Rajib Shaw**

*In recent years, access to safe drinking water has been a major problem in many countries in the world. The scarcity of safe drinking water is increasing due to increase in population, changing lifestyles and urbanization. Bangladesh, known as the "land of water," also faces a safe drinking water crisis. Particularly, the Southwestern part of Bangladesh experiences scarcity of safe drinking water due to salinity intrusion along with arsenic-contaminated groundwater and recurring drought. In this context, an exploratory study is undertaken in two severe safe water scarce areas namely Khulna and Satkhira districts of Bangladesh. The study developed and utilized the SIPE approach to measure safe water adaptability index considering socio-economic, institutional, physiochemical, and environmental perspectives of the targeted area. With regard to overall safe water adaptability index, results show that overall safe water adaptability scores range from 2.16 to 3.13. Moreover, based on the score, five upazilas (sub-districts) have medium, 10 upazilas have low and one upazila has very low adaptability among 16 upazilas in Khulna and Satkhira districts. Through the adaptability index, the capacity of upazilas and gap between different levels is measured which can guide the review of existing policy and provide recommendations for a safe water adaptability action plan.*

**KEY WORDS:** safe water adaptability, salinity, arsenic, drought, southwestern Bangladesh

## Introduction

According to United Nations Committee on Economic, Social and Cultural Rights (2003), access to safe freshwater is now regarded as a universal human right. In addition, extended access to safe drinking water and sanitation is one of the goals of the Millennium Development Goals (UNDP, 2006). As water is indispensable to all forms of life, it is needed in almost all human activities. In recent history, demand for water has increased rapidly with population increase, industrialization and urbanization (Stockholm Water Front, 2009). The UN estimates that one third of the world's population lives in water shortage areas of which about 1.1 billion people live without access to safe drinking water (Shaw & Thaitakoo, 2010). It is expected that in the twenty-first century, the world will



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face the most challenging and devastating problem of availability of safe drinking water.

In the context of Bangladesh, water resources virtually depend on the equitable sharing and management of transboundary rivers. The Southwestern region of Bangladesh, in particular, suffers from a serious safe drinking water crisis (Akber, 2010). There are several reasons that make safe water unavailable for the Bangladeshi people. One is water related problems in the extremes such as flood during monsoon and water scarcity during dry season (Rahaman, 2005). Early and delayed monsoon rains and prolonged dry spell cause drought that aggravates water scarcity in coastal areas.

Two, the Southwestern region is more vulnerable to safe drinking water because both surface and ground water are filthy with acute and high salinity intrusion from the Bay of Bengal along with arsenic contaminated groundwater and drought. Since the Southwestern region is located in the coast, deep groundwater in the coastal area is relatively vulnerable to the contamination of saline water intrusion, which makes groundwater unsuitable for drinking or irrigation (Kim, Kim, Ryu, & Chang, 2006). Likewise, heavy pumping and excessive use of groundwater near the coast increase the intrusion of saline water into the aquifer.

Three, since agriculture is the mainstay of the people in the Southwestern region, agricultural intensification causes the rapid increase in water use for irrigation purposes. As a consequence, increasing demand for water and challenges of water distribution and management become more crucial. Water-related problems pose a grave threat to rural living, livelihood and food security. For example, most of the people in this area use arsenic-contaminated groundwater for drinking by installing shallow hand tube-well without taking into account health impacts.

To address water resources management, the Bangladesh government developed the National Water Policy (NWP) in 1999 and the National Water Management Plan (NWMP) in 2004. In terms of safe drinking water, it can be seen that only the NWP gives emphasis on the facilitation and availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation. Prior to the NWP, the Bangladesh government published the National Policy for Safe Water Supply and Sanitation (NPSWSS) in 1998 with the help of Local Government Division under the Ministry of Local Government and Rural Development and Cooperatives which provides access to safe drinking water services for all at an affordable cost. Later in 2005, the Coastal Zone Policy proposed a number of sustainable management for natural resources initiatives. However, with regard to water, only excavation of ponds, tanks for conservation of water and local technology for water treatment (e.g., pond sand filter) and safe water supply are mentioned.

Aside from policy, various governmental agencies; international, national and local NGOs; the private sector; and community are trying to resolve the problem of safe drinking water individually and/or collectively. In most cases, however, the problem is addressed as a single issue rather than a combined one. For example, to ensure safe water in Southwestern Bangladesh, the Department of Public Health Engineering focus on arsenic and saline free drinking water with the help of various international organizations. On the other hand, the Ishwari Development Foundation works in Southwest region to get saline free drinking water in cooperation with the German International Cooperation.

In general, the problem of safe drinking water adaptability in Southwestern region is caused by the combined effects of salinity, arsenic, and drought that are intimately inter-linked to one another. There is an urgent need to consider all issues and develop an integrated approach that will address better access to safe drinking water in the affected area. Therefore, this article attempts to explore the existing level of safe water adaptability considering the different socio-economic, institutional, physicochemical, and environmental conditions of severe water scarcity affected areas and compare the levels of safe water adaptability among various Southwestern areas. The study seeks to inform GO, NGO, and policy makers of the priority focus areas and actions necessary to overcome safe water scarcity in targeted areas.

## Study Area

The study was undertaken in two severe salinity, arsenic and drought-prone districts namely Khulna and Satkhira located in the Southwestern region of Bangladesh. It comprises 16 upazilas: 9 upazilas from Khulna and 7 upazilas from Satkhira (Figure 1). Geographically, this area extends from 24°22′N to 24°73′N latitude and 88°36′E to 88°20′E longitude. It is divided roughly into coastal and inland areas. The terrain is relatively flat and is located 1–5 m or even more than 5.0 m above mean sea level. The region is part of an inactive delta of large Himalayan Rivers and is protected from tidal surges by the Sundarban mangrove forest (Mahmud & Barbier, 2010; Warrick, Barrow, & Wigley, 1993).

