IMPACT OF IRRIGATION WATER PRICING ON WATER USE BY THE FARMENT'S OF GREATER DINAJPUR DISTRICT

A THESIS

BY

JANNATUL FERDOWS NIPA

Examination Roll No.: 1505289

Session: 2015-2016

Thesis Semester: July-December, 2017

MASTER OF SCIENCE (MS)
IN
IRRIGATION AND WATER MANAGEMENT

DEPARTMENT OF AGRICULTURAL AND INDUSTRIAL ENGINEERING

HAJEE MOHAMMED DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

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DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

Study to 'impact of irrigation water pricing on water use by the farmers' covers 23 Upazilas of Panchagarh, Thakurgaon and Dinajpur districts having gross area of 6,66,048 ha and cultivable area of 5,39,499 ha (IWM, 2015). This study aimed to find out the variation of seepage and percolation loss at different crop growth stages, Crop Water Requirement, identifying different irrigation pricing methods and finally to develop the relationship between seepage & percolation loss and irrigation water pricing. In order to find out the impact of irrigation water pricing on water use by the farmers half blind and half perforated PVC pipes were installed at Ishania, Dinajpur, Maghkhuria, Thakurgaon and Guagram Pradhan Para, Panchagarh districts. At each district at least 5 pipes were installed keeping distance from one pipe to another pipe at least 50 meter. After installing PVC pipes depth of water level measured at a fixed time in everyday considering same reference level for measuring the seepage and percolation loss. Average seepage and percolation loss have been found 5.37 mm/day in Dinajpur district, 5.63 mm/day in Thakurgaon district and 6.43 mm/day in Panchagarh district. The evaporation loss data was collected from evaporation station and for entire season the average evaporation has been found 5.733 mm/day. After measuring seepage and percolation loss and evaporation loss the crop water requirement was calculated. The average crop water requirement has been found 11.10 mm/day for Dinajpur district, 11.30 mm/day for Thakurgaon district and 12.10 mm for Panchagarh district. The observed CWR has been compared with the simulated CWR using CropWat model. The soil textures for each field have been tested at the laboratory of Soil Resource Development Institute. It has been observed that seepage and percolation loss was different at different districts due to different type of soil textures and seepage and percolation loss was different at different crop growth stages. The seepage and percolation loss found very high at vegetative crop growth stage, medium at reproductive stage and lowest at ripening stage. It has been found that Seepage and Percolation loss have major impact on irrigation water pricing. Water pricing in Dinajpur district is lowest, Thakurgaon district is medium and it is highest in Panchagarh district due to highest seepage and percolation loss than other two districts. It has been found from the study, irrigation water pricing has a proportional relationship with seepage and percolation loss and crop water requirement. The seepage and percolation loss mainly depend on the soil texture, surrounding environment and topography of the study area.

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CHAPTER-1

INTRODUCTION

The greatest challenges of Bangladesh are to ensure food security through optimum utilization of the country's resources, with water as a central resource. About 52% of the total area of the country is now used for agriculture but irrigation is provided in about 68% of the agricultural land. Out of the total irrigated area of 5.37 mha, about 78.4% is irrigated by groundwater and the rest by surface water (BADC, 2013). It is now evident that due to the effects of climate change, reduced transboundary flow, deteriorating water quality and increasing in-country water demand, the present water deficit during the dry season is going to increase. Among the consumptive uses of water, agricultural demand overwhelmingly dominates other uses. Hence, less water will be available for agriculture, in general, and for rice, in particular, the crop that consumes the largest amount of freshwater. But, irrigation development must continue unabated, to feed the teeming millions of people. Therefore, development of irrigation, not through more projects but by 'growing more crops with less water' has been advocated. Hence, the only option left out for coping with the imminent increasing water deficit is 'demand management' of water for agriculture. The present level of water use efficiency in agriculture is low and there are ample scopes for its improvement.

Traditionally, rice is grown under continuous standing water of about 2 to 7 cm throughout the crop season for better supply of nutrient and for more effective weed control. Because of high crop water demand, the water productivity of irrigated rice is one of the lowest, ranging from 0.05 to 1.1 g $litre^{-1}$ (Tuong and Bouman, 2003). With increasing water scarcity, rising demand for irrigation and increasing irrigation cost, the future prospects of irrigated rice production is at a crossroad. Therefore, the reduction of water use in rice production and the increase of water productivity have become imperative.

The overall irrigation efficiency of rice production systems in countries of South and Southeast Asia is very low and ranges from 25% to 40% (Perry et.al. 2009). In a recent study, the overall irrigation efficiency in minor irrigation systems of Bangladesh (unlined earthen canal with area based water pricing) was found to be about 30% (Alam, 2011). The efficiency increased with lining, time based water pricing and adoption of alternate wetting and drying (AWD) technology. The highest overall irrigation efficiency of about 41% was achieved for buried pipe systems with time based pricing. It was observed that changing from area based to time based pricing, the average overall efficiency increased by 3.85%. Similarly, by changing from earthen to lined canal, the overall irrigation efficiency has been increased by 3.37%.

Seepage and percolation loss of water is a major reason behind the poor efficiency and water productivity in irrigated rice systems. Specifically, water loss through seepage & percolation constitutes about 50–85% of total applied water in rice systems (Singh et. al., 2002). Seepage & percolation is inevitable in irrigated rice production as water is applied to the fields to maintain a certain depth of standing water in the field. The key strategy for increasing water use efficiency in irrigated rice systems is through minimization of excessive field losses, particularly seepage & percolation, while maintaining the evapotranspiration (ET) at its potential rate.

In the planning and design of irrigation projects, a constant seepage & percolation rate is generally assumed (BWDB, 1985; BWDB & BUET, 1989; IWM, 2003; IWM, 2009), even though it has been observed that seepage & percolation rate depends upon the depth of standing water and varies with the time after transplanting/land preparation (puddling). While calculating the crop ET, the effect of crop growth stage on ET is considered, but seepage & percolation is assumed to remain constant throughout all growth stages. The recent introduction and limited adoption of the AWD method also had a profound impact in reducing the seepage & percolation loss (Tuong, 2009; Saleh et. al., 2009). Although the seepage & percolation rate generally increases with increase in depth of standing water (Tabbal et. al., 1992; Kukal and Aggarwal, 2002), a high variability was observed in the correlation between the two (Soriano &Bhuiyan, 1989). Thus, the Darcy's law which considers homogeneous and isotropic soil does not apply well in predicting the seepage & percolation loss in puddled rice fields.

The seepage & percolation loss is a highly variable component of the total water requirement of rice. Seepage & percolation loss is site specific and depends on soil texture, water table depth, proximity to drainage outlet and farmer's field water management status (Bhuiyan, 1982). In addition to the above factors seepage & percolation loss at the field level is also affected by the extent of puddling and standing water depth status of the rice fields (Tabbal et. al., 2002; Kukal and Aggarwal, 2002).

The seepage & percolation rate also decreases with time during an irrigation cycle (Kukal and Sidhu, 2004). The variation in seepage & percolation loss with time was observed by a number of researchers and the findings were more conclusive (Kukal and Aggarwal, 2002; Rashid et. al., 2009). It was observed that the seepage & percolation rate was high initially but decreased with the passage of time. This decrease is attributed to the clogging of the pores in the top layer by the settling of fine particles in suspension, by algal growth and root effects.

Thus, the review of the past studies exemplifies that the assumption of a constant seepage & percolation rate during the rice growth period of 100-120 days (depending upon variety), as used in the traditional planning and design of irrigation projects, is not a true representation of the field condition and needs to be reconsidered and reviewed. Like crop ET (which varies with crop growth stage), the need for a variable seepage & percolation needs to ascertain.

Bangladesh is an agricultural country. Agriculture is the mainstay of the economic life of Bangladesh. Almost 80% of the people depend on agriculture. Food grain production has increased about three times in last decades, mainly as a result of introduction of minor irrigation and introduction of HYV rice.

Rice is the main crop of Bangladesh and it needs more water than other crops. Irrigation is an important factor for agriculture. There are several irrigation projects in Bangladesh. Most of the farmers use traditional method to irrigate their fields. If there is plenty of water, it has no significant effect of the consideration of water loss. Due to the water scarcity during dry period and increasing demand, water loss is very high using traditional method and cannot be satisfied for the whole irrigable area.

The irrigation system at present, due to change of agro-socio economic situation of the area, High Yield Variety (HYV) Boro rice cultivation is being practiced by the farmers during dry period (Mid December to Mid-May), which require much higher irrigation water. With the current cropping pattern and its irrigation demand, the existing water availability during dry period has to be used in a proper way to cover the entire command area.

CHAPTER-2

REVIEW OF LITERATURE

2.1 Seepage and Percolation Loss in Bangladesh

Seepage is the lateral movement of water from the rice field while percolation refers to the vertical movement of water beyond the crop root zone to the water table. As soil-water movement is a combination of both seepage (S) and percolation (P), seepage & percolation is a collective term and the most important measure of water movement in rice field. The seepage & percolation rate depends upon both soil properties and on-farm water management practices. The major soil properties affecting seepage & percolation rate are texture and structure, shrinkage and cracking. The management practices affecting seepage & percolation are depth and duration of standing water, puddling and sub-surface barriers (plow pan).

Soil texture and structure have significant effect on the seepage & percolation loss. Percolation is assumed to be the main component in sandy soil whereas seepage dominates in clay and clay loam soil (Wickham and Singh, 1978).

Water losses by seepage & percolation account for about 25–50% of all water inputs in heavy soils with shallow groundwater tables of 20–50-cm depth (Cabangon et. al, 2004), and 50–85% in coarse-textured soils with deep groundwater Tables of 1.5-m depth or more (Singh et.al., 2002).

Typical combined values for seepage and percolation vary from 1–5 mm/day in heavy clay soils to 25–30 mm/day in sandy and sandy loam soils (Bouman and Tuong, 2001).

Field experiments in China (silty clay loam soil) and the Philippines (clay soil) show that the percolation rate varied between 2.3 to 3.3 mm/day in China and 4.8 to 5.9 mm/day in the Philippines for continuously flooded fields. But for intermittently irrigated fields, the rates increased to 4.9 to 15.1 mm/day in China (Belder et.al., 2007).

2.2 Review of Different Study Area

- In Bangladesh, the seepage & percolation rates have been measured by a number of researchers. For the sandy loam soil of Thakurgaon Irrigation Project, the seepage & percolation rate varied from 5.3 to 13.2 mm/day (BRRI-BWDB-IRRI, 1986).

- In the silty loam soil of the Rubber Dam Project of Cox's Bazar, the S&P rate during the Boro season was measured as 3.1 mm/day (Saleh and Mondal, 2001).
- The seepage & percolation rate measured during the Aman (Kharif II) season at Godagari, Rajshahi (silty clay loam to silt loam soil) was 7 mm/day (Saleh et. al., 2000).
- For the clay loam soil of G-K Irrigation Project of Kushtia, the seepage & percolation rate varied from 4.7 to 6.7 mm/day and for the silty clay soil of BRRI,
- Joydebpur the seepage & percolation rate varied from 2.6 to 6 mm/day (RituandMondal, 2002).
- Studies by IWM show that for continuously flooded rice fields, the seepage & percolation varied from 4 to 6 mm/day in silty loam soil of Teesta Barrage Project (IWM, 2003).
- In a similar study (IWM, 2009) in Thakurgaon (sandy loam soil) and Dinajpur (silty loam soil), the seepage & percolation for continuous flooded fields varied between 4.8 – 6.6 mm/day (for silt loam soil) and 8.7 – 10.2 mm/day (for sandy loam soil) respectively.

Puddling of soil during land preparation results in the destruction of the macropores and increases the soil's bulk density. As the non-capillary pore space is reduced during puddling, a closer packed soil structure is obtained, which in turn decreases the percolation. Thus, due to puddling the seepage & percolation rates are drastically reduced.

- IRRI researchers measured mean seepage & percolation rates of 2 and 5.7 mm/day for puddled and non-puddled soils, respectively (Wickham and Singh, 1978).
- Field experiments by Mishra et.al. (1991) show that puddling increased the bulk density by 17% under shallow and 14% under medium water table conditions. This increase in bulk density enhanced micro porosity by 11.6% for shallow water table and 5.1% for medium water table soils, but reduced macro porosity, hydraulic conductivity and infiltration rates respectively, by 51.1, 50.7, and

54.1% of shallow water table and 53.6, 54.7 and 51.3% of medium water table soils. The process of water percolation was studied in a puddled sandy loam rice field with three puddling intensities: no puddling (un puddled), two passes of tractor-drawn cultivator one planking (medium-puddling), and four passes of tractor-drawn cultivator one planking (high-puddling), each at shallow (5–6 cm) and normal (10–12 cm) depths. Percolation losses of water decreased with medium-puddling by 54–58%, but it remained unaffected by increased puddling intensity and puddling depth.

The hydraulic conductivity of the puddled layer also decreased with increased puddling intensity (Kukal and Aggarwal, 2002). Increasing puddling tillage intensity to four operations decreased percolation rate of water by 22–40% from that with one operation. Four puddling operations decreased percolation rate of sandy loam soils by 30% from that with one puddling operation. This led to decrease in irrigation water used by 22–27% when puddling tillage intensity increased from one to four operations (Kukal and Sidhu, 2004). Similar findings of Increased puddling intensity on significantly increased depth of puddle and decreased saturated hydraulic conductivity of the puddled layer and percolation loss were also observed in sandy loam and silty clay loam soils of a subtropical environment of north India (Singh et al. 2001). The effect of puddling on soil cracks was studied by Mohanty et. al. (2004) and it was observed that compared to un-puddled soil the length, width and depth of cracks increase with the increase of puddling intensity.

Thus, it is clear that puddling reduces the seepage & percolation losses by eliminating the macropores, destroying the soil structure and increasing the bulk density.

Although rice is grown traditionally under continuous standing water of about 2 to 7 cm throughout the crop season, increasing water scarcity necessitates the development of water-saving technologies in rice production that depart from continuous submergence (where the soil is saturated and anaerobic from crop establishment to close to harvest). Two important water-saving strategies in irrigated lowland rice are emerging: (i) ‘alternate submergence–non-submergence’, which is also called ‘intermittent irrigation’ or the recently introduced concept of ‘alternate wetting-and-drying’, and (ii) ‘flush irrigated’ rice also referred to as ‘aerobic rice’. In intermittent irrigation, irrigation is applied a few days after water has disappeared from the surface so that periods of soil submergence alternate with periods of non-submergence during the whole growing season. Alternate wetting and drying is also a type of intermittent irrigation and as suggested by IRRI, in this technique irrigation should be applied to re-flood the field to a ponded water depth of about 5 cm, when the water level has dropped to about 15-20 cm below the surface of the soil (SAIC, 2007). Aerobic rice is grown in non-submerged and non-saturated aerobic soil and studies in China and the Philippines suggest that yields of around 70% of that realized under continuous flooding can be obtained using about 50% of the water used in continuously flooded systems (Bouman et. al., 2005 and Yang et. al., 2005).

As discussed in article 2.2, there are many studies both in Bangladesh and in the rice growing countries of the world, on water use in irrigated rice with continuous flooding and intermittent irrigation. Most of these studies do not reveal the intra variation of water depth (in continuous flooding or intermittent irrigation) on water use but reveal the inter variation between continuous flooding and intermittent irrigation. Studies in India and the Philippines show that the water input can be reduced by reducing the ponded water depths to soil saturation or by alternate wetting/drying. Water savings under saturated soil conditions were on average 23% (±14%) with yield reductions of only 6% (±6%). For the purpose of increasing the amount of ground water recharge, water infiltration in flooded paddy rice fields in Taiwan was observed and the results show that increasing the ponded water depth from 6 to 16 cm increased the infiltration by 1.5-fold (Chen and Liu, 2002).

In clayey soils, intermittent drying may lead to shrinkage and cracking, thereby risking increased soil water loss, increased water requirements and decreased water productivity (Bouman and Toung, 2001). Higher water use in intermittent irrigation than under continuous submergence was also reported by Lu et. al. (2000) and was attributed to the development of cracks in the plough layer during non-submerged periods. Although higher percolation rates of the ponded water layer in intermittent irrigation was observed over continuous submergence, the seasonal net percolation was still lower under intermittent irrigation than under continuous submergence because of the absence of percolation during the non-submerged days.

The higher percolation rates under intermittent irrigation may be attributed to the repeated swelling and shrinking of clay particles, causing the formation of (micro) cracks (Belderet.Al., 2007). It was also observed that the amounts of irrigation and percolation were closely correlated. The amounts of irrigation and net percolation were both highest for continuous flooding followed by intermittent irrigation and aerobic culture. The amounts of irrigation and net percolation were highly dependent on the soil permeability. At Tuanlin, China, the amount of irrigation water needed to maintain continuous submergence was 1860 mm and at Los Baños, Philippines, it was 2040 mm. These high losses were reduced in the water-saving regimes. For example, at Tuanlin, the intermittent irrigation saved some 600 mm and at Los Baños, water savings was around 800, compared to continuous flooding. At both locations, yields with intermittent irrigation were within 96% of the yield that was attained with continuous flooding at any groundwater table depth.

Although intermittent irrigation has been recognized as a water saving technique in irrigated rice (Shi et. al, 2002; Belder et al, 2002), the impact of intermittent irrigation on yield is inconclusive. Belder et. al.(2004) and Li (2001) reported water savings without yield loss under intermittent irrigations, whereas Mishra et. al., (1990), Singh et. al., (2001) and Tabbal et. al., (2002) reported small yield reductions under intermittent regimes. Studies in China (Cabangon et.al., 2004 and Feng et. al., 2007), India (Mishra et. al., 1997 and Hoek et.al., 2001) and the Philippines (Belder et.al., 2004) have all shown that there were no significant differences in yield between continuous flooding and AWD practices. Although some researchers have reported a yield increase using AWD, according to Bouman et. al., (2007), these are exceptions rather than the rule.

A number of studies conducted in Bangladesh have all reported either an increase or similar yields between intermittent irrigation and continuous flooding. While Rashid et. al. (2005) and Husain and Kabir (2009) have reported no significant difference in yields, Sattar et. al. (2009) and Rahman (2009) have reported average yield increase of 9% and 5%, respectively for AWD over the farmers' practice of continuous flooding. From pilot studies, DAE (2009) has reported an yield increase of 11.4% by AWD over the traditional practice.

Thus, it is evident that even though the impact of intermittent irrigation on the rice yield is inconclusive, there would not be a significant difference in yield between intermittent irrigation and continuous flooding. But, the researchers are unequivocal about the positive role of intermittent irrigation on reducing the water use in rice. Even then, literatures on how water use (or the seepage and percolation rates) changes with respect to depth of flooding during the crop growth stages and also with respect to time after transplantation, are scarce.

Improving the performance and efficiency of water management in agriculture could save water from existing uses. Better management of irrigation water and appropriate water charging possibly will enhance greater efficiency in water use. It is necessary to improve the performance and operations of the existing irrigation systems in Bangladesh for improving water use efficiency. This study used the review of existing literature on irrigation water use efficiency and water pricing in Bangladesh agriculture. It is found that performance and operations of the existing irrigation systems in Bangladesh is too poor in terms of water use efficiency. Moreover, low water pricing is causing excessive and inefficient use of water. Improved management of surface and ground water irrigation and appropriate pricing strategies are suggested for achieving physical ad economic efficiency in water use.

