DISTRIBUTIONAL EQUITY OF IRRIGATION WATER AND ITS IMPACT ON PRODUCTIVITY OF SOME DEEP TUBE WELL COMMAND AREAS

By

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree.

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Dedicated to

My Father

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ABSTRACT

Equity is an increasingly important concern for irrigation, but has not been yet addressed sufficiently by studies in this area after its implementation. The objectives of this study were to assess equity in water distribution among the stakeholders in deep tubewell irrigated area and to identify the impacts of water equity in productivity. Three deep tubewell irrigated areas named East Togori, West Togori and Bhavanipur under Gazipur District are selected for the study with command areas of 35, 28 and 26 hectares respectively. Although the capacities of these tubewells are enough to irrigate their total command areas, fields of tail ends do not get enough water. So, inequity in water distribution frequently occurs in these irrigated areas.

Three main irrigation canals of these tubewell irrigation areas were selected for carrying out the study. Water reaches in each part of three selected canals was calculated at head, middle and tail ends of each canal. For this study, 12 numbers of sample fields from each deep tube well command area totaling to 36 numbers of sample fields were used to calculate how much water reaches to each field. The total irrigation water depth values were used to get the distributional equity. The equity coefficient and Gini coefficient are widely used to measure equity. The value of equity coefficient ranges from 0 to 1 where 1 is the most equitable condition and 0 is the worst. The Gini coefficient is used as a measure of inequality of water distribution. A low Gini coefficient indicates more equal water distribution, while a high Gini coefficient indicates more unequal distribution.

A semi-structured questionnaire survey has been conducted through the direct personal interview technique from selected 36 fields. The questionnaires were followed to collect necessary data such as crop yield data, irrigation water availability and its status of distribution, etc. from the farmers of the study area in 2011-12 Boro season. In this case crop yield of the study area is calculated. Then impacts of water equity on crop yield were analyzed.

The Equity coefficients of East Togori, West Togori and Bhavanipur Deep Tubewell irrigated area under study were found 0.4436, 0.7027 and 0.7471 respectively. The Gini Coefficients of East Togori, West Togori and Bhavanipur Deep Tubewell irrigated area under study were found 0.4754, 0.4427 and 0.4370 respectively. The coefficients thus computed using two methods show that inequity in irrigation water distribution exists in the study area. The highest crop yield (7901.97 kg/ha) was found at head ends of Bhavanipur Deep Tubewell irrigated area applying 863.60 mm of irrigation water, while the lowest crop yield (4214.39 kg/ha) was found at tail ends of East Togori Deep Tubewell irrigated area applying 444.50 mm of irrigation water. The highest crop yield of West Togori Deep Tubewell irrigated area was 7111.78 kg/ha, when the applied total depth of irrigation water was also the highest i.e., 749.30 mm, while the lowest crop production (5004.58 kg/ha) was found at tail ends of West Togori Deep Tubewell irrigated area applying the lowest amount of water (482.60 mm).

The water productivity diminishes from head ends to tail ends with the reduction of irrigation water. When more equal water distribution is achieved along the canal, difference of crop yield between head ends and tail ends gets reduced. Bhavanipur Deep Tubewell irrigated area achieved higher equity coefficient (0.7471) and crop yield difference between head ends and tail ends was found 30%, while tail end fields received 43.13 % of less irrigation water than head ends. So, there is much scope to minimize the inequity in water distribution by proper distribution of excess water from head ends to tail ends. Equitable water distribution is to be ensured for achieving better crop production. The difference of amount of water delivered at head and tail end must be reduced to minimum.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BCR	Benefit-Cost Ratio
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
BP	Bhavanipur
DTW	Deep Tubewell
DAE	Department of Agriculture Extension
DWAF	Department of Water Affairs and Forestry
D-N-D	Dhaka-Narayangonj-Demra
ET	East Togori
FAO	Food and Agriculture Organization
G-K	Ganges-Kobadak
GATT	General Agreement on Tariffs and Trade
GWP	Global Water Partnership
GKF	Grameen Krishi Foundation
HTW	Hand Tubewell
HYV	High Yielding Variety
IWRM	Integrated Water Resources Management
ICJ	International Court of Justice
IMT	Irrigation Management Transfer
IRR	Internal Rate of Return
IWM	Irrigation Water Management
LBP	Lower Bhavani Project
LTRIS	Lower Talavera River Irrigation System
MOSTI	Manually Operated Shallow Tubewell Irrigation
Mha	Milliion hectare
O& M	Operation & Maintenance
STW	Shallow Tubewell
SAAO	Sub Assistant Agricultural Officer
SAE	Sub Assistant Engineer
UAO	Upazila Agriculture Officer
WMA	Water Management Association
WMGs	Water Management Groups
WSS	Water Supply and Sanitation
WT	West Togori
WTO	World Trade Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the context of growing competition over finite and limited water resources, the notions of distributional equity and its impact on productivity have become paramount to the issues of integrated water resources management. The terms equity and water productivity are frequently voiced in most water related national and international forums and gatherings, Thus, several countries around the world, including Bangladesh, are busy institutionalizing these notions in their respective legislations, strategies, policies, and programmes. Significant variations exist in interpretation, estimation methods, and inherent data requirements for operationalizing the notions of equity and water productivity. This has often kept water resource managers and other stakeholders from gaining an encompassing and comparative overview of equity and productivity scenarios in various deep tubewell irrigation systems, particularly in developing countries, where data required by available methodologies hardly exist. To address this methodological gap, this thesis reviews various concepts associated with distributional equity and its impact on productivity and then applies pragmatic methodologies to assess them. This can be helpful in developing a comprehensive understanding of equity and productivity scenarios in deep tubewell irrigation system.

Both large and small scale irrigation systems in Bangladesh were initiated for higher irrigation coverage in order to increase food production through irrigation, flood control and drainage and thus improving the standard of living. Ground water based deep tubewell irrigation system is a crucial point for dry season irrigation. Especially some area where land is relatively high and in dry season ground water table becomes lower, deep tube-well irrigation is a must for those areas. Gazipur district is such a type of region where people face many problems in case of food production through irrigation due to the lack of irrigation water in Boro season. As this district is situated in the Bhawal Garh, where most of the places of this region are mainly highlands, so water is not available here in dry season. Moreover, the water table gets so lower that shallow tubewells are not capable for proper functioning in dry season. For this reason, deep tubewell irrigation is crucial for this region. Due to several technical and physiographical reasons, it was found from questionnaire survey that water is not equitably distributed among the stakeholders. So, inequity frequently occurs in the irrigated area, which ultimately influences the socio economic condition of the area.

Usually, any irrigation development area coherently suffers from unequal distribution of water and consequently embraces many types of social problems like head and tail ends conflicts, disputes over water pricing, environmental degradations, production disparity leading to poverty, dissatisfaction over water management issues, etc. Ground water based deep tubewell irrigation in Gazipur district is not an exception of this.

To increase agricultural production, the role of irrigation is pivotal. Inequity in irrigation access and system management can affect system sustainability and hence food production. So, it is obvious that unequal distribution of water in different parts of the project results in unequal productivity that again leads to social inequality disrupting the promotion of sustainable development and poverty reduction.

Equity is an increasingly important concern for irrigation, but has not been yet addressed sufficiently by studies in this area after its implementation. A focus on increasing productivity, however, often leads to an inattention to equity concerns. Hence, this study focuses on equity in irrigation and its impacts on different stakeholders in deep tubewell irrigation.

1.2 Objectives of the Study

The objectives of this study are:

i) to assess equity in water distribution among the stakeholders in deep tubewell irrigated area; and

ii) to identify the impacts of water equity in productivity.

1.3 Scope of the Study

The study will reveal the existing scenario of water distribution among the stakeholders. The study will also reveal the present socio economic condition of the study area. From the study, the way of socio-economic development of minor beneficiary can be identified which will ultimately lead to the development of socio-economic condition of the nation.

The research study is also supposed to evaluate the important part of the study i.e. productivity status of the stakeholders. The production loss due to irrigation affects the socio-economic condition of the stakeholders of the irrigated areas. The study will create the chance to assess the water equity in broader scale. The further study can be done for the improvement of water distribution management system to mitigate the inequity in water distribution among the stakeholders in deep tubewell irrigated areas which is not yet studied in Bangladesh.

1.4 Organization of the Thesis

This thesis contains five chapters. Chapter One: Introduction provides a detailed background information, objective and scope of the study.

Chapter Two: Literature Review covers previous research carried out in the field of Irrigation systems in Bangladesh, Water Distribution Methods, Criteria for Evaluation of Irrigation System, Equity and water, Equity concept in water management, Equity and efficiency issues in irrigation water distribution, water for irrigation , productivity etc.

Chapter Three: Study Area & Methodology contains detailed information on the study area including as study area location, climatic condition, soil types, topography and cropping pattern of the study area. It also contains the materials and methods for the present study. It looks at the different methods used for data collection. Two methods for assessment of water distributional equity such as Gini Coefficient and Equity coefficient have been applied. For productivity analysis field survey, semi-structured questionnaire survey techniques have been applied.

