Freshwater Resource Indices: Literature Review & Applications

Nelson M.K. Boinnet*, Reshana L. Thomas**

College of Environmental Science & Engineering, Tongji University

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Abstract- Water is a scarce resource hence there is a general concern over its use. In particular, freshwater scarcity is recognized as a prominent environmental concern. As a result, the concept of water footprint as a measure to tackle the potential impacts of water use arose. The balance in water consumption is necessary because freshwater is essential to the daily life of human beings and its supply is also limited. As the global population rises, the need for fresh water grows too. In addition, if human beings do not take steps to keep the water footprint level as low as possible, the world will run short of fresh water. Scholars project that by 2030, the global demand for freshwater will surpass supply by approximately 40 percent (Brown & Matlock, 2014). The reduction in the supply of water will certainly have a negative impact on the global manufacturing and agricultural industries. It is therefore vital to investigate how water footprint is applied at an individual level, the business sector, and the national level. The paper reviews current freshwater indices used globally and categorizes them according to differing requirements:

- Human Requirement
- Economic Requirement
- Ecological Requirement

Keywords: Freshwater Management. Water Indices. Water Resource Management. Water Footprint.

i. INTRODUCTION

ii. WATER FOOTPRINT

The water footprint concept is concerned with the objective to show the hidden links between human consumption and water use as well as between global trade and water resources management. The water footprint concept emerged out of the ecological footprint concept and was first introduced by Hoekstra in 2002 in an attempt to come up with a consumption-based indicator of water use (Hoekstra et al., 2016). Primarily, it is an indicator of use of fresh water that shows the direct and indirect use of water by a producer or consumer.

According to Hoekstra et al (2016), the total water footprint of a product comprises of three components namely the blue, green and gray water footprint. The blue water footprint measures the volume of freshwater that evaporates from the world blue water resources (surface water and groundwater) to make the goods and services that an individual or a community consumes. The green water footprint is the amount of water lost from the global green water resources (rainwater preserved in the soil as soil moisture). Lastly, the gray water footprint measures the amount of polluted water, which associates, with the creation of all goods and services for an individual or community. The gray water footprint is calculated as the amount of water that is required to dilute pollutants to levels that make the quality of the water to remain above the recommended water quality standards.

Many approaches have been used to evaluate the vulnerability of water resources, such as the water scarcity and water stress. However, there have been challenges in the measurement of water vulnerability because of many variables to water use, supply, and scarcity. Choosing the criteria to use in water assessment is often more of a policy decision than a scientific decision. This article explores the various literature reviews that have been written on the methodologies that have been used over the years and the application of the water footprint in different contexts.

1. BASED ON HUMAN REQUIREMENT

Brown & Matlock (2014) describe the scarcity of freshwater as a measure of the available water resources in comparison to the human population. The results are usually displayed in terms of annual per capita water and presented on a national scale. The analogy behind this approach is that when the amount of water required for human demand is known, and then the amount of water available to each can act as a measure of scarcity. The following passages discuss some of the methods used to measure water scarcity based on human water requirements.

1.1. THE FALKENMARK INDICATOR

Falkenmark (2017) defines it as the ratio of the total annual runoff available for human consumption. It is the most widely used indicator to measure the amount of water stress. To come up with the index, surveys were conducted in several countries, and the water use per individual in each economy was calculated. Using the per capita water usage, the water conditions in a particular location can be grouped as no stress, stress, scarcity, and absolute scarcity. The index thresholds of 1, 700m3 and 1, 000m3 per capita per year are taken to be the thresholds between water stressed and scarce areas (Falkenmark, 2017). This index is employed in assessments on a country scale where the data is available and gives results that are easy to understand. The emphasis of the Falkenmark water stress index is placed on the individual water usage and thus avails a way of differentiating between climate and human-induced water scarcity.

1.2. BASIC HUMAN REQUIREMENT

A scholar by the name Gleick (2016) came up with a water scarcity index that looks at scarcity as a measurement of the capacity to meet all water needs for basic human requirements. For example, drinking water for human survival, water for sanitation purposes, water for hygiene as well as modest household needs for preparing food. The minimum amount of water that was proposed to sustain each of the functions is as follows. According to the data from the National Research Council of the National Academy of Sciences the least water required for drinking to ensure human survival under normal temperate climates with regular human activity is approximately 5 liters per person per day (Gleick, 2016). The necessary water requirements for bathing indicate that the minimum volume of water needed for adequate bathing is about 15 liters per person per day. The other aspect that requires the use of water is the disposal of human waste. Nonetheless, with the emergence of modern technology for sanitation globally, proper disposal of human waste can be done with little or even no water. However, water is still used to a large extent in many societies to dispose of wastes. Studies reveal that about 20 liters of water per person per day is required to dispose of human waste. The last primary requirement of water use is food preparation. The proposed minimum requirement for this function is 10 liters per person per day.

