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Blue Water Footprint: An Instrument to Support Urban Water Management with Best Practices

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ABSTRACT

Nowadays, water conservation corresponding to urban development appears as a significant challenge. Academia thought of dealing with this issue through the concept of water footprints (WFs) and suggested policy outlines. However, the calculation of WFs is a big challenge, particularly in spatially large and data-scarce areas. In this study, the researchers used some published experimental data to calculate evaporation, runoff, and the municipality water supply to estimate the values of WFs. The study considers three municipalities of eastern India, as part of the study area. While Ranchi reports the highest WFblue value (108 M^3 per capita), Dhanbad shows the minimum (68.8 M^3 per capita). The study also finds that Purulia and Dhanbad are water-deficit municipalities, a concern for them, while Ranchi faces surplus water available for water users. The authors have suggested a few policies from WF perspective, for efficient conservation, utilization, and skewed distribution of water.

Key words : *Water footprint, Evaporation, Water scarcity, Satellite data, Policy outline*

Introduction

India is the second-highest populous country globally as of July 2018 (US Census Bureau Current Population 2019), and currently, one-third of the Indian population lives in urban areas. The continuous urban-centric migration corresponding to urban growth has made water resource conservation a significant challenge for urban water management (Fialkiewicz *et al.,* 1995). There is always a strong linkage effect that exists between groundwater and urbanization as it can change the quality and quantity of the groundwater in several ways mainly: water shortage, flooding, change in the river stream, and the overall aquifer system (Rogers, 1994). While 56% of urban India depends on groundwater, it constitutes 48% of the share in groundwater supply only for 71 metropolitan cities (Narain, 2012). It is also estimated by India's Ministry of Water Resources, River Development, and Ganga Rejuvenation plan that the per capita accessibility of water in both rural and urban India is decreasing continuously. By 2025 and 2050, it will decrease by 36 and 60%, respectively, compared to what it was in 2001 (Bhat, 2014; KPMG, 2010). Study shows that the per capita accessibility of water in India during 1951 was about6 (* 10-6) BCM, which decreased to 2 (* 10-6) BCM in 1991, and by the year 2011, it had further declined to 1(* 10-6) BCM (Bhat, 2014; Sharma and Bharat, 2009). Approximately 600 million urban people in India are under "extremely high" to "high" water stress conditions. During the last decade, strong evidence for massive groundwater depletion has been found around the urban part of the Gangetic basin, where the aquifers are heavily exploited as it has been used for 50% of the urban water supply (Saha *et al.,* 2018). Additionally, because of the changing land use land cover (LULCs) area, urban development puts pressure on urban infrastructure and the water bodies (Kleidorfer *et al.,* 2014). The lack of interaction between water users and decision-makers has increased the vulnerability of the developmental sectors by causing severe water depletion in the urban domain (WWAP, 2012). Nowadays, the traditional methods for analyzing and assessing water availability are not sufficient to evaluate the utilization, conservation, and sustainable water management due to different ambient conditions between cities (Fialkiewicz *et al.,* 2018).

Academia uses theconcept of Water Footprints (WFs) to deal with the issue of water scarcity andper capita, water accessibility in the urban domain (Hoekstra, 2017; Konar and Marston, 2020) and suggested policy outlines (Paterson *et al.,* 2015; Vanham, 2018). The WFs that consist of green, blue, and gray can be conceptualized in terms of water budget as the total volume of water that evapotranspirates from green water resources (WF_{green}) evaporates from the surface water resources (WF_{blue}) and reflects a specific standard of water quality (WF_{grey}) (Falkenmark, 1995; Willaarts and Colmenero, 2012). WF was introduced to analyze and support better water management; however, the experience at an urban level is limited. Most work on the water footprint has focused on agriculture and food production (Silva *et al.*, 2016). However, growing concern about water scarcity for drinking purposes makes the concept of the water footprint potentially valuable for stakeholders, such as water utility planners, who influence the investments and policies associated with water management in urban areas. Due to that, adopting relevant measures and providing solutions for urban bodies is one of the critical challenges for water footprint analyses (Paterson *et al.,* 2015). Water should be managed from a qualitative and quantitative perspective (Manzardo *et al.*, 2016). With this perspective, this study mainly focuses on WF_{blue} instead of the WF_{green} or WF_{grey} as it helps to establish a nexus link between consumptive use of freshwater resources and human security in terms of food, energy and water supply in the urban (municipal) area (Vanham, 2016; Fialkiewicz *et al.,* 2018).