Chapter Four: Results & Discussions contains the results and discussion of the present study. Results and discussion describes description of the command areas of different deep Tubewells, Water distribution and crop yields of different fields in three deep tubewell irrigated areas. Moreover it describes the Factors affecting the inequity of irrigation water distribution and its impact on crop yield.

Chapter Five contains the conclusions and recommendations of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

For the first quarter century of the new millennium, two mutually reinforcing problems are faced by the people of developing countries: water scarcity and rural poverty. One of the learning lessons of agricultural development of the past is that an adequate amount of food is necessary but not sufficient for eradication of hunger. World grain production has tripled since 1950, and now totals approximately 1.87 billion tons per year (Brown *et.al*, 1999), more than enough to feed properly the world’s 6 billion people. Yet the United Nations Food and Agriculture Organization (FAO, 1999) reports that 790 million people, approximately one out of five in the developing world, are chronically hungry. The impressive increases in national per capita grain production, the result of green revolution has left million of pockets of severe hunger and poverty. The production of more “surplus” food could not solve the problem of hunger because the very poor are unable to buy it, though the prices are historically low (Gardner and Halweil, 2000). Meeting the crop demands projects for 2025, when the population is expected to reach 8 billion, will require an additional 192 cubic miles of water. 60 % of current fresh water diverted for human use goes to irrigation and many developing countries; irrigation’s share is as high as 90%. Water is essential for public health, irrigation, food production, industry, energy production, communication, recreation, fisheries, forestry and ecosystems. The efficient use of irrigation water has become vitally important, particularly in developing countries like Bangladesh where the greatest potential for increasing food production lies in irrigated areas. To fulfill the target of sufficient grain production irrigation systems along with other factors must be improved (Bhutta, 1990).

2.2 General Overview

Now a day, equity is become a critical issue in case of distribution of irrigation water. Besides, in many parts of the world, tail end farmers are facing problems with inequity incase of irrigational water distribution. For example, inequity in irrigation water distribution is very common phenomena in India and Africa. However, maintaining equity in irrigation sector is not an easy task especially in a developing country like

Bangladesh. In fact, Equity is an increasingly important concern for irrigation, but has not been yet addressed sufficiently by studies in Bangladesh. There are a few studies have been conducted regarding equity issue and its impact on productivity in Bangladesh. So, this chapter reviews the available literature related to the proposed study.

Most of the studies related to equity tried to distribute the water proportional to the land holding as observed in the northern India Warabandi system (Malhotra, 1982). However it may be possible that in a scheme with inequitable distribution of water, land towards the head of the system will have a high land price and as a result farmers are likely to have lower land holdings at the head end than the tail end farmers who may be able to buy more land with the same funds (Abernethy, 1986). In this case allocating water according to the land holding may not be fair. According to Levine & Coward (1989), for water allocation, the equity may be based on seniority of water rights of the irrigator, severity of water needed by crops, time or resource sharing on a canal, allocation based on land holdings and water allocation based on family size. The issues in equity in irrigation water management are multiple: whether there should be equity or inequity; the resources to be targeted for equity (whether it should be area irrigated, water delivered or expected returns in terms of crop production or net benefits) and the base of equity (land holding, water rights, water requirement of the area, land price, etc.).

Mukherjee (2004) found from the filed visit (from the beneficiary and officials response) that water at the tail end is completely unavailable and farmers at head end misuse the irrigation water by filling their ponds and doing other household works. Conflict between head and tail-end farmers have been continuing for several years during the irrigation season and sometimes it ends with deadly hostility (Mukherjee, 2004). Moreover, people within the project area have a thought in their mind that the structures and also the irrigation water belong to the Government and it is completely free, which mislead them to participate in water management and always blame BWDB for poor condition of the structure and other related problems (Mukherjee, 2004). In addition, performance of the tail ends of systems is generally poor, as these areas often do not get enough irrigation water because of inequalities in water distribution and inefficient management. So, overall, households in the head and middle reaches have benefited more from irrigation than the tail ends (Ahmed *et.al*, 2004).

2.3 Irrigation Systems in Bangladesh

Both traditional and non-traditional systems of irrigation are in existence in Bangladesh. Traditional irrigation characterized by non-mechanized indigenous techniques are being used by farmers for centuries for irrigating dry season crops. On the other hand, non-traditional mechanized irrigation is relatively recent and generally becoming significant in the last 20 years. For historical and institutional reasons non-traditional irrigation is classified into major irrigation system and minor irrigation system. Major irrigation system consists of gravity canal distribution system with the source of water from primary pumping plants or from gravity diversion schemes and also includes a second lift by low lift pumps. Minor irrigation consists mainly of small manual and powered pumps to lift surface and ground water (MPO, 1986).

2.3.1 Criteria for Evaluation of Irrigation System performance

Bhuiyan (1982) has suggested some criteria or indices for evaluating the irrigation system performance. These include crop yield, cropped area, water use efficiency, irrigation efficiency, relative water supply, and water adequacy and distribution equity.

Better picture of field situation can be obtained by using multiple criteria than by employing a single criterion. Garces (1983) has also proposed same type of criteria for evaluation of irrigation system (Figure 2.1).

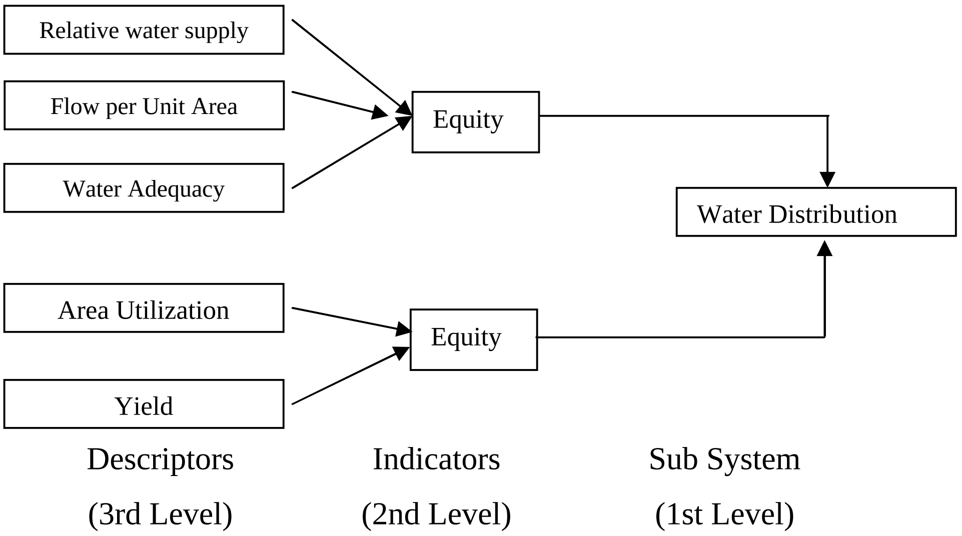

Figure 2.1 Indicators and descriptors proposed in Evaluation of the Irrigation system (Garces, 1983)

Early (1981) mentioned the most often used indicators to evaluate performance of irrigation system that include efficiency, equity and productivity.

Biswas (1984) found two factors responsible for low irrigation efficiency. These factors are – (i) most inadequate funds available for operation and maintenance (O& M) and (ii) O & M assignments are often staffed by inexperienced personnel.

Biswas (1985) has suggested that irrigated agriculture development projects can be examined at four levels for monitoring and evaluation. These are:

i) planning, design and construction of physical facilities;
ii) operation and maintenance of water control facilities;
iii) agricultural production; and
iv) socio-economic impacts of irrigation project.

The following engineering criteria are identified that can simplify the evaluation procedure of an irrigation system (BARC, 1985):

i) adequacy, reliability, efficiency of water delivery;
ii) equity in water distribution;
iii) operation hours; and
iv) frequency of breakdowns.

Gopinath (1985) evaluated an irrigation system located at the Himachal Pradesh State of India analyzing technical, economical and social parameters. The major technical factors examined and analyzed in the evaluation were assessment of the nature and suitability of structures, potential and actual area irrigated effectiveness of water delivery in quantity and timeliness.

Haq *et.al*, (1985) evaluated the performance of G-K project using the parameters: pumping plant efficiency, conveyance efficiency, on-farm water use efficiency, command are efficiency, adoption of high yielding varieties and input use and benefit-cost ratios of cropping pattern.

Jones (1985) has proposed a project evaluation process consisting of four parts: (i) a socio-economic survey to provide data needed to assess the economic and social impact of the project, (ii) a cost study to provide data on investment and operation and maintenance (O & M) cost of the project, (iii) a management and engineering study to assess any organizational or engineering problems and to provide recommendations on how to overcome them or to prevent them in future similar projects and (iv) an economic evaluation (BCR, PB, IRR) to assess the overall economic impact of the project, to identify constraints and to recommend ways of overcoming them.

Baset (1985) has suggested the following criteria by which performance of an irrigation system can be assessed that include (i) total area covered, (ii) yields, (iii) irrigation cost per unit are, (iv) number of farmers participating and (v) number of days that an irrigation device is out of order.