With regard to climatic conditions, the study area shows temperature and rainfall variations over the past few decades (Ahmed, 2008; Miah, 2010). The highest average maximum temperature is 33°C and above during March and May and the lowest average minimum temperature is about 15°C in December and January (Ahmed, 2008; Chowdhury, 2007). On the other hand, the Southwestern (especially Khulna and Satkhira district) region receives an average rainfall of about 1,710 mm per annum, of which about 78 percent falls within the 4 months of monsoon (July–October).

### *Socio-Economic Profile*

The study area covers an area of 8252.79 $km^2$ with a population of 4.267 million. Majority of the upazila's literacy rate is below 50 percent, which is significantly lower than the national average literacy rate of 63 percent in Bangladesh (Table 1) (Ministry of Finance, 2009). Considering all upazilas, the literacy rate of Paikgacha, Koyra, Terokhada, and Botiyaghata upazila is much lower than other upazilas.

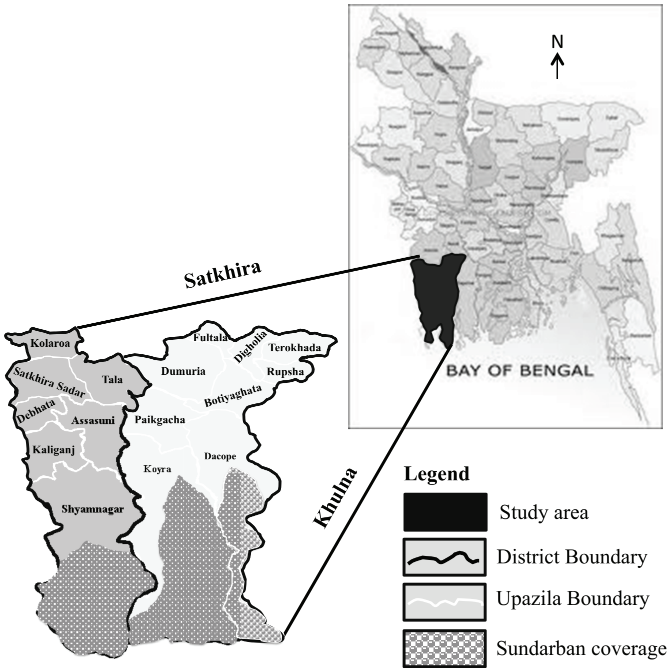


**Figure 1.** Location of Satkhira and Khulna in Bangladesh.

It is observed that the population in the study area is engaged in a diverse set of economic activities. According to Table 1, the status of primary occupation of household heads largely varies in two ways viz. agriculture and shrimp farming (average of 54.56 and 24.88 percent, respectively). On the average, 55 percent people are involved in agriculture. Moreover, an average of 24 percent of people are involved in fisheries including fishing; shrimp and fish culture; and shrimp fry collection, among others, in these two districts. Fishing is the second dominant livelihood next to agricultural labor. Likewise, it is noteworthy that many families are involved in honey collection, commerce, transport, construction, and small enterprises in the study area.

*Environmental Profile*

In earlier sections, it has been stated that the area is coastal; therefore, intrusion of saline water into fresh water is very common. There are several climatic as well as human induced activities, which make this region more prone to salinity intrusion. For instance, intrusion of salinity in the rivers and estuaries increase with tide due to the direct consequence of sea level rise. IWM and CEGIS (2007) mentions that about 327,700 ha of additional area become a high saline water zone (>5 ppt) during dry season because of a 60 cm sea level rise. In addition, establishment of unplanned dams and embankments, and spread of shrimp farming, salinity intrusion is increasing day by day in this region

**Table 1.** Socio-Economic Status of the Study Area

| Name of District | Name of Upazila | Total Area ($km^2$) | Total Population | Household | Population Density (per $km^2$) | Literacy Rate (%) | Livelihood Dependency (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Agriculture | Shrimp Cultivation | Others |
| Khulna | Fultala | 56.83 | 148,405 | 312,11 | 2,611 | 58 | 31 | 27 | 42 |
| | Terokhada | 189 | 132,359 | 35,702 | 700 | 32 | 70 | 9 | 21 |
| | Rupsha | 120.15 | 16,760 | 54,033 | 140 | 55 | 41 | 21 | 38 |
| | Digholia | 86.52 | 173,265 | 40,218 | 2,003 | 55 | 57 | 13 | 30 |
| | Botiyaghata | 235.22 | 150,780 | 21,391 | 641 | 32 | 47 | 36 | 17 |
| | Dumuria | 454.23 | 307,644 | 60,501 | 677 | 49 | 65 | 11 | 24 |
| | Dacop | 991.57 | 183,981 | 27,886 | 186 | 38 | 62 | 21 | 17 |
| | Paikgacha | 414.03 | 289,325 | 24,549 | 699 | 33 | 49 | 38 | 13 |
| | Koyra | 1813.42 | 212,696 | 25,391 | 117 | 32 | 62 | 26 | 12 |
| Satkhira | Satkhira sadar | 403.48 | 441,325 | 19,450 | 1,094 | 35 | 61 | 23 | 16 |
| | Kolaroa | 232.64 | 238,314 | 75,624 | 1,024 | 46 | 71 | 23 | 6 |
| | Tala | 344.15 | 2,940,400 | 62,443 | 8,544 | 46 | 46 | 27 | 27 |
| | Assasuni | 376.43 | 294,294 | 63,336 | 782 | 45 | 37 | 53 | 10 |
| | Debhata | 176.33 | 99,068 | 45,252 | 562 | 50 | 56 | 11 | 33 |
| | Kaligonj | 333.79 | 225,596 | 48,858 | 676 | 32 | 59 | 28 | 13 |
| | Shyamnagar | 1968.24 | 390,028 | 61,890 | 198 | 58 | 59 | 31 | 10 |

*Source*: UNO Office of Khulna and Satkhira District, 2011.

(MoEF, 2005). Finally, establishment of Farakka Barrage over Ganges River is one of the main reasons for salinity intrusion in the Southwestern part of Bangladesh (Islam & Gnauck, 2008). In 1974 India built the Farakka barrage for diverting water from the upstream Ganges River to the Hugli River (Gain, Aryal, Sana, & Uddin, 2007) that causes the reduction of Ganges fresh water flow during dry season. As Bangladesh is a downstream country, water supply is significantly decreased with increasing entry of seawater into the Ganges basin. Consequently, it increases river and groundwater salinity in this region (Gain et al., 2007; Shamsuddin, Xiaoyong, & Hazarika, 2006).