However, water is a complex system (Ray *et al.,* 2018), and calculations of WFs may create specific difficulties (Long *et al.,* 2020). Thus, this study aims to develop a model by integrating hydrologic and economic models (Kanakoudis *et al.,* 2012; Kiptala *et al.,* 2013a,b; Rosegrant *et al.,* 2000; Sullivan, 2002) of WFs for domestic and other water users within the urban domain. This study was taken with the following objectives:

- Methodology to calculate the WF_{blue}
- Estimate the problem of water scarcity vs. water availability
- A few policy recommendation for the benefit of urban water management

Methodology

Study Area

Hoekstra *et al.* (2017) define WF_{blue} as an indicator of consumptive use from fresh/surface water or groundwater resources. The term 'consumptive water use' refers to the cases such as water evaporation; water is incorporated into a particular product; water does not return to the same catchment area and water for a specific period. Looking from these perspectives, the study considers different geographical and socio-economic conditions such as the land use land covers (LULCs), topography, hydrology, meteorology, population, and water supply-demand dynamics as represented by administrative units (municipalities) to signify the concept of WF_{blue}.

The idea was to calculate and compare the WFs, and by using WF_{blue}, we would try to overcome the problem of water scarcity vs. water availability. Our study was conducted in Purulia, Dhanbad, and Ranchi municipalities of West Bengal and Jharkhand, India. The main reasons for choosing these municipalities were that most are water-scarce and have an inadequate municipal water supply system. Furthermore, municipalities having different altitudes (in mt) might result in different evaporation rates without compromising the other aspects of LULCs.

Data

General Characteristics of the Municipalities

The researchers collected the population data for 2011 from the census data. The water department of each municipality has confirmed their actual water supply, which helped the researchers derive the WF_{blue} values. The study used the rainfall data (in mm) of three Municipalities. Rainfall data for Purulia and Dhanbad have been collected from Indian Meteorological Department (IMD), Pune, whereas, for Ranchi, it has been collected from Birsa Agriculture University (BAU). Data for poor and non-poor households have been supplied by the economic and planning department of the respective municipalities. Table 1 describes the socio-economic and geographical characteristics of all three municipalities.

Satellite data

Table 1. General characteristics of the three municipalities

Characteristics	Purulia	Dhanbad	Ranchi
Altitude (mt)	200	222	651
Rainfall in the year 2019 (mm)	1310	1226	1362
Administrative wards	23	55	55
Total area (sq. km)	36.6	231.8	201.5
Poor households	11530	9100	17261
Non-poor households	30470	132900	190375
Poor populations	33630	74517	89452
Non-poor populations	87437	1087955	983975

Satellite data were used to classify different land covers. High-resolution multispectral Sentinel-2 data having four bands, Blue, Green, Red, and Near-Infrared, were used for classification. Three seasons (Jan, May, Oct- 2020); multi-temporal data were also used for classification.

Materials and Methods

The following methods are used to attain the anticipated result using the collected data.

LULC classification of satellite data

The study areas were classified into three categories of LULCs: water, urban, and open (Ai in sq. km.) using multi-season satellite data. A random forest algorithm was used for classifying land cover. Training sites required for this algorithm were obtained using visual interpretation from Google Earth. The classification algorithm provides three land-cover classes with an overall accuracy of 92% and a kappa coefficient of 0.89. In 92 out of 100 cases, the three LULC classes were correctly classified from satellite data.

Estimation of WF_{blue}

WF_{blue} is calculated as follows:

$\mathbf{WF_{blue}} = [A + B + C + D]$, where A is the total evaporation, B is the runoff, C is the total water supplied by the three municipalities, and D is the water loss due to transportation (Hoekstra *et al.*, 2017).

As the calculation of evaporation is a big challenge, particularly in spatially large and heterogeneous, researchers used observed evaporation values from published experimental data. A logical mapping was done from the experimental data of sixteen to the three LULC classes in the present case to normalize the estimation (Kiptala *et al.*, 2013a,b).

Thus, the total evaporation = ([{area of the LULC classes} * {(evaporation coefficients corresponding to LULC classes) * (annual rainfall)}]

Moreover, runoff (B) is calculated using the SCS curve number (CN) method after adjusting the Antecedent Moisture Condition (AMC). $B = (P - 0.2S)2/(P + 0.8S)$, where P is the annual rainfall, and S is the potential maximum retention after runoff begins (Tiwari *et al.*, 2014).