2.3.2 Institutional Issues in Irrigation

There are many institutional issues which may affect the allocation of water resources as well as the efficiency of water use in an irrigation system. These include the issues of participatory management approaches, labour mobilization, water allocation, payment for services and infrastructure, conflict resolution and water rights (Tapay and Early, 1981). When an irrigation system has been developed there is a need for formal and informal rules (institutions) and regularized patterns of interactions (organization) in the system in addition to its physical facilities.

Wickham and Takase (1976) mentioned that institutional problems may be because of inadequate self-servicing communication between farmers and the irrigation personnel of the government agency. They also said that unauthorized behaviour on the part of farmers often goes unpunished but this unauthorized behaviour of farmers is often a reflection of farmers’ need for water under different circumstances.

A social organization in an irrigation system can be primarily responsible for the maintenance, repair, and allocation of water and resolution of minor disputes. These tasks can be accomplished by the Government through an agency or by the farmers or by involvement of the both government agency and farmers. In an irrigation system problems like small holding sizes and hence large number of users per unit area, combined with poor administrative capacity due to lack of adequate or efficient staff make the rotational system of water distribution much more difficult. But creation of water users' associations with the functions of conflict regulation, control and coordination may overcome the above problem (Huppert, 1987).

It requires more input from the systems personnel in terms of farmer's communication, credibility, and extending modern concepts of water management to build up farmer participation and to increase their responsibility in irrigation activities (Wickham *et.al*, 1981). Farmers can participate in irrigation activities at two levels. One is at the farm level i.e. the routine water delivery and distribution; and the other are at a higher policy level. Elected representatives of farmers at the policy level in Taiwan discuss matters pertaining to the larger issues of water apportionment, cropping pattern, setting of membership fee rates and the farm level farmers are grouped in small numbers and take turns in getting water from a control turnout.

Gonzales *et.al*, (1988) presented observations on how Irrigators Association (IA) operates and manages pump irrigation system in Philippines. They hoped that farmers will be able to operate and manage any irrigation system where they will be properly guided and motivated. The key factors for the success are: the procedure of organizing the farmers' into an association; giving necessary training on leadership, financial and system management; imposing relevant policies and setting a standard operation procedure for them to follow.

A study on farm water distribution was conducted by Moya (1979). Detailed documentation of problems in water distribution within the tertiaries of lower Talavera River Irrigation System (LTRIS) was undertaken during the 1979 dry season. It was reported that the physical factors that influence the water supply to the farms are: (i) paddy elevation relative to turnout bed elevation, (ii) physical access to farm ditches, (iii) soil type and (iv) farm ditch density. It was pointed out that giving careful considerations to all factors influencing design accuracy but neglecting topography could result in costly errors that are responsible for the occurrence of some farmer negative irrigation behaviour. Other factors mentioned are social and political, legal and environmental, economic and production. The success of the system depends ultimately on its social acceptability and farmer involvement.

From this review it can be concluded that effective communication between the farmer and the system personnel is essential for efficient operation and management of an irrigation system. Proper guidance and motivation are required to maximize the farmers' participation in operation and maintenance of the system. The reliability of water supply in the system should be ensured to provide an environment for increased water fee collection. Three broad strategies must be taken to water scarcity for food production:

i) Invest in infrastructure to increase the supply of water for irrigation, domestic, and industrial purposes;

ii) Conserve water and improve the efficiency of water use in existing systems through reforms in water management and policy; and

iii) Improve crop productivity per unit of water and land through integrated water management and agricultural research and policy efforts, including crop breeding and water management for rainfed agriculture.

2.4 Water for Irrigation

Irrigation would continue to play an unquestionable role in achieving food self sufficiency, creating grain surpluses, stabilizing food prices, sustaining agricultural growth, absorbing labour force in rural areas, and alleviating rural poverty; all of which are vital for food security. Recent research by many scholars and institutions have shown that the future water supplies are going to fall short of the demand from different sectors, with a differential negative impact on agriculture, if people continues to follow the same trajectory of water resource development and water use as in the past. Given the political economy of growth based on urbanization and industrialization, there will be a greater pressure to allocate an increasing quantum of water for industrial and municipal uses. This will pose a threat to food security at the aggregate level (Kumar, 2003).

It is unfortunate that irrigation schemes which have attempted to move water across the equity divide in the past and the apartheid government was not short on such schemes - have rarely been of much success. Indeed there are many resounding failures too easy to point fingers at. The reasons are often obvious, and linked to social, institutional, infrastructural and especially ownership causes. There are exceptions, but little to suggest that this is the route to take. There remain a number of 'water for irrigation' allocations which have never been taken up and the current approach, in addition to attempts to revitalize some previously failed schemes, is to focus first on getting communities to take up this allocated but unused water (an example being the Mhlathuze catchment) (Versfeld, 2003).

2.5 Water Distribution Methods

Water distribution methods may vary from system to system and from place to place within systems due to the differences in the size of water supply, topography, crops, climate and farmers' custom. There are several methods of water distribution but two methods are considered to be major distinct approach to system operation-continuous or simultaneous distribution and rotational distribution (Tabbal, 1981).

In the continuous method of distribution, water is continuously distributed to main, secondary and tertiary canals and farmers receive water either continuously or at their convenience by an arrangement made among themselves. This method is generally practiced when water supply is not limiting and has the advantage of minimum canal size and simpler operational procedure. In the rotational method of distribution, water is distributed to the canals at a certain interval and farmers receive water for definite periods in a rotation at pre-fixed intervals. Rotation of water in the system can be done in three ways (Chow, 1960): (i) rotation by sections in the main canal i.e., conveying the water to different sections of the main canal by rotation, (ii) rotation by sections in the secondary or tertiary i.e., the flow in the main canal will be continuous and rotation by sections of the secondary or tertiary canal or (iii) rotation in the tertiary outlets i.e., the flow will be continuous in main, secondary and tertiary canals and rotation will be among the outlets or the tertiary canal. The last type of rotation has been found the best than other two types of rotation because the first type requires same capacity of the main canal throughout its length, and second type requires same capacities of secondaries and tertiaries throughout their whole length but in the third case the capacity of main, secondary and tertiary canals gradually becomes smaller towards the tail.

The rotational distribution has the advantage of better regulation ad even distribution of water over the head, middle and tail reaches of the canal system and making the farmers more reliable on the system even during drought and dry season (Kaewkuiya, 1980).

This method again requires competent irrigation personnel, better farmers' cooperation and has the problem of weed growth (Khan, 1978).

Several studies have been undertaken on the comparison between these two delivery methods. Chow (1960) in a study in rotational irrigation in Taiwan found that the yield is higher for rotational irrigation than for continuous irrigation and the amount of water savings by rotational method is at least 20 to 30 percent and sometimes it is as high as 50 percent.

Wickham *et.al*, (1974) in a field study to compare delivery methods in the Philippines reported a slightly higher yield for rotational method.

'Warabandi', a rotational method of water distribution has been in existence in the irrigation system of North-west India and Pakistan from the start of major irrigation development and it is observed that the water utilization efficiency of the irrigation system is much higher where this method was practicing (Berkoff, 1987). This method is a simplified water distribution method and ensures a reliable, timely, predictable and equitable water allocation. The positive results of this system in North-West India encouraged in mid 1970s to promote the introduction of rotational water supply in a number of projects throughout the country (Huppert, 1987).

Kathpalia (1980) studied the present practice of water distribution in different irrigation project in India (Punjab, Haryana, Rajasthan, Uttar Pradesh, Bihar, Tamil Nadu, Gujrat and Andhra Pradesh). He reported that the main canals of all irrigation systems run continuously but a wide range of practices are followed in different projects, with regard to rotation of supplies in branches, distributaries and minors up to the outlets.

Palanisami (1984) in a study in Lower Bhavani Project (LBP) which is a large canal irrigation system in Tamil Nadu State of India critically analyzed the water distribution method in the system. The pattern of water distribution occurs at three principal levels:

i) at the higher level year to year rotation in the main canal;

ii) at the middle level with rationing among different seasons; and

iii) at the farm level with the rotation among the farmers.

Murray, *et.al*, (2000) reported the current pattern of water distribution in Sindh irrigation system which was unfair and inequitable. From the head of the system at each level of operation, increasing unreliability in volume and timing of deliveries were experienced. While water users always feel the effects, the causes may be well above their level of responsibility, even with the establishment of Farmer Organizations who will take over full control of operation and maintenance at secondary canal level. To accomplish the restoration of effective and fair water distribution within the Sindh irrigation systems several enabling conditions are required. According to them, four seem to be particularly important and are likely to underlie the success or failure of current activities and these are i) Water Rights and Due Share, ii) Measurement Capacity, iii) Transparency and iv) Communication.

Brewer, *et.al*, (1997) explored the relationship of water distribution rules to water distribution performance. Specifically, they found two arguments from various irrigation systems in Tamil Nadu, India:

- If the water distribution rules of an irrigation system define a pattern of water delivery that does not match technically feasible irrigation services desired by the users, then the users, often in cooperation with system managers, will modify or subvert the rules to bring water delivery into accord with their desires. Subversion of the water distribution rules will adversely affect water delivery performance, especially equity of distribution, and will raise the cost of irrigation to the users.