Data in Table 2 reveals that the level of salinity in both surface and groundwater varies from upazila to upazila in the study area. In terms of both surface and groundwater, findings show that almost all upazilas exceed the critical limit (<600 ppm) (as given by Bangladesh drinking water standard) except for Fultala and Tala upazilas. Most of the upazilas' surface and groundwater salinity lie between 600 and 1,500 ppm. In some upazilas, for example, Koyra and Dacope upazilas, salinity level goes above 2,000 ppm which not only makes the drinking water unsafe for the community, but also hinders the utilization of this water for domestic and irrigation purposes in the area. Hence, access to safe drinking water is very difficult making the condition of health centers crucial.

Furthermore, the presence of arsenic in groundwater resource makes groundwater unfit for rural livelihood which many are dependent on. Arsenic makes the groundwater unsuitable for human consumption especially for drinking and cooking purposes. The arsenic drinking water standard recommended by WHO is 10 μm/L whereas the Government of Bangladesh (GoB) recommends an arsenic drinking water standard of 50 μm/L which is five times higher. However, it has been reported by Uttaran, a local NGO, that 79 percent of the tested tubewells of shallow aquifers in the southwestern region are contaminated with arsenic (Farhana, 2011). In most cases, arsenic concentration in groundwater exceeds the GoB and WHO standards (Table 5). Therefore, it can be seen that none of upazilas meet the WHO recommendation (arsenic concentration <10 μm/L). Only seven out of 16 upazilas, namely Fultala, Dumuria, Terokhada, Tala, Debhata, Botiyaghata, and Shyamnagar pass GoB's drinking water standard. The rest of the upazilas show a higher concentration of arsenic in groundwater.

Lastly, apart from salinity and arsenic, drought has indirect impacts on drinking water access and supply in the study area during dry season. As can be seen from Table 2 above, almost all upazilas show medium levels of drought (BARC, 2001 classifies drought severity areas based on yield loss). The variation of drought frequency is also observed among upazilas. Table 2 shows that five upazilas face drought once in an interval of 5 years or more, four upazilas face once in every 2 years, two upazilas face once a year, and five upazilas have no data regarding drought frequency and level. As a result of drought during dry season, there is an increase of surface water dry up and groundwater level depletion which enhances safe water scarcity in the region.

**Table 2.** Present Salinity, Arsenic, and Drought Scenario of all Upazila

| Name of District | Name of Upazila | Salinity: Salinity Level (ppm): Surface Water | Salinity: Salinity Level (ppm): Groundwater | Arsenic (As): As Level (ppb) | Arsenic (As): No of As Patient | Arsenic (As): As Free Safe Water Users' Coverage (%) | Arsenic (As): % of As Pollution in Tubewell | Drought: Frequency | Drought: Level (Based on BARC, 2001) |
|---|---|---|---|---|---|---|---|---|---|
| Khulna | Fultala | <600 | <600 | <50 | 28 | 85.18 | 14.83 | Once in 5 years or more | Medium |
| | Koyra | >2,000 | >2,000 | >250 | 11 | 72.17 | 27.83 | Once every 2 years | Medium |
| | Paikgacha | 1,000–1,500 | 600–1,000 | 50–150 | 45 | 49.50 | 50.50 | Once a year | Medium |
| | Rupsha | >2,000 | <600 | 50–150 | 115 | 70.54 | 29.46 | No data | Medium |
| | Terokhada | >2,000 | 1,500 | <50 | 30 | 73.87 | 26.13 | Once every 2 years | Medium |
| | Dumuria | 600–1,000 | 600–1,000 | <50 | 102 | 65.00 | 35.00 | No data | Medium |
| | Dacope | >2,000 | >2,000 | 50–150 | No data | 58.00 | 42.00 | Once every 2 years | Medium |
| | Digholia | 1,000–1,500 | 1,000–1,500 | 150–250 | 265 | 71.90 | 28.10 | No data | Medium |
| | Botiyaghata | >2,000 | 600–1,000 | <50 | 06 | 94.23 | 5.77 | Once in 5 years or more | Medium |
| Satkhira | Debhata | >2,000 | 600–1,000 | <50 | 78 | 66.60 | 60.79 | Once a year | Medium |
| | Tala | <600 | <600 | <50 | 192 | 38.00 | 54.91 | Once in 5 years or more | Medium |
| | Kaliganj | 1,000–1,500 | 600–1,000 | 50–150 | 26 | 13.83 | 25.91 | Once in 5 years or more | Medium |
| | Sadar | 1,000–1,500 | <600 | 50–150 | No data | 36.00 | 59.79 | Once in 5 years or more | Medium |
| | Kolaroa | 1,500–2,000 | 600–1,000 | 50–150 | 669 | 39.17 | 77.70 | Twice every year | Medium |
| | Assasuni | 1,500–2,000 | <600 | >250 | 286 | No data | 57.55 | No data | Medium |
| | Shyamnagar | 1,000–1,500 | <600 | <50 | 01 | 91.33 | 6.47 | No data | Medium |

*Source*: DPHE, Khulna and Satkhira District, 2011.

### *Institutional Profile*

It can be observed from Table 3 that different institutions work on three different issues viz. salinity, arsenic, and drought. The Department of Public Health Engineering (DPHE) plays a lead role in safe water supply and access in the Southwestern part of Bangladesh. It is the primary governmental agency responsible for ensuring access to safe drinking water. Similarly, the Local Government Division (LGD) of the Ministry of Local Government, Rural Development, and Cooperatives (LGRD&C) has overall responsibility for the water and sanitation sector. The government has been in the process of preparing a cost sharing strategy for water services (MoLGRDC, 2005).

Apart from these, various governmental agencies such as Bangladesh Rice Research Institute and Bangladesh Agricultural Research Institute have been developing saline-tolerant varieties. At the government level, screening and identification of arsenic contamination from hand-driven tube wells are the first steps to arsenic mitigation. In times of drought, the government undertakes relief measures by providing drinking water, food grains, and food subsidies to special groups and through food-for-work programs.