The entire suggested water requirement for essential human functions totals to approximately 50 liters per person per day. Various stakeholders recommend that the relevant international organizations, as well as water providers, adopt the stated water requirements to meet the basic needs. Besides, Gleick came up with the "benchmark indicator" of 1,000m3 as a reference that was even adopted by the World Bank.

1.3. SOCIAL WATER STRESS INDEX

Ohlsson (2015) builds on the Falkenmark indicator by integrating the "adaptive capacity" of a society and examining at how variables such as economic, technological, among others affects the general availability status of freshwater of a region. Ohlsson posits that the ability of a society to adapt to harsh scenarios is a function of the spread of wealth, education opportunities as well as political participation (OhIsson, 2015). The most widely accepted indicator used in the assessment of such societal factors is the UNDP Human Development Index (HDI). The HDI operates as a weighted measure of the Falkenmark indicator to account for the capacity to adapt to water stress and is referred to as the Social Water Stress Index.

2. BASED ON ECONOMIC REQUIREMENT

2.1. PHYSICAL AND ECONOMICAL WATER SCARCITY

Author Egan (2012) carried out an analysis with the involvement of renewable freshwater resources available for human consumption, with respect to the main water supply. The examination considered countries to be physically water scarce if more than 75 percent of the flow of the rivers is diverted for purposes such as agriculture, industry and domestic consumption (Egan, 2012). Using this approach, it means that dry areas are not considered as water scarce. Signs that indicate the scarcity of water include diminishing groundwater, severe environmental degradation as well as water allocations that support some sectors over others. On the same note, nations that have sufficient renewable resources with less than 25 percent of water from rivers diverted for human use, but require to make considerable improvements in existing water systems to make such resources available for use are considered to be economically water scarce.

The most recent methodology was developed by Hoekstra (2016) and calculates water scarcity by incorporating green, blue and grey water prints. Also, Hoekstra introduced a new concept known as water pollution level that measures the volume of water flow pollution using grey water. In Hoekstra's calculation, polluted water is regarded as unusable water and is therefore not included in the calculation of water resource availability. In the development of his concept, Hoekstra faults other methodologies for not including various factors. One of the arguments raised is that water withdrawals partly go back to a catchment (Hoekstra et al., 2016). Therefore, using water withdrawal as the main indicator of use of water is not an appropriate approach of evaluating the impact of the withdrawal at the scale of the catchment. Instead, Hoekstra posits that blue water consumption in a region would be best expressed in terms of a blue water footprint. The second point that Hoekstra elicits is that the availability of water ought not to be solely defined by total runoff because it overlooks the proportion of the runoff needed to maintain the environment. Rather, the environmental demand needs to be subtracted from the total runoff. Lastly, evaluating the scarcity of water, as a function of the annual water usage and resource availability does not factor in the variations during the year. Instead, it would be more accurate if monthly values are considered. In Hoekstra's approach, the overall evaluation of water scarcity can be derived by summing up all the water footprints (Hoekstra et al., 2015). The water scarcity in this methodology can be obtained at local, river basin as well as global levels while including ecological, policy, socio-economical, and human impacts.

Ridoutt et al. (2015) came up with a methodology that compares the carbon and water footprint concepts. The main effects of including water consumption on product life cycles were determined. In this study, the scholars suggest that the potential damage to the quality of freshwater ecosystem through minimized environmental flows be the focus (Ridoutt et al., 2015). Carbon footprinting is recognized as a simple concept whereby the emissions from all main greenhouse gases are additive and is displayed as a single figure in the units of carbon dioxide equivalents. A lot of water footprints are expressed as a single figure too only that they are not configured using a standardization procedure. In addition, many water footprints that have been published are a raw collection of all types of water consumption, that is, blue, green and even dilution of water. Ridoutt et al. argue that various kinds of water consumption ought not to be simply summed up to produce a total water footprint because the opportunity cost, as well as the impacts linked with each form of uses differ.

