Contribution of Rainwater to the Irrigation Requirement for Paddy Cultivation at Tanore Upazila in Rajshahi, Bangladesh

Authors: Hasan, Md Rashidul, Nuruzzaman, Md, and Mamun, Abdullah Al

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Md Rashidul Hasan[1], Md Nuruzzaman[1] and Abdullah Al Mamun[2]

[1]Department of Civil Engineering, Bangladesh Army University of Engineering & Technology (BAUET), Natore, Bangladesh. [2]Department of Civil Engineering, International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia.

ABSTRACT: Groundwater extraction for irrigation in Bangladesh has caused groundwater depletion, especially in the Northern region. As such, shifting reliance from groundwater to surface water is one of the solutions to mitigate this problem. This study aims at investigating the contribution of effective rainfall to the total consumptive use requirement of rice cultivated in Tanore, Rajshahi, in Bangladesh. The prospect of rainwater harvesting using ponds and its contribution to the consumptive use requirement of rice was also determined. Effective rainfall, temperature, monthly percentage of bright sunshine hours, and consumptive use factor for rice data were collected from Bangladesh Meteorological Department (BMD) and Barind Multipurpose Development Authority (BMDA). Blaney-Criddle method was used to calculate total consumptive use requirement of rice. Analysis results showed that from June to September, there is no requirement of irrigation due to high rainfall in this period. It was revealed that total consumptive use requirement of rice in Tanore averaged at 436 million m^3 of water between the period of 2005 and 2012. Effective rainfall contributed to about 38% of the total consumptive use in this period. It was also found that another 5% of the total consumptive use requirement could be supplied by rainwater harvesting using the ponds of Tanore.

KEYWORDS: Groundwater, rain, Bangladesh, water supply, ponds

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CORRESPONDING AUTHOR: Abdullah Al Mamun, Department of Civil Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia. Email: mamun@iium.edu.my

Introduction

Bangladesh is one of the most densely populated countries in the world and it had a population of about 120 million in its 147 570 km^2 (14.57 million ha) of land in 2011[1] and now the population has increased to 160 million. The country is suffering from food shortage. As a result, agricultural land is cultivated more than two to three times in a year requiring more irrigation water than the past. With the increasing use of groundwater for irrigation, the annual extraction of groundwater is far higher than the net average recharge from natural sources. It can lead to lowering of the groundwater table[2] increasing the cost in extraction of groundwater. Future crop production may be hampered by this depleted groundwater table.[3,4] Aeschbach-Hertig and Gleeson[2] collected and showed the evidence that groundwater across the world is on decline. Excessive extraction for agricultural use has been identified to be the main reason behind this phenomenon.[5] Konikow[6] confirmed that United States is also experiencing groundwater depletion. It has been confirmed by plenty of studies that groundwater across the globe is depleting at an alarming rate.[5,7–10] It has been reported that the rainfall amount in the northeastern region of Bangladesh is progressively declining.[11] Alam et al[12] warned that western part of Rajshahi district in Bangladesh might experience chronic to severe drought in the future. It has been found that groundwater in Rajshahi district was receding at a rate of 0.23 m/year during the period between 2000 and 2014.[13] Moreover, a study on Tanore Upazila in Rajshahi revealed that groundwater in Tanore is depleting at an average rate of 0.22 m/year.[14] The impact of climate change on water requirement of rice was investigated by Shahid.[15] It was concluded that paddy crop itself will not require extra amount of water, but the warmer climate will require more water to be pumped, which will ultimately aggravate the already stressed groundwater resources of Bangladesh. Mainuddin et al[16] estimated that irrigation water requirement can increase by 1% to 5% in 2050 based on type of crop and time of sowing. To reduce this problem, the excess rainwater yielded as surface runoff can be harvested in ponds and other reservoirs and may contribute to the consumptive use of crops in dry season.