The need for efficient, equitable, and sustainable water allocation policies in water resources management has become important with growing scarcity and increasing competition among different water using sectors (Cai, Ringler and Rosegrant 2001). With the increasing competition for water among neighboring farmers and competition between agricultural and non-agricultural water use, the efficiency of water use is brought utmost consideration. The crops can be grown with limited quantities of water rather than unlimited quantities of water that is often caused for waterlogging and salinization of agricultural lands. Tom improve the efficiency in water use a more sophisticated water management is essential rather than traditional water use. Efficient use of water for crop production is now often a major goal in designing and management of irrigation systems (Burt et al. 1997). Besides, agricultural water pricing plays a significant role in promoting water use efficiency and cost recovery (Akter 2007). Lower water price may leads the inefficiency in technical water use for irrigation. Irrigation water price in Bangladesh is low and does not reflect the actual value of water.

The term water use efficiency is often misstated. Irrigation efficiency is described by various terms and is used to describe how efficiently irrigation water is applied and/or used by the crop (Environment Canterbury n.d.). Incorrect usage of these terms is common and can lead a misinterpretation of how well and irrigation system is performing (Irmak et al. 2011). “The physical efficiency compares the volumes of water delivered and consumed; economic efficiency relates the value of output and opportunity costs of water used in agricultural production to the value of water applied. A further definition compares the water applied to the biomass or yield output” (Cai, Ringler and Rosegrant 2001). It is not always clear the relationships between these various measures of water use efficiency but all of these efficiency concepts can be useful for irrigation water management and have important policy implication.

Firstly, all measures of water use efficiency are essentially physical, referring to either technical efficiency or to, at best, partial measures of economic efficiency. Secondly, there are multiple measures of water use efficiency each focusing upon a particular issue and objective. Finally, while irrigators are price and cost conscious, ultimately whether or not an irrigator seeks to increase their water use efficiency depends on whether doing so will improve income, lower risks or reduce labor input, or improve the trade-offs between these.

The possible benefits of water use efficiency for on-farm and within irrigation schemes include operating and pumping cost savings, improved environmental performance of irrigation systems, restore river flows and groundwater recharge and the potentiality of irrigating a larger area with a given volume of water (Environment Canterbury n. d.). Private sector involvement in irrigation sector started in early 1980s through the withdrawal of rental system of Deep Tube Wells (DTWs). Previously mentioned, public sector managed minor irrigation specially the DTWs and Low Lift Pumps (LLPs) under the rental system of BADC were found not successful. Inefficient rental system and lack of repair and maintenance of irrigation equipment were the constraints of the success of public sector led minor irrigation projects. However, the Barind Multipurpose Development Authority (BMDA) in northwest Bangladesh operates 4000 rental DTW units and another project managed by DAE in southern Bangladesh rents LLP’s and power tiller to the farmers are found successful due to conscious management and satisfactory services to the farmers. The rental recovery of BMDA and DAE projects were 95 percent and 90 percent, respectively (Rahman 2002).

A policy changes from public rental system of DTWs to private selling system and withdrawal of imports restriction of irrigation equipment resulted dramatically increase the irrigation equipment and irrigation area coverage in Bangladesh. The operation of minor irrigation equipment and area under Shallow Tube Wells (STWs) and LLPs were tremendously increased. Hossain (2009) showed that the privatization of minor irrigation sector helped to mobilize the private savings for irrigation investments, removed delaying in equipment installation repair and maintenances, lowered water charges by increasing competition in the water market and capacity utilization of the machines are increased. The small and medium farmers could afford to invest in small irrigation equipment like STWs and LLPs. On the other hand, the use of DTW is decreasing due to high capital cost and maintenance. However, DTW based irrigation is found in Barindtrat area mainly supported by subsidies the aquifer is not reached by the STWs

The water use efficiency in Bangladesh agriculture is very poor. Low physical and economic efficiency of water use still a problem in agriculture in spite of significant expansion of irrigated agriculture since 1960s in Bangladesh. Previous water resource development policies targeted to expand the irrigation areas, to improve institutional arrangements and mode of water use rather than bringing water use efficiency in the irrigation projects. Increasing efficiency (physical and economic) both in farmer’s level and system level of irrigation projects was always ignored in those policies. One of the main aims on National Water Policy is to increase water use efficiency (physical) through various measures including drainage water recycling, rotational irrigation, and adoption of wearer conservation crop technology and conjunctive use of groundwater and surface water. Water use efficiency is extremely low in agriculture sector due to water loss in irrigation channels, over use of water in rice fields and lack of technical knowledge of farmers. On an average, 25-30 percent of irrigation water is used by crops and rest of the water is lost because of faulty design of flood irrigation system (Karim 1997, Mondal 2005 in Mondal 2010). In their analysis they mainly refer the physical efficiency of water use.

Chowdhury (2010) emphasized to increase the efficiency of irrigation water. She showed that Bangladeshi farmers comparatively more efficient using labor, fertilizer, and ploughing with power tiller than that of use of irrigation water. Moreover, efficiency of privately owned STWs and LLPs were higher compare to the farmers using canal irrigation projects and publicly owned DTW projects. She found that there was no increase in the amount of output as a result of increasing irrigation expenditure. This means that inefficiency of water use still exists in irrigation water. She identified that irrigation charging system is a factor responsible for the overuse of irrigation in private sector. Mandal (2003) also showed that the water use under DTW operated area is less efficient compare to the water use in STW operating projects.

The large irrigation projects in Bangladesh have been built on the philosophy of "protective irrigation" technology that protects crops, human animal lives from flood. In the large scale projects, the areas supplied by irrigation were significantly less than planned. Moreover, the farmers were receiving insufficient water to cover the full water requirement of the land in an average rainfall year. Papademetriou et al. (eds. 2000) discovered some limitations of large irrigation project including the different objectives of individual farmer with the scheme management, few control structure of irrigation systems, high maintenance cost and low level of irrigation services. These factors brought inefficiency in large scale projects with unreliable water delivery, water logging, salinity and insufficient cost recovery. From the above discussions it is clear that, the farmers in Bangladesh are not technically efficient in using irrigation water. Large parts of the country already suffering from the shortage of water in their crop fields but some farmers are using excess water.

Water use efficiency in agriculture has been extensively researched for many years but unfortunately the studies on allocative or economic efficiency in water use in very thin in Bangladesh (Chowdhury 2010). It is very difficult to find an applicable solution for improving the efficiency in water use due to different context and huge variations in agricultural practices. Technical efficiency can be achieved through suitable crop selection, proper irrigation scheduling, alternative irrigation methods, and using different sources of water for irrigation. It should be noted that increasing technical efficiency lead to economic water use efficiency as long as the marginal benefits of additional water use are larger than the marginal costs of additional improvements (Cai, Ringler and

Rosegrant 2001). A farm is said to be economically efficient when it is technically and allocative efficient. Improving the technical efficiency in water use, crop water requirement,

2.3 Justification of the study from the management and economic point of view

The aim of the study is to show the impact of irrigation water pricing system on water use by the farmers. The whole analysis has been designed to provide the best irrigation system to the farmers at lowest cost depending on certain characteristics of the soil properties, irrigation method, irrigation water requirement at different crop growth stages etc. Since the selected three districts provide irrigation using ground water the losses of irrigation water need to determine first. That's why seepage and percolation loss, evaporation loss have to determine first.

It has been observed that the seepage and percolation loss mainly depended on the soil texture and crop water requirement is totally different on vegetative, reproductive and ripening stages. From the management and economic point of view proper irrigation scheduling can be done depending on crop water requirement at different crop growth stage which can save a huge amount of irrigation cost. After testing the soil textures the water loss or finally the total irrigation cost can also be assumed which will do an immense help to select the crop to be cultivated. For example, every season a farmer decides which crop he will cultivate at which field or for a fixed crop like rice different variety of rice is available and irrigation requirement is not same for all types of rice. If the field soil texture test says higher seepage and percolation loss then some variety rice can be selected which requires less irrigation. So, this analysis can help to select the crop or variety of crop.

During farmers survey for irrigation water pricing it has been found that selection of irrigation method have major impact. Deep tube well irrigation method provides the lowest irrigation cost to the farmers and electric motor pump provides very close to deep tube well irrigation cost. From the economic point of view farmers can be motivated to take the benefits of deep tube well irrigation where available or can make available with minor investment. In other areas a group can be formed to install the electric motor pump. So it can be summarized that from both management and economic point of view this study has broad contribution to the irrigation and water management division.

CHAPTER-3

MATERIAL AND METHODOLOGY

3.1 Description of the Study Area

3.1.1 Geographical Location

This study has been focused on a pilot area of three different districts having three different types of irrigation system at each area. The three districts were located in the Northwest region of the country. The project area covers different types of land properties of Bangladesh. The **Figure 3-1** shows the study area.

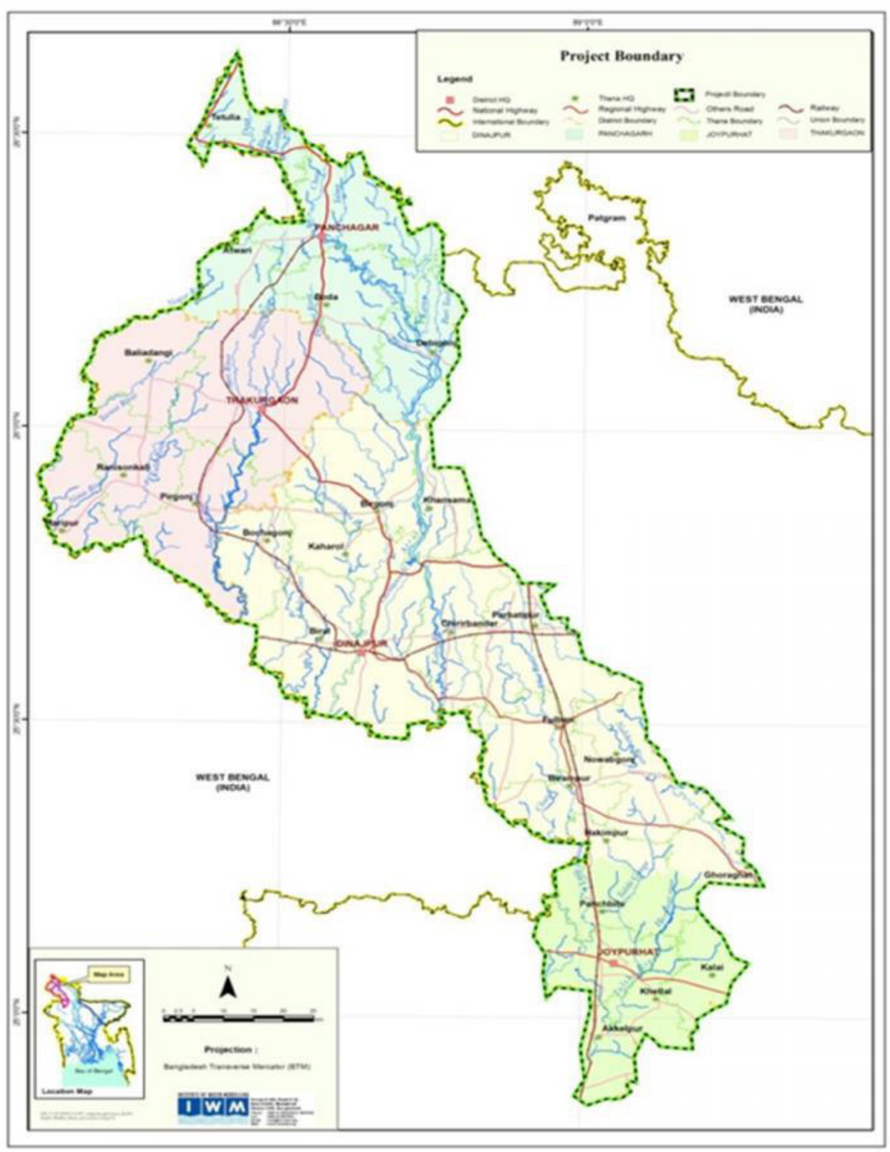

Figure 3-1: Geographical location of the study area

3.1.2 Main Features of the Thesis

The ground water was the main source of irrigation for the study area. The project area were very high with respect to any other projects because these three districts is fully dependent on agriculture. There is no industrial activity during the whole project area. Since there is no big river at the three districts the whole irrigation function was fully dependent on ground water. Water being brought to the surface using mechanical mechanism mainly dependent on Shallow Tube Well (STW), Deep Tube Well (DTW) and Electric Pumps. Only one district have 1-2 solar pump irrigation system as an initial trial irrigation method but due to high initial cost the poor farmers are not much interested with it. After bring at the surface the irrigated water being diverted through canals depending on the field demand.

For Shallow Tube Wells (STWs) the canals used very narrow and length very small to cover small area. But for Deep Tube Wells (DTWs) the canals are much bigger than the STWs and length very long. Recently Barandra started using underground cement pipes to save agriculture land and make the irrigation process faster and cost effective. The DTWs have very big area coverage and for most of the cases the pipe lengths becomes 3-4 kilo meter on an average. Compared to STWs the DTWs provide less cost and irrigation process takes very small time which saves valuable time of the farmers. For some specific areas where DTWs are not feasible to install and maintain electric pumps being used for irrigation. The availability of lower cost irrigation method is also very few because most of the area don’t have any electricity coverage and poor farmers can’t afford the latest irrigation methods like solar pump or electric motor. So depending on the availability farmers are bound to use rent machine or higher cost irrigation methods.

3.1.3 Topography of the Study Area

A well-prepared digital elevation model (DEM) is essential for visualizing the floodplain topography and for accurate modelling. A DEM of 300 m resolution has been developed to define the topography of the study area and used in the model. Topographic data for the study area has been extracted from the topographic database developed by FAP-19 based on irrigation planning maps available at IWM. Utilizing these topographic data, a Digital Elevation Model (DEM) Of 300 m resolution has been developed to define the topography (**Figure 3-2**) of the study area. The DEM has been updated using the surveyed data.

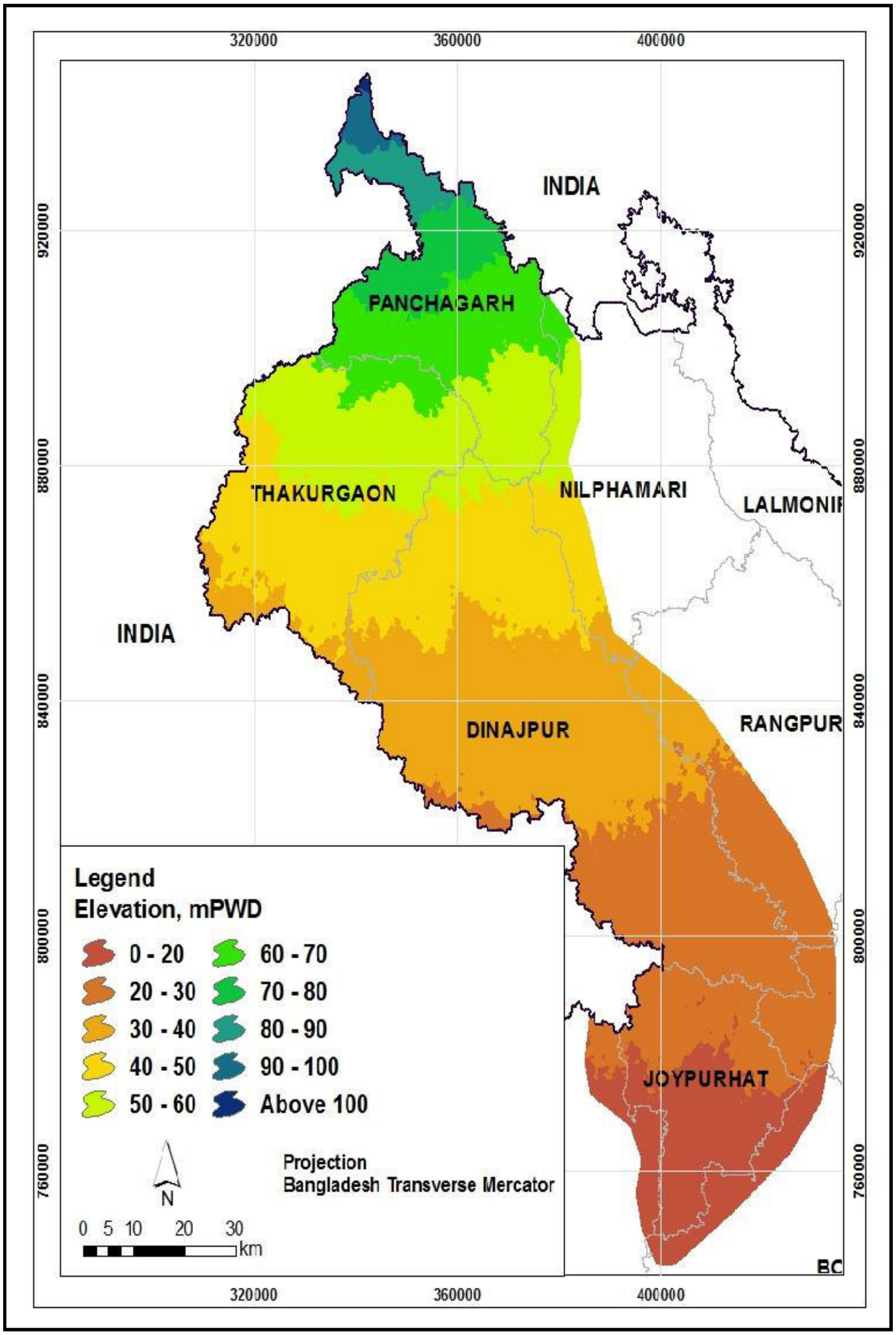

Figure 3-2: Topography of the Study area

3.1.4 Climate of the Study Area

The study area experiences a tropical humid monsoon climate. In summer the mean maximum temperature is 33^0C whereas in winter the mean minimum temperature is 10^0C. The cool weather begins in October and continues up to the end of March. The early summer is dry, with scorching winds, but the rainy season is quite wet with a range of 2000 mm to 3000 mm rainfall. Almost 80% of the rainfall occurs during June to October. The relative humidity in the study area varies from 72% to 87%.

3.1.5 Soil Type and Physical Properties

The soil type and their physical properties of the three different districts were tested at Soil Resource Development Institute (SRDI), Dhaka which included in table 3-1.

