RENEWABLE WATER RESOURCES AND AN OVERALL WATER DEMAND-AVAILABILITY ANALYSIS FOR BANGLADESH

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ABSTRACT

Freshwater is the major source of water for human consumption. Renewal rate of fresh water resources determines the availability of fresh water for human use. Renewable water resources are the total amount of water resources which is generated through the hydrological cycle and is often measured for a country on annual basis. Availability of sufficient quantity of water throughout the year is necessary for food production, economic development and life. In a general view, a country like Bangladesh may often be treated as water abundant. But the situation is different when the water demand and availability in a short term basis are compared. This study quantifies the seasonal distribution of renewable water availability, sectorwise monthly consumption pattern and ultimately the water conservation required at specific month to counteract seasonal water scarcity in Bangladesh. Water demand of the main three sectors; agricultural, domestic and industrial are computed for the specific year. The agricultural water demand is estimated based on hydrologic and agronomic characteristics using in the modeling approach of Rosegrant and Cai (2002).The industrial & domestic water demand is estimated on the basis of secondary data .The availability of internal renewable water resources is estimated using long term monthly average precipitation pattern whereas that of external renewable water resources is estimated based on transboundary river flow pattern. The greatest drain of water supplies is agriculture (40.08 km^3/year), followed by household use (4.14 km^3/year), and industry and energy (1.03 km^3/year). The water demand is found to be very high from November to March and the maximum demand occurs in March (12.44 km^3).Water shortage is found in the months of January to March. The study suggests a water management plan for reserving 22.25km^3 water from November & December which can mitigate the shortage from January to March. The outcome of this study emphasizes on the necessity of adopting suitable mitigation strategy against water shortage.

Keywords: *Renewable water resources, seasonal variability, water availability, water scarcity*

1. INTRODUCTION

Water, the most widespread substance to be found in natural environment, occupies a special place among all renewable resources. The magnificent properties of natural waters- their renovation during water cycle and their ability for self-purification allowed a state of relative purity, quantity & quality of fresh waters to be retained for a long time. The humanity depends on planet's renewable water supply for use over long term. Renewable water resources include waters replenished yearly in the process of water turnover of the earth that falls from sky, seeps into ground or collects in the rivers or lakes, and flows back to sea from which it was first drawn up by the sun. These are mainly runoff from rivers and formed either within a specific region or from external sources, including groundwater inflow to a river network. This kind of water resources also includes the yearly renewable upper aquifer groundwater not drained by river systems. However, on global scales these volumes are not large compared with the volume of river runoff and are of importance only for individual specific regions.

Fresh water availability is dictated by timing and location of precipitation and by evaporative demand in large parts of the world. The finite nature of renewable fresh water resources makes it a critical resource in context of population growth. Rapid population growth & urbanization coupled with climate change may reduce water supply globally during twenty-first century (Murad et al. 2007; Wheida and Verhoeven 2007). Environmental degradation due to recent growth of global economy in many countries of the world is reducing human access to safe potable water. More water will be needed in future because earth's population will rise to 9 billion by the end of 2050. For quantifying the relationship between population growth and water availability, Swedish hydrologist Malin Falenmark originated idea of “water stress” and “water scarcity” with specific thresholds. These benchmarks can help in indicating adverse consequence related to water shortage and in predicting future urgency related to fresh water availability. Countries with less than 1,700 cubic meters per person experience water stress and those with less than 1,000 cubic meters experience water scarcity. When renewable fresh water availability falls below 500 cubic meters per person that countries experience absolute scarcity. The per capita average fresh water availability has reduced from 23.415 m^3 in 1960 to 9.820 km^3 in 1995 and it is estimated to further decrease in in 2025 and 2050.

There are many previous studies on global renewable water resources and water use for different sectors of economy, most of which focuses on water withdrawal. The mean value of global renewable water resources is estimated as 42,700 km^3 per year and they are extremely variable in space and time. In absolute values, the largest volumes of water resources are those of Asia and South America (13,500 and 12,000 km^3/year respectively). The smallest are typically those for Europe and Australia with Oceania (2900 and 2400 km^3 per year respectively). For individual years, the extent of water resources can vary $\pm$ 15-25% of their_average values.