A study conducted in the South-Eastern part of Bangladesh revealed that about 13.94% to 100% of the total consumptive use requirement could be fulfilled by effective rainfall for different parts of the year for rice cultivation.[17] The study used Potential Evapotranspiration/Precipitation Ratio method, United States Department of Agriculture (USDA), Soil Conservation Service (SCS) method, and Renfro equation to estimate the effective rainfall percentage of the total consumptive use requirement. A recent study reconfirmed the depletion of groundwater table decline in Rajshahi district and suggested potential measures to release the stress on groundwater. One of the suggestions was to Boro rice transplantation by November so that late monsoon rain can contribute to the consumptive use requirement.[18] Another study investigated the opportunity of rainwater harvesting (RWH) in Godagari, Rajshahi.[19] The study showed that in Boro season, rice cultivation was fully dependent on irrigation water. It also depicted that there were 15 ponds located in Godagari, which could be used to store runoff and supply irrigation water during dry period. Water requirements for various crops in the Barind region of Bangladesh were determined using the available data from 1985 to 2013. Blaney-Criddle formula was employed to determine the consumptive use requirement of the crops. During this period, the maximum value of consumptive use was found to be 27.88 cm for rice in April.

In Faisalabad, Pakistan, study showed that the rainwater contribution for wheat and maize was around 7.5% and 15.5% per year.[20] The study used CROPWAT computer model to determine consumptive use requirement in that region. Wisser et al[21] performed a global scale study on quantifying the significance of water captured by small reservoirs for crop production. It was reported that 623 to 1122 km^3 of water can be supplied for irrigation worldwide through the water captures in local small reservoirs. An increase of 35% in global cereal production is expected due to this supply of irrigation water. However, it was also mentioned that 20% of the water stored in the reservoirs can get evaporated before use. Another study suggests that climate change will reduce the global crop production by 9%, which can be balanced by harvesting 25% of the rainwater to supply for irrigation.[22] The study suggested to adopt a combination of water management strategies to enhance crop production. A model was developed to assess hydro-economic benefit of RWH system for irrigation in India.[23] Impact of on-farm reservoir (OFR) irrigation system was simulated and compared with the rainfed agriculture. It was revealed that the water use efficiency of the OFR system was 82% more efficient than the rainfed system. Total gain value due to the OFR irrigation system was estimated to be 74% and 14% greater than the rainfed system in the dry and wet season, respectively. Future water requirement and availability in terms of blue and green water was estimated by Rockström et al.[24] Green water is the soil moisture obtained through rainfall used by the plants and blue water is the water available in the surface and ground. It was reported that in 2050, 36% of the world population will have to tackle green and blue water shortage and 59% of world population will encounter blue water scarcity. It was also mentioned that currently, there are many countries who are blue water short, but they have sufficient green water, which combined with blue water is sufficient to produce enough food. It was suggested that proper management of local green water resources can increase resilience to climate change. A countrywide study on Pakistan revealed that effective rainfall contribution to consumptive use requirements of crops grown in Pakistan varied from 13.03% in the Rabi season (October to April) and 21.31% in the Kharif season (May to September) to almost 100% in different parts of Pakistan.[25] The study used data from 58 meteorological stations across Pakistan covering irrigated plains. Among the methods employed by the study involved Renfro equation, US Bureau of Reclamation method, USDA method, and SCS method. Effective rainfall contribution is expected to increase in the future, especially in the Northern part of Pakistan.[26] On the other hand, in case of drought event, severity is going to be intensified in the arid and semi-arid region of Pakistan.[27] Under this circumstance, storing of water for the dry spells may prove to be a viable option for smooth water supply. Djaman et al[28] studied the water requirement of rice in Senegal. It was found that based on location and season, water requirement of rice in Senegal varied between 632 and 929 mm.[28] On the other hand, rainfall amount in Senegal is less than 190 mm, which accounts for 20% to 30% of the total water requirement of rice.