Table 0-1: Analytical Results of Soil Texture

Station	Station No.	Lab No.	Textural Class	Sand%	Silt%	Clay%
Dinajpur (Ishania)	1	4110	Silt Loam	37	51	12
	2	4111	Silt Loam	23	59	18
	3	4112	Loam	39	48	13
	4	4113	Silt Loam	34	53	13
	5	4114	Loam	39	45	16
Thakurgaon (Maghkhuria)	1	4115	Silt Loam	29	63	08
	2	4116	Silt Loam	37	55	08
	3	4117	Silt Loam	34	58	08
	4	4118	Silt Loam	39	53	08
	5	4119	Loam	41	46	13
Thakurgaon (Khochabari)	1	4120	Sandy Loam	51	44	05
	2	4121	Sandy Loam	51	44	05
Panchagarh	1	4122	Silt Loam	27	57	16
	2	4123	Silt Loam	32	60	08
	3	4124	Silt Loam	42	51	07

3.1.6 Measurement of Seepage and Percolation

Seepage (S) is the lateral subsurface flow of water from a bounded rice field and percolation (P) is the downward flow of water below the root zone. Both S and P occur simultaneously during land preparation and crop growth period and are governed by the water head (depth of ponded water) on the field and the resistance to water movement in the soil. Because they are difficult to separate in the field, S and P are often taken together as one term seepage & percolation

In a bounded rice field, the seepage & percolation rate is measured from the difference of the ponded water levels of successive days. The ponded water levels are measured by installing either an inclined meter (slope of 1H : 5V) or a perforated 1m long (50 cm below the field level and 50 cm above) 2.5 cm diameter PVC tubes. The measured difference in water level of a day is the sum of the S&P rate and crop evapotranspiration (ET). For rice grown in bounded fields with ponded water, the pan evaporation well represents the ET (Tomar and O'Toole, 1980). Hence, the seepage & percolation rate can be estimated by subtracting the daily pan evaporation from the corresponding daily difference in ponded water levels.

3.2 Method

In order to find out the impact of irrigation water pricing on water use by the farmers a step by step procedure has been followed starting from data collection for seepage and percolation rate from field experiment data, evaporation rate from government institutions, Cropwat software data and pricing information's from farmer's survey data. The study involves the estimation of Crop water requirement which involves the determination of seepage and percolation loss. The whole study was conducted from February 2017 to May 2017.

3.2.1 Step-1: Measuring Seepage and Percolation Loss

Primary data's on field water status for calculating seepage and percolation for irrigated Boro rice, collected from different districts named Dinajpur, Thakurgaon and Panchagarh as shown in **Figure 3.3**.

•

The water used in HYV boro season requires lots of analysis about how much water is being given through various sources like STW, DTW, Electric pump, solar irrigation etc. Sometimes water comes from natural actions like rain, flood etc. Every day how much water is being given through irrigation also need to measure accurately. To calculate the water use in HYV Boro season all kinds of water losses were determined first. The water losses include seepage and percolation loss and evaporation loss.

For seepage and percolation loss measurement purpose half perforated and half blind pipes used as shown in Figure. The reason for using this type of special perforated pipe is that water need to move freely inside the pipe and it can come easily to the reference level to the blind portion. Those are installed in the rice field indicating a reference level of 30cm as shown **Figure 3-5.** While installing in the field it was put in such a way that the soil surrounding the perforate portion becomes loose otherwise the mud inside the pipe can be clogged and water level cannot meet the reference level accurately. For keeping the reference level steady a fixed indicator brick was used so that due to irrigation, rain or other disaster cannot change that level. To record accurate data every 24 hours at same time in every day the reference level was recorded shown in **Figure 3-6.**

Since three different districts were selected for analysis, each filed up to five pipes was used and pipe to pipe distance was at least 50 meters. The pipes were numbered so that daily recorded data don't mismatch and at each district and each field five pipes used. The whole pipes were at same length and same diameter and made at a time. For better analysis at each district the selected field was of same category (not much higher level and not much lower level) so that abnormal seepage and percolation can't occur. Since, farmers use different irrigation method depending on availability of irrigation method pipes were tried to install in such way that field pipes can get different irrigation system and seepage and percolation rates can be measured on different irrigated fields having different irrigation method.

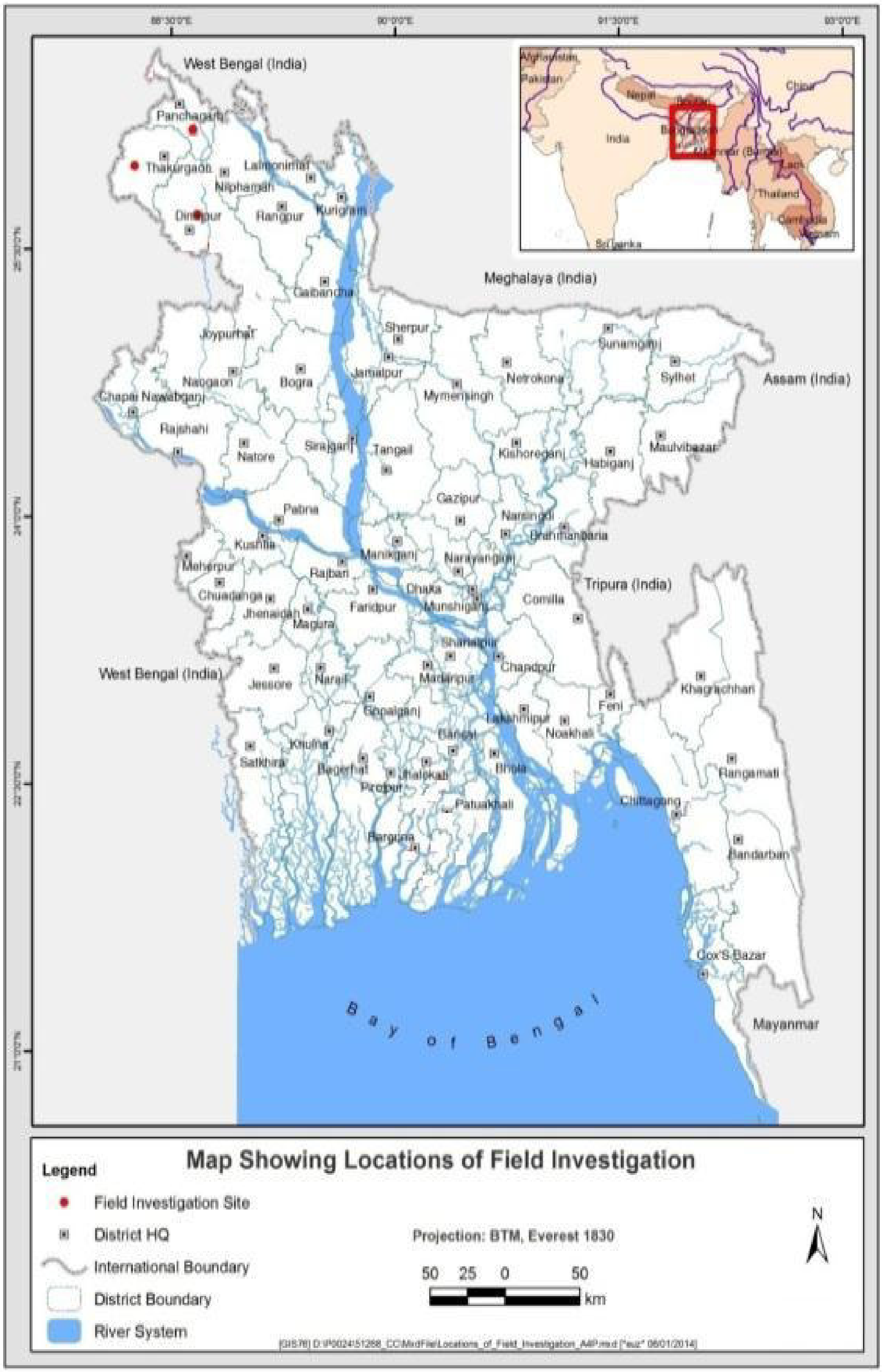

Figure 3-3: Location Map of the Seepage and Percolation Measurement

Figure 3-4: Sample of PVC Pipe to Measure Seepage and Percolation

Figure 3-5: Installation of PVC Pipe for Measuring Seepage and Percolation Loss

The procedure is same for measuring seepage and percolation loss in three different districts. The field water status data were collected by installing perforated 1m long (50 cm below the rice field level and 50 cm above) and 2.5 cm diameter PVC tubes at each of the measuring sites (farmers' fields). The field water status was measured each day at the same time for the full crop season (from the date of transplanting to harvest). It was observed that the crop growth period varied from 100 to 110 days at different locations and depended upon the variety of rice (and only HYV and hybrid varieties were grown). The data table of on-farm water level data collected from the farmer's field is shown in **Figure 3-6.**

Figure 3-6: Field Data Collection by the Observer for Seepage and Percolation

Table 3-2: Field Data for Measurement of Seepage & Percolation at Maghkhuria, Thakurgaon

Day	Date	Depth (cm) Pipe-1	Difference of Pipe-1	Selected Data of Pipe-1	Remarks
1	19-02-2017	24			
2	20-02-2017	20	-4		Irrigation
3	21-02-2017	22.5	2.5		
4	22-02-2017	24	1.5	1.5	
5	23-02-2017	24.5	0.5	0.5	
6	24-02-2017	23	-1.5	1	Irrigation
7	25-02-2017	25.5	2.5		
8	26-02-2017	23	-2.5		Irrigation
9	27-02-2017	23.5	0.5	0.5	
10	28-02-2017	24	0.5	0.5	
11	1/3/2017	25	1	1	
12	2/3/2017	25.3	0.3		Irrigation
13	3/3/2017	22.5	-2.8		
14	4/3/2017	24.3	1.8	1.8	
15	5/3/2017	25	0.7	0.7	Irrigation
16	6/3/2017	23	-2		
17	7/3/2017	23.8	0.8	0.8	
18	8/3/2017	24.3	0.5	0.5	Irrigation
19	9/3/2017	23.5	-0.8		
20	10/3/2017	25.1	1.6	1.6	
21	11/3/2017	26.4	1.3	1.3	
22	12/3/2017	23	-3.4		Irrigation
23	13/3/2017	23.7	0.7	0.7	
24	14/3/2017	24.9	1.2	1.2	
25	15/3/2017	23	-1.9		Irrigation
26	16/3/2017	23.9	0.9	0.9	
27	17/3/2017	24.5	0.6	0.6	
28	18/3/2017	23	-1.5		Irrigation
29	19/3/2017	23.8	0.8	0.8	
30	20/3/2017	24.7	0.9	0.9	
31	21/3/2017	22	-2.7		Irrigation
32	22/3/2017	22.8	0.8	0.8	
34	24/3/2017	26.4	1.4	1.4	
35	25/3/2017	28	1.6	1.6	
36	26/3/2017	31	3		
37	27/3/2017	32	1	1	
38	28/3/2017	24	-8		Irrigation
39	29/3/2017	26	2		
40	30/3/2017	30	4		
41	31/3/2017	27	-3		Irrigation
42	1/4/2017	28	1	1	
43	2/4/2017	29.3	1.3	1.3	

Day	Date	Depth (cm) Pipe-1	Difference of Pipe-1	Selected Data of Pipe-1	Remarks
44	3/4/2017	31	1.7	1.7	
45	4/4/2017	32.1	1.1	1.1	
46	5/4/2017	33.8	1.7	1.7	
47	6/4/2017	24	-9.8		Irrigation
48	7/4/2017	25.9	1.9	1.9	
49	8/4/2017	23.2	-2.7		Irrigation
50	9/4/2017	25	1.8	1.8	
51	10/4/2017	27	2		
52	11/4/2017	24.1	-2.9		Irrigation
53	12/4/2017	25.8	1.7	1.7	
54	13/4/2017	24	-1.8		Irrigation
55	14/4/2017	26.3	2.3		
56	15/4/2017	26	-0.3		Irrigation
57	16/4/2017	27.3	1.3	1.3	
58	17/4/17	29.8	2.5		
59	18/4/2017	31	1.2	1.2	
60	19/4/2017	32.9	1.9	1.9	
61	20/4/2017	34.8	1.9	1.9	
62	21/4/2017	30	-4.8		Irrigation
65	24/4/2017	35	1	1	
66	25/4/2017	24	-11		Irrigation
67	26/4/2017	25.8	1.8	1.8	
68	27/4/2017	27	1.2	1.2	
69	28/4/2017	28.8	1.8	1.8	
70	29/4/2017	30.7	1.9	1.9	
			AVG of P1	**1.23**	

Total 14 different pipes were prepared and put at three different districts. At each area on an average 4-5 pipes were used for data collection. **Table 3-3** shows the locations of Seepage & Percolation Measurement.

Table 3-3: Locations of Seepage & Percolation Measurement

Serial No.	Locations			ID No.
	Village	**Upazila**	**District**	
1	Ishania	Bochagonj	Dinajpur	IBD -1
2	Ishania	Bochagonj	Dinajpur	IBD -2
3	Ishania	Bochagonj	Dinajpur	IBD -3
4	Ishania	Bochagonj	Dinajpur	IBD -4
5	Ishania	Bochagonj	Dinajpur	IBD -5
6	Maghkhuria	Pirganj	Thakurgaon	MPT-1
7	Maghkhuria	Pirganj	Thakurgaon	MPT -2
8	Maghkhuria	Pirganj	Thakurgaon	MPT -3
9	Maghkhuria	Pirganj	Thakurgaon	MPT -4
10	Maghkhuria	Pirganj	Thakurgaon	MPT -5
11	Khochabari	Thakurgaon	Thakurgaon	KTT-1
12	Khochabari	Thakurgaon	Thakurgaon	KTT -2
13	Guagram	Pachpir	Panchagarh	GPP-1
14	Guagram	Pachpir	Panchagarh	GPP -2

3.2.2 Assessment of Seepage and Percolation Loss

The water balance equation in a bunded rice field is of the form:

$$\Delta d + I + R = ET + S\&P + Ro \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (3.1)$$

Where, I is the irrigation, R is the rainfall, ET is crop evapotranspiration, seepage & percolation is the seepage and percolation loss, Ro is the runoff and Δd is the change in the bund storage, all expressed in mm/day. In a bonded rice field, the difference of the standing water levels of successive days (without any rainfall, runoff or irrigation) is the amount of daily crop water use or the bund storage (Δd). With known Δd, when the ET (represented by crop evapotranspiration for each of the rice growth stages) is subtracted from the daily crop water use (Δd), the resultant is the seepage & percolation loss, expressed in mm/day.

While estimating the S&P from the daily field water level data, the days when irrigation was applied or when there was rainfall, were not considered in the analysis. This was done because it was not possible estimate the amount of on-farm irrigation or rainfall. As the study was conducted during the Boro season (with very little rainfall), it was assumed that there was negligible runoff. Moreover, the possible days when runoff may have occurred (days with rainfall and/or irrigation and days immediately after irrigation/rainfall) were not considered in the analysis.

3.2.3 Assessment of Variability of Seepage & Percolation

The variation in Seepage & Percolation loss during a crop season at each of the sites was studied by comparing the present method of averaging the Seepage & Percolation loss over the crop season with the computed Seepage & Percolation losses at each of the three crop growth stages: vegetative, reproductive and ripening (50+ 30+ 30 days after transplanting for each crop growth stage). This was done for both the continuously flooded and intermittently irrigated fields. The temporal variation of S&P loss (stage-wise) was compared with the present averaged S&P loss. The effects of average S&P loss and stage-wise S&P losses on the overall seasonal crop water requirement were ascertained.

In order to assess the effect of depth of standing water on the S&P rate, the average depth of standing water in each of the crop growth stages was compared with the corresponding S&P rate. For the intermittently irrigated fields, the duration of dry days (without standing water) was determined. The effect of dry days on the seasonal S&P loss computation was ascertained.

From the soil textural analysis of each site, the spatial variation S&P loss with soil texture was also analyzed.

3.2.4 Cropwat Model

The Cropwat model is needed to calculate the reference evapotranspiration (ETo), crop water requirement (Etc) and finally scheme water requirement. Irrigation scheduling is prepared according to irrigation requirement on the field. To calculate crop water requirement, all terms and definitions under this section have been taken from FAO Irrigation and Drainage Paper No. 56, Rome, Italy (FAO, 1998).

3.2.5 Reference Crop Evapotranspiration

Reference crop Evapotranspiration (ETo) is defined as the rate of Evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Doorenbos and Pruitt, 1977, ref. FAO, 1998).

A large number of empirical methods have been developed over the past 50 years by numerous scientists and specialists worldwide to estimate Evapotranspiration from different climatic variables. Relationships were often subject to rigorous local calibrations and proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly, and yet Evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design. To meet this need, guidelines were developed and published (Doorenbos and Pruitt, 1977, ref. FAO, 1998). To accommodate users with different data availability, four methods were presented to calculate the reference evapotranspiration: the Blaney-criddle, radiation, modified Penman and Pan Evaporation methods.

The recommended method by FAO is the Penman-Monteith equation which determines the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related.

3.2.6 Step-2: Measuring Evaporation Loss

The evaporation loss data was collected from evaporation station which works under Bangladesh Water Development Board. And every districts evaporation data being recorded at each station. For analysis, the boro season total four months data was collected from the institution.

3.2.7 Step-3: Irrigation Method

3.2.7.1 Farmers' Survey

A farmers' survey was conducted at each of the fields where PVC tubes were installed for S&P loss measurement. The purpose of the survey was to find out the details about the crop management practices by the farmers (rice variety, age of seedlings at transplantation, transplanting and harvesting dates, source of water, crop yield etc.).

3.2.7.2 Different method of Irrigation Adopted by Farmers

In 1980s, there was a surge in private sector involvement in ground water extraction mostly by shallow tube wells. Over time the government shifted emphasis to small scale projects, fielding power pumps to lift surface water from creeks and canals and tube wells for extraction of groundwater. Since then many farmers switched to 2 rice crops and vegetables and other crops which require much less water instead of 3 rice crops during the *boro* season and also moved to shallow tube wells instead of deep tube wells. This was the time when government emphasized groundwater irrigation. Generally, the well length is less than 30 m (100 ft), the engine Horsepower is 4-8, and the discharge rate is less than 28 lit/sec (1 cusec). The pipe diameter is 10-12 cm (4-5 inches). Shallow machine works by suction mood. At present, shallow tube wells are used intensively in all parts of Bangladesh as irrigation purpose and used as prime mover. **Figure 3-7** shows the shallow tube well (STW) at panchagarh district. Shallow machine cost related with machine rent, diesel cost, mobile cost etc.

There are various institutional forms of ownership and management of STW. Many STWs are jointly owned by relatives, neighbors or friends. Usually a pump operator is engaged for the whole irrigation season who may also be the owner or one of the users for a fixed

Figure 3-7: Shallow Tube Well (STW) at Panchagarh

Seasonal fee in cash or kind. In many places water is paid by one fourth of the gross crop harvested and delivered to the tube well owner. A large part of capital costs and operation and maintenance costs come from outside the village like business, service and remittances.

In Bangladesh informal water markets for irrigation have developed quickly with the rapid expansion of tube well irrigation over the last decade. In case of shallow and deep tube wells, the owners of the irrigation equipment enter into deals for irrigation services with neighboring farmers in addition to using the equipment for irrigating their own land. With the expansion of water markets in the private sector, the pricing system has also undergone changes to suit varying circumstances. There is no single rate or uniform method for payment of irrigation water. Per hectare water rates vary not only from one area to another but also depend on the type of well within a particular area (Biswas and Mandal, 1993).

In the initial stage, the most common practice was sharing one-fourth of the harvest with the owner of the equipment in exchange for water. That gave way to a flat seasonal fee, the rate depending on the availability of electricity and the price of diesel. In recent years, the market has moved toward fees per hour of tube well operation. In Bangladesh, the major source of irrigation is the shallow tube wells and power pumps mostly run by diesel as many places in rural Bangladesh still do not have electricity connection. Diesel pumps usually have higher costs and lower water extraction capacity than electricity operated pumps (Wadud and White, 2002). Diesel being a major agricultural input in the cultivation of *boro*rice, the cost of *boro* cultivation is very sensitive to the price of diesel.