Global fresh water withdrawal has increased nearly seven-fold in the past century (Gleick, 2000). With a growing population coupled with changing diet preferences, water withdrawals are expected to continue to increase in all sectors in coming decades. The main water consuming sectors are: agricultural, industrial and domestic. The minor sectors (forestry, livestock, environment etc.) water consumption being very negligible is omitted here. Agriculture is considered as significant priority sector to increase food production through development programs in many countries. Worldwide agriculture is the single biggest drain on water supplies, accounting for about 69% of all use. Demand for higher agricultural productivity is increasing day by day due to expansion & diversification of agricultural products while maintaining self-sufficiency in food grain production. On the other hand, about 23 percent of water withdrawals go to meet the demands of industry & energy, and just 8 percent to domestic or household use. Industry, a category that includes energy production, uses water for cooling, processing, cleaning and removing industrial wastes. Nuclear and fossil-fueled power plants are the single largest industrial users, applying staggering amounts of water to the job of cooling. The proportion of water used for industrial development is seen as an indicator of economic development. Domestic water use, including drinking, food preparation, washing, cleaning gardens and service industries such as restaurants and laundries- accounts for only a small portion of total use in most countries. The amount of water people apply to household purposes tends to increase with rising standards of living, and variations in domestic water use are substantial.

The long term average annual renewable water resource (RWR) of Bangladesh is 1227 km^3, out of which 1122 km^3 is external and only 105 km^3 is internal renewable water resources. Indeed, absolute values don’t fully reflect uniform water availability within the country as they differ so much in area and population numbers. Again water consumption and withdrawal within the country are also on the increase. Rapid population growth and increasing demand of water for agriculture and livelihood has become a great challenge for Bangladesh. FAO estimated the total water withdrawal in 2008 about 35.87 km^3 out of which 31.5 km^3 (about 88%) for irrigation and livestock, 3.6 km^3 (about 10%) for domestic and 0.77 km^3 (about 2%) for industrial purpose. SHI (1998) projected that the total water withdrawal of Bangladesh will be 49.8 km^3 in 2025 which was 27.3 km^3 in 1995. Although the total water withdrawal is only 2.92% of the total renewable water resources of the country, the timing of the availability of water is the most crucial thing to be known in making the optimum utilization of the water resources. The notion of an abundance of water in Bangladesh is somewhat misleading. There is a wide seasonal and regional variation in the quantity of water available. There are some months when water availability is excessive than requirement. But in some other months the scenario is totally opposite. For optimizing the excessive available water to remove scarcity, it is necessary to know when the shortage occurs and how much water is required to mitigate it. The aim of this study is to assess annual renewable water availability and seasonal distribution at country level. More specifically, the study is guided by the following objectives: 1) quantifying sectorwise water demand within the country on a monthly basis, 2) simulating monthly water demand and supply for investigating the gap between them and subsequently suggest policies regarding water management for building resilience against water scarcity.

2. METHODOLOGY

2.1 Renewable Water Availability

The monthly distribution of renewable water availability or exploitable renewable water resource can be calculated as follows:

$$\text{Available RWR} = \text{ERWR} + \text{IRWR} - \text{EWR} \tag{1}$$

Where, ERWR is external renewable water resources, IRWR is internal renewable water resources and EWR is environmental water requirement. The transboundary river discharges mainly constitute the external renewable water resources. The mean monthly discharge of Ganges (1950-2004) and Brahmaputra (1953-2004) at Hardinge bridge and Bahadurabad stations respectively are obtained from Jian et al (2009). Other transboundary river discharges are estimated based on the Ganges-Brahmaputra monthly discharge pattern. The generation of internal renewable water resources of the country is mainly from the precipitation within the country. Based on this, the internal renewable water resources is distributed among the months as per monthly rainfall proportion of the country. Environmental water requirement, which is required to maintain a fair condition of fresh water ecosystem, ranges from 20-50% of the mean annual river flow (Smakhtin, 2004). We considered 20% of the Ganges-Brahmaputra-Meghna (GBM) mean annual discharge into Bay of Bengal as the minimum EWR.

2.1.1 Water Demand

Agricultural water demand consists of water demand for irrigation, livestock, etc. For Bangladesh, livestock and other agricultural water demands are very negligible compared to irrigation water demand. So, irrigation water demand is considered as agricultural water demand in this study. The monthly irrigation water demand is calculated in 3 steps:

Monthly irrigation water demand is assessed using a modeling approach based on agronomic and hydrological characteristics of the country (Cai & Rosegrant, 2002). A countrywide approach is followed with the country divided into 7 hydroloical regions.