- Inconsistencies in the water distribution rules create difficulties in system operations that lead to inefficient and inequitable water distribution performance. Farmers and system managers in the Irrigation Systems systematically subvert water distribution rules that interfere with delivering water as desired by the farmers. This subversion leads to loss of control by the system managers, to inequitable and unpredictable deliveries, and to raising the transaction costs of getting water.

2.6 Equity and Water

According to Chambers (1988), equity is not just equality in the sense of providing equal amount of resources to users over different periods. Equity implies equality, fairness and even-handed dealing. Equity deals with the distribution of water amongst users. Equity is based on a principle of fairness that is accepted by all members of the community involved in sharing a common resource. The fairness reflects the values of the society and does not have to be based on equal share. Some people may get a larger share of water than others either due to prior rights, in compensation for more input in system construction or maintenance.

Water equity is not just about how much water people have access to for basic needs or livelihoods, but also the ease and security of that access. A full consideration of equity should go beyond matters of the (absolute, relative, marginal) price of water, to also include differences in relation to labour burden, quality of water, security of access, historical contributions to maintenance of water services (through conservation and infrastructure), vulnerability to shocks or risks, the role different groups play in decision making and so on.

According to Sampath (1989), Water equity has social, economic, spatial and temporal dimensions. Depending on the scale of analysis distribution of water can vary between:

- Sectors of an economy (e.g., industry versus agriculture),
- Countries on a river,
- Upstream-downstream communities along a water course,
- Households reliant on a common water source.

Socially we can understand water equity in terms of differences in access and use between:

- men and women,
- ethnic majorities and minorities,
- Indigenous and non-indigenous,
- Rich and poor,
- Livelihoods,
- Rural and urban people,
- Present and future generations.

2.7 Equity Concept in Water Management

Sheng, (2002) stated that water is life, water is power, and water is social struggle. In a world of growing scarcity and increasing inequality between the water haves and have-nots, the issues of equitable water distribution in irrigation and appropriate water management are likely to become two of the most urgent issues in the 21st century.

Equity consideration in natural resource management is an important requirement for the promotion of the goals of sustainable development. Water is an indispensable resource and how this natural resource is managed has critical implications on economic development and social prosperity. In pursuing integrated water resources management (IWRM), the GWP (2000) stresses that equity should be among the overriding criteria that take into account of social, economic and environmental conditions. To make progress towards the goals of sustainable development, decision makers need to have clear understanding of what is implied by equity. How to absorb equity consideration in policies and mechanisms of IWRM has been discussed in GWP (2003). Equity concern in natural resource management has been discussed by Deshpande *et.al*, (2004).

Water management decision should ensure that no one is deprived of prevailing opportunities for livelihoods, and particular attention is needed to the water dependent subsistence activities. The equity concept implies that water management decision should be free from bias and should ensure social justice in the distribution of social costs and benefits of water management project. Equity also implies protection to water rights, and access to safe drinking water is to be ensured as it is a basic human need. Water resources are common property resources. Water management project should not be such that is serves the interest of a group of the society but adversely affect the interests of others in the community. Provisions are required to protect the needs of vulnerable groups and the prevailing livelihood opportunity. Focused attention to socio-economic vulnerability of low-income groups such as marginal farmer, fisherman, boatman, etc. is essential for fairness in decision making. Equity requires that the interests of people living in poverty need to be considered and affirmed (GWP, 2003).

According to Human Rights and Equal Opportunity Commission (1994) Human intervention, whether through technology or governance, alters the allocation of water.

Whilst there is no ‘natural’ distributive justice in water availability, with significant variations between seasons, upland and lowland areas, and regions, human regulation sees water re-distributed according to the economic and social objectives of those who control structures at a given scale. Associated with the physical control of water is a social, economic, institutional and policy process of governance which greatly determines the extent to which water is distributed in an equitable, efficient and sustainable way. This process of negotiation between various actors, whether they be neighbours sharing a well or countries sharing a large river, is shaped by underlying issues of power, culture and values, and thus differs greatly according to context. Intervention into such a context by ODA organizations, whether in the area of urban or rural water supply and sanitation (WSS), water policy priority setting or river basin management, has the potential to influence the equitable distribution of water, in positive and negative ways.

2.8 Importance of Equity in Irrigation Water Distribution

Water is a scarce resource in many tropical countries and it is advisable to achieve the maximum productivity in its use. The objective of social justice in these countries in the irrigation scheme is very important and many people’s livelihoods depend on irrigation supplies. Thus, the allocation of water to achieve the maximum productivity is not the only objective but also to allocate those resources such as water and area equitably according to the prevailing equity objectives is necessary to ensure social justice. Usually, inequality of water distribution depends on the economical condition of the farmer. As for example, the relatively poor farmer gets less quantity of water than the economically solvent farmer. It is now widely recognized that irrigation has many direct and indirect impacts on the livelihoods of the poor, and that it is important for poverty reduction. In a large-scale irrigation project, by improving equity of access to water can enhance the livelihoods. However, the direct impact is severely reduced by poor management of water distribution at a local level. Even within small areas some farmers can get an adequate supply of water while others have insufficient water and may even be forced to abandon their crops. If water were distributed proportionately to the crop needs for area farmed, then poor farmers would be able to make better use of their land (Sheng, 2002).

Sheng (2002) stated that Scarcity of resources does not cause problem more serious than inequity in distributing such resources to the public. To share the scarcity of water, development of rotational cropping and irrigation in Taiwan, particularly during the period of 1950s to 1980s had fulfilled its designated contemporary goal of producing adequate food to meet the need of that era with comparatively small amount of water. This achievement might attribute to the technical renovation on water management and heavy investment in the improvement of irrigation facilities. Contemplatively, this practice had enabled water controllers to convince water users that the scarcity of water is being distributed equitably to a maximum extent so that the use of water in the field could maintain orderly, of which might ascribe equally or even more than the technical amelioration and heavy investment to the success and sustainability of water management. According to Sheng (2002), if the practice of rotational cropping and irrigation in the last forty years in Taiwan is deemed to be successful, the crystal of success is equity; not the technical amelioration and heavy investments. Without the spirit of equity, this practice would not be sustainable.

Kumar (2003) argues that the allocation of tradable private property rights in water will lead to overall enhancement in the economic efficiency of water use and higher productivity in agriculture. The enforcement of tradable private property rights will ensure equitable access to water in water scarce regions for agriculture, and also for all classes. This is critical from the point of view of local and domestic food security. Moreover, as in water abundant regions, it can also provide the landless farmers with sufficient incentives to invest in development and transfer water for highly productive uses elsewhere, and generate income. The volumetric pricing of water from public canals and unit pricing of electricity in the farm sector with carefully designed structures, along with properly enforced water rights, can, not only improve the physical efficiency of the water use in agriculture, but also provide the rich and poor farmers with equal income earning opportunities from farming.

2.9 Factors affecting Inequity

Zaag (2007) stated that because of asymmetry the equitable sharing of water resources between upstream and downstream users will always imply that upstream users will have to forego some of the potential water benefits. In this context it is important to recognize and acknowledge the asymmetrical situation in canal basins, whereby downstream uses may not impact upstream users, if at all, but upstream uses do cause downstream impacts.

Another aspect that is frequently linked to watershed and catchment management problems is the existence of large power differences between actors. It is often suggested that social homogeneity facilitates collective action (Turton and Henwood 2002).

2.10 Effect of Inequitable Water Distribution

Many studies have also been undertaken to find out the problems of water distribution in an irrigation system. Early (1981) described the generally observed problems in gravity irrigation systems in Philippines, Pakistan and Thailand. There is a general tendency for a mal-distribution of water to occur over the length of the irrigation system resulting in serious deficiencies at the tail reaches and excess water at the head reaches.

Jamtsho (2002) find that the upstream, downstream water sharing discrepancy hampers the canal conveyance efficiency improvements and also the variation in yield i.e. the upstream farmers get greater yields and the downstream farmers get fewer yields.

Yeshy & Bhujel (2006) found that one of the major factors contributing to the conflicts within seven communities is due to inequity in resources sharing, which is purely ruled by traditional systems and also due to a small volume of stream water, which is not sufficient for irrigating rice fields in the seven villages. Food security is threatened without an appropriate conflict resolution mechanism in place between these communities. There is a lack of equity in water resource allocation in the Lingmutey Chhu watershed at various levels. First, the people who settled first in the watershed have more access rights to water resources, than those who settled later. Secondly, communities located nearer the water resource have more rights to the resource than those who live further away from it. This is resulting in conflicts both between and within communities.

Taylor (1976) in his study of Asian gravity flow irrigation systems cited some problems associated with the inequitable water distribution in the system level.

These are:

- iv) the system is not operated with full effectiveness
- v) tendency of excess use of water at head reaches; and
- vi) schedule of water delivery is inadequately planned or not adhered to in practice.
- vii) Upstream farmers divert the full flow in the canal without respecting the needs of the downstream farmers.

Rosegrant, *et.al,* (2002) mentioned that Water scarcity will get much worse if policy and investment commitments from national governments and international donors and development banks weaken further. The Global water crisis scenario, predicated on the worsening of a number of already evident trends, would lead to a breakdown in domestic water service for hundreds of millions of people, devastating loss of wetlands, serious reductions in food production, and skyrocketing food prices that would force declining per capita food consumption in much of the world. Failure to adopt water-saving technology improvements and policy reforms could make demand for non-irrigation water grow even faster than projected, further worsening water scarcity.