3.2 WATER RESOURCES AVAILABILITY AND CEREAL IMPORT

Yang & Zehnder (2012) indicate that approximately 70 percent of the global freshwater withdrawals are used for agriculture. Hence, there is a link between the water resources that are available and the capacity to produce food. Countries that have scarce freshwater compensate for the inadequacy by importing food. The primary type of food that is imported includes cereal grains. Scholars such as Yang and Zehnder postulate that using the quantity of food that is imported; a model can be developed to serve as a water-deficit indicator (Yang & Zehnder, 2012). Then from the developed model, experts can establish a threshold that can give a regional separation between water-scarce and water-abundant statuses. Regions that fall below the established thresholds would lack the necessary amount of water needed for local food production; hence cereal grains ought to be imported to fill the gap left by the water deficit.

During the development of a model using cereal grain imports, yearly average data was used for each country, which represents a single unit because the available data were annual as well as country based. Also, it was noted that there was ease to quantify water transfer across political boundaries. Mainly, Africa and Asia were used in the analysis because their total net annual cereal grains imports amounted to above 110 million tons in the 1990s, which means that all excess freshwater resources from all other continents are required (Chapagain & Orr, 2013). Besides, the two continents are home to a majority of people living in poverty and inadequate food. During the analysis, a water availability of 5000m3 per capita year was used as the cutoff value to ensure that the countries with water scarcity were put in mind while allowing for a comparison with countries that had abundant water. Moreover, the countries that were analyzed were limited to only those that have inhabitants exceeding one million.

From the analysis, Yang et al found out that in almost all the countries that were under the water-deficit threshold, there was a rise in per capita cereal import. Nevertheless, per capita import remained unchanged in the countries above the threshold, indicating that no measurable relationship exists between changes in their per capita water resources and the amount of cereal import. Comparing Falkenmark's threshold of 1,700m^3 per capita year, studies indicate that it falls within the threshold calculated by Yang et al. (2012). Nonetheless, the threshold calculated by Yang et al. is dynamic and can change with irrigation practices or improvement measures inefficient water use as opposed to Falkenmark's threshold which is fixed. Moreover, the threshold suggested by Yang et al. does not account for the use of non-renewable groundwater because of the lack of systematic data. Therefore, the threshold may not provide accurate results in some instances.

3. BASED ON ECOLOGICAL STRESS AND SUSTAINABLE USE

3.1. WATER RESOURCES VULNERABILITY INDICES

The indices discussed in the above passages only measure the status of water resource relying on human water needs as well as water availability, majorly on a national scale but do not incorporate renewable water supply, and national, yearly demand for water. However, authors such as Shiklomanov and Markova suggest the use of estimates of current and projected water-resources use by region and sector in 1987 (Shiklomanov & Markova, 2013). They grouped the water use into industrial, domestic and agricultural sectors and examined water lost from reservoir evaporation as well. In the analysis, economic and population variables were used. Later on, Raskin et al. used Shiklomanov's water resource availability results to improve on the approach by substituting water demand with water withdrawal. Raskin et al. argued that water demand varies across cultures, societies and regions hence the use of the term was prone to give inaccurate assessments (Raskin et al., 2016). The Water Resources Vulnerability Index also known as the WTA ratio was then described as the fraction of the total yearly withdrawals to available water resources (Raskin et al., 2016). From this ratio, a country whose annual withdrawals lie between 20 and 40 percent is considered water scarce whereas that whose annual withdrawals exceed 40 percent is considered severely water scarce (Raskin et al., 2016). This approach and the 40 percent threshold is popularly used in analyzing water resources and is termed as the "criticality ratio."

4.2 WATERSHED SUSTAINABILITY INDEX

Scholars Chavez and Alipaz (2017) suggest the use of a Watershed Sustainability Index (WSI) which combines hydrology, life, environment, and policy; each having the variables pressure, state, and response. The Watershed Sustainability Index is structured in a manner to be watershed or basin-specific and is intended to cover an area that does not exceed 2,500 km2. Therefore, vast areas need to be broken into smaller sections. The Watershed Sustainability Index is a mean of four indicators namely the life indicator, the policy indicator, the hydrologic indicator, and the environmental indicator (Chaves & Alipaz, 2017). Each of the parameters is assigned a score of 0, 0.25, 0.50, 0.75, or 1.0 (Chaves & Alipaz, 2017). All the indicators are equal in weight, but parameters may change from one basin to another and therefore should be picked by consensus among stakeholders. However, the use of WSI relies on the availability of information that is specific to watersheds. Most regions lack such information hence making the application of this model on a global scale not feasible.