Net crop water demand of a particular crop in a particular month depends upon the growth stage or stages that fall within that month and also the reference evapotranspiration (ET_0) of that month apart from the crop area. Part of all crop water demand can be satisfied by effective rainfall (PE), which is the rainfall infiltrated into the root zone and available for crop use (USDA, 1967). Again agricultural practices, soil and irrigation water characteristics like salinity and hydrological conditions result in additional water requirements like leaching. Thus, the net irrigation water demand (*NMIWD*) in a particular month considering effective rainfall use and salt leaching requirement is,

$$NMIWD = \sum_{cp} \sum_{st} (kc^{cp,st}.ET_0 - PE^{cp,st}).AI^{cp}.(1 + LR) \tag{2}$$

Where, *cp* is the index of the crops, *st* is the index of growth stages, *kc* is monthly crop coefficient, ET_0 is the monthly reference evapotranspiration, *PE* is the effective monthly rainfall, *AI* is the irrigated area under each crop and *LR* is the salt leaching factor, which is characterized by soil salinity and irrigation water salinity.
Again for months containing paddy, additional water is required for land preparation and flooding apart from it's consumptive requirements. The nursery area is assumed 10% of total irrigated area (*A paddy* in m^2) and the kc_{lp} value for land preparation are assumed from cropwat 8.0. Flooding water requirement is assumed 2cm for every month after the month of land preparation .Thus the net monthly irrigation water demand is,

$$NMIWD = \sum_{cp} \sum_{st} \left(\left(k^{cp,st} \cdot ET_0 - PE^{cp,st}\right) \cdot AI^{cp} \cdot (1 + LR) \right) + \left(kc_{lp} \cdot ET_0 \cdot 0.9AI^{paddy}\right) + (0.02 \cdot AI^{paddy}) \tag{3}$$

Crop calendar of Bangladesh and crop wise irrigated area in each hydrological region for each season were collected from Yearbook of Agricultural Statics-2012. Irrigated crop calendar (Figure 2) of Bangladesh was collected from FAO Aquastat. The crop coefficient varies in time, as a function of plant growth stage. During initial and mid-season stages, kc is a constant and equals $kc_{.ini}$ and $kc_{.mid}$ respectively. During the crop development stages, kc is assumed to linearly increase from $kc_{.ini}$ to $kc_{.mid}$. In the late season, kc is assumed to decrease linearly from $kc_{.mid}$ to $kc_{.end}$. The kc values of different growth stages of crops were estimated from Doorenbos and Pruitt (1979) and Allen et al. (1998). For paddy, the kc values were adopted from cropwat 8.0. For jute, the kc values were adopted for consecutive 10 weeks after transplantation from Odofin et al. (2011). The growth stages of different crops were estimated from Allen et al. (1998) and the Yearbook of Agricultural Statics-2012 based on local varieties. The growth stage based kc values were then adjusted to find out the monthly kc values as per the calculation procedure described in "Irrigation Water Demand: Irrigation water needs, Training Manual No.3".

