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Potential of water footprint assessment as a decision support tool for sustainable water allocation option in Dhaka city

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ABSTRACT: Sustainable water allocation option has always been a challenge for any overpopulated city. Dhaka, the capital of Bangladesh faces additional challenges due to its phenomenal expansion in the recent decades and huge population has overstressed its existing natural water resource. The surface water bodies being polluted, excessive extraction of groundwater and filling of wetlands have threatened the sustainable water allocation options. Water Footprint assessment can be used as an effective decision support tool in this situation. Water Footprint can be assessed for a process, a product or for a group of consumers and the spatial variation can be classified as in terms of global average, national or regional, or a catchment specific. This paper deals with the potential of using Water footprint assessment as a decision support tool. A proposed model framework has been presented in this paper for assessing the water footprint of a geographically delineated area, Dhaka and how this water footprint assessment approach can be used for water allocation decision. The rationale of the spatiotemporal detail proposed in this approach has been discussed and coherence between blue, grey and green water footprint for Dhaka has been defined. This paper also focuses on future scope of water footprint assessment in national level in Bangladesh.

1 INTRODUCTION

1.1 *Dhaka and its challenge in sustainable water allocation*

Rapid urbanization and increased growth rate of population has caused immense stress on earth's natural resource over the last few decades. The situation is more critical for the overpopulated mega cities. Dhaka, the capital of Bangladesh is no exception and has a similar scenario. Dhaka has an enormous population, having around 11,875 thousand people living in an area of 1,464 km^2 with a growth rate of 1.8% (BBS.2011). The city is surrounded by a series of peripheral river networks. However, there is a phenomenal expansion in the city boundary due to rapid but unplanned development and industrialization. As a result, more peoples from the underdeveloped and rural areas are migrating to Dhaka for livelihood. The amalgamated effects of all these factors are causing serious level of environmental degradation, among which the filling of wetlands and surface water bodies, discharging domestic and industrial waste into the peripheral rivers and water bodies are of major concern. On the other hand, the DWASA depends chiefly on groundwater for supplying water to its consumers, which is causing groundwater depletion at an alarming rate. Water security in Dhaka in terms of accessibility and availability of water is vulnerable and the whole situation creates serious challenges for ensuring sustainable water allocation in Dhaka. An integrated decision support tool for water sector can play a vital and effective role if it can visualize and compare various aspects of water quality, water availability and consumptive water use in process basis, product basis or specific catchment area basis. Water Footprint Assessment can be used as a decision support tool.

1.2 *Concept of Water Footprint Assessment*

The Water Footprint Assessment is a recent concept and gained much interest after its first introduction by Hoekstra (Hoekstra, 2003). The water footprint can be regarded as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. Water Footprint Assessment can be performed for specific products, process, or consumers of a catchment area or within a geographically delineated area. There is clear distinction between Water Footprint and traditional water withdrawal or water extraction concept in supply chain process or water content in products. Also, traditionally withdrawal or consumptive use of water is assessed in terms of "blue water" (as defined in 3.1) only, but Water footprint assessment includes both green and grey water, their direct and indirect presence.

2 SCOPE

2.1 *Objective*

This paper aims to evaluate the potential of Water Footprint Assessment in different aspects of sustainable water allocation option in Dhaka in a proposed model framework. In this framework, the rationale of using blue, green and grey water footprint has been presented. The level of spatiotemporal detail in this framework has been considered based on the present available database of Dhaka in different agencies. This paper also aims to seek the plausible options of how this model framework can be used to visualize and simulate the water related scenario in Dhaka and act as a decision support tool.

2.2 *Limitation*

The framework presented in this paper focuses on evaluating the potential of using Water Footprint Assessment for a geographically delineated area. The water footprint assessment itself is a comparatively new concept, and previously a few study of global coverage focusing the green, blue and grey water footprint of production and consumption (Mekonnen et al. 2011) has covered national water footprint of Bangladesh. According to that, average water footprint of Bangladesh is 769 m^3/year per capita. And part of footprint falling outside of the country is 17.4 %. However, to use water footprint assessment as a tool in sectoral decision support, like a specific crop yield and irrigation, a specific framework with more spatiotemporal exposure will be required.