2.11 Productivity

Emerging approaches to water resources development and management typically highlight equity and productivity as two main objectives. In the context of integrated water resources management within a river basin, managers and stakeholders often need a comparative assessment of different options for water augmentation and/or allocation. Pitting such options against predefined objectives, such as equity and productivity, requires an assessment of the effects that available options will have on these objectives. Available documentation indicates that not only does the interpretation of such objectives vary widely, but also the available methods for assessing equity and productivity run into significant limitations in the availability of adequate data. This limitation has largely kept decision makers from gaining a comprehensive overview of equity and productivity scenarios, whether within or across sectors, that could facilitate better-informed decisions (Prasad *et.al*, 2006).

The outcomes of the analysis of Kumar and others (2004) showed that limiting water application through “water delivery control mechanisms” and “micro irrigation systems” can lead to enhancement in water productivity. But the first type of intervention would result in reduced yield due to reduction in consumptive use of water in most situations where the yield response to irrigation was positive. The strategy can work in regions where water is scarce, and where scope exists for expanding the area under cultivation exists. But in situations farmers are applying excessive irrigation leading to yield losses, simple water delivery control would result in both yield and water productivity gains. Further analyses show that improving the quality of irrigation – through intermediate storage systems and reliable power supplies would result in enhanced yield and water productivity. Finally, growing certain crops in regions with low level of aridity and medium to high rainfall would result in higher water productivity for the same crop as compared to that in regions with higher aridity and low rainfalls.

According to Ahmad *et.al*, (2004), despite reasonable economic growth, about half of Bangladesh's population still lives in poverty and about a third in extreme poverty. The problem is worse in rural areas, where huge inequities in water distribution hit the poorest hardest. Agricultural productivity is low and irrigation systems are not performing as well as they should be. In reality, the performance of two irrigation systems is less satisfactory than others. Irrigation intensity (the ratio of net irrigated area to the designed command areas) is low, varying widely across seasons and reaches of the systems. Crop yields per hectare are relatively low as well, mainly because farmers do not use enough productivity-enhancing inputs. In addition, performance of the tail ends of systems is generally poor, as these areas often do not get enough irrigation water because of inequalities in water distribution and inefficient management. So, overall, households in the head and middle reaches have benefited more from irrigation.

Roost, N. (2003) stated that equity is another essential issue that deserves some additional comments. Although the ‘high efficiencies’ scenario achieves a slightly higher overall production than the ‘equity’ scenario, it does so in a much less equitable manner. This scenario actually disadvantages downstream divisions in a both direct and indirect way. The first, direct disadvantage relates to the defined upstream priority for main canal water allocation. The second disadvantage is a side effect of the former: downstream divisions are allocated less water in an ‘efficient’ canal system, which results in limited groundwater recharge, and thus limited potential for sustained groundwater use. Yet, it is precisely in such situations of unfair canal water allocation that groundwater is more critically needed downstream. Beyond the evident social benefits, improving water allocation equity is also a way to raise water productivity in the study area.

Some authors (Abernethy, 1986; Khepar *et.al*, 2000) have argued that the equitable distribution of water is also necessary for maximizing productivity. They argue that the farmers at the head of the system generally apply more water than needed for potential yield and excess water will not improve the productivity but will reduce it. If instead the excess water were diverted to another part of the scheme receiving less water than needed to produce potential yields, then the production would have increased. From field survey it was found that when water is scarce and not managed properly, the productivity and equity become conflicting issues, as observed by Gorantiwar and Kalu *et.al*, (1995).

2.12 Optimum Performance with Limited Water Supply

Gorantiwar & Smout (2005) found the non-uniformity of soils, weather, fields, cropping pattern and canal systems in most surface irrigation schemes makes irrigation water management complex, but optimum performance is important particularly in irrigation schemes with limited water supply in the semi-arid region. Often the irrigation managers or authorities of these heterogeneous irrigation schemes also need to deal with different allocation rules. The allocation plans and the corresponding water delivery schedules during the allocation process were estimated with the help of a simulation–optimization model for different allocation rules based on cropping distributions (free and fixed), water distributions (free and fixed-area proportionate), irrigation depth (full, fixed depth and variable depth irrigation) and irrigation interval (from 14 to 35 days). The performance measures of productivity (in terms of net benefits and area irrigated), equity (in water distribution), adequacy and excess were assessed for these different allocation plans and schedules. These were further compared with the performance measures of the existing rule (fixed depth irrigation at a fixed interval). The analysis revealed that these performance measures are in some cases complimentary and in other cases conflicting with each other. Therefore, it would be appropriate for the irrigation managers to understand fully the nature of the variation in performance measures for different allocation rules prior to deciding the allocation plans for the irrigation scheme.

Managing water for food security needs a multipronged approach. At the aggregate level, the irrigation water supplies and the demand for irrigation need to be balanced. This offers two challenges: water supply management and judicious inter-sectoral water allocation. At the next level, greater equity needs to be ensured in accessing and controlling water from aquifers and public systems. At the third level, farmers should maximize production from available land and water resources with the least environmental consequences such as land degradation and groundwater depletion, through efficient resource use. The existing water resource development technologies have a great bias towards the rich. The author also shows that under the current pricing system for electricity in the farm sector, the conventional water saving technologies favour the rich with greater opportunities. Micro-irrigation technologies can greatly enhance the ability of the poor to maximize production from limited water supplies they have access to. Integrated land and water management practices such as organic farming and agronomical activities would be the key to enhancing land and water use productivity on a sustainable basis; but small and marginal holders would face severe constraints in adopting them. Subsidies are needed for poor farmers to adopt technologies that would reduce their dependence on biomass, increase biomass use efficiency, and invest in integrated land and water management techniques to improve land and water use productivity (Kumar, 2003).

CHAPTER THREE

STUDY AREA AND METHODOLOGY

3.1 Area and Geographical Location of the study area

Gazipur Sadar is an Upazila of Gazipur District in the Division of Dhaka, Bangladesh. It is the largest upazila in terms of population and is the second largest Upazila in terms of area in the district. It is comprised of former Joydebpur and Tongi thanas. The upazila occupies an area of 446.38 sq. km. including 6.96 sq. km. river area, 1.25 sq. km. large pond area and 54.52 sq. km. forest area. It is located between $24^{0}01'$ and $24^{0}21'$ north latitudes and between $90^{0}18'$ and $90^{0}34'$ east longitudes. The upazila is bounded on the north by Sreepur upazila, on the east by Sreepur and Kaliganj uapzilas and Rupganj upazila of Narayanganj district, on the south by Uttara thana and Mirpur thanas of Dhaka City and on the west by Kaliakair and Savar upazilas. Gazipur Sadar has 8 Unions/Ward, 1 (One) paurasava, 213 Mauzas/Mahallas and 244 villages (Banglapedia, 2007).

3.2 Population and Occupation

As of the 2001 Bangladesh census, Gazipur Sadar has a population of 866,540 but as of the 1991 Bangladesh census the population was 419,790. Males constitute are 54.44% of the population, and females 45.56%. The town has a population of 123531; male 52.52% and female 47.48%. According to population census 2001, population density in the upazila was 1,941 persons per sq. km. which was more than that of 1991 by 623 persons per sq. km. Decadal growth of the population of Gazipur Sadar upazila during 1991-2001 was less than that of the previous decade by 8.7 percentage points (BBS, 2006). The main occupation of people of Sadar Upazila are Agriculture 26.63%, agricultural labourer 7.68%, wage labourer 2.94%, industry 1.41%, commerce 14.71%, transport 4.73%, construction 1.79%, service 28.31%, Foreign Service 7%, others 4.8% (Banglapedia, 2007).

3.3 Climate

The climate of the study area is tropical monsoon which is more or less the average for the country as a whole, characterized by the two distinct seasons- the wet season from

May to October, the dry season from November to February and the summer season during the rest of the year. The average temperature of the project area varies between 5.6^{0}c to 42.2^{0}c. The lowest average temperature is about 13^{0}c which was found from December to January. During April-May, hot-waves are felt by the people of Gazipur. High wind speed is observed during March to April (BBS, 2005).

Daily evaporation rate is higher during pre-monsoon season (March and April) and lower during winter (December and January). Total annual evaporation is about 1350 mm. From the long term statistics (1961-1990) of Bangladesh Meteorological Department (BMD, 1996), Dhaka it is also seen that, the monthly distribution of rainfall in the study area follows the usual pattern of monsoon with heavy rains starting in May and ending in September and very little or no rainfall during the rest of the year (Figure 3.1). Monthly Rainfall is very low (less than 75 mm) from November to March. In the study area, the mean annual rainfall is 1515 mm, which is lower than the national average of 2540 mm (BBS, 2005). In Gazipur, the rainfall pattern shows a uni-modal characteristic. About 70% of the annual rainfall occurs between June and October (BBS, 2005) and 30 percent occurs in the rest of the year. Therefore, agricultural production cannot be carried out throughout the year in the study area without irrigation.