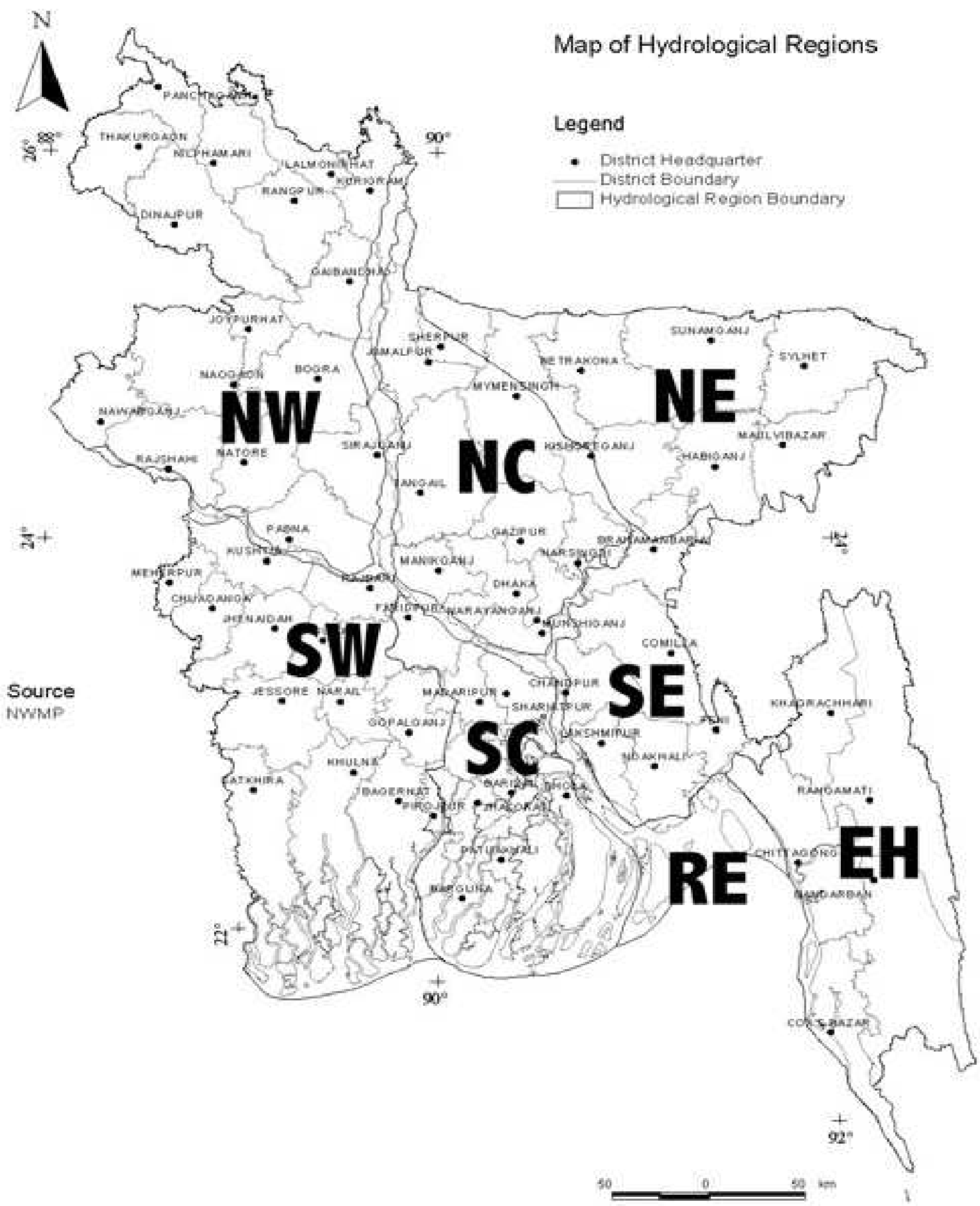

Fig. 1: Hydrological regions of Bangladesh (NWMP, 2001)

The necessary data of monthly maximum and minimum temperature, humidity, wind speed, precipitation and sunshine hour of 35 stations were collected from Bangladesh Meteorological Department. The monthly data of the respective stations within each region are averaged to get the mean monthly data for that region. The monthly reference evapotranspiration (ET_0) in each hydrological region was calculated by using Penman-Monteith method. The effective precipitation was estimated by USDA Soil Conservation Method from the mean monthly precipitation data.

Among the 7 hydrological regions, the salinity problem in soil and irrigation water is very threatening in southern coastal parts of Bangladesh (South-west and South-central hydrological zones in particular, apart from few parts of South-east and Eastern Hill regions).The dry season and premonsoon months suffer maximum soil salinity (D. Clarke, 2015 ; H. M. Rasel, 2013). It is evident from various studies (Baten ,2015) that the dry season crops are specially in threat of yield reduction as salinity increases in that time due to lack of flow from