As mentioned earlier, northern part of Bangladesh is suffering from declining rainfall and depleting groundwater table. Hence, this region needs immediate attention and research should be executed to solve the water problem in this region. With an aim of addressing the issue, this study has chosen Rajshahi district. The approach of the study is to find out the water requirement of the main crop, ie, paddy produced in this region, and find alternative solution to meet the water demand of the crop. There are studies on global scale as well as countrywide studies. However, studies on micro scale or localized studies are rare. Localized studies are more important because rainfall amount and crop water requirement for the same crop vary from region to region. This study aimed at investigating the contribution of effective rainfall to the total consumptive use requirement of rice in Tanore Upazila, Rajshahi, Bangladesh. Storing runoff water by RWH and supplying in the dry season is a prospective solution to the groundwater depletion problem in the region. Hence, the contribution of rainfall runoff through RWH is also estimated in this study.

Methodology

Study area

The study area is located in the Barind tract situated in the Northern part of Bangladesh (Figure 1). Tanore is a part of greater Rajshahi district. The co-ordinates of Tanore are 24° 29′ N to 24° 43′ N in latitudes and 88° 24′ E to 88° 38′ E in longitude. Population of Tanore is about 173 495. Total area of Tanore is 295.8 km^2 (29580 ha). Total cultivable land is about 226.56 km^2 (22 656 ha). Nearly 43% of the people are involved in agricultural activities. With the expansion of irrigation in Tanore Upazila in the mid-1980s, a revolutionary change occurred in the agricultural sector of Tanore. Introduction of high-yielding varieties (HYV) paddy combined with groundwater supply for irrigation made it possible to increase the yields of rice. Single cropped agricultural lands are now producing three crops in one agricultural year after the start of groundwater extraction. The cropping intensity in Tanore is about 262% which is high compared with the national average of 180%.[1] Rice in Bangladesh is grown in three distinct seasons, namely Boro (January to June), Aus (April to August), and Aman (August to December).[29,30]

Estimation of consumptive use and field irrigation requirement

Evaporation (E_T) or consumptive use (U) is the total amount of water lost from a cropped or irrigated land due to evaporation from the soil and transpiration by the plants or used by the plants in building up of plant tissue. It is usually expressed as a depth (cm, mm) over the area.

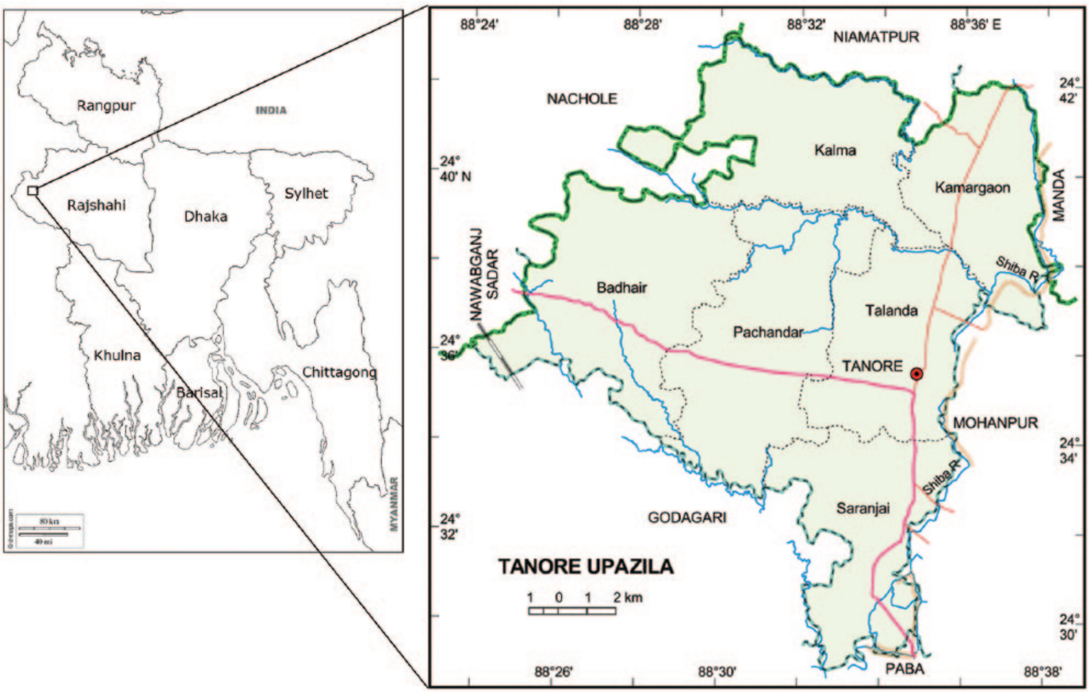

Figure 1. Location map of study area.