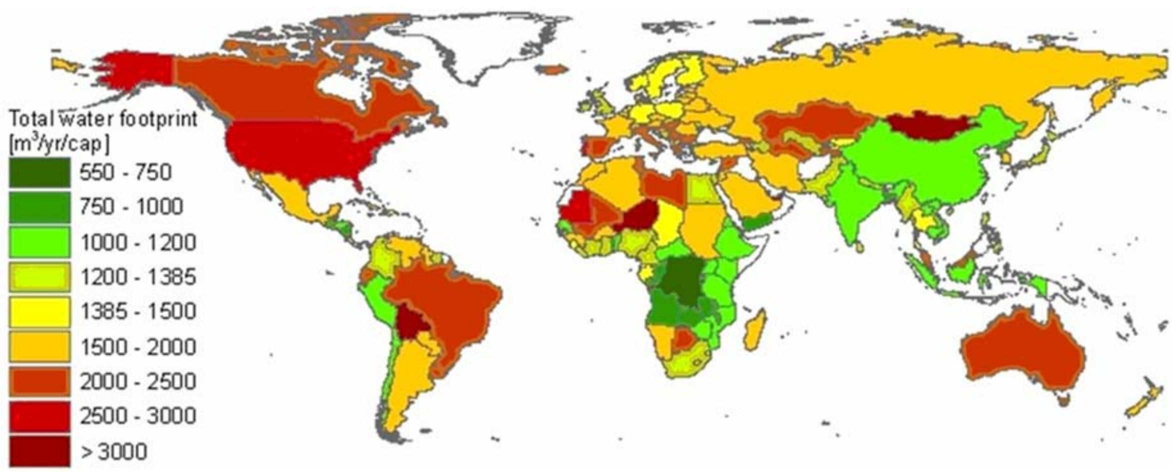

Figure 1. Average water footprint of national consumption in m^3 per year per capita in the period 1996-2005. Countries shown in green have a water footprint smaller than the global average; and yellow-red have a water footprint larger than the global average. (Source: Mekonnen et al. 2011).

3 METHODOLOGY

3.1 *Concept of blue, green and grey water footprint*

In water footprint assessment, the term "blue water" refers to the fresh surface and groundwater. Hence, the blue water footprint is an indicator of consumptive use of so-called blue water. The term "green water" to the precipitation on land that does not run off or recharges the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. Eventually, this part of precipitation evaporates or transpires through plants. (Hoekstra et al, 2011). The distinction between the blue and green water footprint is important because the hydrological, environmental and social impacts, as well as the economic opportunity costs of surface and groundwater use for production, differ distinctively from the impacts and costs of rainwater use (Hoekstra and Chapagain, 2008). The grey water footprint of a process step is an indicator of the degree of freshwater pollution that can be associated with the process step. It is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. (Hoekstra et al, 2011). The grey water footprint concept has grown out of the recognition that the size of water pollution can be expressed in terms of the volume of water that is required to dilute pollutants such that they become harmless.

While setting up a water footprint assessment function, the boundary depends on the objective of the assessment. The function can include only blue water footprint, or blue and green water footprint or all three components. For Dhaka, blue water resources or fresh surface and ground water is highly significant then green water footprint, as there is less vegetation cover in Dhaka but consumption of ground water and use of surface water in peripheral rivers and water bodies is a integral part of this city. But in context of the sustainable water allocation option, grey water footprint plays a vital role in case of Dhaka as the environmental degradation scenario can be visualized through it. The untreated industrial effluent and domestic waste discharged in peripheral rivers and canals has created an alarming pollution scenario for surface water bodies. The groundwater is also subsequently polluted by the percolation of waste through the soil.

In this research, the blue, green and grey water has been taken into account for the proposed water footprint assessment framework.

3.2 *Proposed Model Framework*

A model framework for water footprint assessment of Dhaka is presented here which has 3 phases as described in Figure 2. The phase-1, specific objective of the study and selection of geographically delineated area is the trendsetter. The study area can be fixed for full boundary of the city; here Dhaka as the case. This framework can also be applied for other municipal city as well. The phase-2 of the framework is the actual assessment step for water footprint. In This phase, the individual component of the whole area is defined and calculation is performed. The component wise distribution is discussed in 3.3.

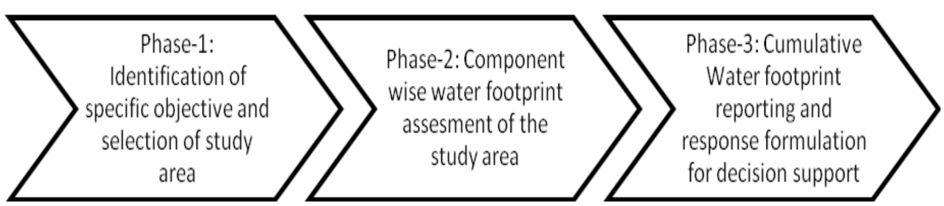

Figure 2. Three phases of the proposed framework of water footprint assessment

After component wise calculation, cumulative water footprint is reported either sector wise or classified as relevant to assist the decision support for the particular area of interest. According to Hoekstra, after the accounting phase (phase-2 in this framework) is the phase of sustainability assessment, in which the water footprint is evaluated from an environmental perspective, as well as from a social and economic perspective. In the final phase, response options, strategies or policies are formulated. However, It is not necessary to include all the steps in one study. (Hoekstra et al, 2011). For this reason the sustainability assessment is incorporated in phase-2 of proposed this framework.