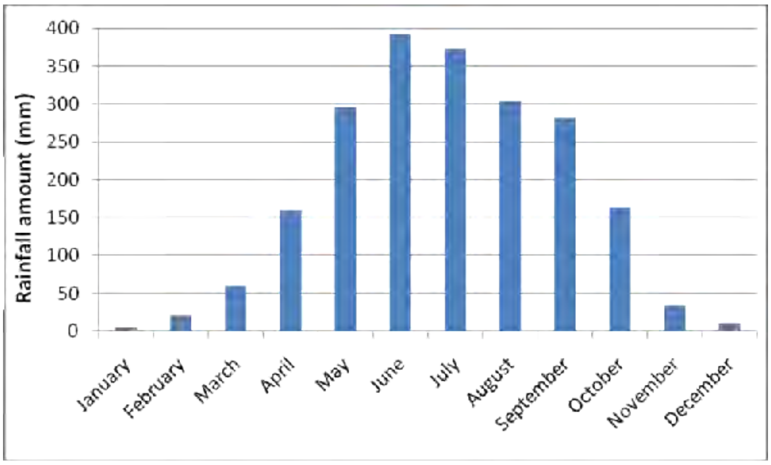

Figure 3.1: Monthly Rainfall of 30 years average

3.4 Geology

Gazipur sadar upazila is formed with three agroccological zones i.e. a) Madhupur Tract, b) Mixed Madhupur Tract and young Brahmaputra Flood plain and c) Young Brahmaputra Flood plain. Figure 3.2 shows that these three zones have covered about

68.0, 22.0, and 1.4 percent area of the Upazila consecutively. The rest portion of the area is covered by household area, ponds and rivers and canals. Besides, the soil characteristics of the study area can be described by the geological succession consisting of a series of inter-bedded silt or clay and sandy layers.

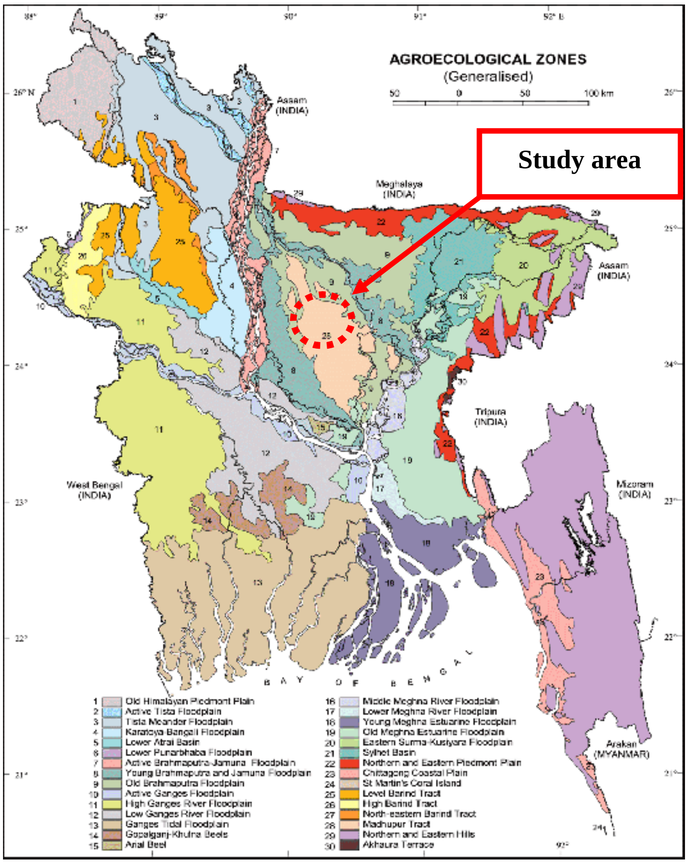

Figure 3.2: The map of Agroecological zone showing the study area

It is observed from the geological cross section that inter-bedded layers of very loose to loose and loose to medium dense non-plastic fine sandy silt and silty fine sand exist in the area. Layers of very loose to loose and very soft to soft silt or fine sand mixed with trace to little silt and traces of mica are also observed. Inter-bedded layers of medium dense silt and fine sand having granular composition and plasticity characteristics similar to the upper silt and fine sand layers underline these layers.

a) Madhupur Tract: Total area of this zone is about 28336 hectare, almost 68 percent of the total upazila. The zone exists in all upazillas. The soil consists of primitive materials named “Madhupur kardam”. The topography of this area is mostly serpentine type with valleys.

b) Mixed Madhupur Tract and Young Brahmaputra Flood Plain: the total area of this zone is 9186 hectare, almost 22 percent of the total upazila and also exists in all upazillas. This zone has some non-plained danga (hillocks) and bills.

c) Young Brahmaputra Flood Plain: The total area is 576 hectare which is 1.4 percent of the total area. Mirzapur and Basan Unions are in this zone. Most of the areas in this zone are plain (BARC, 2005).

3.5 Soil Status

The area consists of inter-bedded layers of very loose to loose and loose to medium dense non-plastic fine sandy silt and silty fine sand. Organic matter content generally exceeds 2% in the top and subsoil. Available moisture holding capacity y is inherently low. They have high CEC, and general fertility level is medium to high.

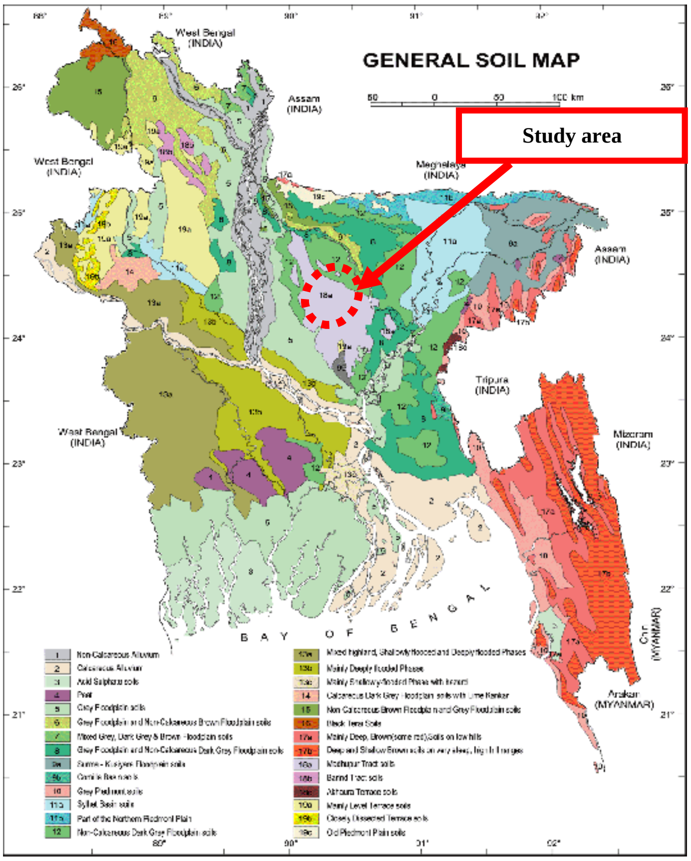

Figure 3.3: General soil map showing the soil of study area

Figure 3.3 shows that the soil status of Gazipur Sadar Upazilla mainly consists of 12 and 18a type soil categories where 12 types mean Non-calcareous Dark Floodplain soils and

18a means Madhupur Tract soils. A Madhupur tract soils is the major general soil type. The moisture holding capacity of this type of soil is Poor and Surface water drains out very early (SRDI, 2007).

3.6 Land Use Pattern

Total land area of Gazipur Sadar Upazilla is about 41300 hectares whereas cultivable land is 30645 hectares, fallow land 1140 hectares and forests 5052 hectares. Single crop is 49.3% of total crop production whereas double crop is 26.2% and treble crop land 24.5% and land under irrigation 42%. The total landless people is almost 21.1% of the total, marginal 49.4%, intermediate 24.3%, and 19.20% rich; per capita land 0.05 hectares (SRDI, 2007).

3.7 Hydrology

Gazipur Sadar Upazila is situated in the north central hydrological region of Bangladesh. The river and drainage system of Gazipur Sadar Upazila is characterized by the rivers forming its boundary- the old Brahmaputra, Shitalakshya, Turag, Bangshi, Balu, and Banar. The main sources of surface water in this region are river, canal and ponds. Turag river flows over the west and southern boundary of this upazila, Lubundhaha river flows to the west inside this upazila and Balu river flows over the eastern boundary of the upazila. Besides, there are some dead river and bills in this upazila. Water can be stored in this water body for the irrigation. The water bodies are used for various purposes including washing, bathing, waste water disposal and irrigation (BARC, 2005).