Blaney-Criddle formula was used to determine the consumptive use requirement of rice.[31,32] Considering the available data, this method was used. Other methods, eg, Penman equation could not be used because of lack of required data. The Blaney-Criddle formula is as follows:

$$U = k\Sigma f$$

$$f = \frac{p\,(4.6t + 81.3)}{100}$$

where U is the seasonal consumptive use (cm), t is the mean monthly temperature (°C), p is monthly percentage of hours of bright sunshine (of the year), k is the monthly consumptive coefficient, and f is the monthly consumptive use factor

The field irrigation requirement is the amount of water to be supplied by the crop by irrigation; it is determined by subtracting the effective rainfall from the crop consumptive use requirement.

Effective rainfall is the amount of rainwater generated as runoff after deducting the infiltration loss. To determine effective rainfall, a runoff coefficient (C), which is below 1, is multiplied to the actual rainfall depth. The value of runoff coefficient depends on soil type. Sandy soil will have lower value of C and clayey soil will yield higher C value. Hence, P_e can be determined as follows:

$$P_e = CP$$

where C is the runoff coefficient and P is the actual depth of rainfall (cm).

The value of C was considered to be 0.8 for Tanore as suggested by Barind Multipurpose Development Authority (BMDA). Field irrigation requirement (FIR) is the difference between consumptive use and effective rainfall:

$$FIR = U - P_e$$

where FIR is the field irrigation requirement and P_e is the effective rainfall.

RWH calculation

In estimating the volume of water from RWH from the areas where land is not cultivated, rational formula was used as follows:

$$Q = CAP$$

where Q is the volume of water from RWH yield (m^3), C is the coefficient of runoff of 0.8 for Tanore (according to BMDA), A is the land area not cultivated (m^2), and P is the rainfall depth (m).

The amount of cultivated land in Tanore is $22\,656 \times 10^4\,m^2$ (22 656 ha). The remaining land which is not cultivated is $6924 \times 10^4\,m^2$ (6924 ha) and hence, $A = 22656 \times 10^4\,m^2$.

Data collection

Rainfall data, monthly average bright sunshine hours, and temperature data of the study area were collected from the Bangladesh Meteorological Department (BMD). Number of ponds, pond dimensions, total cultivable area of the study, and consumptive use factor for rice in different months were collected from the BMDA.

Available dataset for the meteorological parameters mentioned above ranges from 2005 to 2012. The data were monitored, sorted, and bias corrected, ie, the quality of the data was maintained by the BMD. It records three hourly data for rainfall and hourly data for temperature. Then the data are bias corrected and averaged for monthly period. The monthly averaged data were provided by the BMD. There is no missing data in the above-mentioned range. The resolution of the rainfall and temperature data is 20 km.

Results and Discussions

Figure 2 shows temperature variation throughout the year from 2005 to 2012. December and January are the winter season and the temperature is lowest in these months. On the other hand, summer persists in April and May and the temperature rises near 40 C in these months. The temperature never went below 20 C even in the winter season, which is not the typical case in Bangladesh. In most part of the year, temperature in Tanore remained above 30°C.

Rainfall variation in different months of the year is depicted in Figure 3. June and July are considered monsoon in Bangladesh and monthly total rainfall depth up to 49.2 cm occurred in this period. Tanore Upazila experiences the lowest amount of rainfall during winter season (December and January) and the trend starts in November and continues until February. This has great implication on rainwater contribution to the irrigation requirement, ie, the winter season can be considered as the driest period in a year and irrigation water requirement will be high. Monthly total rainfall depth varied from 0 cm in winter to 49.2 cm in monsoon. Almost 92% of the total rainfall occurred between May and October in the period of 2005 to 2012.