## Methodology

To measure the safe water adaptability index, this section develops and uses the SIPE approach considering salinity, arsenic contamination and drought. There is no specific method to measure safe water adaptability. In this regard, the concept of adaptability and the development of a safe water adaptability index are discussed in the following.

### *Concept of Adaptability*

According to the GRID-Arendal of the United Nations Environment Program (1996), adaptability is the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptability is the manifestation of adaptive capacity and represents ways of reducing vulnerability. Adaptability measures include improving information and monitoring systems on surface and groundwater resources, providing water managers with technical training, and applying a range of natural and built water storage solutions. Adaptability is similar to or closely related to a host of other common concepts including adaptive capacity, coping ability, management capacity, stability, robustness, flexibility, and resilience. In general, it can be said that safe water adaptability is the degree of the capacity of humans to manage solidity against water scarcity and safe water access. The IPCC and other bodies point out the importance of building adaptive capacity and resilience in water management practices in order to respond to future uncertainties. In the past 20 years, many indices have been developed qualitatively and quantitatively to evaluate water resources adaptability and/or vulnerability (e.g., water scarcity or

**Table 3.** Different Institutional Involvement for Salinity, Arsenic, and Drought Risk

| Institution | Salinity | Arsenic | Drought |
|---|---|---|---|
| Government | | | |
| Department of Public Health Engineering (DPHE) | √ | √ | |
| Department of Agricultural Extension (DAE) | | | √ |
| Bangladesh Water Development Board (BWDB) | √ | | |
| Donor agency, INGO, & NGO | | | |
| Australian Agency for International Development (AUSAID) | √ | | |
| Oxfam International | √ | | |
| United States Agency for International Development (USAID) | | √ | |
| United Nations International Children's Fund (UNICEF) | √ | √ | |
| German International Cooperation (GIZ) | √ | | |
| Sushilan | √ | | |
| Uttaran | √ | | |
| NGO-Forum | | √ | |
| Jagrata Jubo Shangha (JJS) | | √ | |
| Ishwari Development Foundation (IDF) | √ | | |
| Research organization | | | |
| Bangladesh University of Engineering and Technology (BUET) | | √ | |
| Bangladesh Rice Research Institute (BRRI) | √ | | √ |
| Bangladesh Agricultural Research Institute (BARI) | √ | | |
| Bangladesh Institute of Nuclear Agriculture (BINA) | √ | | |
| Soil Resources Development Institute (SRDI) | √ | | |

water availability or water stress). However, the difficulty of characterizing water adaptability is that there are many equally important facets to water use, supply and scarcity.

### *Development of SIPE Approach for Measuring Safe Water Adaptability Index*

Different studies use various approaches to measure water scarcity and watershed sustainability, among others. For example, Gleick (1996) develops a water scarcity index as a measure of the ability to meet all water requirements for basic human needs: drinking water for survival, water for human hygiene, water for sanitation services, and household needs for preparing food. In addition, Chavez and Alipaz (2007) proposes a Watershed Sustainability Index (WSI) that incorporates hydrology, environment, life, and policy-each having the parameters pressure, state, and response. Moreover, Molden (2007) uses indicators for physical water scarcity that include acute environmental degradation, diminishing groundwater, and water allocation that support some sectors over others.

Similarly, Joerin and Shaw (2011) develop a comprehensive measurement of urban resilience through the Climate Disaster Resilience Index (CDRI) with the inclusion of five dimensions (physical, social, economic, institutional, and natural). For instance, in the case of the physical dimension, the parameters considered are electricity, water, sanitation, and solid waste disposal, accessibility to roads, housing, and land use. Similarly, Habiba, Shaw, and Takeuchi (2011) uses the SIP approach to measure drought resilience considering Socio-economic, Institutional, and Physical aspects of a drought-affected area. Furthermore, Uy, Takeuchi, and Shaw (2012) develops another approach to analyze ecosystem-based resilience using five dimensions (Ecological, Physical, Economic, Social, and Institutional) with potable water, water supply, and water quality as measures of the parameter, water, and sanitation.

Based on the above, this study develops the SIPE approach that generates a set of compound dimensions for measuring safe water adaptability, which is presented in Table 4. Four dimensions are developed that reflects the socio-economical, institutional, physicochemical, and environmental (SIPE) aspects of a water scarce area. Moreover, each dimension consists of primary and secondary indicators justified through rigorous literature review. Altogether, there are 20 primary indicators ($4 \times 5$) (five each for socio-economical, institutional, physicochemical, and environmental, respectively) and 100 secondary indicators ($4 \times 5 \times 5$) (each of the primary indicators are divided into five secondary indicators).

Data on each of these primary and secondary indicators were collected through a comprehensive set of questionnaires. Each question was ranked between 1 (poor, not sufficient/existent) and 5 (very good) in a five-point rating scale. The individual parameters questions were ranked on the basis of specific guidelines furnished in the questionnaire, for example, level of groundwater arsenic concentration which fulfills the WHO requirement ($<10\,\mu g/L$) is assigned as 5 or very good water quality. Similarly if it is as per the guideline of Bangladesh Drinking Water Standards ($<50\,\mu g/L$) it is assigned as 4 or good water quality. Concentration beyond these permissible limits is assigned as 1 (very poor), 2 (poor), or 3 (medium) based on their varying degree of arsenic contamination. Efforts have been made to integrate national and international guidelines in the indexing systems. For the other parameters where such guidelines are not applicable, a general perception and indexing guideline is developed through expert opinion. Additionally, survey respondents were requested to assign weights for the indicators and dimensions in order to reflect the priorities of the upazila and the relevance of the indicators to the local situation.