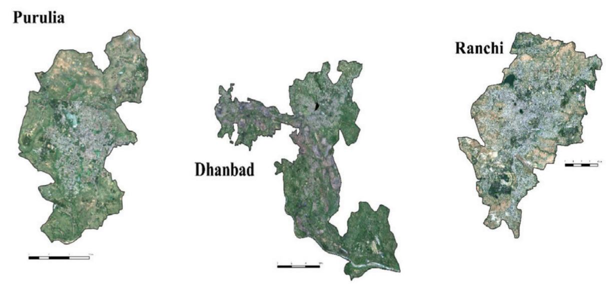

Fig. 1. The satellite images of Purulia, Dhanbad, and Ranchi Municipality areas

Water Availability vs. Water Scarcity

Subsequently, to compare water availability with water scarcity, this study estimated the total water supply in each municipality, considering the poor and non-poor households vis-a-vis poor and non-poor populations. The following steps have been taken to separate the poor from the non-poor in the total population:

- First, calculate the ratio of non-poor to poor households
- Then, apply the ratio to the total population to get non-poor and poor population

We want to clarify that this study errs on making a higher estimate of the non-poor population while a lower estimate of the poor. The general trend shows that poor households reflect a higher population than non-poor households.

Seventy liters of water supply per head per day (lphd) as a minimum standard for poor and 135 lphd for non-poor has been considered standard normative water supply per the Indian Standard Code of Basic Requirements for Water Supply, Drainage, and Sanitation (Standard, 1993).

Multiplication of the normative water supply and the population will provide the total supply, i.e., how much water ought to be supplied to the general public to make it sufficient. Finally, the subtraction of normative water supply and the actual water supply from the municipalities will showcase whether enough water is available in the municipalities or the municipalities are water-scarce. This study uses 'water balance' as a proxy parameter to denote this entire calculation.

Water Balance = [{Actual Water Supply (liters per head per day (lphd))} - [{Poor population * Normative Water Supply (70 lphd)} + {Non-poor population * Normative Water Supply (135 lphd)}]]

Results and Discussion

Classifications

The study areas were classified into three LULCs, water, urban, and open land, using 2020 Sentinel 2 data. Table 2 represents the area covered by each municipality, respectively.

Table 2: LULC details of Municipalities areas in sq. km

LULCs	Purulia	Dhanbad	Ranchi
Water Bodies	0.5	7.3	1.7
Urban Area	7.4	54.7	73.2
Open Space	2.2	27.2	38.8
Total	10.1	89.2	113.7

LULC classification demonstrates that all the municipalities reflect the maximum area in the urban domain. Ranchi manifests the highest area covered under urban areas compared to the other two. The minimum areas in all three municipalities are water bodies, a point to remember for the municipality authority, and they must act according to that. An intuitive look at the images confirms that though we are not considering vegetation area in our assessment, it plays a crucial role in these regions, and activities under vegetation such as agriculture are considered the primary source of livelihood within the territory of the municipal area.

Assessment of WFblue

Figure 3 indicates the results of evaporation and the

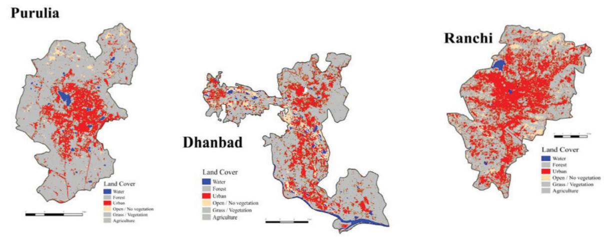

Fig. 2. LULC classes from satellite data of three Municipalities

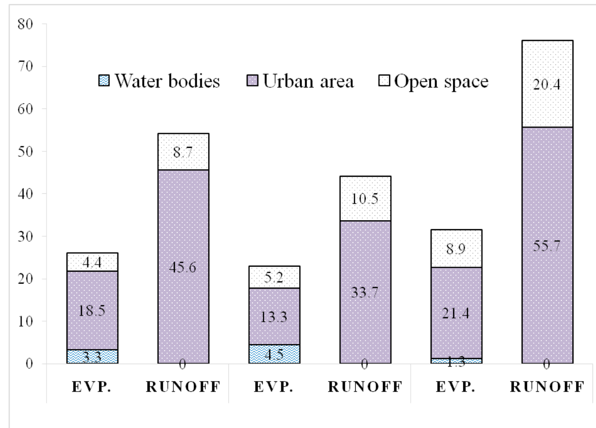

Fig. 3. The Result of Evaporation and Runoff Volume of Three Municipalities

runoff volume for three municipalities in M^3 per capita for the year 2019. All three municipalities reveal the central area as urban/built-up and minimum under water bodies because of the land cover area. The evaporation and runoff are mapping likewise and report an identical pattern. The water loss is highest in the urban areas, followed by open space and water bodies. For Water Bodies, the runoff volume is zero as the CN value is zero.