3.3 *Proposed component wise assessment model for Dhaka*

For Dhaka, the component wise water footprint assessment is divided into 6 classes. It is presented in Table 1.

3.4 *Division of area into suitable grid*

In this framework, the study area is proposed to divide into suitable but non-uniform grid. This individual grid wise division will assist for further spatial analysis. Each grid will be treated as the working unit and using high resolution satellite image, the land use pattern will be identified in terms of water bodies, vegetation cover and settlement. Statistical data of population, number of households, existing source of fresh water supply from DWASA and water supply-demand ratio will be combined in grid specific manner and a total spatial working database will be developed. The minimum spatial range of each grid will depend on the features it contains.
After compiling grid database, process in each grid will be identified as per blue, green and grey water. Process water footprint is exclusively chosen as it is the basic building block of all other water footprint, and is

applicable in this framework for Dhaka. The water footprint of a process is expressed as water volume per unit of time. In case of Dhaka, the water footprint within this geographically delineated area can be expressed as water volume per unit of time. It can be expressed in terms of water volume per monetary unit when divided over the income in the area.

Table 1. Component in water footprint assessment model for Dhaka

Component	Plausible data Source
a) Division of area into suitable grid	Existing high resolution digital elevation model (DEM)
b) Classification of spatial features and land use pattern in terms of vegetation cover, water bodies and settlement	Available satellite image
c) Specific grid wise classification of settlement in terms of house and industry	Statistical data from BBS and satellite image analysis
d) Specific grid wise blue water footprint assessment for consumptive use and process	Based on data of actual water consumption in process
e) Specific grid wise green water footprint assessment for consumptive use and process	Water consumption and meteorological data
f) Specific grid wise grey water footprint assessment for process	Extent of pollution spatially in water bodies and level of concentration

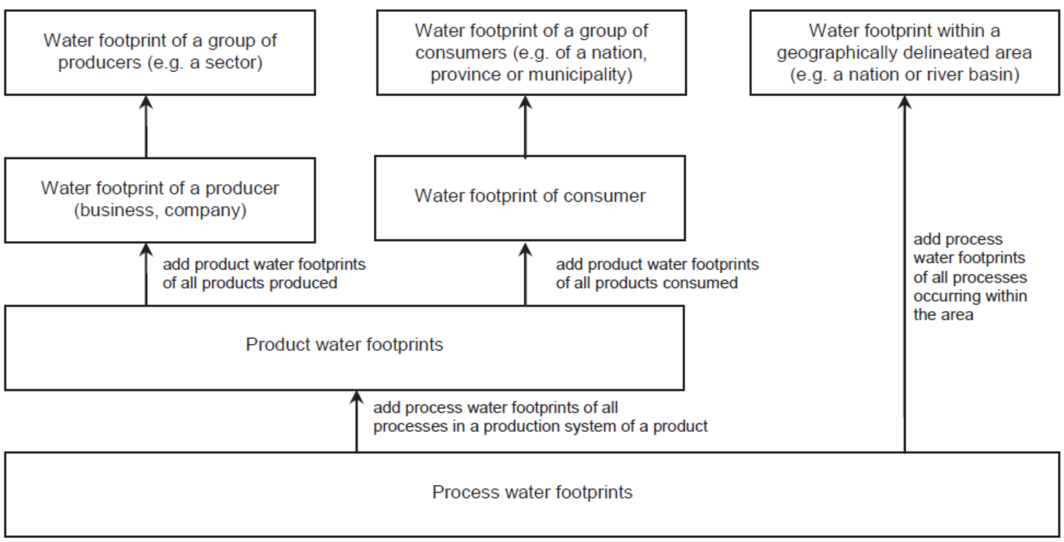

Figure 3. Process water footprints as the basic building block for all other water footprints (Hoekstra et al, 2011)

3.5 *Grid wise blue water footprint assessment*

Grid wise blue water footprint measures the amount of water available in a certain period that is consumed (in other words, not immediately returned within the same catchment). Thus, in case of Dhaka, it provides a measure of the amount of available blue water consumed by humans. The remainder, the groundwater and surface water flows not consumed for human purposes, is left to sustain the ecosystems that depend on the groundwater and surface water flows. The blue water footprint of process can be expressed as Equation 1 below

$$WF_{blue} = BlueWater\ Evaporation + BlueWater\ Incorporation + Lost\ Return\ flow \quad (1)$$

The lost return flow is the part of the return flow that is not available for reuse within the same catchment within the same period of withdrawal. In each grid, the blue water footprint of the process is further categorized into households and industrial process. The total water consumed in each industry is unique, but depends on the number and types of factories in that grid. For example, all textile factories has a similar pattern of blue water consumption. By taking one textile factory as the base and dividing the total water consumption by number of people in that factory, we get the unit blue water footprint for textile factory. For another textile factory, the unit blue water footprint can be used by multiplying with total number of people as a rough estimate. Similarly, if water footprint of a individual consumer in a household can be justified, the total water footprint in each household can be roughly estimated by using the statistics of total number of people.