Deep Tube-Well (DTW)

The largest water lifting device for pumping groundwater for irrigation and domestic purposes is the deep tube well. Generally, the well length is 60-90 m (200-300 ft), the engine Horsepower is 20-30 and the discharge is 56-84 lit/sec (2-3 cusec). The diameter of the pipe varies from 15-25 cm (6-10 inches).

Figure 3-8 shows the supply network for irrigation by Deep Tube well. Turbine pumps are used for lifting water. They can be operated if the groundwater level is beyond the suction limit. Usually it works at force mood.

Figure 3-8: Water Supply Network for Irrigation by Deep Tube Well (DTW)

For DTW the cost is paid through rechargeable card system. Depending on the soil type and weather the farmers insert pre-paid card at the deep tube well machine and collect necessary irrigated water at the field. For DTW the water passes through underground pipe line and goes at the field from outlet points through drainage.

Electric Motor Pumps

The electric motor pumps are recently being used in some areas where electricity available only. Normally a group of farmers shares all kinds of initial investments of electric motor and pump. Costs are measured through electric meter and depending on power used the farmer's and each month depending on use and the farmers shares their amount. **Figure 3-9** shows Electric Pump at Panchagarh District.

Figure 3-9: Electric Pump at Panchagarh District

Solar Pumps

Solar pumps are being used at some areas only at Dinajpur district having a very small area coverage. Basically, uses of solar pump is newly introduced at Bangladesh and only few farmers are interested on solar pumps due to very high initial investment. In this irrigation system electricity is produced by solar plant. **Figure 3-10** shows solar pump plant at Dinajpur District.

Figure 3-10: Solar Pump plant at Dinajpur District

3.2.8 Step-4: Irrigation Pricing System

Depending on irrigation method at each field a complete survey was conducted and pricing data was recorded. At different district different pricing system was used such as for shallow tube well irrigation some farmers used own machine which shows lower water pricing but some farmer had to rent machines for irrigation. Due to price variation of fuel irrigation water pricing varied. For deep well irrigation the price is nearly close to each other for different districts but for electric motor and solar pump the initial investment is high which increase the water pricing.

After observing the details farmers survey the pricing data has been recorded and finally for different type of irrigation method the pricing per bigha has been recorded and depending on various parameters the lowest cost irrigation method has been suggested to the farmers.

3.3 Data Collection and Processing

3.3.1 Data for field water status

The field water status data collected from the subjected fields every day at a fixed time. Every day the depth of the water level measured based on the standard set for measuring the crop water requirement accurately. **Table 3-4**, **Table 3-55** and **Table 3-6** shows the field water level status data for Dinajpur, Thakurgaon and Panchararh districts.

3.3.2 Data Requirement for CropWat Model

3.3.2.1 Location

Altitude above sea level (m) and latitude of the location in degrees should be specified. These data are needed to adjust some weather parameters for the local average value of atmospheric pressure (a function of the site elevation above mean sea level) and to compute extraterrestrial radiation (Ra) and, in some cases, daylight hours (N). A positive latitude value is used for the northern hemisphere and a negative value for the southern hemisphere.

3.3.2.2 Temperature

The (average) daily maximum and minimum air temperatures in degrees Celsius (°C) are required. Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of ETo will probably occur due to the non-linearity of the saturation vapor pressure - temperature relationship. Using mean air temperature instead of maximum and minimum air temperatures yields a lower saturation

Vapor pressure es, and hence a lower vapor pressure difference (es - ea), and a lower reference Evapotranspiration estimate.

3.3.2.3 Humidity

The (average) daily actual vapor pressure, ea, in kilopascals (kPa) is required. The actual vapor pressure, where not available, can be derived from maximum and minimum relative humidity (%), psychrometric data (dry and wet bulb temperatures in °C) or dew point temperature (°C).

3.3.2.4 Relative humidity

The relative humidity (RH) expresses the degree of saturation of the air as a ratio of the actual (ea) to the saturation (es(T)) vapor pressure at the same temperature. In another word, relative humidity is the ratio between the amount of water the ambient air actually holds and the amount it could hold at the same temperature. It is dimensionless and is commonly given as a percentage. Although the actual vapor pressure might be relatively constant throughout the day, the relative humidity fluctuates between a maximum near sunrise and a minimum around early afternoon.

3.3.2.5 Relative sunshine duration (n/N)

The relative sunshine duration is another ratio that expresses the cloudiness of the atmosphere. It is the ratio of the actual duration of sunshine, n, to the maximum possible duration of sunshine or daylight hours N. In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours (n = N) and the ratio is one, while on cloudy days n and consequently the ratio may be zero. Monthly average (daily sunshine hours) have been used for required ETo calculation for this study.

3.3.2.6 Wind speed

The (average) daily wind speed in meters per second (m/s) or km/day measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ.

3.3.2.7 Land Use and Cropping Pattern

Cropping pattern, percentage of area under different types of crops with irrigated area was collected from Directorate of Agriculture Extension (DAE) based on the data of 1999-2000 and 2000-2001 (BWDB and IWM, 2004). The study site has been visited thoroughly during data collection to check the current situation in the field comparing to the previous cropping pattern. It has been observed that more than 90% of the area was covered with HYV-Boro. This percentage of HYV-Boro is differed from the previous collected data during 1999-2000. The following picture shows the present crop covering in the study area. It has been observed that almost the whole study area was covered with rice.

3.3.2.8 Data Requirement for Measured water level:

Different water level among three districts including irrigation and rainfall data given in **Table 3-4*Table 3-*.**

Table 3-4: Observed Water Level on Paddy Field at Ishania, Dinajpur

Days	Measured Water Level	Irrigation	Rainfall	Remarks
1	27.4			
2	23.2	20		Irrigation
3	24.1			
4	24.7			
5	25.9			
6	24.1	24.1		Irrigation
7	25.9			
8	23.7	23.7		Irrigation
9	24.5			
10	24.8			
11	24.88			
12	24.82	24.82		Irrigation
13	24			
14	25.42			
15	25.62	25.62		Irrigation
16	24.3			

Days	Measured Water Level	Irrigation	Rainfall	Remarks
17	24.8			
18	25.4	25.4		Irrigation
19	24.72			
20	26.36			
21	27.12			
22	24.32	24.32		Irrigation
23	24.88			
24	25.66			
25	23.54		23	Irrigation
26	24.24			
27	25.04			
28	23.4	23.4		Irrigation
29	23.66			
30	24.92			
31	22.74	22.74		Irrigation
32	23.48			
33	25.54			
34	28.48			
35	30.56			
36	32.66			
37	33.66			
38	25.78	25.78		Irrigation
39	26.8			
40	30.86			
41	25.26		27	Irrigation
42	27.1			
43	28.36			
44	29.98			
45	31.28			
46	32.94			
47	26.08	26.08		Irrigation
48	27.18			

Days	Measured Water Level	Irrigation	Rainfall	Remarks
49	25.1	25.1		Irrigation
50	26.84			
51	29.32			
52	24.54	24.54		Irrigation
53	25.78			
54	24.24		24	Irrigation
55	26.46			
56	25.58	25.58		Irrigation
57	27.68			
58	29.94			
59	31.72			
60	33.64			
61	35.12			
62	29.84	29.84		Irrigation
63	32.14			
64	34.04			
65	34.92			
66	24.2	24.2		Irrigation
67	25.7			
68	27.5			
69	29.42			
70	25.24			

Table 3-5: Observed Water Level on Paddy Field at Maghkhuria, Thakurgaon

Days	Measured Water Level	Irrigation	Rainfall	Remarks
1	26.58			
2	25.9			
3	25.7			
4	27.4			
5	24.16		20.2	

Days	Measured Water Level	Irrigation	Rainfall	Remarks
6	24.2		20.5	
7	22.5	22.5		
8	27.18			
9	28.22			
10	29.14			
11	30.34			
12	22	22		
13	26.8			
14	28.06			
15	28.344			
16	29.44			
17	23.5	23.5		
18	29.3			
19	28.1			
20	28.78			
21	27.78			
22	29.02			
23	29.9			
24	30.4			
25	24	24		
26	26.8			
27	27.68			
28	28.86			
29	30.54			
30	33.28			
31	35.925			
32	39.02			
33	39.14			
34	42.14			
35	39.84			
36	23.9	23.9		

Days	Measured Water Level	Irrigation	Rainfall	Remarks
37	26.66			
38	27.84			
39	29.52			
40	29.3			
41	23		23	
42	24	24		
43	32.94			
44	28.5		28.5	
45	29.2			
46	30.94			
47	32.1		32.1	
48	26		26	
49	27		27	
50	29.44			
51	24.5	24.5		
52	27.8			
53	29.7			
54	31			
55	35.2		35.2	
56	26		26	
57	28.3		28.3	
58	26		26	
59	31.92			
60	35.84			
61	35		35	

Table 3-6: Observed Water Level on Paddy Field at Guagram, Panchagarh

Days	Measured Water Level	Irrigation	Rainfall	Remarks
1	33.43			
2	25	25		
3	32.78			
4	33.78			
5	33.52			
6	24.5	24.5		
7	32.82			
8	33.65			
9	35.80			
10	33.90			
11	32.84			
12	33.38			
13	25	25		
14	33.78			
15	24.2	24.2	24.2	
16	31.17			
17	32.13			
18	27.7	27.7	27.7	

3.3.3 Calculation of evaporation

The raw data has been collected from Bangladesh Water Development board for the months of February 2017 to May 2017 and using standard formula "**Evaporation = Rainfall + (No of cups added – No of cups removed) * 0.508"** those are converted into useable date which has shown in the below tables. **Figure 3-11**- **Figure 3-14** shows graph for February to May.

Table 3-7: Observed Evaporation for the Month of February

Month: February'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
01-02-2017	0	6	0	3.048	
02-02-2017	0.00	6	0	3.048	
03-02-2017	0.00	7	0	3.556	
04-02-2017	0.00	7	0	3.556	
05-02-2017	0.00	7	0	3.556	
06-02-2017	0.00	8.5	0	4.318	
07-02-2017	0.00	7	0	3.556	
08-02-2017	0.00	7.5	0	3.810	
09-02-2017	0.00	6.8	0	3.454	
10-02-2017	0.00	9	0	4.572	3.647
11-02-2017	0.00	8.5	0	4.318	
12-02-2017	0.00	7.5	0	3.810	
13-02-2017	0.00	8	0	4.064	
14-02-2017	0.00	7	0	3.556	
15-02-2017	0.00	8	0	4.064	
16-02-2017	0.00	9	0	4.572	
17-02-2017	0.00	8.5	0	4.318	
18-02-2017	0.00	7	0	3.556	
19-02-2017	0.00	7.5	0	3.810	
20-02-2017	0.00	6.8	0	3.454	3.952
21-02-2017	0.00	9	0	4.572	
22-02-2017	0.00	8.5	0	4.318	
23-02-2017	0.00	7.5	0	3.810	
24-02-2017	0.00	7	0	3.556	
25-02-2017	0.00	8.5	0	4.318	
26-02-2017	0.00	8	0	4.064	
27-02-2017	0.00	7.5	0	3.810	
28-02-2017	0.00	7.9	0	4.013	3.973
	0.00			**3.874**	

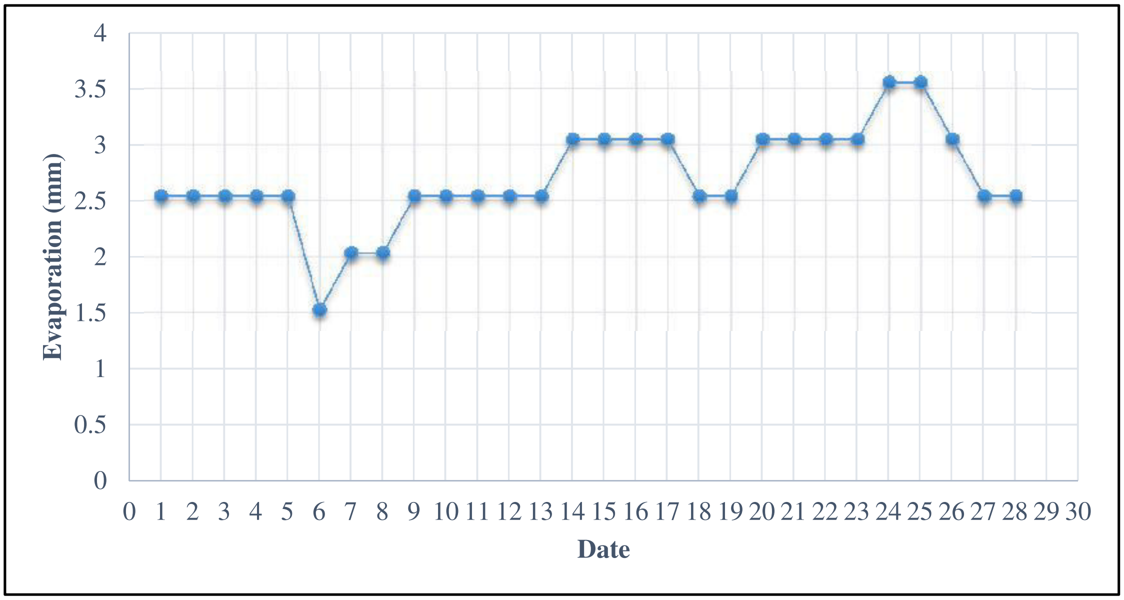

Figure 3-11: Evaporation rate for February' 2017

Table 3-8: Observed Evaporation Rate for the Month of March

Month: March'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
01-03-2017	0	9	0	4.572	
02-03-2017	0.00	9.5	0	4.826	
03-03-2017	0.00	10	0	5.080	
04-03-2017	0.00	9.5	0	4.826	
05-03-2017	0.00	11	0	5.588	
06-03-2017	0.00	10	0	5.080	
07-03-2017	0.00	9	0	4.572	
08-03-2017	0.00	12	0	6.096	
09-03-2017	0.00	10	0	5.080	
10-03-2017	0.00	11	0	5.588	**5.131**
11-03-2017	14.30	0	17	5.664	
12-03-2017	15.20	0	20	5.040	
13-03-2017	0.00	11	0	5.588	
14-03-2017	0.00	12	0	6.096	
15-03-2017	0.00	11.5	0	5.842	
16-03-2017	0.00	12	0	6.096	**5.795**

Month: March'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
17-03-2017	0.00	12	0	6.096	
18-03-2017	0.00	11	0	5.588	
19-03-2017	0.00	12.5	0	6.350	
20-03-2017	0.00	11	0	5.588	
21-03-2017	6.50	0	2	5.484	
22-03-2017	0.00	12	0	6.096	
23-03-2017	0.00	13	0	6.604	
24-03-2017	0.00	12	0	6.096	
25-03-2017	26.40	0	40	6.080	
26-03-2017	0.00	11	0	5.588	
27-03-2017	0.00	13	0	6.604	
28-03-2017	2.50	12	0	8.596	
29-03-2017	0.00	11	0	5.588	
30-03-2017	0.00	11.5	0	5.842	
31-03-2017	0.00	12	0	6.096	**6.243**
	64.9			**5.740**	

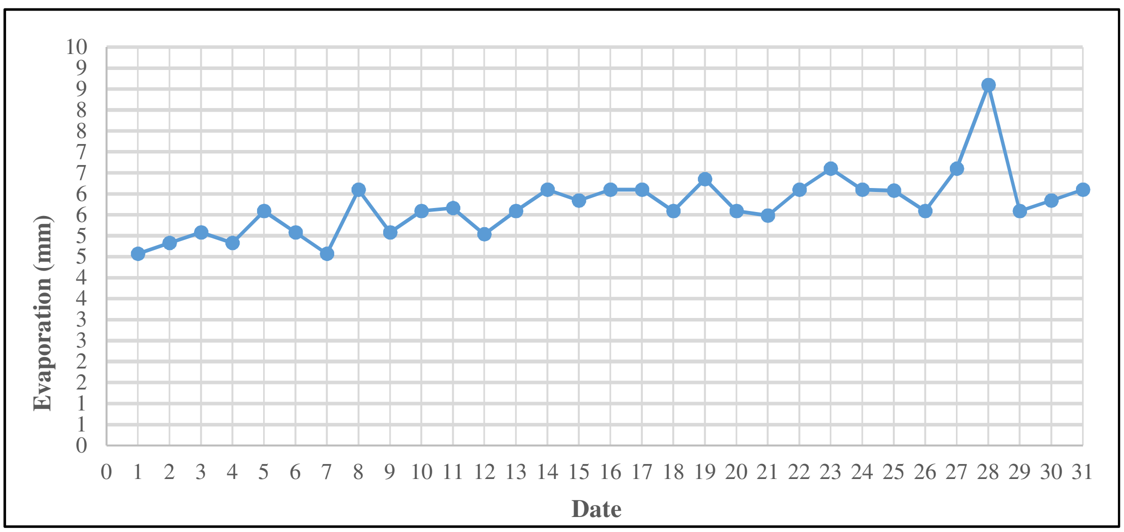

Figure 3-12: Evaporation rate for March'2017

Table 3-9: Observed Evaporation Rate for the Month of April 2017

Month: April'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
01-04-2017	0	12	0	6.096	
02-04-2017	0.00	13	0	6.604	
03-04-2017	0.00	12.5	0	6.350	
04-04-2017	0.00	11	0	5.588	
05-04-2017	0.00	13	0	6.604	
06-04-2017	0.00	12.5	0	6.350	
07-04-2017	0.00	13.5	0	6.858	
08-04-2017	0.00	12	0	6.096	
09-04-2017	0.00	12.5	0	6.350	
10-04-2017	0.00	12	0	6.096	**6.299**
11-04-2017	0.00	13	0	6.604	
12-04-2017	0.00	13.5		6.858	
13-04-2017	0.00	13	0	6.604	
14-04-2017	0.00	12.9	0	6.553	
15-04-2017	0.00	13.6	0	6.909	
16-04-2017	16.80	0	21	6.132	
17-04-2017	0.00	13.9	0	7.061	
18-04-2017	0.00	13.5		6.858	
19-04-2017	5.30	0	0	5.300	
20-04-2017	0.00	14		7.112	**6.599**
21-04-2017	6.50	0	1	5.992	
22-04-2017	23.40	0	33	6.636	
23-04-2017	3.40	6	0	6.448	
24-04-2017	5.60	2	0	6.616	
25-04-2017	0.00	13.8	0	7.010	
26-04-2017	0.00	12.9	0	6.553	
27-04-2017	0.00	13	0	6.604	
28-04-2017	0.00	13.8	0	7.010	
29-04-2017	0.00	13.7	0	6.960	
30-04-2017	0.00	14	0	7.112	**6.694**
	61			**6.531**	