3.8 Cropping Pattern and Production

Four improved cropping patterns such as i) BRRIdhan28 – Fallow - BRRIdhan30, ii) BRRIdhan28 -Fallow - BRRIdhan31, iii) BRRIdhan29 – Fallow – BRRIdhan30 and iv) BRRIdhan29 – Fallow – BRRIdhan31 were evaluated in the farmers field along with the farmers’ existing major cropping patterns BR14 – Fallow – BR11 and BR14 – Fallow – Pajam in six blocks under Sadar upazilla of Gazipur district. In all location, pattern BRRIdhan29 – Fallow – BRRIdhan31 gave higher grain yield and higher gross margin compared to other patterns. The replacement of BR14 in Boro season and BR11 and

Pajam in T. aman season by the varieties BRRIdhan29 and BRRIdhan28 in Boro season and BRRIdhan31 and BRRIdhan30 in T. aman season. In a Boro-Fallow-T. aman cropping pattern in the medium highland would be a better option to increase the agro-economic productivity of the existing system (Quddus *et.al*, 2004). The dominant cropping pattern in these lands is Boro-Fallow-T. aman which is about 22% of the total land occupied by 34 major cropping patterns. The productivity of the existing cropping pattern i.e. Boro-Fallow-T. aman is low (Mandac *et.al*, 1987). Vivekananda (1999) reported that the growth rate in productivity varies by zones and periods and the production of cereals depends on irrigation and the seeds of high yielding variety. In the study area, by variety, BR14-Fallow-BR11 and BR14-Fallow-Pajam are the most dominant cropping patterns for double cropped rice lands.

3.9 Location of Deep Tubewells and Sample Fields

For the assessment of equity and its impact on productivity and socio-economy three deep tubewell command areas were selected from the three Unions of Gazipur Sadar Upazilla and the figure 3.4 shows the location of three deep Tubewell command areas.

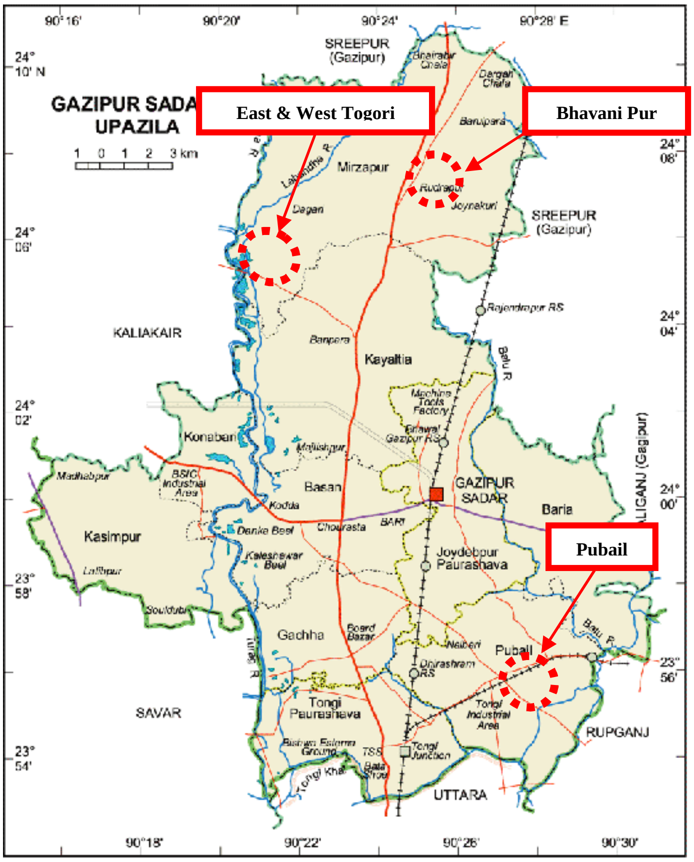

Figure 3.4: Location map of the deep tubewell irrigation areas.

The position of selected 36 sample fields from three deep Tubewell command areas i.e. East Togori, West Togori and Bhavanipur are shown in Figure 3.5, 3.6 and 3.7 respectively.

Figure 3.5: Satellite Image Showing DTW irrigated area and selected sample fields of ET

Figure 3.6: Satellite Image Showing DTW irrigated area and selected sample fields of WT

Figure 3.7: Satellite Image Showing DTW irrigated area and selected sample fields of BP

3.10 Methodology

A number of attempts have been taken by several researchers to evaluate the equity in resources use. Christianson coefficient, Interquartile ratio, Modified interquartile ratio, Coefficient of variation, Theil’s index, Gini coefficient and Equity coefficient are the most well-known equity assessment tools (Gorantiwar & Smout, 2005). But most of them are complex and were widely used for the assessment of income, land use inequity whereas the use of Equity and Gini coefficients are rather easy and can be adapted to assess the water use inequity. So in this study assessment of water distribution equity was done by calculating Equity and Gini coefficients. The detailed methodology of the study is described in the following sections.

Ground water based deep tubewell irrigation system is crucial for dry season irrigation in Gazipur district, where some areas are relatively high and ground water table goes lower during dry period cultivation. Four tubewell irrigated areas from three unions of Gazipur sadar upazila namely Bhavanipur, Pubail and Mirzapur were selected for the study. The tubewells were selected based on their capacity and full functioning of the pumps and in consultation with Upazila Agriculture Officer (UAO) and Sub Assistant Engineer (SAE) of Department of Agriculture Extension (DAE) under Gazipur Sadar Upazila. Though the deep tubewell of Podoarbaik village under Pubail union functioned properly for first two months of the Boro season, afterwards it gave trouble and was excluded from the study. Finally, three deep tubewells from three command areas three villages namely East Togori, West Togori and Bhavanipur under two unions were selected for the study.

3.11 Data Requirement

It has been said earlier that for assessing equity in water distribution among the stakeholders in deep tubewell irrigated areas using Equity and Gini Coefficient data regarding the quantity of canal water (depth of the irrigation water in mm) entering into each fields of the selected deep tubewells were necessary to collect through measurements. Afterwards production data of 2011-12 Boro season (crop yield in kg/ha) at measured depth of irrigation water locations of the selected deep tubewells were also collected from respective farmers to see the effect of unequal distribution of irrigation water along the conveyance canals from head to tail ends through questionnaire survey.

3.12 Irrigation Data Collection

Data of irrigation water applied to each field is an important part of this study. Irrigation applied to each field was measured by using measuring scale in terms of depth. Usually 2 inches to 1 inch irrigation is provided considering head, middle and tail part of irrigation canal throughout the irrigation season. The farmers of the study area were identified with the help of local Sub Assistant Agricultural Officer (SAAO). They were 36 in numbers and were from selected 36 fields (12 numbers of sample fields from each deep tubewell irrigated area totaling to 36 numbers) for which depth of irrigation water measurements were carried out. When the fields are irrigated, total depths of irrigation data are collected each time and calculate how much water reaches to each field for 2011-12 Boro season. The depth of water was calculated in mm. Information about quantity of irrigation water provided in each field was collected and verified in consultation with farmers. Thus, the quantity of canal water entering into each field has been computed along the main irrigation canal, secondary canal and tertiary canals for the selected deep tubewells. Total depths of irrigation water are carried out at three parts named as Head part, Middle part and Tail part of each mentioned canal.

3.13 Questionnaire Survey for Crop yield data collection

The second part of the study includes the impact of unequal distribution of water in different parts of the study area. Productivity is measured by area utilization and yield. Area utilization means the area irrigated per unit of area.

A semi-structured questionnaire survey has been conducted through the direct personal interview technique. The questionnaires are given in Appendices A. The questionnaires were followed to collect necessary data such as yield data, irrigation water availability and its status of distribution, etc. from the farmers of the study area. In order to collect reliable and valid information from the rice growers, an interview schedule was prepared in line with the objective of the study. The data were collected from the sampled farmers from head, middle and tail ends of each irrigated area through the personal interviewing during December 2011 to May 2012 (2011-12 Boro season) regarding the available water reached in each fields per irrigation in terms of depth. In this case Crop Yield in mond/bigha from each field were collected. Then total crop yield (rice yield) for each field were converted in kg/ha. The interview with the farmers during questionnaire survey is shown in Photograph 3.1.

Photograph 3.1: Field questionnaire survey

The information about study area was collected from secondary sources like Bangladesh Rice Research Institute (BRRI), Department of Agricultural Extension (DAE), Bangladesh Agricultural Research Council (BARC) etc. Literature review was done downloading e-materials through internet, using institute library and going through existing completed Master's thesis, journals etc.

3.14 Distributional Equity

3.14.1 Equity Coefficient

Equity coefficient is the most well-known equity assessment tool. The value of equity coefficient ranges from 0 to 1 where 1 is the most equitable condition and 0 is the worst.

For calculating equity coefficient, skewness in water use per unit area is calculated. Calculation of skewness is done by considering amount of water reached in every field of different parts of the irrigation area. The average amount of water reaches in each unit area of field is calculated separately. These values are used to get the skewness from where equity coefficient is found.

3.14.2 Skewness

Skewness is an attribute of distribution. A distribution that is symmetric around its mean has skewness of zero, and is hence equitable.

Skewness is calculated as per Prasad, *et.al*, (2006):

$$S = \frac{n}{(n-1)(n-2)} \sum \left(\frac{X_j - \overline{X}}{S} \right)^3 \text{ .... } (4.1)$$

Where, n is number of data, X_j is individual data value, X is mean and S is standard deviation. To capture the spatial variation in water use in three parts of the irrigated areas, skewness in water uses per unit area of each part of the deep tubewell irrigated areas is computed. Thus, computed skewness for the indicators was transformed into equity coefficients by using the following equation as per Prasad, *et.al*, (2006):

$$\text{Equity Coefficient} = e^{-\text{Absolute [skewness]}} \text{ ....(4.2)}$$

The above equation gives a positive value for equity coefficient in the range of 0 to 1 where 1 is the most equitable condition, and zero, the worst.