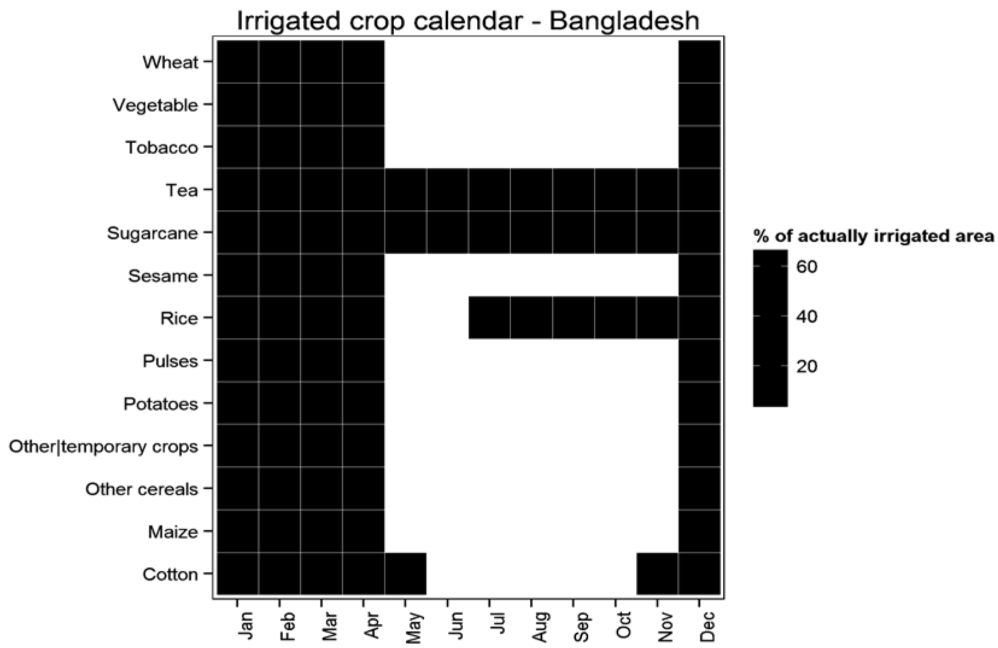

Fig. 2: Irrigated crop calendar of Bangladesh

freshwater sources like rivers and also due to small amount of precipitation during that time. The extent and degree of soil salinity varies depending on soil type, drainage facilities and other geographical and climatic characteristics in these regions. In some parts, the salinity is so high that even leaching cannot prevent yield reduction. Again, salinity tolerances of crops also vary. Considering all these factors and based on the findings of the above mentioned studies, a leaching fraction of 0.10 for Boro paddy for 90%-100% yield potential and 0.25 for other dry season crops for 80%-100% yield potential are assumed in these two regions.
The monthly total irrigation water demand (MIWD) is calculated as

$$MIWD = \frac{NMIWD}{EE} \tag{4}$$

Where EE is defined as effective efficiency (Keller, 1995). It is measured as the ratio of beneficial water use (crop evapotranspiration and salt leaching requirement) to the total water depleted from the sources of supply within the country. The overall effective efficiency of irrigation in Bangladesh is assumed 0.7 based on the estimates of FAO and Cai et al. (2002).

Industrial water demand (INWD) is assessed based on production growth rate (Bangladesh country fact book economy). In Bangladesh, it is very difficult to get information on water demand for every industry. As industrial water demand varies with production growth rate. For the analysis presented here, the consumptive use of water for the industrial sector is adjusted on annual percentage increase in industrial production (includes manufacturing, mining and construction). The monthly water demand for industrial production is assumed to be distributed in uniform manner over a year.

Domestic Water Demand (DOWD) includes urban/municipal and rural domestic water demand. For water demand calculation, it is crucial to know the details of actual water use and its end use such as drinking, washing of utensils, toilet flushing, bathing and clothes washing on a household level. However, in most developing countries including Bangladesh, it is very difficult to get such information. Therefore, the data on water consumption pattern are synthesized based on literature and available estimates. These estimates measure the propensity to consume per capita water with respect to size and inherent characteristics of area. We projected total water demand considering per person per day water consumption as 180 lpcd for city corporation areas, 100 lpcd for upazilla towns, 120 lpcd for zilla towns and 50 lpcd for rural areas. There is a significant variation of water demand in dry season (November-May) and monsoon season (June-October). As total water demand in Dhaka city varies from 2100 to 2300 MLD with seasonal variation, the dry season demand can be assessed by multiplying a factor to monsoon season demand.

3. ILLUSTRATIONS

3.1 Water Demand Scenario of Bangladesh

The total water demand in the year 2012 is found to be 45.26 km^3 which was 35.87 km^3 in 2008.It is generated from mainly three sectors: agriculture 40.08 km^3 (88.57%), domestic 4.412 km^3 (9.15%) and industrial sector 1.03 km^3 (2.28%). The maximum demand occurs in March (12.44 km^3) and the minimum demand occurs in June (0.43 km^3).Agricultural water demand dominates the monthly total water demand except the month June.

3.2 Agricultural Water Demand

Agriculture is the major water using economic sector while rice is the most water consuming crop (consumes 78.45% of the total water demand). The net irrigation water demand found is 28.05 km^3 which was 24.56 km^3 in 2008.The agricultural withdrawal is found 40.08 km^3 which was 31.5 km^3 in 2008