Monthly percentage of bright sunshine hours (p) measured by BMDA are illustrated in Figure 4 in the Whisker-Box plot. The value of p is lowest in July – median value is 4.4% due to heavy rainfall in this month. The median value of p in August is 5.2%, which also experiences heavy rainfall. The months of December and January, which are in the winter season also have low p values - medians are 4.8% and 5.6%, respectively. As p value is directly proportional to the consumptive use requirement, a lower p value will reduce the consumptive use requirement.

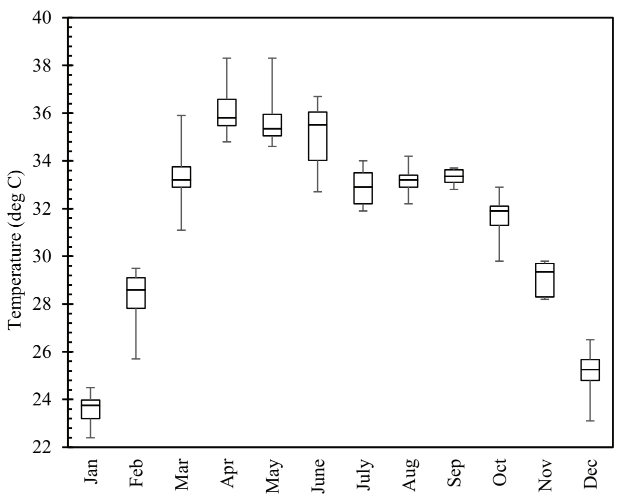

Figure 2. Box and Whisker plot of monthly temperature data from 2005 to 2012.

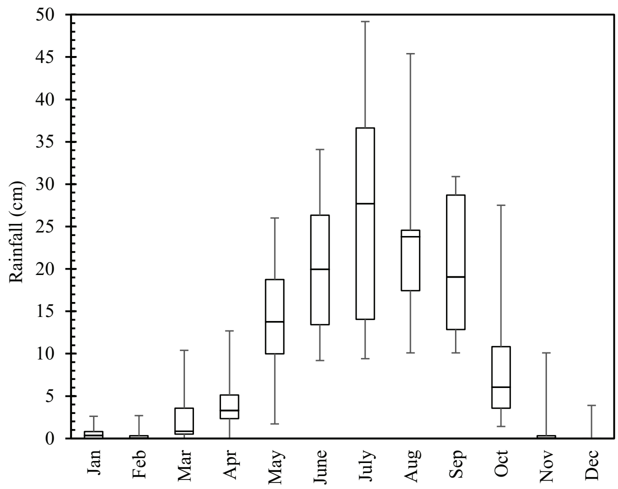

Figure 3. Box and Whisker plot of monthly total rainfall from 2005 to 2012.

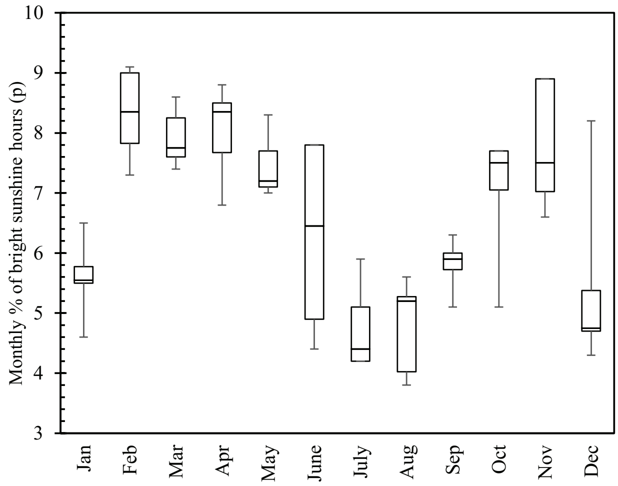

Figure 4. Box and Whisker plot of monthly % of sunshine hours (p) from 2005 to 2012.