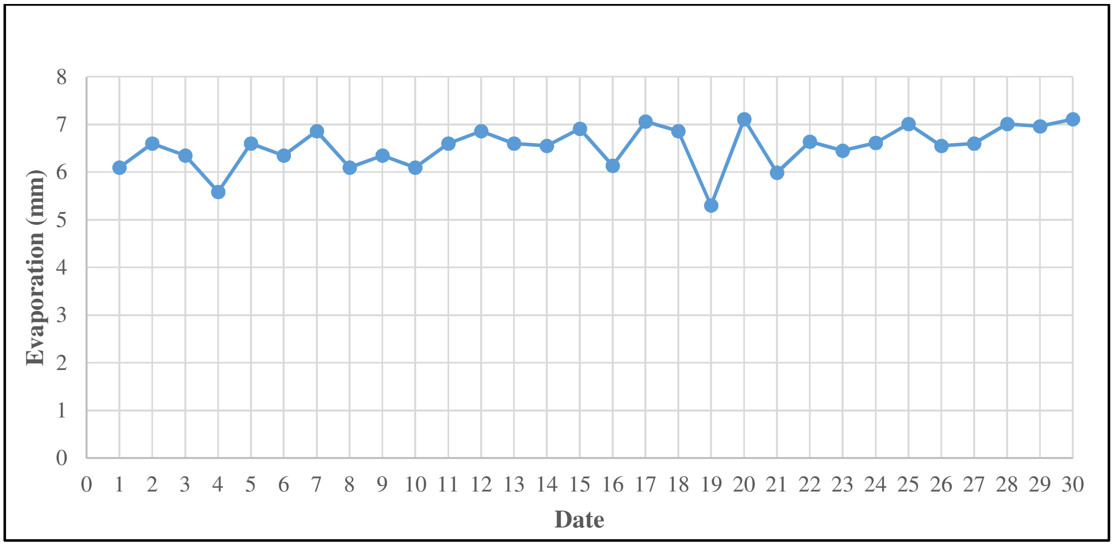

Figure 3-13: Evaporation rate for April' 2017

Table 3-10: Observed Evaporation Rate for the Month of May

Month: May'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
01-05-2017	0	12		6.096	
02-05-2017	28.70	0	44	6.348	
03-05-2017	10.20	0	8	6.136	
04-05-2017	2.30	8	0	6.364	
05-05-2017	5.50	0	0	5.500	
06-05-2017	0.00	13.9	0	7.061	
07-05-2017	0.00	13.5		6.858	
08-05-2017	28.50	0	43	6.656	
09-05-2017	0.00	13.8	0	7.010	
10-05-2017	2.00	10	0	7.080	**6.511**
11-05-2017	0.00	12	0	6.096	
12-05-2017	0.00	13	0	6.604	
13-05-2017	0.00	13.5		6.858	
14-05-2017	55.20	0	96	6.432	
15-05-2017	45.30	0	76	6.692	
16-05-2017	62.20	0	109	6.828	
17-05-2017	0.00	13.5	0	6.858	
18-05-2017	0.00	13.5	0	6.858	
19-05-2017	0.00	13.5	0	6.858	
20-05-2017	2.30	13	1	8.396	**6.848**

Month: May'2017					
Date	**Rainfall**	**Cups of water added**	**Cups of water removed**	**Evaporation**	**Decade-wise average (mm/day)**
21-05-2017	20.30		28	6.076	
22-05-2017	195.30		371	6.832	
23-05-2017	0.00	12	0	6.096	
24-05-2017	7.50	0	2	6.484	
25-05-2017	0.00	12.9	0	6.553	
26-05-2017	0.00	12.9	0	6.553	
27-05-2017	0.00	13	0	6.604	
28-05-2017	0.00	13	0	6.604	
29-05-2017	5.20	13	0	11.804	
30-05-2017	0.00	13	0	6.604	
31-05-2017	0.00	13	0	6.604	**6.983**
	470.5			**6.787**	

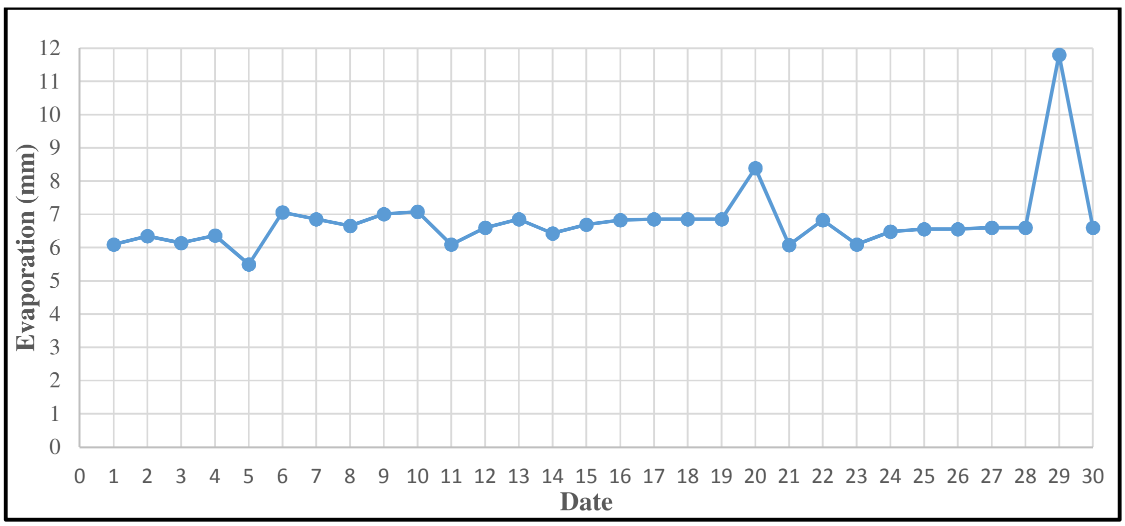

Figure 3-14: Evaporation rate for May' 2017

3.3.4 Seepage and Percolation Rate

The average seepage and percolation rate for the three districts has been calculated by subtracting the evaporation data from the daily collected difference of water level status data. **Table 3-11** shows the seepage and percolation rate of the three districts.

Table 3-11: Seepage and Percolation rate

Year	Location	Irrigation Method	Type of Tube well	No. of Irrigation per Season	Charge/Season/Bigha (Tk.)	Yield/Bigha /mon	Type of Rice	Method/ System Preferred by Farmer	Method/ System Preferred by STW/DTW Owner
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	DTW	DTW	15	1080	35-40 mon	Boro BR-29	DTW	DTW
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	Motor	Motor	15	1550	35-40 mon	Boro BR-29	DTW	DTW
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	STW	STW	15	1900	35-38 mon	Boro BR-29	DTW	DTW
2016	Vill: Singia, Union: Jagannathpur, Dist: Thakurgaon	DTW	DTW	23	1070	40 mon	Boro BR-29	DTW	DTW
2016	Vill: Singia, Union: Jagannathpur, Dist: Thakurgaon	STW	STW	23	1900	40 mon	Boro BR-29	DTW	DTW
2016	Vill: Maghkhuria, Union: Syedpur, Thana: PirganjDist: Thakurgaon	STW	STW	30	2100	30 mon	Boro BR-29	DTW	DTW
2016	Vill: Maghkhuria, Union: Syedpur, Thana: PirganjDist: Thakurgaon	DTW	DTW	22	1060	30 mon	Boro BR-29	DTW	DTW

Location	Seasonal Avg. Crop water Requirement (mm/day)	Avg. Evaporation Loss (mm)	Avg. Seepage and Percolation Loss (mm)
Dinajpur	11.10	5.733	5.37
Thakurgaon	11.37	5.733	5.63
Panchagarh	12.17	5.733	6.43
	11.54	**5.73**	**5.81**

3.3.5 Survey data for water pricing

During field visit a survey was conducted for finding suitable irrigation method. Based on farmers verbal feedback the survey data have been enlisted in below **Table 3-12.** During survey it was found that most of the area the type of irrigation method used was STW and DTW. Only very few places solar irrigation method was found at Dinajpur district.

Table 3-12: Irrigation Water Pricing of Thakurgaon District

Year	Location	Irrigation Method	Type of Tube well	No. of Irrigation per Season	Charge/Season/Bigha (Tk.)	Yield/Bigha /mon	Type of Rice	Method/ System Preferred by Farmer	Method/ System Preferred by STW/DTW Owner
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	DTW	DTW	15	1080	35-40 mon	Boro BR-29	DTW	DTW
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	Motor	Motor	15	1550	35-40 mon	Boro BR-29	DTW	DTW
2016	Vill: Bandigor, Post: 19 No. Begunbari, SadarThakurgaon	STW	STW	15	1900	35-38 mon	Boro BR-29	DTW	DTW
2016	Vill: Singia, Union: Jagannathpur, Dist: Thakurgaon	DTW	DTW	23	1070	40 mon	Boro BR-29	DTW	DTW
2016	Vill: Singia, Union: Jagannathpur, Dist: Thakurgaon	STW	STW	23	1900	40 mon	Boro BR-29	DTW	DTW
2016	Vill: Maghkhuria, Union: Syedpur, Thana: PirganjDist: Thakurgaon	STW	STW	30	2100	30 mon	Boro BR-29	DTW	DTW
2016	Vill: Maghkhuria, Union: Syedpur, Thana: PirganjDist: Thakurgaon	DTW	DTW	22	1060	30 mon	Boro BR-29	DTW	DTW

Table 3-13: Irrigation Water Pricing of Panchagarh District

Year	Location	Irrigation Method/System	Type of Tube well Used	No. of Irrigation per Season	Charge/Season/ Bigha (Tk.)	Yield/Bigha/ mon	Type of Rice	Method/ System Preferred by Farmer	Method/ System Preferred by STW/DTW Owner
2016	GuagramProdhan Para, Post: Boirati, Boda, Panchagara	STW	STW	15	2250	27 mon	Boro BR-29	STW	DTW
2016	GuagramProdhan Para, Post: Boirati, Boda, Panchagara	DTW	DTW	15	1050	27-28 mon	Boro BR-29	DTW	DTW
2016	GuagramProdhan Para, Post: Boirati, Boda, Panchagara	Electric Motor	Pump	15	2000	27-28 mon	Boro BR-29	Electric Motor	Electric Motor

Table 3-14: Irrigation Water Pricing of Dinajpur District

Year	Location	Irrigation Method/ System	Type of Tube well Used	No. of Irrigation per Season	Charge/ Season/ Bigha (Tk.)	Yield/Bigha / mon)	Type of Rice	Method/ System Prefered by Farmer	Method/ System Prefered by STW/DTW Owner
2016	2 no Palashbari, Vandarai, Birgonj, Dinajpur	Solar	solar	22	2500	26-28 mon	Boro BR-28	Solar	Solar
2016	2 no Palashbari, Vandarai, Birgonj, Dinajpur	DTW (Borendra)	DTW	22	1040	35-38 mon	Boro BR-29	DTW	DTW
2016	2 no Palashbari, Vandarai, Birgonj, Dinajpur	STW/Saso naly	STW	22	1950	35-38 mon	Boro BR-29	DTW	DTW
2016	2 no Palashbari, Vandarai, Birgonj, Dinajpur	Motor	Pump	22	1500	35-38 mon	Boro BR-29	DTW	DTW
2016	Vill: Isania, Post: Isania, Thana: Bochaganj, Dist: Dinajpur	STW	STW	18	1850	37-38 mon	Boro BR-29	DTW	DTW
2016	Vill: Isania, Post: Isania, Thana: Bochaganj, Dist: Dinajpur	DTW	DTW	18	1080	37-38 mon	Boro BR-29	DTW	DTW

3.3.6 Crop water requirement for CropWat software

The daily crop water requirement has been calculated by field data and using CropWat software.

Table 3-2 shows the value of Kc in different month and irrigation requirement. **Table 3-3** shows the comparison of daily crop water requirement for observed and simulated data.

Table 3-2: Simulated ETc and Irrigation Requirement by CropWat Model (8.0)

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Nurs	1.20	0.21	1.9	11.3	0.0
Jan	2	Nurs/LPr	1.08	2.03	20.3	18.8	72.4
Jan	3	Nurs/LPr	1.06	2.65	29.1	12.5	151.7
Feb	1	Init	1.10	3.20	32.0	0.0	32.0
Feb	2	Init	1.10	3.59	35.9	0.0	35.9
Feb	3	Deve	1.11	4.15	33.2	0.1	33.1
Mar	1	Deve	1.14	4.78	47.8	13.3	34.6
Mar	2	Deve	1.17	5.46	54.6	19.9	34.7
Mar	3	Mid	1.19	5.90	64.9	10.7	46.2
Apr	1	Mid	1.19	6.25	62.5	6.1	56.4
Apr	2	Mid	1.19	6.60	66.0	0.6	65.4
Apr	3	Mid	1.19	6.69	66.9	42.2	24.8
May	1	Late	1.16	6.58	65.8	104.2	0.0
May	2	Late	1.08	6.22	62.2	148.1	0.0
May	3	Late	1.04	5.96	6.0	11.2	6.0
					649.1	407.1	593.0

Table 3-3: Comparison of Decade-wise Crop Water Requirement by Observed Data and CropWat Model

Month	Crop water Requirement by Observed Data			Crop water Requirement by CropWat Model			
	S&P+E (mm)	Evaporation (mm)	CWR	ET	S&P+E	S&P	CWR
February	11.3	6.131	51.69	28.5	11.3	5.169	33.669
	11.3	6.848	44.52	31.4	11.3	4.452	35.852
	11.3	6.983	34.536	29.1	11.3	4.317	33.417
March	11.3	5.131	61.69	41.7	11.3	6.169	47.869
	11.3	5.795	55.05	47.3	11.3	5.505	52.805
	11.3	6.243	55.627	54.8	11.3	5.057	59.857
April	11.3	6.299	50.01	51.8	11.3	5.001	56.801
	11.3	6.599	47.01	53.8	11.3	4.701	58.501
	11.3	6.694	46.06	53.8	11.3	4.606	58.406
May	11.3	6.511	47.89	51.9	11.3	4.789	56.689
	11.3	6.848	44.52	47.8	11.3	4.452	52.252
	11.3	6.983	47.487	4.4	11.3	4.317	8.717
Total			586.09	Total			554.835

CHAPTER-4

RESULTS AND DISCUSSIONS

After analyzing the data sets collected from the fields and farmers survey it was observed that the farmers practiced different types of irrigation method in different area depending on various criteria. The selected districts majority of the field's irrigation system is done by ground water and most of the farmers uses either shallow tube well irrigation method or deep tube well irrigation method. Only few area or farmer uses electric motor or solar pump irrigation.

The subjected three districts have different types of soil properties given in **Figure 4-1** and result found variation in average seepage and percolation rate. The soil texture was tested at Soil Resource and Development Institute (SRDI) for analyzing the soil texture. Figure 4.1

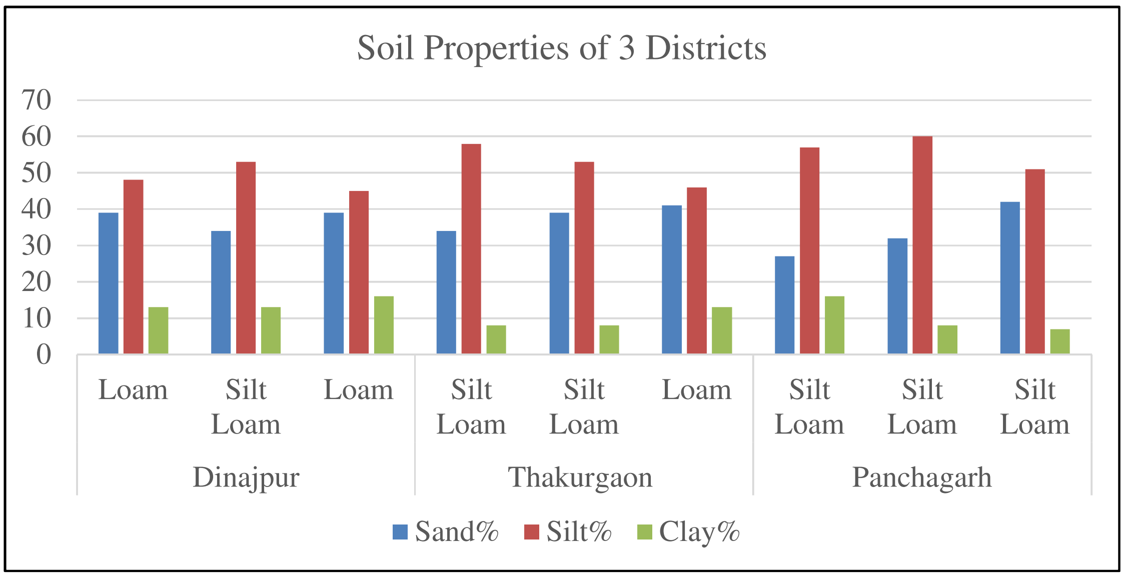

Figure 4-1: Major Soil Texture of Three Districts

Shows the soil properties of three districts for the selected fields of analysis. The soil texture found in the subjected fields is silt loam and loam type having higher silt percent and sand percent. The clay percent in the subjected fields are very less resulting higher seepage and percolation rate.

Due to different soil texture of the three districts after having same type of irrigation method shows different seepage and percolation rate. In Dinajpur District found less seepage and percolation rate, Thakurgaon District shows medium seepage and percolation rate and Panchagarh district shows the highest seepage and percolation rate. This is because most of the soil texture of Dinajpur District is loam or silt loam type having higher clay percent than other two districts. **Figure 4-2** shows the average seepage and percolation rate.

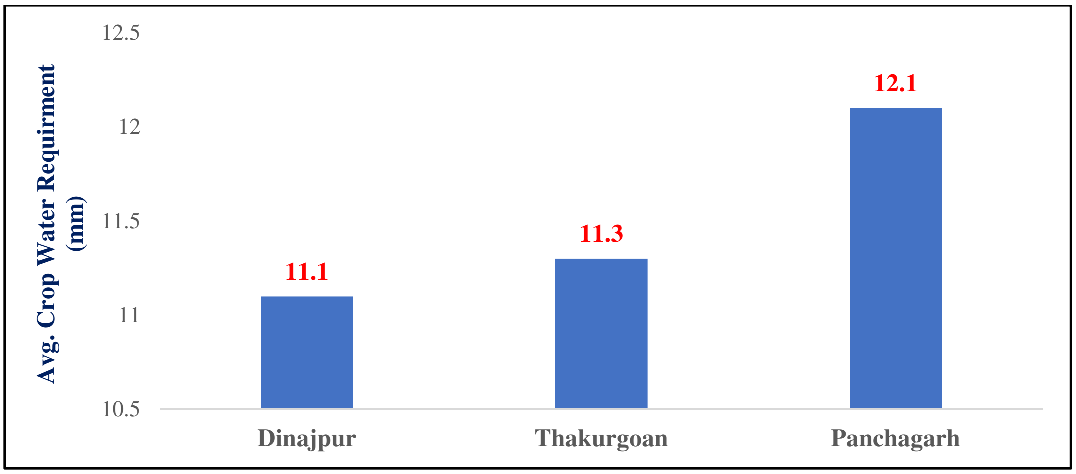

Figure 4-2: Average Crop Water Requirements at Different Districts

The crop water requirement for rice boro season has been divided into three different crop growth stages comprising of vegetative 50 days, reproductive 30 days and ripening 30 days. The crop stage shows totally different crop water requirement in these stages.

The average crop water requirement rates for the mentioned three different growth stages has shown in **Table 4-1**.

Table 4-1: Average crop water requirement at different crop growth stages

Location	Crop Growth Stage			Seasonal Average (mm/day)
	Vegetative (mm/day)	Reproductive (mm/day)	Ripening (mm/day)	
Dinajpur	12.7	10.9	9.7	11.10
Thakurgaon	13.1	11.1	9.9	11.37
Panchagarh	14.2	12.1	10.2	12.17

The table explains that crop water requirement rate is different in three crop growth stages. The rate is very high at vegetative stage and very low in the ripeining stage. The reason behind high crop water requirement rate is that the water volume at initial stage remains high and soil pore space is also remains high that's why deep percolation occurs and water quickly moves to ground water. At reproductive stage the plant hight and crop root zone develops and the seepage and percolation comparatively becomes slower. Finally at the ripening stage the plant growth becomes maximum and sedimentations occurs due to continuous irrigation and becomes one layer above the soil surface and that's why seepage and percolation rate becomes very lower.