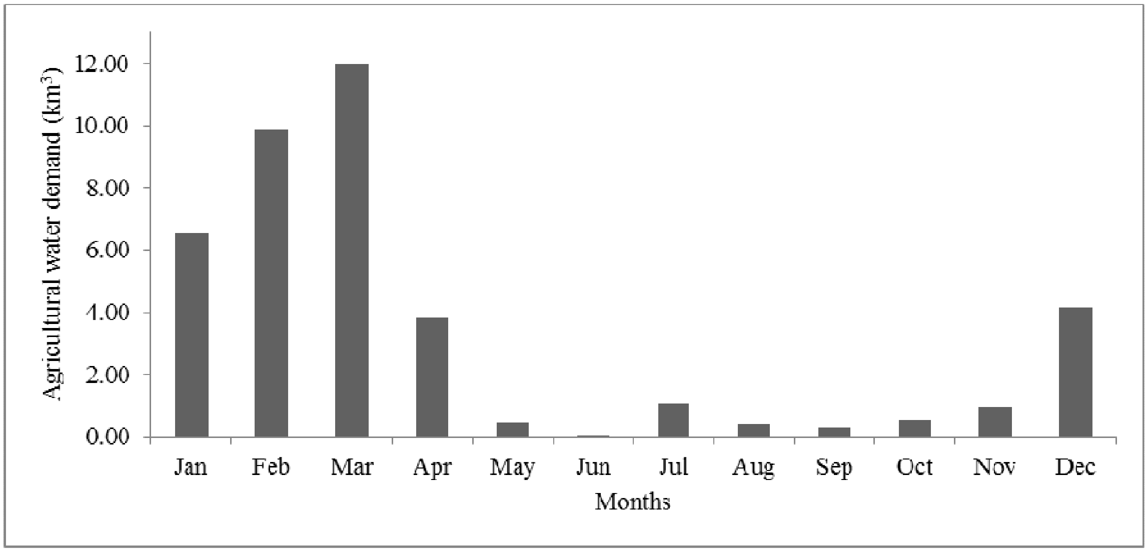

Figure 3: Monthly Irrigation Water Demand of Bangladesh (km^3)

Irrigation water demand varies greatly throughout the year (Figure 3). The year starts with high demand and the highest demand occurs in March (12.00 km^3). In the pre-monsoon months (March-May) the demand gradually lowers. In the monsoon months the demand is low. The month June shows minimum demand (.01km^3). As the dry Rabi season starts, the demand gradually increases. The dry season (November –February), pre-monsoon (March-May) and the monsoon (June-October) irrigation water demand constitute about 53.63%, 40.58% and 5.79% of the total annual irrigation water demand respectively.

The 7 hydrological regions also show the same pattern (Table 1). All the regions show the highest demands in February and March. June is the month of lowest agricultural water demand in all the regions and in most regions the analytical values are zero. This is because of the cropping pattern of the country and also because irrigated area of the country in this month is the lowest (Figure 2).

The northwest region has the largest irrigated area of all regions. It forms about 37.18% (14.902 km^3) of the total agricultural water demand. The north central region is the most industrialized and urbanized region of the country, which includes the capital city Dhaka. The agricultural water demand of this zone is 4.265 km^3. The north-east and the south-east region have agricultural water demand of 6.268 km^3 and 3.171 km^3 respectively. Eastern hill has the minimum demand for agriculture (1.213 km^3) where the other demand is as usual. The agricultural water demand of the south-west and south-central zone are 7.015 and 3.250 km^3 respectively. Problems like soil salinity is creating additional irrigation demand and also reducing the crop production in these two southern coastal regions.

Table 1: Zone wise Agricultural Water Demand (km^3)

Months	North-west	North-central	North-east	South-west	South-central	South-east	Eastern Hill
January	2.373	0.794	1.114	0.705	0.566	0.677	0.292
February	3.359	1.148	1.825	1.443	0.775	0.962	0.363
March	4.267	1.356	2.381	2.021	0.715	0.971	0.285
April	1.842	0.273	0.281	1.075	0.153	0.133	0.049
May	0.159	0.005	0.002	0.282	0.006	0.001	0.002
June	0.006	0.000	0.000	0.006	0.000	0.000	0.000
July	0.401	0.060	0.034	0.321	0.251	0.009	0.006
August	0.237	0.015	0.008	0.083	0.068	0.002	0.002
September	0.102	0.015	0.008	0.083	0.068	0.002	0.002
October	0.231	0.102	0.015	0.104	0.069	0.003	0.002
November	0.481	0.041	0.053	0.168	0.137	0.023	0.038
December	1.445	0.456	0.546	0.725	0.440	0.387	0.173
Total	14.902	4.265	6.268	7.015	3.250	3.171	1.213

3.3 Domestic Water Demand

The seasonal variation of domestic water demand is very significant. It shows two patterns. The monsoon season (June-October) demand is 0.327 km^3 and dry season (November-May) demand is 0.358 km^3. The total domestic water demand in 2012 is found to be 4.12 km^3 whereas it was 3.6 km^3 in 2008. As the population is increasing day by day, the domestic water consumption will go up gradually.