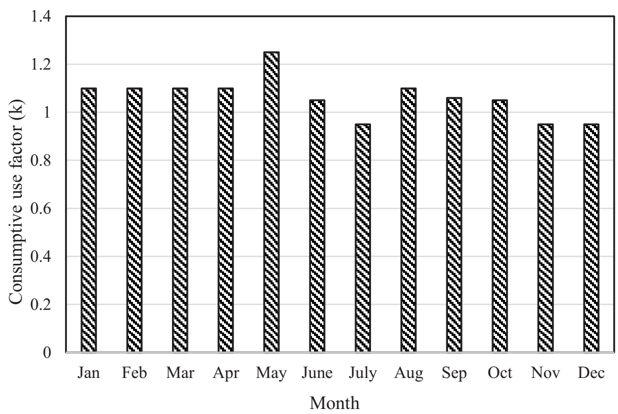

Figure 5. Consumptive use factors for different months.

Figure 5 illustrates the consumptive use factors (k) of rice for different months determined by BMDA. The highest and lowest values of k are in May – 1.25 and in July, November, and

December – 0.95. A higher k value will yield a higher consumptive use requirement.

Figure 6 demonstrates variation of monthly consumptive use. Due to low temperature, consumptive use was lowest in December. Lower percentage of bright sunshine hours in July helped in lowering the consumptive use requirement. On the other hand, consumptive use was highest in April and May due to high temperature in this period. The consumptive use requirement varied between 7.7 and 26.7 cm.

Field irrigation requirements after deducting the effective rainfalls from the consumptive uses are given in Figure 7. It can be clearly observed that between June and September,

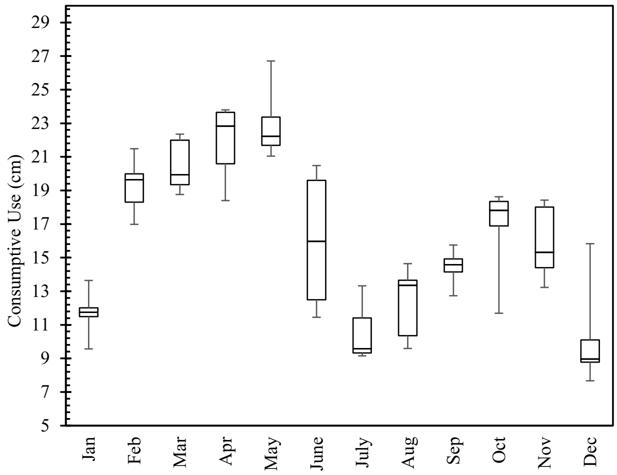

Figure 6. Box and Whisker plot of monthly consumptive use requirement from 2005 to 2012.

rainfall amount is excessive than the consumptive use requirements and hence, FIR is negative. On the other hand, from February to April, FIR is high – average is near 18 cm. Although consumptive use is not high in the winter, low amount of rainfall keeps the consumptive use and FIR almost same – around 10 cm. From the analysis, it can be stated that lands are needed to be irrigated in 8 months of a year. Consumptive use requirement of the remaining 4 months can be fulfilled by rainfall alone.

Existing water reservoir capacity

In the study area, there are total of 34 existing ponds having a total volume of 432 753 m^3. These ponds can be used for storing rainwater and runoff and supply water for irrigation in other times of the year. Pond dimensions and water reservoir capacity of these ponds are shown in Table 1.

Figure 8 shows the percentage of consumptive use requirement that rainwater contributed from 2005 to 2012 and the rainfall runoff water that could be used to supply for irrigation purpose in non-raining season. The total consumptive use varied between 411 and 450 mm^3 of water per year and field irrigation water requirement was between 164 and 304 mm^3 per year. Consumptive use water requirement and field irrigation water requirement averaged at 436 and 213 mm^3 of water per year, respectively. Effective rainfall contributed 33% to 46% of water to the consumptive use requirement of rice between 2005 and 2012. The average contribution of effective rainfall was about 38%, whereas in Faisalabad, Pakistan, rainfall accounted