Figure 4-3 shows the graphical representation of average crop water requirement rate which gradually decreases for different crop growth stages.

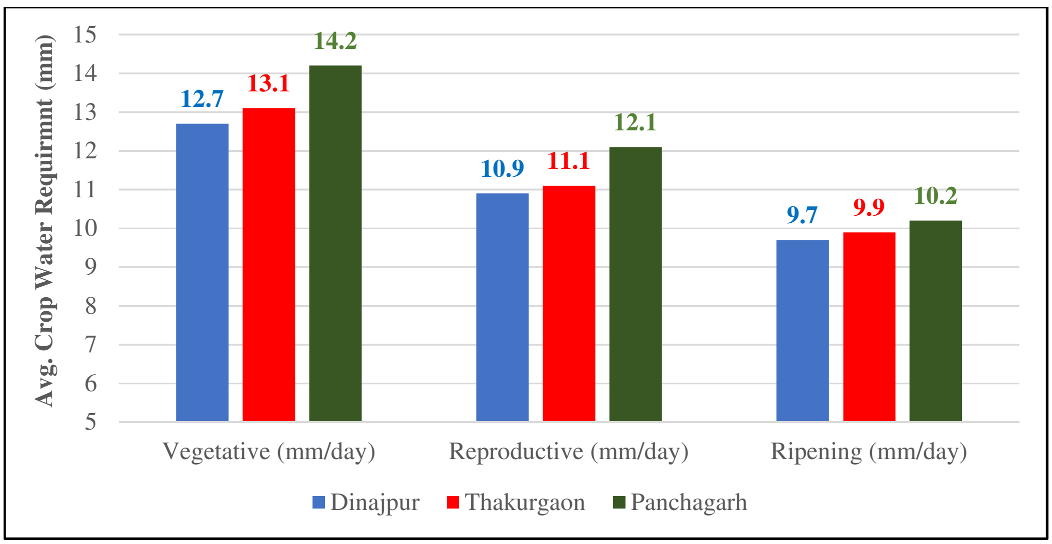

Figure 4-3: Average crop water requirement per Day at different crop growth stages

The following **Figure 4-4, Figure 4-5 &**
Figure 4-6 explains the daily water level variation due to seepage and percolation at three districts which was recorded at a fixed time in every 24 hours. To keep the crop growth rate stable and optimum at a fixed interval basis irrigation was done using ground water through STW, DTW, Electric pump etc. Sometimes rainfall occurred and water level measured that day was very high.

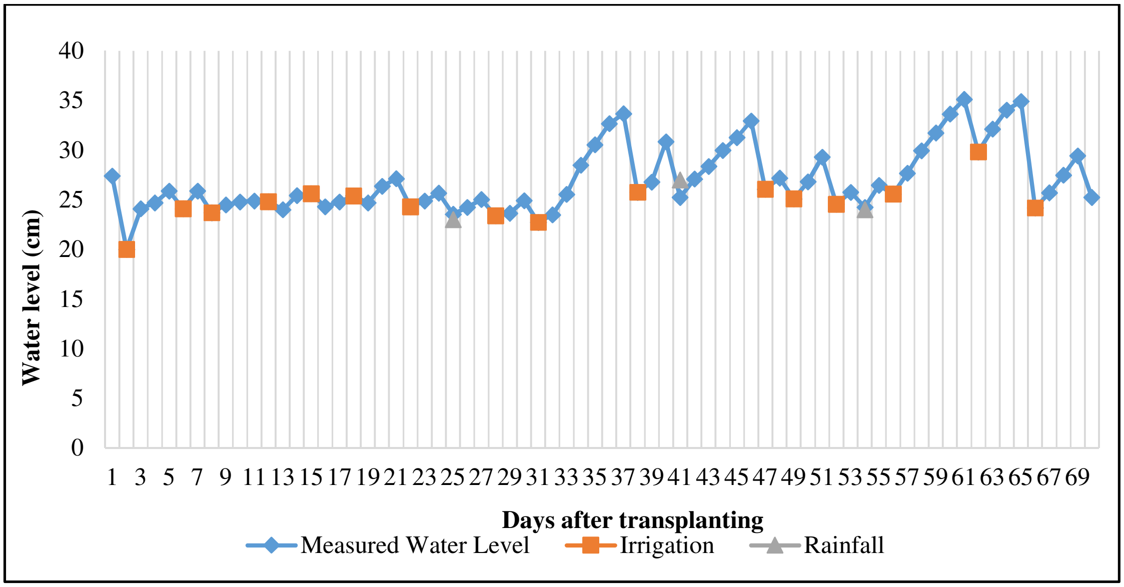

Figure 4-4: Water Level Status on Paddy Field at Ishania, Dinajpur

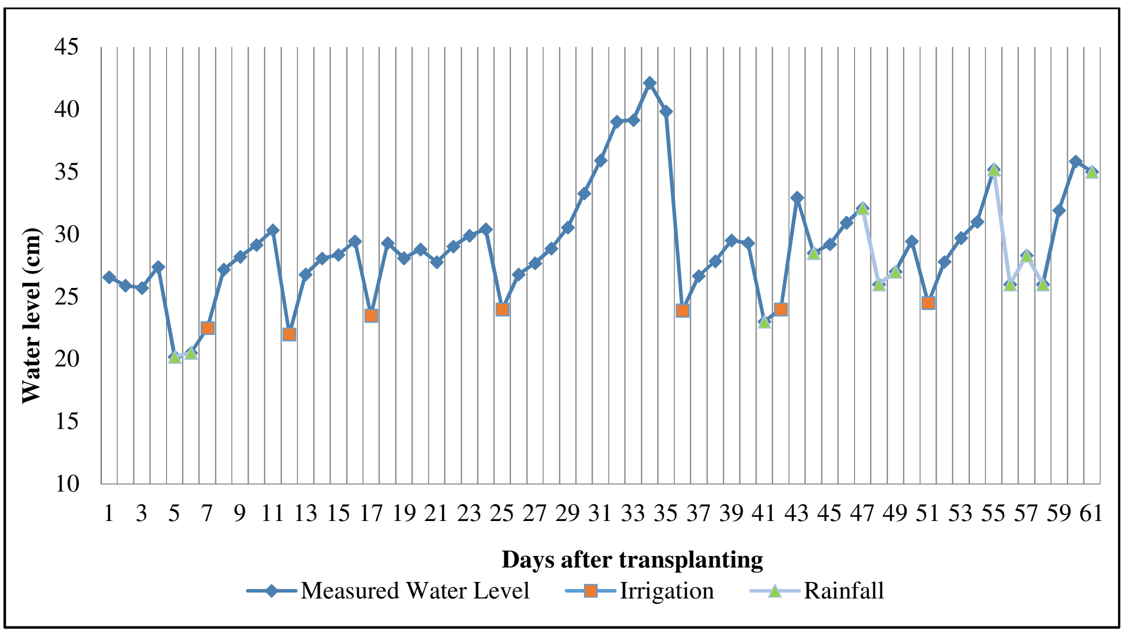

Figure 4-5: Water Level Status on Paddy Field at Maghkhuria, Thakurgaon

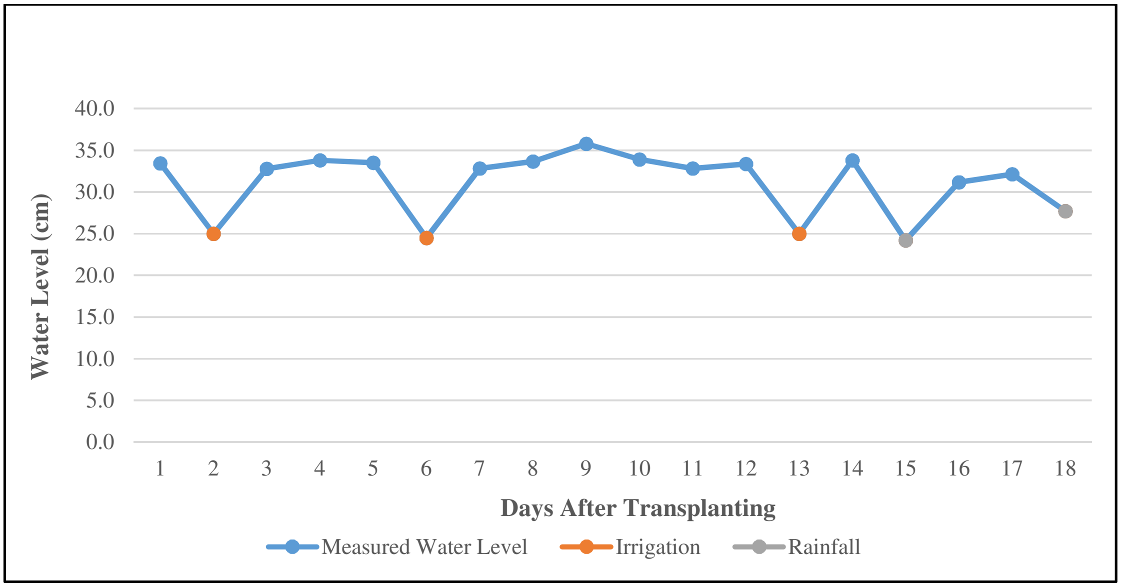

Figure 4-6: Water Level Status on Paddy Field at Guagram, Panchagarh

Evaporation loss very important factor in calculating crop water requirement.The field data crop water requirement was calculated by the seepage, percolation and evaporation values. Evaporation data was collected from evaporation station which works under Bangladesh Water Development Board (BWDB). The average evaporation rate of the three districts has shown in **Figure 4-7**.

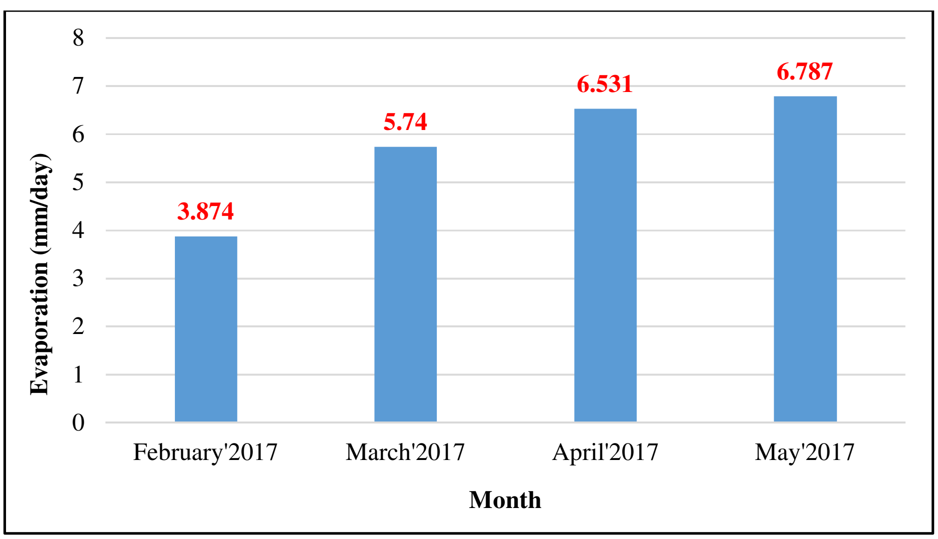

Figure 4-7: Average Evaporation Rate in Boro Season

The seepage and percolation loss in the three districts found variations due to different soil textures and evaporation rates. **Figure 4-8** shows the average seepage and percolation rate having DinajpurDistrict 5.37 mm, Thakurgaon district 5.63 mm, Panchagarh district 6.43 mm. The average seepage and percolation for the three district is 5.81 mm.

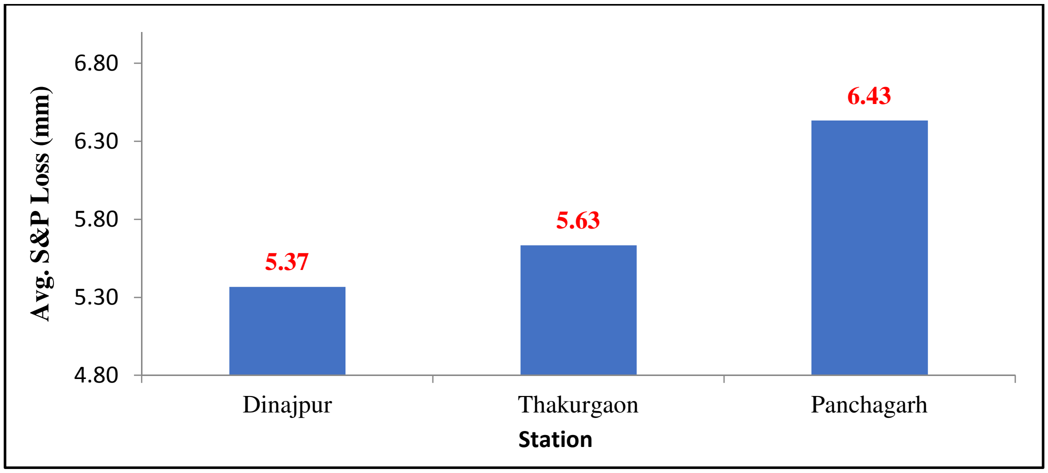

Figure 4-8: Average Seepage and Percolation Rate

CropWat 8.0 version software was used for calculating crop water requirement and irrigation requirement. This standard software works based on different parameters such as soil type, climate, irrigation, crop growth stage etc. After putting these different environmental data using one empirical formula Kc was found. Then after addition of seepage and percolation data with Kc the crop water requirement was found. **Figure 4-9** shows the comparison between simulated and observed data. The Kc value data was found in every decade.

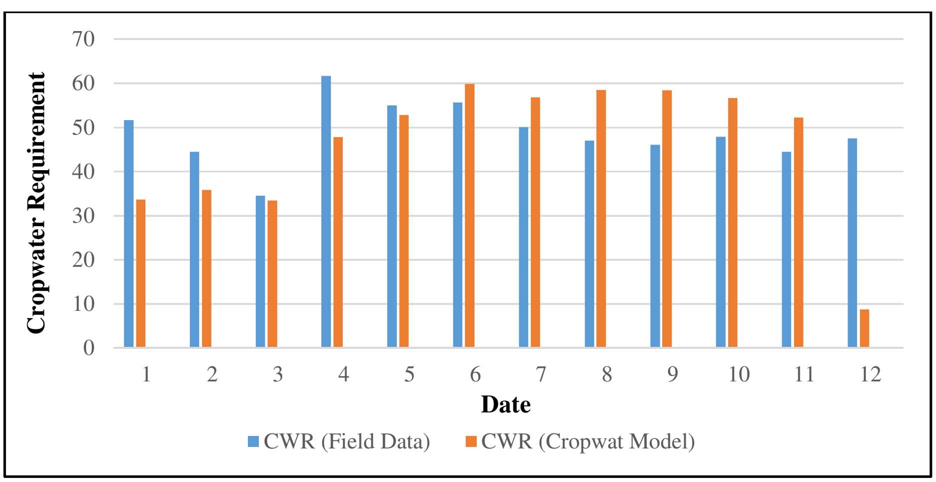

Figure 4-9: Comparison of Simulated and Observed CWR

For water pricing farmer's survey data mainly collected after discussing with the farmer and other senior citizens of the particular villages. It has been observed that preference of irrigation system is different in different district. This is because farmers didn't get all kinds of irrigation facility available in all fields. So most of the farmers are bound to the available irrigation method. Other low-price method application is possible but due to high initial cost or hassle they don't prefer it. **Figure 4-10** shows the water pricing data of Thakurgaon district.

The figure shows that three types of irrigation method was available in that area and the average pricing was totally different due to application of different irrigation method. It is observed that the deep tube well irrigation provides the lowest cost of irrigation to the farmers and electric motor irrigation method provides highest water pricing due to initial heavy investment and lower coverage than deep tube well. The shallow tube well provides medium pricing between deep tube well and electric motor irrigation and this is the mostly used irrigation method in that area.

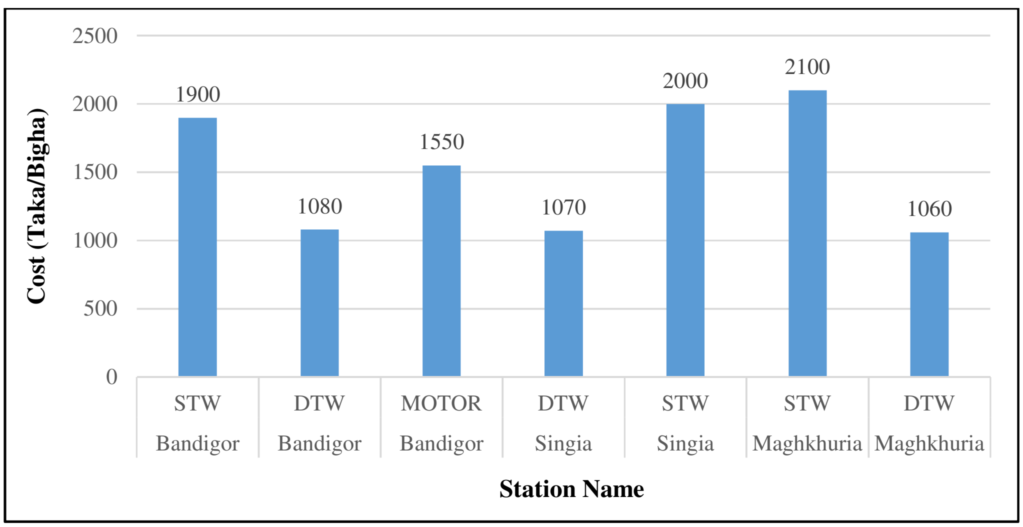

Figure 4-10: Water Pricing at Selected Surveyed Area of Thakurgaon District

Figure 4-11 shows the irrigation pricing of shallow tube well, deep tube well and electric motor pump of Panchagarh district. The deep tube well irrigation method provides the lowest cost at GuagramProdhan Para which is above 1100 taka per bigha. At the same time the same village shows shallow tube well irrigation price higher than deep tube well but lower than the electric motor irrigation pricing.