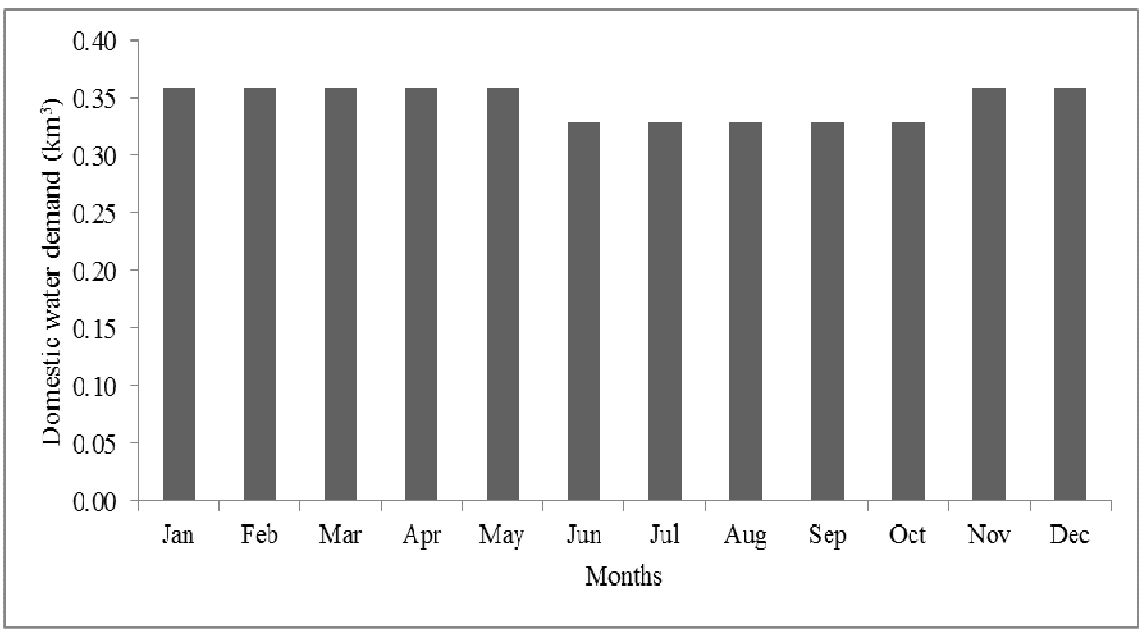

Figure 4: Domestic Water Demand of Bangladesh (km^3)

3.4 Industrial Water Demand

Uniform industrial water demand is found throughout the year and the monthly demand is 0.086 km^3. The total industrial water demand in 2012 is 1.03 km^3 whereas in 2008 it was 0.77 km^3. As the industrial production growth rate in 2012 is higher than that was in 2008, it is logical that demand is increasing in proportion.

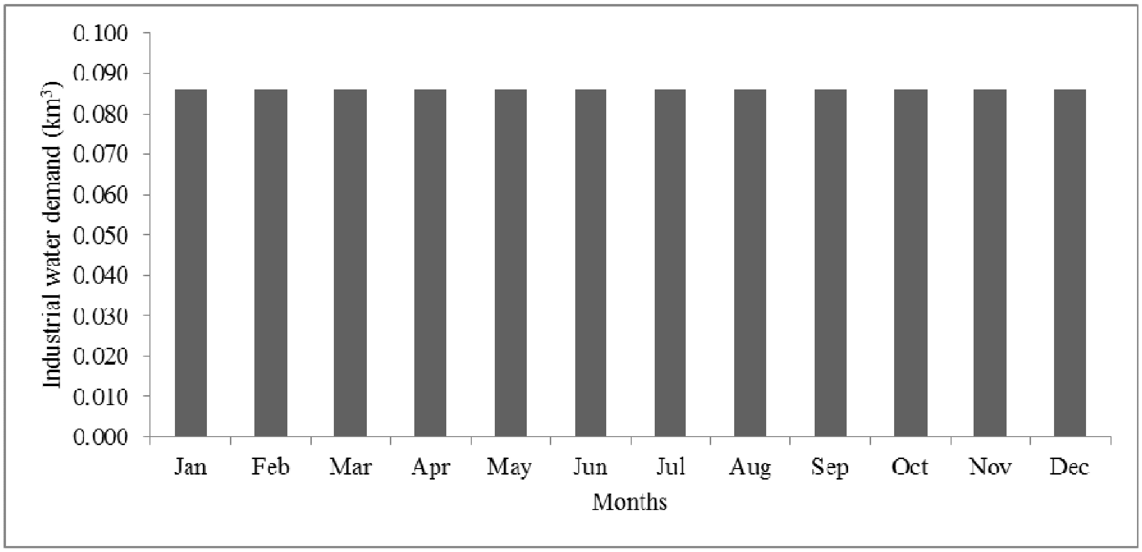

Figure 5: Industrial Water Demand of Bangladesh (km^3)

3.5 Renewable Water Availability

Maximum internal renewable water generates in month July (22.81 km^3) while the maximum external renewable water generates in August (245.42 km^3). Environmental water requirement has 3 patterns (20.42 km^3, 18.45 km^3 and 19.77 km^3) based on month duration. Renewable water availability varies throughout the year. January, February and March are the three months having very low water availability with February having the lowest (.67 km^3 only) available water.