3.2. WATER SUPPLY STRESS INDEX

McNulty et al. (2014) proposes a methodology that attempts to measure the relative magnitude of water supply as well as demand at the 8-digit USGS Hydrologic Unit Code level. In the model, the water supply stress index was calculated for every 8-digit Hydrologic Unit Code watershed in the US and focusses on the water-stressed locations that are ignored in assessments of larger areas. The water supply stress index is different from other water availability measurement methods because it incorporates anthropogenic water demand (McNulty et al., 2014). It is thus possible to have areas with high yearly levels of precipitation with a high water supply stress index value.

4. CONCLUSION

According to Brown & Matlock (2014), evaluation of water footprint and taking the right measures is necessary for the survival of humankind and other organisms. The balance in water consumption is necessary because freshwater is essential to the daily life of human beings and its supply is also limited. As the global population rises, the need for fresh water grows too. In addition, if human beings do not take steps to keep the water footprint level as low as possible, the world will run short of fresh water. Scholars project that by 2030, the global demand for freshwater will surpass supply by approximately 40 percent (Brown & Matlock, 2014). The reduction in the supply of water will certainly have a negative impact on the global manufacturing and agricultural industries.

It is therefore vital to investigate how water footprint is applied at an individual level, the business sector, and the national level. To start with, there are recommended levels of water footprint that individuals are not supposed to exceed. People use fresh water for bathing, cooking, and other domestic use. According to Egan (2012), companies that supply water to people's places of residence can better get a hint of the volume of water they are required to supply to cater for domestic use. Using the estimates, the companies can reduce wastage by supplying only the needed amount. The rationing makes people practice responsible use of water. Many individuals when presented with the figures of the required water footprints for their daily use, they strive to keep it at a minimum low. Thus, the figure is important for public awareness. It is important that everybody knows what is happening in regards to water availability so that each person takes steps in contributing to the sustenance of natural resources.

Jeswani & Azapagic (2012) point out that many businesses especially those that involve production use the water footprint figures to make sure that their activities are in tandem with the requirements. In many companies, fresh water is a basic requirement for their activities. After use, the industries release effluents that could result in the pollution of the local water system. Originally, most companies decided to adopt sustainable practices only after public pressure. However, many companies presently are beginning to embrace responsible practices in the use of fresh water. The businesses realize that failure to engage in sustainable practices might taint the corporate image, financial risks caused by pollution, a threat of increased regulatory control, and inadequate freshwater available for operations (Jeswani & Azapagic, 2012). Currently, many business ventures are adopting alternatives to conserve water. For instance, some restaurants provide their customers with special hand wipes that eliminate the need for tap water upon the realization that many people waste too much water while washing their hands. Besides, many companies are recycling water. For instance, water that is used for washing purposes can be recycled and used to flush the loos.

Brown & Matlock (2014) also suggest that different governments mainly use the water footprint figures to enforce various measures. The government can instruct the water supply companies to ration the water supply so that it does not exceed the maximum amount stipulated. Moreover, most countries are instituting regulation measures regarding how water ought to be used in the various freshwater bodies. For example, the government can ban all the irrigation activities that use fresh water from certain water bodies. The production activities of various companies that rely on the fresh water can also be limited so that the amount of water consumed does not rise above footprint level (Brown & Matlock, 2014). Therefore, the government mainly takes the enforcement role, whereby individuals or entities that are found to go against the laid down measures are arrested and charged accordingly.

To conclude, Water management is very essential. Owing to the changes in the global climate as well as the increase in population, it is necessary that steps be taken to conserve fresh water for posterity. It is the reason why different scholars have attempted to devise the methodology of coming up with a water footprint measure. Although all the methodologies discussed vary, they all express the need to conserve the various freshwater bodies. Perhaps it is accurate to note that the variation arises out of what form of water ought to be included in the calculation. The various water footprint levels are used by individuals, companies, and governments to evaluate their use of freshwater.

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AUTHORS

- **Nelson Mark Kipkemoi Boinnet** - Bsc. Dryland Natural Resource Management (2015), Registered Associate Environmental Expert(National Environmental Management Authority; Nairobi, Kenya.), Msc. (Current) Environmental Science, Tongji University, nboinnet@yahoo.com

- **Reshana Thomas,** BA Geography (2015) – University of Guyana, MSc. Environmental Science (Current) – Tongji University

Correspondence Author

Nelson Mark Kipkemoi Boinnet – nboinnet@yahoo.com