### *Data Collection Through Questionnaire Survey*

In order to fulfill the objectives of this study, a SIPE questionnaire survey was conducted at institutional level in the study area between January and February 2012 with the help of the Deputy Commissioner (bureaucratic head of the district) of Khulna and Satkhira districts. The questionnaire was filled up by the Upazila Nirbahi Officer (UNO) (who is responsible for supervising all upazila level administrative/development works as well as preparing and coordinating upazila development plans of the upazila) with the agreement of other officials like Engineer of Department of Public Health and Engineering (DPHE), Upazila Agriculture Officer, Upazila Fisheries Officer, Upazila Statistics Officer, Upazila Health Officer and so on. The first author personally visited the relevant offices in each upazila level to explain the importance of the indicators and questionnaires

**Table 4.** Measures of Safe Water Adaptability in SIPE Approach

| Dimension | Primary Indicator | Secondary Indicator |
|---|---|---|
| Socioeconomic | Education-awareness | % of population having education on water security, % of drop out due to water insecurity, Taking preventive measure, Information dissemination, Safe water awareness-raising activities |
| | Social capital | Leadership, Social norms, Social network, Social abnormalities (divorce), Migration (Regional shifting) |
| | Social facilities | Domestic use, Participation on community water system, Water reuse, Existence of Pond sand filter, Household expenditure on water |
| | Health | Arsenic affected people, Diseases related to water scarcity, Health care facilities & Health awareness-raising activities, Health care worker visit, Level of preparedness on health issues |
| | Water dependent livelihood | Agriculture, Shrimp culture and fisheries, Employment for water construction & maintenance, Drinking water supplier, Salt production activities |
| Institutional | Policy | Arsenic mitigation policy, Salinity mitigation policy, Surface water quality standard, Ground water quality standard, National water (drinking) policy |
| | Management | Training program, Public awareness program, Warning system, Monitoring and evaluation, Support/Subsidies |
| | Co-ordination | Interrelation between GO& NGO, Interrelation between GO & community, Interrelation between NGO & community, Interrelation between GO and international donor agencies, Public private partnership |
| | Budget | Allocation for water sector, Proper utilization of budget, External fund sourcing, Cost-effectiveness of expenditure, Budget sharing |
| | Institute | Knowledge sharing, Municipal wastewater treatment, Government agencies capacity, Water activities by village organization/community based organization, Devolvement of function |
| Physicochemical | Water quality | Arsenic level, Salinity level in surface water, Salinity level in groundwater, pH level, Level of iron |
| | Water quantity | Surface water reserve ($m^3$), Ground water reserve ($m^3$), Recharge rate, Annual rainfall (mm), % of safe water availability |
| | Infrastructure | Existence of water distribution network, Water treatment center, Water conservation, Water reservoir (tank, dam), Rain water harvest |
| | Land use | % of built up area, % of water bodies, % of vegetation, % of area under shrimp cultivation, % of cultivable land |
| | Water supply and access | % of population having access to safe drinking water, % of area having access to irrigation for agriculture, % of arsenic free tube well, Piped water supply, Distance to nearest safe drinking water source |

(*Continued*)

**Table 4.** (*Continued*)

| Dimension | Primary Indicator | Secondary Indicator |
|---|---|---|
| Environmental | Biodiversity | Extinction of fresh water fishes, Provisioning (water), Species (change in number of species and population size), Ecosystem (change in natural habitats), Natural resource management program |
| | Soil degradation | Soil pH, Soil structure, Drainage, Fertility (nutrient balance), Accumulation of salts |
| | Salinization | People affected, Area affected, Impact of shrimp cultivation on environment, Crop loss (yield), Introduction/cultivation of saline tolerant varieties |
| | Extreme event | Cyclone, Flood, Drought, Heat wave, Cold wave |
| | Contamination/pollution | Presence of Cd (Cadmium), Presence of Na (Sodium), Presence of microorganism (*Coliform* Bacteria), Level of biological oxygen demand (BOD), Level of chemical oxygen demand (COD) |

to reduce uncertainties in filling out the questionnaires as well as conducted focus group discussions with the local officials.

During the questionnaire survey period, secondary data were also collected from government offices, NGOs, and donor agencies in Bangladesh such as Soil Resources Development Institute (SRDI), Climate Change Cell of Ministry of Environment and Forest (MoEF), Livelihood Adaptation and Climate Change (LACC) of Comprehensive Disaster Management Program (CDMP) under Ministry of Food and Disaster Management, Bangladesh Meteorological Department (BMD), Bangladesh Agricultural Research Council (BARC), Center for Environmental and Geographic Information Services (CEGIS), national NGOs namely Uttaran, Sushilan, NGO-Forum, and Ishwari Development Foundation (IDF) at upazila (sub-district), district and division levels. The data collected include rainfall, temperature, arsenic level, number of arsenic patients, salinity level, land use, natural resources, services and facilities, water resources, safe water supply activities, and related problems.

### *Data Analysis*

Simple arithmetic functions such as weighted mean index and aggregate weighted mean index were used to calculate the scores for the indicators and dimensions, respectively. In the above, it was discussed that "SIPE" approach consists of four dimensions (Table 4) which is defined by another five primary indicators which are again represented by five secondary indicators measuring a dimension in more detail. As a result, 100 secondary indicators divided evenly into 20 primary indicators and four dimensions define the safe water adaptability of a particular area; whereby, each secondary indicator (x1, x2 …, x5), allows five different choices between very poor or not available (score 1) with a best score of 5. In addition, a weighting scheme requires that secondary indicators within primary indicators, consisting of five secondary indicators, be ranked (w1, w2 …,

$$\text{Weighted Mean}: \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} = \frac{w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5}{w_1 + w_2 + w_3 + w_4 + w_5}$$

**Figure 2.** Formula—Weighted Mean for Calculating a Score of a Primary Indicator.

w5) depending on their importance (low importance [1], high importance [5]) in shaping the final score of a particular primary indicator and dimension. Because of this simple structured questionnaire with the uniform numbers for each primary indicator and secondary indicator ranging between 1 and 5, it allows a transparent adoption of the formula called weighted mean (Figure 2) to calculate the SIPE scores for each secondary indicator, primary indicator, and dimension in a standardized and harmonized approach.