Table 2: Monthly RWR (IRWR, ERWR and Available RWR) Distribution

Months	Ganges & Brahmaputra Discharges (km^3)	Other Trans boundary Rivers Discharge (km^3)	IRWR (km^3)	Monthly RWR (km^3)	EWR (km^3)	Available RWR (km^3)
January	22.5	2.32	0.33	25.15	20.42	4.73
February	16.58	1.71	0.83	19.12	18.45	0.67
March	18.61	1.92	1.97	22.50	20.42	2.08
April	26.18	2.7	4.99	33.87	19.77	14.10
May	48.75	5.04	11.68	65.47	20.42	45.05
June	95.39	9.85	20.13	125.37	19.77	105.60
July	181.6	18.76	22.81	223.17	20.42	202.75
August	222.44	22.98	18.16	263.58	20.42	243.16
September	197.9	20.44	14.05	232.39	19.77	212.62
October	111.55	11.52	8.05	131.12	20.42	110.70
November	46.39	4.79	1.61	52.79	19.77	33.02
December	29.06	3	0.39	32.45	20.42	12.03

3.6 Demand –Availability Comparison

Water shortage occurs in months January to March and maximum shortage occurs in March (10.36 km^3).

Table 3: Demand vs. Availability Scenario

Months	Water Demand (km^3)	Availability of Renewable Water (km^3)	Excess (+) or Shortage (-) (km^3)
January	6.96	4.73	-2.24
February	10.32	0.67	-9.65
March	12.44	2.08	-10.36
April	4.25	14.10	9.85
May	0.90	45.05	44.15
June	0.43	105.60	105.18
July	1.50	202.75	201.25
August	0.83	243.16	242.34
September	0.69	212.62	211.92
October	0.94	110.70	109.76
November	1.39	33.02	31.64
December	4.61	12.03	7.41

3.7 Water scarcity in Bangladesh

Water shortage is regional as well as seasonal. The overall availability of water is, therefore, apparently dependent on external portion which is mainly from transboundary rivers. The water overall countrywide shortage is found in three months; January (2.24 km^3), February (9.65 km^3) and March (10.36 km^3). In February, the flow in the rivers (18.29 km^3) are less than the environmental water requirements (18.45 km^3).The shortages in these 3 months lead to excess ground water extraction from deep aquifers which is the main reason of lowering ground water table.

3.8 Conservation of Excess Available Water to Counter Shortage :

The countrywide shortage of water occurs in months January to March. The total amount of shortage is 22.25 km^3. In other months, water is available. So, the conservation can be made from the immediate previous two months November-December as the excess available water in these two months is 39.05 km^3 which is greater than the shortage. We propose a 5 month long program to confront water shortage. The monthly reserves from November and December are proportional to the excess water of these two months. The conservation can be made in the following way.

Table 4: Conservation of Excess Available Water

Months	Availability of RWR (km^3)	Total Demand (km^3)	Excess(+) or Shortage (-) (km^3)	Monthly Reserve (km^3)	Cumulative Reserve (km^3)
November	33.02	1.39	31.64	18.05	18.05
December	12.03	4.61	7.41	4.2	22.25
January	4.73	6.96	-2.24	0	20.01
February	0.67	10.32	-9.65	0	10.36
March	2.08	12.44	-10.36	0	0

4. CONCLUSIONS

Water use for livelihood, agriculture, industry and infrastructure has increased during last few decades in Bangladesh. Above all, due to increase in population, per capita availability of water is declining. Water availability is not optimum when required for various sectors to their efficient utilization. There are many agro climatic variables which governs water resource in Bangladesh such as water conflicts, groundwater extraction, irrigation based rice farming, and inadequate water flow in rivers during dry and of seasons, variability in rainfall events and inefficient irrigation. The cumulative effects of these factors have led to water scarcity situations of varying extent in different parts of Bangladesh. The study shows that water resources have become inadequate and scarce in dry season from January to March. But there exists excess available water in rest of the months around the year. Scarcity of fresh water can directly affect the long-term prospects for sustainable development. Excessive nonrenewable water extraction during dry season from deep aquifer is causing water table lowering and making groundwater more unavailable. Due to unavailability of water, cropping pattern of the country is also changing and facing yield reduction. Without an adequate water supply, factories depending on water may have to be closed down temporarily; workers may be unproductive; fisheries may be destroyed.

How to relieve the worsening water crisis has become a major common-concerned strategic issue from agricultural perspectives in the 21st century for Bangladesh. In order to build resilience against water shortage related problem, it is necessary to know the durations as well as the amount of water shortage. This study can serve as the base of sustainable water use and management related planning, projection and action. For further research it is important to assess the spatiotemporal variability of fresh water availability and how much water can sustainably be used in a certain country without adversely affecting the ecosystem.

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