Figures 4, 5, and 6 report three municipalities' water supply distribution networks (the number in the parenthesis reflecting the total amount of water (mld) distributed). The study finds that while Dhanbad and Ranchi have three main water reservoirs to supply water for the entire city, Purulia has an additional source of spot boring though the amount of water withdrawn from that is minimal. Dhanbad transport water from water bodies such as dam/reservoir from 30-35 km far and then distribute that through elevated surface reservoirs (ESR). Ranchi follows the same process of water management. Purulia is the only municipality to use groundwater. Mapping the water distribution with the total population reports that Ranchi supplies more water than Dhanbad and Purulia.

Table 3. Result of the WF_{blue} of Municipalities (M^3 per capita)

Characteristics	Purulia	Dhanbad	Ranchi
Total evaporation	27.1	24.5	31.6
Runoff	54.3	44.2	76.1
Water supplied by the municipalities	.08	.05	.23
Transportation loss	.02	.03	.04
Total	81.5	68.8	108

Table 3 reports the final value of WF_{blue}. Ranchi reflects the highest WF value while Dhanbad reflects the least. The table explains that all three municipalities produce nearby values in terms of evaporation. However, Ranchi produces maximum WF_{blue}, followed by Dhanbad and Purulia, because of the runoff volume, which creates the absolute value difference. Such a high runoff volume (76.1 M^3 per capita) resulted in this municipality because of high CN values in this municipality, showing that water loss (108 M^3 per capita) from the system is also high, which is a significant concern for the policymakers. Small municipality such as Purulia, which reflects a total of 10.1 sq. km under this study, loses 27.1 M^3 per capita of water as part of evaporation and 54.3 M^3 per capita of water as part of runoff. Then it is a matter of concern for utilization, conservation, and sustainability.

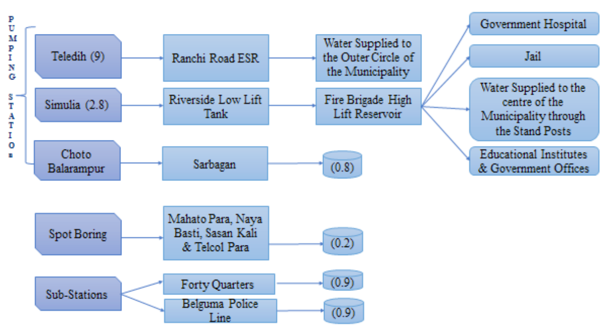

Fig. 4. Water Supply Distribution Network of Purulia

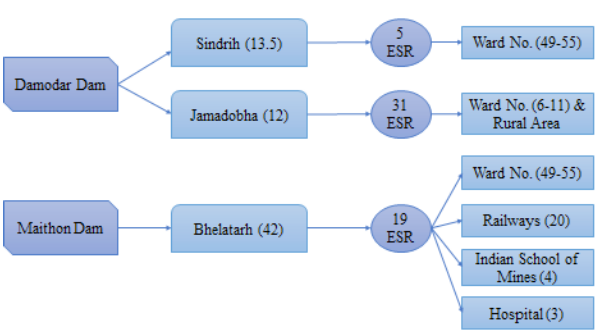

Fig. 5. Water Supply Distribution Network of Dhanbad

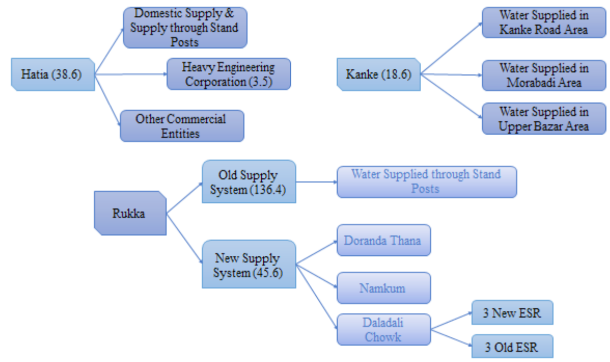

Fig. 6. Water Supply Distribution Network of Ranchi

The study reports fewer water bodies in these Municipalities, yet the government took no action in this area. Therefore, the aim should be to increase the number of water bodies by constructing reservoirs/check dams, etc., to minimize the water loss (Batchelor *et al.*, 2003).

Soil and conservation structures should be made using concrete. The frequency number of the structures per unit km of stream length should be more in Ranchi compared to the other two municipalities. This will felicitate to recharge the groundwater aquifer. In addition to water, soil loss would also be minimal.