### *Limitation of the Study*

The study used both scientific and perception-based questions in the questionnaire which raised an important challenge of obtaining accurate answers for each question. For instance, the social capital indicator in the socio-economic dimension utilizes leadership, social norms, social network, social abnormalities related questions which are based on perceptions. Considering the uncertainty of appropriate answers to perception-based questions, a series of discussions were conducted with the respective officials in the targeted area. Moreover, some of the questions require a scientific answer for which background data were collected simultaneously. Likewise, to measure the safe water adaptability index of different upazilas, it was deemed important to ask many questions and get an answer within a 5-point scale. Since all data were not available in the form of published documents, officials gave their responses based on their evaluation and perception.

## Results and Discussion

After collecting data through questionnaire survey, the data are analyzed. The results are discussed in the following.

### *Overall Safe Water Adaptability Index*

The results obtained from the analysis are shown in Table 5. It depicts the overall, socio-economic, institutional, physicochemical, and environmental adaptability index toward safe water. It can be seen from Table 5 that overall safe water adaptability index scores range from 2.16 to 3.13 where the Debhata upazila demonstrates the highest overall safe water adaptability index (3.13) because it has socio-economical (2.81), institutional (3.67), physicochemical (3.21), and environmental (2.81) adaptability values. The Dacope upazila of Khulna district, on the other hand, shows the lowest water adaptability index (2.16) because of its socio-economical (1.87), institutional (2.69), physicochemical (1.69), and environmental (2.37) adaptability values.

Depending on the value of the score, the safe water adaptability index is divided into five categories viz. very high (>3.7–5), high (3.3–3.7), medium (2.8–3.2), low (2.3–2.7), and very low (1–2.3>). Considering these categorizations, it can be seen from Figure 3 that most of the upazilas demonstrate low to medium levels of safe water adaptability index. Specifically, 5 upazilas have medium, 10 upazilas have low, and 1 upazila has very low safe water adaptability scores. None of the upazila shows very high and high water adaptability which reflects the upazilas' very low to medium water adaptability to safe water access and supply. However, variations occur among upazilas because of insufficient safe surface and groundwater bodies, inadequate infrastructure, lack of surface and groundwater standards, poor economic conditions, lack of education & awareness, poor health-care facilities, high frequency of extreme events and contamination of water bodies, lack of budget, and poor salinity and arsenic policies at upazila level, among others. These are the main reasons why some upazilas illustrate medium, low, and very low overall safe water adaptability.

### *Socio-Economical Adaptability Index*

In terms of the socio-economic dimension, results reveal that the highest and lowest socio-economic adaptability scores are found in the Kolaroa (2.99) and Dacope (1.87) upazilas, respectively (Table 5). Considering the scale of the adaptability index, Debhata, Dumuria, and Kolaroa upazilas show medium level of socio-economical adaptability (Figure 3). In general, most of the upazilas demonstrate medium to very low socio-economical adaptability. Hossain, Siwar, Mokhter, Dey, and Jaafar (2009) explains that socio-economic factors are interrelated and are influenced by one another. In the study area, activities and management of safe water access and supply are found to depend entirely on the community that is influenced by socio-economic characteristics of that particular community. The reasons for having medium to very low socio-economical adaptability can thus be given as poor education on water security, limited as well as insufficient safe water awareness-raising activities, poor preparedness on health issue and inadequate health care facility. In addition, agriculture and shrimp farming-based livelihood use contaminated water resource. Finally, the relationship among community members is found to be weak. It can be observed from the Dacope upazila that there is competition within the community to get safe drinking water. Sometimes water related conflicts occur and people do not care about each other.

### *Institutional Adaptability Index*

In terms of institutional adaptability, Table 5 shows that both the Rupsha and Dumuria upazilas demonstrate the highest level of institutional adaptability (3.73)