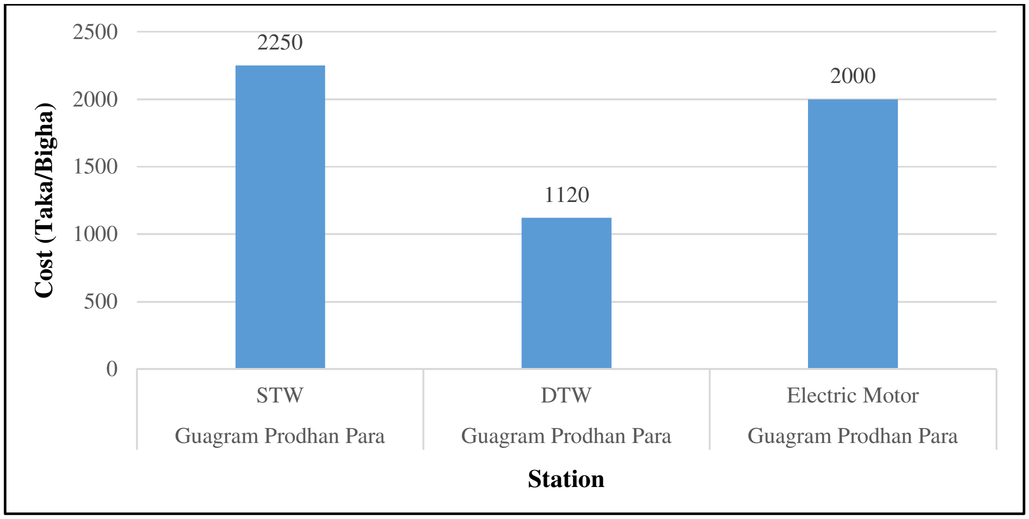

Figure 4-11: Water Pricing at Selected Surveyed Area of Panchagarh District

Figure 4-12 shows shallow tube well, deep tube well, electric motor pump and at the same time solar pump irrigation water pricing at Dinajpur district. In all fields deep tube well, water pricing is lowest and shallow tube well water pricing medium cost and both electric and solar motor pump has highest irrigation water pricing. The reason behind that due to initial investment is high but it will lowest after using 3-4 year and when all farmers will start using or start sharing the same solar or electric pump the cost will be lower.

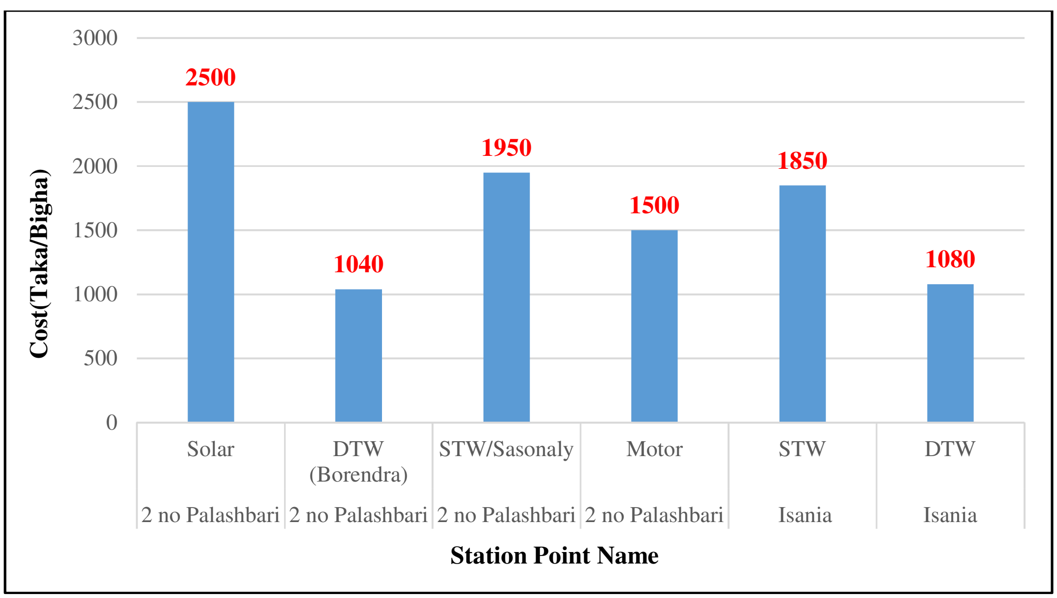

Figure 4-12: Water Pricing at Selected Surveyed Area of Dinajpur district

Figure 4-13 shows the pricing details of shallow tube well irrigation method costing of three districts. It can be shown that the irrigation cost is lowest at Dinajpur district having slower seepage and percolation rate. The Panchagarh district shows the highest cost than other two districts.

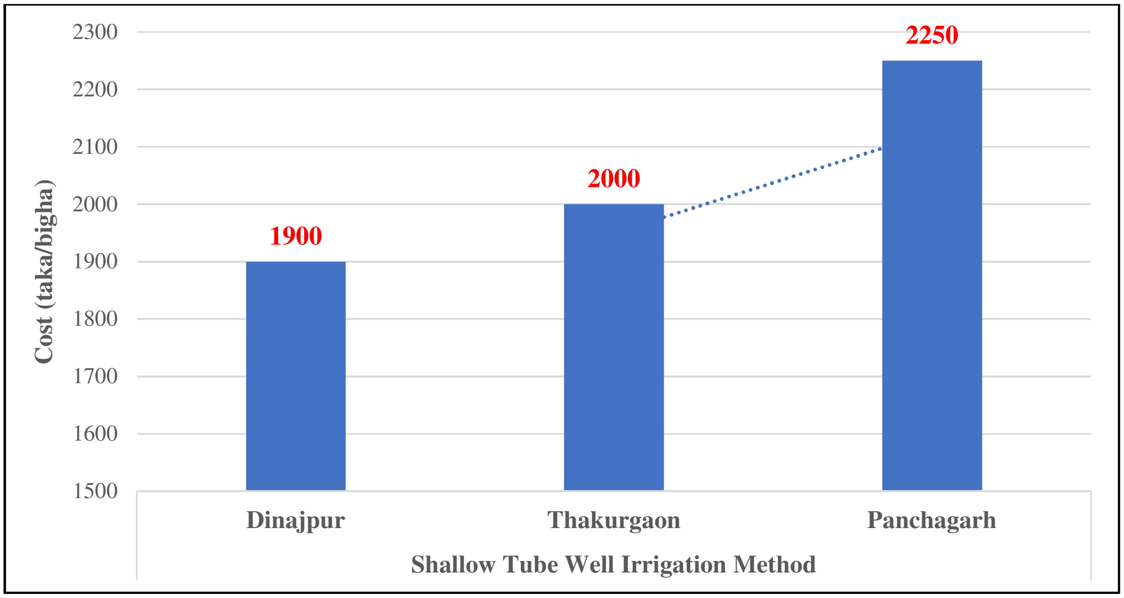

Figure 4-13: Shallow Tube Well Pricing of Three Districts

Figure 4-14 shows deep tube well irrigation methods costings for three districts showing very close irrigation water pricing rate but due to higher seepage and percolation rate Panchagarh district have highest water pricing rate.

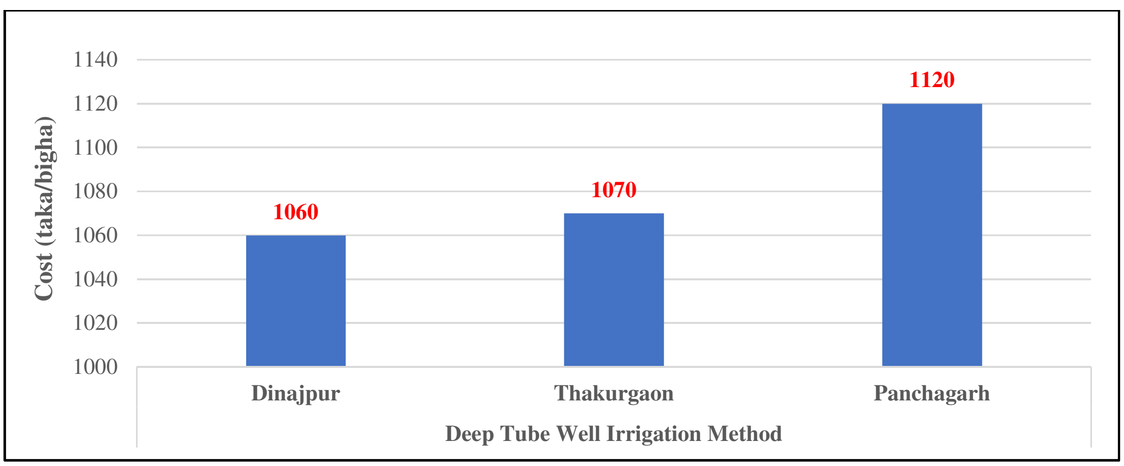

Figure 4-14: Deep Tube Well Pricing in Three Districts

Figure 4-15 shows the costing for irrigation method for electric motor. Figure shows that high cost in Panchagarh district and low cost in Dinajpur district.

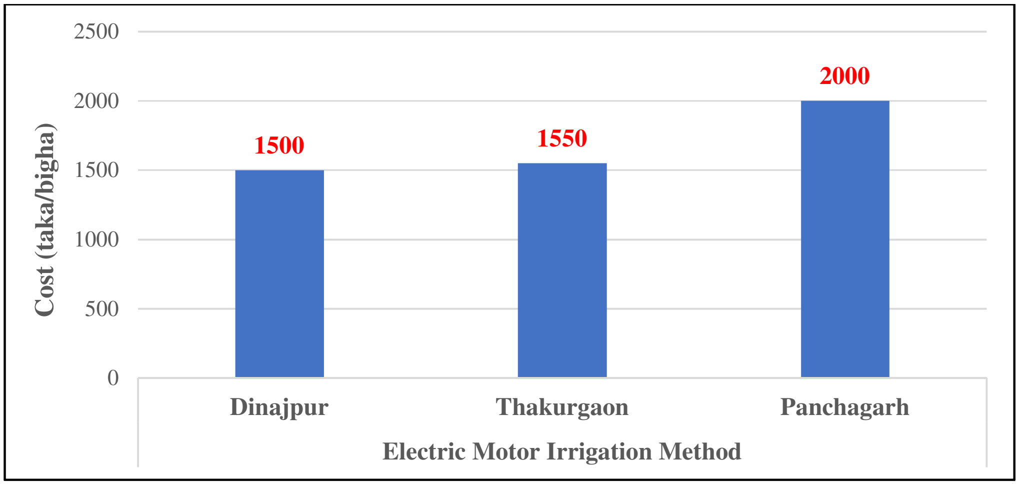

Figure 4-15: Electric Motor Irrigation Pricing of Three Districts

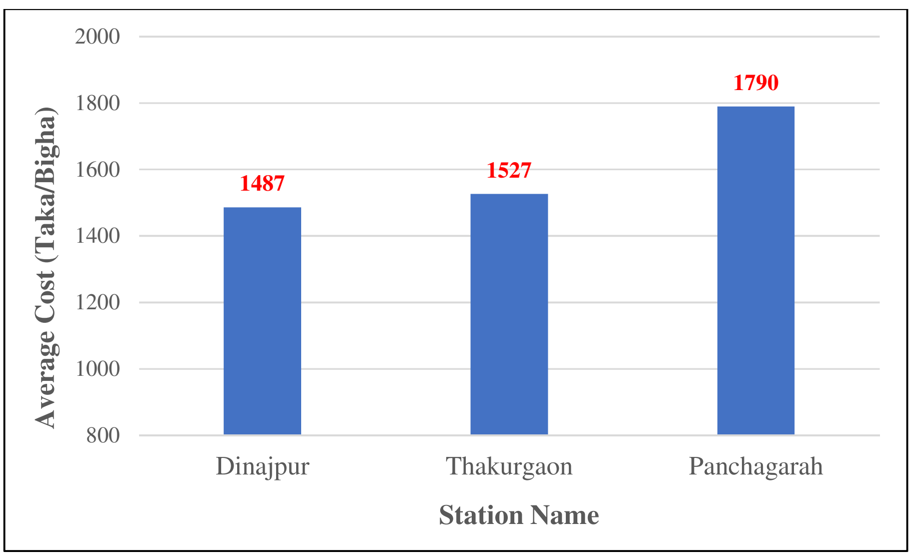

Figure 4-16: Average Irrigation Water Pricing of Three Districts

Figure 4-16 shows the average water pricing for irrigation of the selected three districts. It has been found that the Dinajpur district showed the lowest irrigation cost among the three districts due to less seepage and percolation rate.

CHAPTER-5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

It has been emphasized to find-out the better water irrigation pricing method and its associated other parameter, such as crop evapotranspiration, which varies with crop growth stage, the need for a variable seepage and percolation rate based on crop water requirement keeps a major impact on duration and number of irrigation. The selection of proper irrigation method can save a remarkable amount of irrigation cost of the poor farmers if they can use the cost-effective method. This research project aimed to study the variation of S&P loss with the passage of time and reviews the impacts of the present practice of the impacts of water pricing on water used by the farmers on the planning and design of irrigation projects.

The primary data on field water status of irrigated Boro rice collected from 18 farmers' fields spreading over three districts was the basis of this study. Most of the farmers in these districts practiced ground water irrigation. The conclusions of the study are as follows:

1. For non-submerged rice fields, the Crop Water Requirement (CWR) rate varies with crop growth stages. It has been found in this study Crop Water Requirement was 12.7 mm at vegetative stage, 10.9 mm at reproductive stage and 9.7 mm at ripening stage.

2. It has been observed that there is a close proportional relationship between Seepage and Percolation (S&P) loss, CWR and Irrigation Water Pricing. If the (S&P) loss rate is high then the Crop Water Requirement is being higher and the corresponding paddy field, Irrigation Water Pricing is also high.

3. From this study it has been observed that the seepage and percolation loss varies with topography of the land.

4. The observed Crop Water Requirement for rice from the observed field data and the simulated CWR from CropWat model have been found slightly variation due to considering homogeneous field condition in the study area.

5. Total irrigation cost depends on soil texture, surrounding environment and the availability of irrigation method in the area. The irrigation cost using Deep Tube-Well (DTW) is lower and faster comparing to the other means of irrigation equipment (i.e. STW, Electric Motor pump, solar pump etc.).However, farmers in all areas are not getting benefit from DTW as limited no. of DTW.

6. From Focus Group Discussion (FGD) survey, the farmers opined that the electric motor pump irrigation method could be the second suitable irrigation method but it also covers very limited area. The newly developed solar pump irrigation method could be a good option as it has no fossil fuel consumption and environment friendly but initial investment is high comparing to other irrigation equipment. If it could be brought into cost-effective limit, in future it could also be a popular method for irrigation.

7. It has been found from the analysis that the irrigation cost is lower in Dinajpur district compare to Thakurgaon and Panchagarh district. It has been happened because of soil texture.

5.2 Recommendations

Efforts were made to incorporate the best irrigation method having lowest irrigation cost and faster irrigation time during this study. However, there is still scope for further improvement. The following recommendations are made under this perspective.

i. The present study has been done considering Boro season, the same study can be done on other season to observe the variation in terms of Seepage & Percolation loss and irrigation cost.
ii. From this study only, crop water requirement has been measured and simulated with CropWat model. But it could be more cost effective in terms of water savings for farmers if irrigation scheduling could be done and implement in proper way.
iii. The crop water requirement could also be calculated to observe the relation among different variety of rice and other crops. It will help to farmers to select the rice varieties or other crops based on field.
iv. The seepage and percolation rate was measured using half blind and half perforated PVC pipe. The same analysis can be done using inclined meter to see the variation.
v. During study in limited locations Seepage & Percolation were measured and corresponding soil samples were collected and tested due to time & fund constraint. In future more areas could be covered to measure the same data which will better represent the entire study area.

CHAPTER-6

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CHAPTER-7

APPENDIX

Table 7-1: Average Crop Water Requirement of Dinajpur District

Date	Depth (cm) P-1	Diff of P-1	Selected Data of P-1	Depth (cm) P-2	Diff of P-2	Selected Data of P-2	Depth (cm) P-3	Diff of P-3	Selected Data of P-3	Depth (cm) P-4	Diff of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
19-02-2017	24			31			30			27			25			
20-02-2017	20	-4		22	-9		25	-5		24	-3		25	0		irrigation
21-02-2017	22.5	2.5		24	2		24	-1		25	1	1	25	0		
22-02-2017	24	1.5	1.5	24	0		25	1	1	25	0		25.5	0.5	0.5	
23-02-2017	24.5	0.5	0.5	26	2		25.5	0.5	0.5	27	2		26.5	1	1	
24-02-2017	23	-1.5	1	24	-2		24	-1.5		25.5	-1.5		24	-2.5		irrigation
25-02-2017	25.5	2.5		26.5	2.5		26.5	2.5		26	0.5	0.5	25	1	1	
26-02-2017	23	-2.5		24	-2.5		24.5	-2		25	-1		22	-3		irrigation
27-02-2017	23.5	0.5	0.5	25	1	1	25	0.5	0.5	24	-1		25	3		
28-02-2017	24	0.5	0.5	25.5	0.5	0.5	24	-1		25	1	1	25.5	0.5	0.5	
1/3/2017	25	1	1	26	0.5	0.5	23	-1		25	0		25.4	-0.1		
2/3/2017	25.3	0.3		26.5	0.5	0.5	25.5	2.5		21.5	-3.5		25.3	-0.1		irrigation
3/3/2017	22.5	-2.8		23	-3.5		25.3	-0.2		25.4	3.9		23.8	-1.5		
4/3/2017	24.3	1.8	1.8	25	2		26.8	1.5	1.5	26	0.6	0.6	25	1.2	1.2	
5/3/2017	25	0.7	0.7	25.5	0.5	0.5	27	0.2		25.3	-0.7	0.7	25.3	0.3	0.3	irrigation
6/3/2017	23	-2		23.5	-2		26	-1		24	-1.3		25	-0.3		
7/3/2017	23.8	0.8	0.8	24	0.5	0.5	26.4	0.4		24.3	0.3	0.3	25.5	0.5	0.5	
8/3/2017	24.3	0.5	0.5	24.7	0.7	0.7	27	0.6	0.6	25	0.7	0.7	26	0.5	0.5	irrigation
9/3/2017	23.5	-0.8		23	-1.7		27.5	0.5	0.5	26.6	1.6	1.6	23	-3		
10/3/2017	25.1	1.6	1.6	26	3		26.7	-0.8		27	0.4	0.4	27	4		
11/3/2017	26.4	1.3	1.3	27	1	1	26.9	0.2		27.8	0.8	0.8	27.5	0.5	0.5	