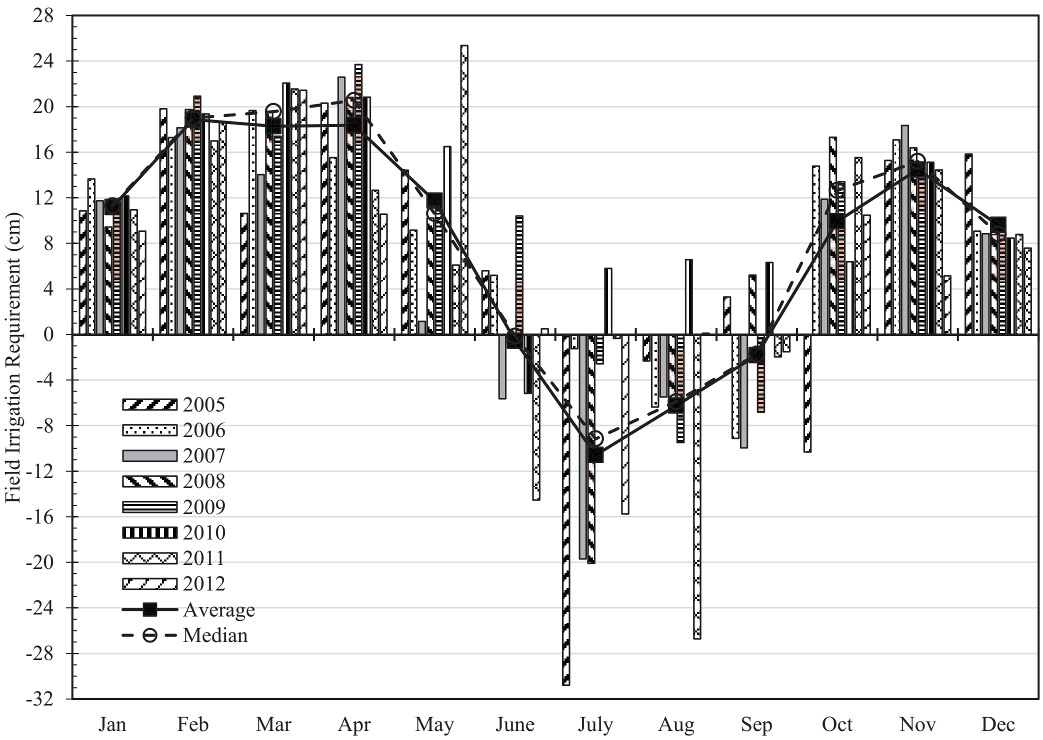

Figure 7. Field irrigation requirement from 2005 to 2012.

Table 1. Reservoir capacity in Tanore Upazila.

NAME OF MOUJA	POND NO.	POND DIMENSION		VOLUME (M^3)
		AREA (M^2)	AVERAGE DEPTH (M)	
Chuniapara	1	2954.31	3.43	10133.28
	2	3035.25	5.30	16086.83
	3	2104.44	3.84	8081.05
Malbandha	1	6556.14	3.96	25962.31
	2	2549.61	3.44	8770.66
	3	2468.67	3.48	8590.97
	4	2468.67	3.74	9232.83
	5	2509.14	3.37	8455.80
Biloshni	1	4249.35	3.81	16190.02
Kolma	1	2913.84	2.46	7168.05
	2	1416.45	4.05	5736.62
	3	4856.4	4.09	19862.68
	4	1537.86	3.76	5782.35
Chokortiram	1	3075.72	2.97	9134.89
Pipra	1	4208.88	3.00	12626.64
Azizpur	1	1740.21	3.95	6873.83
	2	3601.83	4.02	14479.36
	3	2671.02	3.68	9829.35
Jogisho	1	2913.84	3.43	9994.47
Saidhara	1	2185.38	4.36	9528.26
	2	3278.07	4.17	13669.55
	3	2832.9	4.10	11614.89
	4	3035.25	4.43	13446.16
	5	2832.9	3.80	10765.02
Soronzai	1	5706.27	4.41	25164.65
Telupara	1	5584.86	4.21	23512.26
	2	7122.72	4.49	31981.01
	3	4775.46	4.54	21680.59
Zotgokul	1	2913.84	4.03	11742.78
	2	3237.6	3.30	10684.08
Zotgorib	1	2063.97	4.31	8895.71
	2	3966.06	3.99	15824.58
	3	1537.86	4.01	6166.82
	4	1456.92	3.49	5084.65
Total volume (m^3)				432753