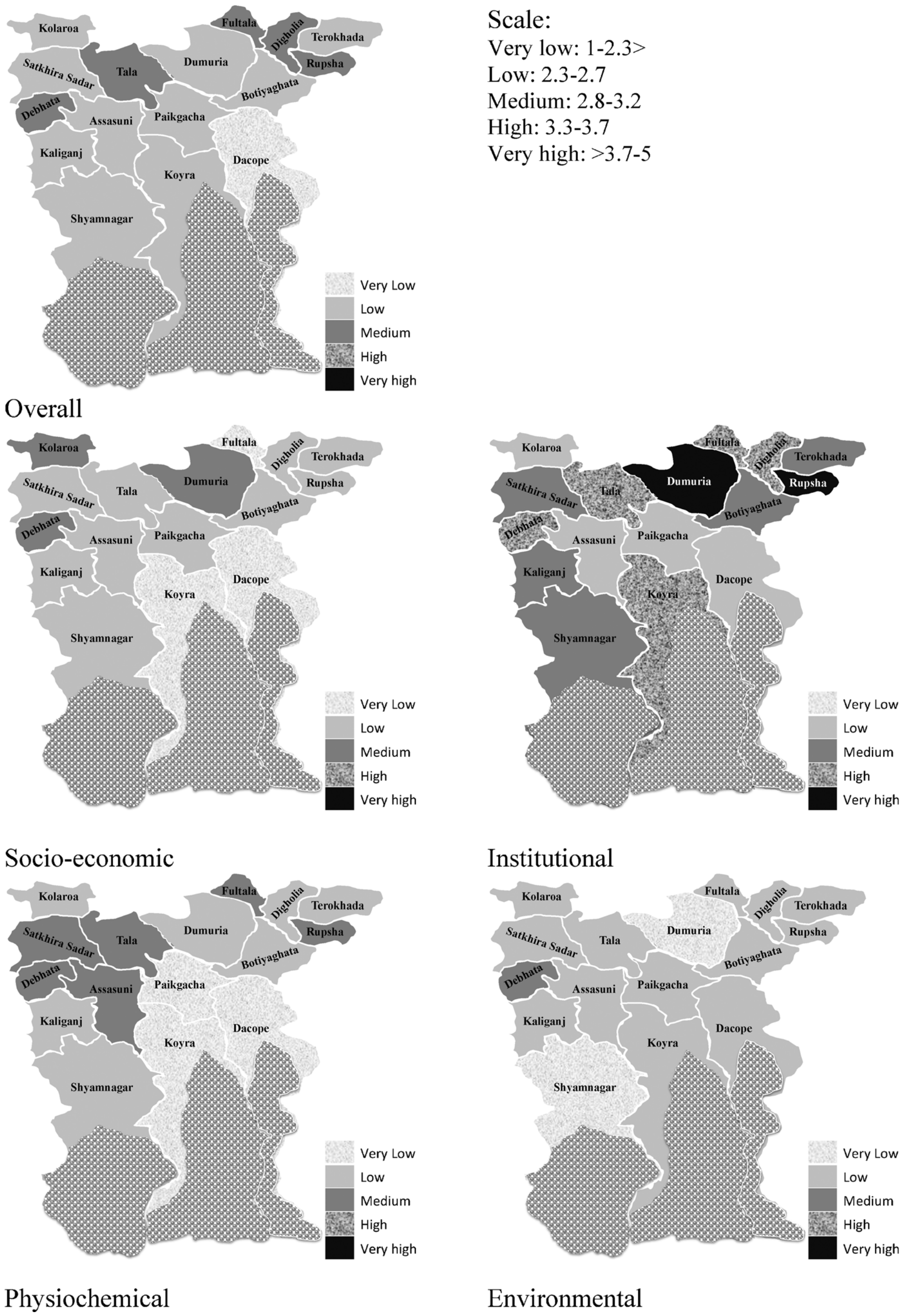


**Figure 3.** Overall, Socio-Economic, Institutional, Physiochemical, and Environmental Adaptability Levels of all Upazila.

**Table 5.** Safe Water Adaptability Scores of All Upazilas

| District | Upazila | Socioeconomic Adaptability | Institutional Adaptability | Physicochemical Adaptability | Environmental Adaptability | Overall Adaptability | Adaptability Category |
|---|---|---|---|---|---|---|---|
| Khulna | Fultala | 2.21 | 3.32 | 3.27 | 2.63 | 2.86 | Medium |
| | Kyora | 2.07 | 3.35 | 1.47 | 2.40 | 2.32 | Low |
| | Paikgacha | 2.76 | 2.61 | 2.24 | 2.40 | 2.50 | Low |
| | Rupsha | 2.75 | 3.73 | 3.08 | 2.39 | 2.99 | Medium |
| | Terokhada | 2.44 | 3.16 | 2.49 | 2.44 | 2.63 | Low |
| | Dumuria | 2.91 | 3.73 | 2.56 | 1.87 | 2.77 | Low |
| | Dacope | 1.87 | 2.69 | 1.69 | 2.37 | 2.16 | Very Low |
| | Digholia | 2.65 | 3.55 | 2.37 | 2.61 | 2.80 | Medium |
| | Botiyaghata | 2.41 | 3.01 | 2.59 | 2.77 | 2.70 | Low |
| Satkhira | Debhata | 2.81 | 3.67 | 3.21 | 2.81 | 3.13 | Medium |
| | Tala | 2.41 | 3.51 | 2.91 | 2.67 | 2.88 | Medium |
| | Kaliganj | 2.38 | 3.26 | 2.76 | 2.69 | 2.77 | Low |
| | Sadar | 2.32 | 3.17 | 2.96 | 2.48 | 2.73 | Low |
| | Kolaroa | 2.99 | 2.47 | 2.53 | 2.71 | 2.66 | Low |
| | Assasumi | 2.79 | 2.37 | 3.04 | 2.53 | 2.68 | Low |
| | Shyamnagar | 2.59 | 3.18 | 2.37 | 2.13 | 2.57 | Low |

because of the presence of appropriate national water quality standards; adequate training program and early warning system; strong co-ordination; and collaboration among Governmental Organization (GO), NGO and community people; satisfactory allocation in the water sector; proper utilization of budget and knowledge sharing activities, among others. In addition, the Rupsha and Dumuria upazilas have carried out some specific water related activities with the cooperation of national government as well as international agencies viz. The Hygiene, Sanitation and Water Supply (HYSAWA) Project. Lastly, the DPHE of Rupsha upazila is continuously working to screen arsenic contaminated tube-wells to provide safe drinking water at the community level.

Figure 3 depicts the medium institutional adaptability index of Debhata upazila. Because of this, the upazila establishes shallow and deep tube wells and constructs community-based arsenic and iron removal plants through such institutions as DPHE and a local company named Delta. It can also be seen that the Dacope upazila has low institutional adaptability index as there is no safe water related activities carried out by institutions. Dacope upazila was among those heavily devastated and suffered from severe safe water related problems after cyclone AILA in 2009. However, the upazila already initiates freshwater shrimp farming instead of saline water farming.

Finally, Assasuni upazila shows the lowest institutional adaptability index (2.37) because of non-existent policies for arsenic and salinity-free water, poor collaboration and coordination among different stakeholders, lack of budget, less training, and public awareness program related to safe water availability, poor sharing on safe water access and security, and so on. The success of institutions in the upazila primarily depend on need-based development programs, coordination and collaboration among stakeholders and institutions working on water issues.

*Physiochemical Adaptability Index*

It is evident from Table 5 that the Fultala upazila shows the highest level of physiochemical adaptability index (3.27) whereas Koyra upazila shows the lowest level of physiochemical adaptability index (1.47) among all upazilas. From the results, it can be seen that Fultala upazila has acceptable limits of arsenic and salinity for both surface and ground water, improved infrastructure and better access to safe drinking water and safe water source for households. On the contrary, Koyra upazila has a higher level of arsenic and salinity in drinking water that is much higher than the drinking water standard of Bangladesh and World Health Organization (WHO). It also has less sweet water bodies or fresh water reservoir and very limited agricultural land with people struggling to collect safe drinking water far from their houses. Furthermore, there are very limited alternative options for safe drinking water access and supply such as rainwater harvesting facilities, water reservoir (tank, dam, etc.) and piped water supply system.