3.6 *Grid wise green water footprint assessment*

Grid wise green water footprint is the indicator of volume of rainwater consumed during the production process. It is expressed as Equation 2:

$$WF_{green} = GreenWater\ Evaporation + GreenWater\ Incorporation \quad [\text{volume/time}] \tag{2}$$

Based on climatic data collected from meteorological station located in Dhaka, and using either empirical formula or CROPWAT, evaporation is calculated.

3.7 *Grid wise grey water footprint assessment*

Grid wise grey water footprint is the indicator of the degree of freshwater pollution that can be associated with the process step. It is calculated by dividing the pollutant load (L, in mass/time) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration c_{max}, in mass/volume) and its natural concentration in the receiving water body (c_{nat}, in mass/volume). It is expressed as Equation 3:

$$\mathrm{WF}_{grey} = \left(\frac{L}{c_{max} - c_{nat}} \right) \tag{3}$$

The natural concentration in a receiving water body is the concentration in the water body that would occur if there were no human disturbances in the catchment. For human-made substances that naturally do not occur in water, C_{nat}=0. The assimilation capacity of a receiving water body depends on the difference between the maximum allowable and the natural concentration of a substance. The ambient water quality standards are specified for different pattern of pollution and water bodies as referenced in schedule -3, 9 and 10 of Environmental Conservation Rules-1997. (ECR 1997).

A grey water footprint larger than zero does not automatically imply that ambient water quality standards are violated; it just shows that part of the assimilation capacity has been consumed already (Hoekstra et al, 2011). As long as the calculated grey water footprint is smaller than the existing river flow or groundwater flow, there is still sufficient water to dilute the pollutants to a concentration below the standard. When the calculated grey water footprint is precisely equal to the ambient water flow, then the resultant concentration will be exactly at the standard. For the peripheral rivers of Dhaka, the direct discharge of pollution from surrounding industries is a critical problem, causing point source pollution. In case of point source pollution, the pollutant load can be calculated as the effluent volume (*Effl*, in volume/time) multiplied by the concentration of the pollutant in the effluent (c_{effl}, in mass/volume) minus the water volume of the abstraction (*Abstr*, in volume/time) multiplied by the actual concentration of the intake water (c_{act}, in mass/volume). The grey water footprint can then be calculated as Equation 4;

$$\mathrm{WF}_{grey} = \left(\frac{L}{c_{max} - c_{nat}} \right) = \frac{Effl - C_{effl} - Abstc \times C_{act}}{c_{max} - c_{nat}} \tag{4}$$

In this framework, the grid wise grey water footprint from households is easily measurable from the spatial database. In case of the industries, a further classification based on types of industries, production per day, availability and usability of effluent treatment plant in the industry is added.

4 WATER FOOTPRINT SUSTAINIBILITY ASSESSMENT FOR DECISION SUPPPORT

The total water footprint from individual grid of the framework is the key tool for decision support. For this purpose, water footprint sustainability assessment is applicable. This assessment of sustainability helps to visualize the overall condition and assists in policy formulation. The sustainability assessment has three aspects; environmental, social and economical. As per this framework, water footprint within the grids will be considered sustainable when the total water footprint will be relevant to the available water. If the total blue, green and grey water footprint for any grid is high compared to the available water, then within that grid the water footprint is not sustainable. Also, high grey water footprint in any grid indicates high rate of environmental degradation.

The cumulative water footprint from all the grids helps to visualize the integrated result of the whole water cycle pattern in the area and assists to identify areas with high environmental degradation, areas with economic use of etc. and for each case; it helps as a tool for specific water allocation decision and subsequent policy formulation or development work.

5 CONCLUSION

For sustainable water allocation and addressing the present and future challenges in water resource sector of Dhaka, water footprint assessment is indeed a powerful and effective decision support tool. The framework proposed in this study can be further modified in spatiotemporal resolution to apply it in other cities of Bangladesh. In national level, water footprint assessment can play a particularly important role in agricultural related decision support. As the major crops of Bangladesh faces challenges in proper irrigation, water footprint assessment of individual crops can assist to prioritize and manage irrigation system. To lean towards sustainable development, a policy for reducing the local and national water footprint of Bangladesh is important

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