An ideal example of the watershed approach for Ranchi municipality would be Deep Continuous Contour Trenches (DCCT). It is created in hilly areas, particularly on the upper hilly tract, which helps conserve soil and water, and thus the water would percolate down (Poyatos *et al.*, 2003). Excavation of more such water bodies would strengthen the water supply sources and conserve water by recharging the groundwater.

Furthermore, traditional water conservation techniques result in significant water loss through a hydrological cycle. Therefore, educating farmers on adopting sustainable best practices, such as more micro-irrigation techniques, drip, irrigation, etc., could be highly beneficial. The International Water Management Institute developed a model for 118 countries and reports that 93% of the world's population estimated a rise in 50% water demand by 2025.

Water Availability vs. Water Scarcity

As described in the methodology section, we calcu-

Table 4. Results of the Municipalities Water Balance (M^3 (*10^3) per day)

Water Balance / Municipalities	Municipality Water Balance (M^3 (*10^3))					
	Types of Residence	Population	Normative Water Supply (lphd)	Total Normative Water Supply	Actual Water Supply	Water Balance
Purulia	Poor	33630	70	14.2	10.2	**(-) 4**
	Non-poor	87437	135			
Dhanbad	Poor	74517	70	152.1	62	**(-) 90.1**
	Non-poor	1087955	135			
Ranchi	Poor	89452	70	139.1	242.2	**(+) 103.1**
	Non-poor	983975	135			

*Where, Total Normative Water Supply = [(70*Poor Population) + (135 * Non-poor Population)]

late the water balance in a demand-supply framework keeping in mind both normative and positive water supply. Table 4 reflects the three Municipalities' surface water balance (surplus/deficit) to represent whether enough water is available for the water users or whether there is water scarcity. The positive sign highlights the water surplus, and the negative sign is the deficit. Current situations for Purulia and Dhanbad municipalities are alarming. Water is scarce in these municipalities, and per capita, availability would be less. Ranchi came up as a water surplus municipality.

As water is a public good, it should be the primary responsibility of the governments to ensure safe access to water for both domestic and other economic users (Baer, 2014 and Smith, 2009). However, the researchers believe that these Municipalities give more preference to the industry than the domestic sector though they have other means of getting water, such as multiple numbers of personal bore wells. The Municipalities prefer them to earn a few extra pennies. Indian railways, a few particular PSUs, and some commercial entities are there to whom they supply water in a bulk quantity by ignoring the domestic sector, as confessed by the Municipality engineers while giving interviews. Thus, to reach the economies of scale in urban water supply governance, the municipality authorities should create a balance in water supply between primary and secondary sectors to ensure a free and fair water supply.

Therefore, this study is with the opinion that initially, the municipality should make sure that the poor get the minimum standard of 70 lphd and then allocate the rest of the amount to the non-poor as they have their alternative sources of fetching water. As Ranchi enjoys a surplus of water, after distributing 70 lphd to the poor and 135 lphd to the non-poor, the municipality could allocate the rest of the resource to the industry. The secondary sector should not feel ignored and could contribute to the path of the municipality's development as we are well aware that within the municipality's territory, the chances of setting up industry are more petite.

Conclusion and Future Work

The Important findings of this study are four folds; those are as follows:

- Using satellite images and historically experimented data, the researchers can map and calculate the LULCs and the evaporation coefficients, respectively, which are the ingredients to find the value of WF_{blue}. The range of areas is significantly high, which reports a maximum in the urban area for Purulia (7.4), Dhanbad (54.7), and Ranchi (73.2) in Sq. Km respectively. As far as coefficients are concerned, the open space with the least evaporation rate revealed the most negligible value of 0.18, and the water body depicts the highest value of 0.59.
- The WF_{blue} values depict that Ranchi reports the highest (108 M^3 per capita), followed by Purulia (81.5 M^3 per capita), and Dhanbad reports the least (68.8M^3 per capita).
- Moreover, the study also found that in the case of municipality water supply, Purulia and Dhanbad are going through a deficit water supply situation (4 and 90 mld, respectively), which is a significant concern for these cities. However, Ranchi shares a positive water balance of 103.1 mld, though few areas of the capital are still in misery.

At the outset of this 21st century, water scarcity and insecurity became inextricable in almost every region. The paucity of water is severely impairing the sectoral prosperity of India. Like many other natural resources, we have taken the availability of water for granted; we continue to expect bounty as soon as we turn on the tap, i.e., who owns water, who can access it, and how much is allowed to be used. These are some of the crucial topics that people should be concerned about.

In a nutshell, this study provides a specific direction to supplement the evaluation of adequate water supply, its deteriorating infrastructure, and appropriate water policies. All of these are the novelty of this study.

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