*Environmental Adaptability Index*

Environment is a key component of human development and global sustainability for natural resources management and processes. Hence, the environmental dimension is another vital aspect for safe water adaptability index. Results from Table 5 show that the Debhata upazila obtains the highest environmental adaptability index (2.81) whereas the Dumuria upazila receives the lowest level of environmental adaptability index (1.87) among all upazilas. Based on the safe water adaptability index scale, environmental adaptability varies between very low to medium in all upazilas. The reasons for the high environmental adaptability value in Debhata upazila include healthy ecosystem, high soil fertility and good condition of drainage facilities, low frequency of extreme events such as cyclone, flood and drought and low degree of environmental contamination. On the contrary, Dumuria upazila has the lowest environmental adaptability index value due to extinction of fresh water fishes, vulnerable natural habitats for living beings, negative impacts of shrimp cultivation, crop loss by salinization, soil degradation, depletion of organic matter, and high level of environmental contamination, among others.

## Important Issues for Implementing SIPE Approach in Micro Planning

Various water related policies have been existed in Bangladesh over the past 10 years. These policies, however, mostly focus on river basin management; planning and management of water resources; water rights and allocation; public and private involvement; public water investment; water supply and sanitation; water and agriculture; water and industry; water and fisheries and wildlife; water and navigation; water for hydropower and recreation; water for the environment; water for preservation of Haors, Baors and Beels; economic and financial management; research and information management; and stakeholder participation, among others. Moreover, these policies do not give emphasis on institutional capacity development to better deal with safe water supply in saline, arsenic, and drought affected areas. Among 15 priority activities, National Adaptation Program of Action (NAPA) (2005) addresses the provision of drinking water in coastal communities to combat enhanced salinity due to sea level rise as a second priority activity. Up to the present, however, the implementation of programs mentioned in the policy is far from being realized and demand in the affected areas remains unmet. Nevertheless, some promising work related to safe water access and supply is under way or has been done by different organizations in the region. In most cases, these organizations focus on only one problem such as salinity or arsenic but do not address all the issues related to safe drinking water scarcity in the Southwest region of Bangladesh.

In this regard, the newly developed SIPE approach provides a method to measure the safe water adaptability index covering all issues related to safe drinking water access and supply in an area. Specifically, the SIPE approach comprises the socio-economic, institutional, physicochemical, and environmental condition of a safe drinking water scarcity area. The findings of the study suggest that the variations among upazilas require each upazila to be addressed differently when developing a safe water adaptability strategy. For example, in terms of institutional dimension, more than half of the officials (57 percent) give importance to institutes because they can be utilized for improved knowledge sharing, creation and facilitation of community/village based water activities, development of water related activities and strengthening governmental agencies capacity on safe water access and supply. Similarly, it can be seen from the socioeconomic dimension that 63 percent of the officials prioritize education & awareness. Through education & awareness, safe water awareness related activities can be strongly promoted to help in taking preventive measures against water scarcity derived from salinity, arsenic, and drought.

Furthermore, the dimensions and indicators of the SIPE approach need to be addressed at various levels to identify gaps for the effective implementation of water adaptability actions. For instance, the safe water adaptability level in Dacope upazila shows that there is an utmost need not only to strengthen the physicochemical and socioeconomic dimensions but also the environmental and institutional dimensions. In particular, the allocation of budget for the water sector and its proper utilization need to be improved because budget is a key component for governance of water related activities. Therefore, this in-depth analysis helps to identify needs and gaps to the provision of safe drinking water.

Finally, depending on the safe water adaptability index, this approach can be used as a tool at micro/upazila level primarily because micro level information provides the background data for macro level planning. Without micro level analysis, it will be difficult to develop an effective plan or policy governed at national level/macro level. Any development program to be implemented over a state or region needs micro-level information and planning such as the identification of appropriate areas, allocation of funds, monitoring of activity, and evaluating results. In addition, macro-level analysis cannot capture the overall demand, needs, priorities, and limitations of an area. It cannot highlight root causes and encounters difficulty in identifying needs and gaps of a particular situation. In this way, the SIPE approach provides a pragmatic approach to depict the overall scenario of a severe water scarcity area and assist in building safe water adaptability toward salinity, arsenic, and drought. Therefore, the SIPE approach needs to be undertaken at the local or micro-level and become an integral part of policies related to safe water access and supply especially for agriculture and food security.

## Conclusion

Bangladesh, particularly the Southwestern region, being located downstream greatly faces safe drinking water supply problems due to salinity in surface water and arsenic in groundwater as well as the frequency of drought. The sectoral uses of water, institutional arrangements, database and information system, and groundwater management are common to all water related policies, but the effective method of implementation of practices is lacking in most.

It is suggested that the understanding of institutional perceptions and assessment of adaptive and proactive capacities is important for creating successful safe water adaptability programs. In this regard, this study attempts to explore the existing level of safe water adaptability index through an extensive questionnaire survey at institutional level of severe water scarcity affected areas. For this, the SIPE approach is utilized considering all four aspects of socio-economic, institutional, physicochemical, and environmental conditions in the targeted areas. The results of the SIPE approach show a medium to low safe water adaptability index toward safe water access and supply in all upazilas in the study area. It enumerates a number of socio-economic, institutional, physicochemical, and environmental factors that provide insights on safe water availability in the study area. Although there is adequate water in the study area, salinity, arsenic, and drought events collectively cause a safe drinking water crisis. Therefore, it is of utmost importance to link together all the three mentioned issues to minimize safe water scarcity. In this context, this integrated approach describes key points that need to be considered and makes recommendations on how to effectively manage the water sector from local to national level to secure access to safe water and supply of drinking water in the region. Moreover, the successful implementation of any action plan requires various stakeholder actions. Thus, by pointing out the roles and responsibilities of stakeholders, collaboration, and co-ordination among different sectors can be strengthened. Finally, this approach offers information and guidelines for government, researchers, and policymakers as a way of understanding and summarizing the status of safe drinking water access and supply and ranking areas for prioritization and intervention in safe drinking water adaptability policies and actions to address safe drinking water scarcity.

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**Md. Anwarul Abedin** is in Graduate School of Global Environmental Studies, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto 606-8501, Japan.
**Rajib Shaw** is in Graduate School of Global Environmental Studies, Kyoto University, Yoshida Honmachi, Sakyo-ku, Kyoto 606-8501, Japan.

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