Date	Depth (cm) P-1	Diff of P-1	Selected Data of P-1	Depth (cm) P-2	Diff of P-2	Selected Data of P-2	Depth (cm) P-3	Diff of P-3	Selected Data of P-3	Depth (cm) P-4	Diff of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
12/3/2017	23	-3.4		24	-3		24.5	-2.4		25	-2.8		25.1	-2.4		irrigation
13/3/2017	23.7	0.7	0.7	24.6	0.6	0.6	25	0.5	0.5	25.5	0.5	0.5	25.6	0.5	0.5	
14/3/2018	24.9	1.2	1.2	25.3	0.7	0.7	25.8	0.8	0.8	26	0.5	0.5	26.3	0.7	0.7	
15/3/2018	23	-1.9		22.8	-2.5		24	-1.8		23.9	-2.1		24	-2.3		irrigation
16/3/2018	23.9	0.9	0.9	23.5	0.7	0.7	25	1	1	24	0.1		24.8	0.8	0.8	
17/3/2018	24.5	0.6	0.6	24.9	1.4	1.4	25.7	0.7	0.7	24.8	0.8	0.8	25.3	0.5	0.5	
18/3/2018	23	-1.5		24.9	0		23	-2.7		22.8	-2		23.3	-2		irrigation
19/3/2018	23.8	0.8	0.8	23.8	-1.1		23.4	0.4		23.3	0.5	0.5	24	0.7	0.7	
20/3/2018	24.7	0.9	0.9	24.9	1.1	1.1	24.7	1.3	1.3	25	1.7		25.3	1.3	1.3	
21/3/2018	22	-2.7		22.3	-2.6		23	-1.7		23.1	-1.9		23.3	-2		irrigation
22/3/2018	22.8	0.8	0.8	23	0.7	0.7	23.7	0.7	0.7	24	0.9	0.9	23.9	0.6	0.6	
25/3/2019	28	1.6	1.6	30	3		30	0		32	3		32.8	2.8		
26/3/2019	31	3		32	2		33	3		33.3	1.3	1.3	34	1.2	1.2	
27/3/2019	32	1	1	33.6	1.6	1.6	33.8	0.8	0.8	33.9	0.6		35	1		
28/3/2019	24	-8		26	-7.6		26	-7.8		25.9	-8		27	-8		irrigation
29/3/2017	26	2		26.9	0.9	0.9	26.6	0.6	0.6	27	1.1	1.1	27.5	0.5	0.5	
30/3/2019	30	4		31	4.1		30.3	3.7		32	5		31	3.5		
31/3/201	27	-3		24	-7		24.3	-6		25	-7		26	-5		irrigation
1/4/2017	28	1	1	29	5		25.4	1.1	1.1	26.1	1.1	1.1	27	1		
2/4/2017	29.3	1.3	1.3	30.1	1.1	1.1	27	1.6	1.6	27.3	1.2	1.2	28.1	1.1	1.1	
3/4/2017	31	1.7	1.7	32	1.9	1.9	28.8	1.8	1.8	28.9	1.6	1.6	29.2	1.1	1.1	
4/4/2017	32.1	1.1	1.1	33.2	1.2	1.2	29.9	1.1	1.1	30.2	1.3	1.3	31	1.8	1.8	
5/4/2017	33.8	1.7	1.7	34.3	1.1	1.1	31.7	1.8	1.8	32	1.8	1.8	32.9	1.9	1.9	
6/4/2017	24	-9.8		25	-9.3		25.6	-6.1		27	-5		28.8	-4.1		irrigation
7/4/2017	25.9	1.9	1.9	26	1	1	26.8	1.2	1.2	28	1		29.2	0.4	0.4	

Date	Depth (cm) P-1	Diff of P-1	Selected Data of P-1	Depth (cm) P-2	Diff of P-2	Selected Data of P-2	Depth (cm) P-3	Diff of P-3	Selected Data of P-3	Depth (cm) P-4	Diff of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
8/4/2017	23.2	-2.7		25	-1		24.8	-2		26.1	-1.9		26.4	-2.8		irrigation
9/4/2017	25	1.8	1.8	27	2		26.9	2.1		27.8	1.7	1.7	27.5	1.1	1.1	
10/4/2017	27	2		29.3	2.3		29.8	2.9		30.1	2.3		30.4	2.9		
11/4/2017	24.1	-2.9		24.4	-4.9		24	-5.8		25.2	-4.9		25	-5.4		irrigation
12/4/2017	25.8	1.7	1.7	25.9	1.5	1.5	25	1	1	26	0.8		26.2	1.2	1.2	
13/4/2017	24	-1.8		24.1	-1.8		23.8	-1.2		24.5	-1.5		24.8	-1.4		irrigation
14/4/2017	26.3	2.3		26	1.9	1.9	26.7	2.9		26.3	1.8	1.8	27	2.2		
15/4/2017	26	-0.3		25.2	-0.8		25.1	-1.6		25.8	-0.5		25.8	-1.2		irrigation
16/4/2017	27.3	1.3	1.3	27.5	2.3		27.6	2.5		28	2.2		28	2.2		
17/4/17	29.8	2.5		30	2.5		29.3	1.7	1.7	30.2	2.2		30.4	2.4		
18/4/2017	31	1.2	1.2	32	2		31.2	1.9	1.9	32.1	1.9		32.3	1.9	1.9	
19/4/2017	32.9	1.9	1.9	34.7	2.7		32.8	1.6	1.6	33.9	1.8		33.9	1.6	1.6	
20/4/2017	34.8	1.9	1.9	36.3	1.6	1.6	34.4	1.6	1.6	35	1.1		35.1	1.2	1.2	
21/4/2017	30	-4.8		31	-5.3		29	-5.4		29.2	-5.8		30	-5.1		irrigation
22/4/2017	32	2		32.8	1.8	1.8	31.7	2.7		32	2.8		32.2	2.2		
23/4/2017	34	2		34.5	1.7	1.7	33.8	2.1		33.9	1.9		34	1.8	1.8	
24/4/2017	35	1	1	35.3	0.8	0.8	34.7	0.9	0.9	34.7	0.8		34.9	0.9	0.9	
25/4/2017	24	-11		23	-12.3		24.2	-10.5		24.8	-9.9		25	-9.9	0.96	irrigation
26/4/2017	25.8	1.8	1.8	25	2		25.8	1.6	1.6	25.9	1.1	1.1	26	1	1	
27/4/2017	27	1.2	1.2	27	2		27.8	2		27.7	1.8	1.8	28	2		
28/4/2017	28.8	1.8	1.8	28.7	1.7	1.7	29.9	2.1		30	2.3		29.7	1.7	1.7	
29/4/2017	30.7	1.9	1.9	30	1.3	1.3	31	1.1	1.1	31.3	1.3	1.3	3.2	-26.5		
AVG of P1			**1.23**	**AVG of P2**		**1.09**	**AVG of P3**		**1.11**	**AVG of P4**		**1.03**	**AVG of P5**		**0.98**	

Table 7-2: Average crop water requirement of Thakurgaon District

Date	Depth (cm) P-1	Difference of P-1	Selected data p-1	Depth (cm) P-2	Difference of P-2	Selected data p-2	Depth (cm) P-3	Difference of P-3	Selected data p-3	Depth (cm) P-4	Difference of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
10/3/2017	23.3			30			28.1			28			27.6			irrigation
11/3/2017	20.2	-3.1		26	-4		25.6	-2.5		24.8	-3.2		24.2	-3.4		
12/3/2017	20.5	0.3	0.3	27.5	1.5	1.5	23.6	-2		24.5	-0.3		24.9	0.7	0.7	
13/3/2018	22.5	2		28.3	0.8	0.8	24.5	0.9	0.9	25	0.5	0.5	26.4	1.5	1.5	
14/3/2018	24.3	1.8	1.8	30.5	2.2		25.8	1.3	1.3	26.8	1.8	1.8	28.5	2.1		
15/3/2018	26.5	2.2		31	0.5	0.5	26.8	1	1	27.2	0.4	0.4	29.6	1.1	1.1	
16/3/2018	28.5	2		31.2	0.2	0.2	27.7	0.9	0.9	28.3	1.1	1.1	30	0.4	0.4	
17/3/2018	30	1.5	1.5	32	0.8	0.8	28.7	1	1	29.5	1.2	1.2	31.5	1.5	1.5	
18/3/2018	22	-8		27.2	-4.8		30.5	1.8	1.8	26.4	-3.1		25.8	-5.7		p1,p2,p4, p5
19/3/2018	22.5	0.5	0.5	28.5	1.3	1.3	31.5	1	1	26	-0.4		25.5	-0.3		
20/3/2018	24	1.5	1.5	30.5	2		32	0.5	0.5	26.3	0.3	0.3	27.5	2		
21/3/2018	24.5	0.5	0.5	31	0.5	0.5	32	0		26.4	0.1	0.1	27.82	0.32	0.32	
22/3/2018	25.8	1.3	1.3	30	-1		35	3		27	0.6	0.6	29.4	1.58		
23/3/2018	23.5	-2.3		27.8	-2.2		35.5	0.5	0.5	29	2		29.7	0.3		p1,p2,,p5
24/3/2018	24.8	1.3	1.3	30.2	2.4		36	0.5	0.5	31	2		24.5	-5.2		p5
25/3/2019	25	0.2	0.2	31	0.8	0.8	36.5	0.5		26.5	-4.5		21.5	-3		p4
26/3/2019	27.4	2.4	2.4	31.5	0.5	0.5	25.9	-10.6		28	1.5	1.5	31.1	9.6		p3
27/3/2019	29.2	1.8	1.8	31.8	0.3	0.3	26.5	0.6	0.6	28.3	0.3	0.3	23.1	-8		
28/3/2019	31	1.8	1.8	32.3	0.5	0.5	27.5	1		29.8	1.5	1.5	24.5	1.4	1.4	
2/3/2019	31.5	0.5	0.5	33	0.7	0.7	28	0.5	0.5	31.5	1.7	1.7	25.5	1	1	
30/3/2019	32	0.5	0.5	33.8	0.8	0.8	29.2	1.2	1.2	31	-0.5		26	0.5	0.5	
31/3/17	24	-8		27.4	-6.4		30	0.8	0.8	30.7	-0.3		28.7	2.7		

Date	Depth (cm) P-1	Difference of P-1	Selected data p-1	Depth (cm) P-2	Difference of P-2	Selected data p-2	Depth (cm) P-3	Difference of P-3	Selected data p-3	Depth (cm) P-4	Difference of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
1/4/2017	**24.9**	**0.9**	**0.9**	**30.5**	**3.1**		**30.3**	**0.3**	**0.3**	**27.3**	**-3.4**		**21**	**-7.7**		**p4**
2/3/2017	**26**	**1.1**	**1.1**	**31.5**	**1**	**1**	**30.5**	**0.2**	**0.2**	**28.1**	**0.8**	**0.8**	**22.3**	**1.3**	**1.3**	
3/4/2017	**27.2**	**1.2**	**1.2**	**32.1**	**0.6**	**0.6**	**31.2**	**0.7**	**0.7**	**29.3**	**1.2**	**1.2**	**24.5**	**2.2**		
4/4/2017	**31**	**3.8**		**32.5**	**0.4**	**0.4**	**32**	**0.8**	**0.8**	**30.7**	**1.4**	**1.4**	**26.5**	**2**		
5/4/2017	**33.4**	**2.4**		**35**	**2.5**		**33.5**	**1.5**	**1.5**	**34**	**3.3**		**30.5**	**4**		
6/4/2017	**39**	**5.6**		**38.5**	**3.5**		**28.2**	**-5.3**		**38**	**4**		**34.5p3**	**#VALUE!**		
7/4/2017	**43**	**4**		**44**	**5.5**		**28.6**	**0.4**	**0.4**	**41.2**	**3.2**		**38.3**	**#VALUE!**		
8/4/2017	**47**	**4**		**48.1**	**4.1**		**31**	**2.4**		**27.6**	**-13.6**		**42**	**3.7**		**p4**
9/4/2017	**50.2**	**3.2**		**51.6**	**3.5**		**34.3**	**3.3**		**29.1**	**1.5**	**1.5**	**45.5**	**3.5**		
10/4/2017	**53.5**	**3.3**		**27**	**-24.6**		**37.6**	**3.3**		**32**	**2.9**		**49.1**	**3.6**		
11/4/2017	**23.9**	**-29.6**		**28.5**	**1.5**	**1.5**	**39.5**	**1.9**		**32**	**0**		**52**	**2.9**		**p1**
12/4/2017	**26**	**2.1**		**30.5**	**2**		**26**	**-13.5**		**27.2**	**-4.8**		**23.6**	**-28.4**		**p3,p4,p5**
13/4/17	**27.2**	**1.2**	**1.2**	**31.5**	**1**		**27**	**1**	**1**	**27.5**	**0.3**	**0.3**	**26**	**2.4**		
14/4/17	**30.5**	**3.3**		**33**	**1.5**		**28.4**	**1.4**	**1.4**	**28.5**	**1**	**1**	**27.2**	**1.2**	**1.2**	
15/4/17	**34**	**3.5**		**25.5**	**-7.5**		**29.5**	**1.1**	**1.1**	**29**	**0.5**	**0.5**	**28.5**	**1.3**	**1.3**	**p2**
16/4/17	**23**	**-11**		**27.2**	**1.7**	**1.7**	**29.8**	**0.3**	**0.3**	**29.5**	**0.5**	**0.5**	**29.5**	**1**	**1**	**p1**
17/4/17	**24**	**1**	**1**	**26.8**	**-0.4**		**36**	**6.2**		**30.2**	**0.7**	**0.7**	**35.3**	**5.8**		
18/4/17	**27**	**3**		**31**	**4.2**		**39.5**	**3.5**		**30.2**	**0**		**37**	**1.7**	**1.7**	
19/4/17	**28.5**	**1.5**	**1.5**	**32**	**1**	**1**	**26**	**-13.5**		**27.1**	**-3.1**		**26**	**-11**		**p3,p4,p5**
20/4/17	**29**	**0.5**	**0.5**	**34**	**2**		**27.2**	**1.2**	**1.2**	**28.5**	**1.4**	**1.4**	**27.3**	**1.3**	**1.3**	
21/4/17	**30.6**	**1.6**	**1.6**	**36**	**2**		**29**	**1.8**	**1.8**	**30.2**	**1.7**	**1.7**	**28.9**	**1.6**	**1.6**	
22/4/17	**32.1**	**1.5**	**1.5**	**38**	**2**		**30.5**	**1.5**	**1.5**	**32.1**	**1.9**	**1.9**	**30.6**	**1.7**	**1.7**	
23/4/17	**26**	**-6.1**		**28.1**	**-9.9**		**32**	**1.5**	**1.5**	**33**	**0.9**	**0.9**	**32**	**1.4**	**1.4**	**p1,p2**

Date	Depth (cm) P-1	Difference of P-1	Selected data p-1	Depth (cm) P-2	Difference of P-2	Selected data p-2	Depth (cm) P-3	Difference of P-3	Selected data p-3	Depth (cm) P-4	Difference of P-4	Selected data p-4	Depth (cm) P-5	Difference of P-5	Selected data p-5	Remarks
24/4/7	**27**	**1**	**1**	**30.8**	**2.7**		**28.5**	**-3.5**		**28**	**-5**		**24.8**	**-7.2**		**p5**
25/4/17	**28.3**	**1.3**	**1.3**	**32.6**	**1.8**	**1.8**	**30.2**	**1.7**	**1.7**	**30**	**2**		**26.1**	**1.3**	**1.3**	
26/4/17	**24.5**	**-3.8**		**25.5**	**-7.1**		**33**	**2.8**		**27.5**	**-2.5**		**28**	**1.9**		**p1,p2,p4**
29/4/17	**26**	**1.5**	**1.5**	**27**	**1.5**	**1.5**	**28**	**-5**		**26**	**-1.5**		**32**	**4**		**p1,p2,p3, p4**
30/4/17	**27.5**	**1.5**	**1.5**	**35**	**8**		**31**	**3**		**28.5**	**2.5**		**26.5**	**-5.5**		**p5**
1/5/2017	**30**	**2.5**		**38.5**	**3.5**		**28.5**	**-2.5**		**29**	**0.5**	**0.5**	**29**	**2.5**		**p3**
2/5/2017	**35.2**	**5.2**		**28**	**-10.5**		**30**	**1.5**	**1.5**	**32**	**3**		**36**	**7**		**p2**
3/5/2017	**26**	**-9.2**		**27**	**-1**		**32.4**	**2.4**		**35.5**	**3.5**		**38.2**	**2.2**		**p1,p2**
4/5/2017	**28.3**	**2.3**		**29.5**	**2.5**		**35**	**2.6**		**37**	**1.5**	**1.5**	**39.8**	**1.6**	**1.6**	
5/5/2017	**26**	**-2.3**		**31**	**1.5**	**1.5**	**29.5**	**-5.5**		**31.5**	**-5.5**		**29**	**-10.8**		
6/5/2017	**28**	**2**		**33.2**	**2.2**		**32.7**	**3.2**		**34**	**2.5**		**31.7**	**2.7**		
7/5/2017	**31.7**	**3.7**		**36**	**2.8**		**36.5**	**3.8**		**38**	**4**		**37**	**5.3**		
8/5/2017	**35**	**3.3**		**40.1**	**4.1**		**41**	**4.5**		**42**	**4**		**41.8**	**4.8**		
AVG of P1			**1.17**	**AVG of P2**		**0.92**	**AVG of P3**		**0.98**	**AVG of P4**		**0.99**	**AVG of P5**		**1.19**	

Table 7-3: Average crop water requirement of Panchagarh district

	STW (26.125039, 88.65576)						DTW (26.127722, 88.648853)						Motor (26.124918, 88.649729)						
Date	Depth (cm) P-1	Difference of P-1	selected data	Depth (cm) P-2	Difference of P-2	selected data	Depth (cm) P-1	Difference of P-1	selected data	Depth (cm) P-2	Difference of P-2	selected data	Depth (cm) P-1	Difference of P-1	selected data	Depth (cm) P-2	Difference of P-2	selected data	Remarks
5/4/2017	41.7			33.2			38.5			36			25.2			26			
6/4/2017	25	-16.7		34	0.8	0.8	39.9	1.4	1.4	37.8	1.8	1.8	26.5	1.3	1.3	25.3	-0.7		
7/4/2017	25.4	0.4	0.4	36.8	2.8		41	1.1	1.1	40	2.2		27.3	0.8	0.8	26.2	0.9	0.9	
8/4/2017	27.5	2.1		38.3	1.5	1.5	42.8	1.8	1.8	41.2	1.2	1.2	27.8	0.5	0.5	25.1	-1.1		
9/4/2017	29.7	2.2		31.7	-6.6		43.3	0.5	0.5	42.1	0.9	0.9	25.3	-2.5		29	3.9		
10/4/2017	24.5	-5.2		32.3	0.6	0.6	45	1.7	1.7	43.2	1.1	1.1	27.1	1.8	1.8	27.5	-1.5		
11/4/2017	25.3	0.8	0.8	35.5	3.2		40	-5		41	-2.2		28.9	1.8	1.8	26.2	-1.3		
12/4/2017	26.4	1.1	1.1	38	2.5		41.1	1.1	1.1	41.3	0.3	0.3	30	1.1	1.1	25.1	-1.1		
13/4/2017	28.2	1.8	1.8	40	2		42.6	1.5	1.5	42.6	1.3	1.3	32.4	2.4		29	3.9		
14/4/2017	29.4	1.2	1.2		0		44	0		43.7	0		24.5	0		27.9	0		
15/4/2017	31.9	2.5			0		40	-4		40.6	-3.1		25.2	0.7	0.7	26.5	-1.4		
16/4/2017	32	0.1	0.1		0		41.3	1.3	1.3	42.2	1.6	1.6	26	0.8	0.8	25.4	-1.1		
17/04/2017	25	-7		32	32		43	1.7	1.7	43.4	1.2	1.2	25	-1		29.2	3.8		
18/04/2017	26.3	1.3	1.3	33.2	1.2	1.2	43.5	0.5	0.5	45.1	1.7	1.7	26.5	1.5	1.5	28.1	-1.1		
19/04/2017	24.2	-2.1		28	-5.2		39	-4.5		39.3	-5.8		22.5	-4		27.4	-0.7		
20/04/2017	26	1.8	1.8	28.5	0.5	0.5	39.5	0.5		42.1	2.8	2.8	24.6	2.1		26.3	-1.1		
21/04/2017	28.2	2.2		29	0.5	0.5	41	1.5	1.5	43.3	1.2	1.2	26.3	1.7	1.7	25	-1.3		
22/04/2017	27.7	-0.5		27.3	-1.7		41.5	0.5	0.5	40.7	-2.6		25.5	-0.8		30	5		
AVG of P1			1.06	AVG f P2		0.85	AVG f P1		1.22	AVG f P2		1.37	AVG f P1		1.20	AVG f P2		0.90	