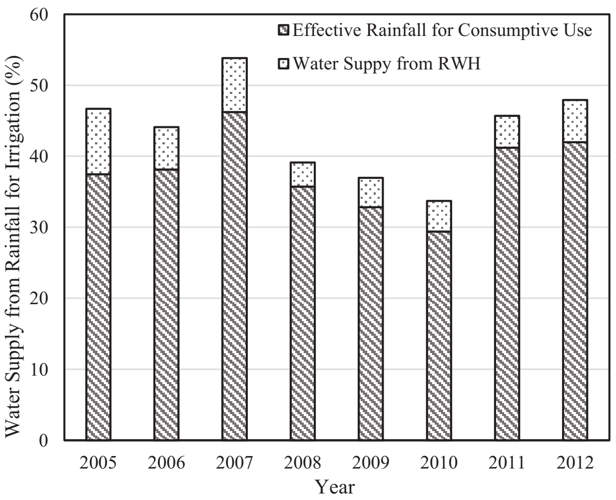

Figure 8. Rainwater contribution to the consumptive use requirement of rice.

for 7.5% and 15.5% of yearly consumptive use requirement of wheat and Maize, respectively.[20] On the other hand, for other parts of Pakistan, rainfall contribution was found to be between the range of 13.03% and 100%, depending on the season and location.[25] In Senegal, it was found that rainfall contributes less than 30% of the evapotranspiration requirement of rice.[28] The stored runoff water could supply 4% to 9% of consumptive use requirement. The average water that could be stored from runoff and supplied for irrigation was 22 mm^3, which accounts for roughly above 5% of total consumptive use. On an average, the effective rainfall and stored runoff in the reservoir ponds could supply 43% of the total consumptive use requirement between 2005 and 2012 in Tanore Upazila.

Conclusions

This study has shown the contribution of effective rainfall and potential contribution of RWH in total consumptive use requirement of rice in Tanore, Rajshahi. Monthly effective rainfall depth in Tanore varied between 0 and 49.2 cm. It has been revealed that from June to September, there is no requirement of irrigation water as amount of rainfall exceeds the consumptive use requirement in these months. Effective rainfall contributed from 33% to 46% of total consumptive requirement of rice between the period of 2005 and 2012. Another 4% to 9% of consumptive use requirement can be met by storing rainfall runoff water in ponds located in Tanore Upazila. It is expected that irrigation water supply from stored runoff in the ponds if implemented can release the stress on groundwater at least to some extent. Now, the managers can take the decision of implementing the RWH in local ponds and increasing the capacity of local reservoirs by constructing more ponds. This will not only help solving the groundwater depletion problem, but also enhance resilience of irrigation water supply system during dry spells and benefit in the long run. Researchers can take this study as an example to quantify effective rainfall contribution to the crop water requirement as well as potential of RWH in other regions of Bangladesh, especially in groundwater depletion vulnerable areas. This study used only one method to estimate water requirements of rice in the region. We suggest using other methods too in estimating water requirements of rice and other crops. It will help to pinpoint the exact water requirement of crops and reduce errors. Future research can focus on variability of climate in the region and crop water requirements under those conditions.

Author Contributions

MRH checked for the accuracy of the data, analyzed the reservoir capacity and rainwater harvesting potential and collected detailed information on the study area.

MN calculated the consumptive use requirement, rainwater contribution and developed the overall methodology of the work.

AAM analyzed the rainfall data, assisted in developing the methodology and drawing the conclusions.

ORCID iD

Abdullah Al Mamun https://orcid.org/0000-0002-7324-5514

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