3.14.3 Gini Coefficient

The Gini Index was developed by the Italian statistician Corrado Gini and published in his 1912 paper "Variabilità e mutabilità" ("Variability and Mutability"). It is strictly linked to the representation of income inequality through the Lorenz Curve. In particular, it measures the ratio of the area between the Lorenz Curve and the equi-distribution line (henceforth, the concentration area) to the area of maximum concentration.

The Gini coefficient is a measure of statistical dispersion most prominently used as a measure of inequality of water distribution or inequality of wealth distribution. The Gini coefficient is defined as a ratio with values between 0 and 1. A low Gini coefficient indicates more equal water distribution, while a high Gini coefficient indicates more unequal distribution. 0 corresponds to perfect equality (everyone having exactly the same water) and 1 corresponds to perfect inequality (where people of head part use all water, while the people of tail part use zero water).

The Gini Coefficient is traditionally applied to the measurement of income inequality, but has also been applied to measure water inequality.

The Gini Co-efficient can be displayed graphically as a plot of the distribution of the size fractions of ordered individuals. This is termed the Lorenz curve and is shown in figure 3.8. In a perfectly equal distribution the Lorenz curve would plot as a straight line. This is termed the line of equality. In most cases, however, the Lorenz curve plots below this line of equality, showing the inequality in the distribution of income, land or, now, water between members of a community.

The Gini index is the Gini coefficient expressed as a percentage, and is equal to the Gini coefficient multiplied by 100. (The Gini coefficient is equal to half of the relative mean difference.) The Gini coefficient is also a ratio of the areas on a Lorenz curve and a measure of the inequality of a distribution. If the area between the line of perfect equality and Lorenz curve is A, and the area under the Lorenz curve is B, then the Gini coefficient is A/(A + B), which is shown in Figure 3.8.

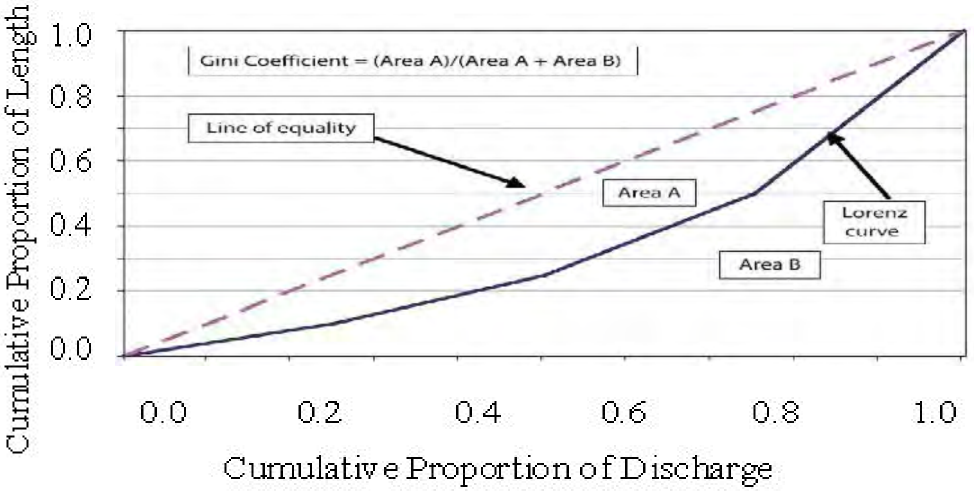

Figure 3.8: Lorenz Curve and Gini Coefficient

Since A + B = 0.5, the Gini coefficient is calculated as per Cullis and Koppen, (2007),

$$G = A/(.5) = 2A = 1 - 2B \quad \text{(4.3)}$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

Water is a limited resource and volumetric water uses depend on water availability, which in turn are determined by resource endowment. Referencing water use against resource endowment provides a convincing basis for assessing who is using how much water compared to the endowment. If water is considered a common pool resource, the entire deep tubewell irrigated area is arguably entitled to an equitable share in the available water. Thus, the endowment can be described in terms of per unit water availability. In addition, in case of deep tubewell irrigated area where the water availability is predominantly contributed by ground water, water availability per unit of area can be taken as a reliable basis for assessing resource endowment. Accordingly, the distributions of water for irrigation per unit area of each part of the deep tubewell irrigated area are considered here for the assessment of equity.

To assess equity in water distribution among the stakeholders, three deep tubewell irrigated areas from Gazipur sadar upazila named Bhavanipur (Bhavanipur Union), East Togori and West Togori (Mirzapur Union) were selected and 12 nos. of sample fields from each deep tubewell totaling to 36 sample fields were used to calculate unequal distribution of irrigation water in fields. The main irrigation canal, secondary irrigation canals and tertiary irrigation canals at three parts (Head, Middle and Tail part) were selected to carry out the study. In total, 36 farmers were interviewed during 2011-12 Boro season regarding the available water reached in each fields per irrigation in terms of depth.

4.2 Characteristics of Deep Tubewells

Table 4.1 shows the major characteristics of the three deep tubewell irrigation areas. Deep Tubewells of East Togori, West Togoi and Bhavanipur were established in 1974, 1978 and 1974 respectively. The depth of the tubewells also varied. The depth of East Togori was 300 ft. where as that of West Togori and Bhavanipur were 280 ft and 352 ft. respectively.

Table 4.1: General characteristics of three Deep Tubewells

Parameter	East Togori	West Togori	Bhavanipur
Command area (in hectare*)	35.43	28.34	25.51
Canal Length** (in km)	1.1	0.7	0.65
Year of Installation	1974	1978	1974
Depth of DTW, feet	300	280	352

* 1 Hectare =7.057 bigha

**Distance from Tubewell to one of the farthest field of the Tubewell command area

The command area (total irrigated area) of Bhavanipur deep tubewell was the smallest (25.51 hecatare) whereas East Togori deep tubewell was the largest command area (35.43 hectare). So, the total Canal Length from the deep tubewell to the end of the farthest field of East Togori Deep Tubewell was 1.1 km - the longest one, while of west Togori and Bhavanipur deep tubewells were almost of the same length i.e. 0.7 km. and 0.65 km. respectively.

4.3 Assessment of Distributional Equity Using Equity Co-efficient

Total depths of applied irrigation water at various points of irrigated areas are correlated with the assessment of distributional equity. To find out the distributional equity, irrigation water depths at various fields are identified and calculated for the 2011-12 Boro season.

4.3.1 Assessment of Distributional Equity of East Togori Deep Tubewell

East Togori (ET) Deep Tubewell irrigated area was divided into three parts named as Head part, Middle part and Tail part for data collection such as for the measurement of total depths of irrigation in mm. Each part consists of four fields which were selected according to spatial variation (proximity to the source). So in total, there were 12 (twelve) sampling fields from where applied irrigation data were collected in terms of depth. For easy identification of these fields, 12 fields are categorized as ET1, ET2, FT3, ET4, ET5, ET6, ET7, ET8, ET9, ET10, ET11 and ET12. From these fields, ET1 to ET4 fields are selected from head part, ET5 to ET8 are from middle part and ET9 to ET12 are from tail part. The calculations of total water received per fields are shown in Appendix B.

Table 4.2 shows the calculation of equity co-efficient by total water received data of different sampling fields. From the table, it is clear that 711.20 mm of water was received in the head end point ET1, whereas it was quite less in the tail end point ET12 i.e. 444.50 mm. It is also found from head end four sampling fields that average irrigation of water received in terms of depth was 711.20 mm. It also means that head ends of Deep Tubewell irrigated areas received the highest amount of water for irrigation, whereas the middle and tail ends received less. They are 641.35 mm and 515.94 mm of water respectively.

Table 4.2: Equity computations for East Togori Deep Tubewell irrigated area

Different parts of Irrigated area	Sampling fields	Total Irrigation Water Received (in mm)	Average Irrigation Water Received	No. of Data, n	n/(n-1)(n-2)	Mean,	Xj-	Standard Deviation, S	$X_j - \bar{X}$	Skewness	Equity coefficient (·)
Head	ETI	711.20	711.20	3	1.5	622.83	88.37	98.94	0.7125	-0.8128	0.4436
	ET2	711.20									
	ET3	711.20									
	ET4	711.20									
Middle	ET5	622.30	641.35				18.52		0.0066		
	ET6	622.30									
	ET7	622.30									
	ET8	698.50									
Tail	ET9	565.15	515.94				-106.89		-1.2610		
	ET10	488.95									
	ET11	565.15									
	ET12	444.50									
								Total	-0.5419		

Note: n = number of data, Xj= individual data value

Skewness of the equity coefficients of East Togori Deep Tubewell irrigated area was found 0.4436. The value indicates the presence of inequity of irrigation water distribution in the irrigated area under East Togori Deep Tubewell. If all the canals point (i.e. 12 points) received the same quantity of irrigation water, the value would have been 1(one). The value 0.4436 for the East Togori deep tubewell irrigation area implies that the prevailing pattern of water received for agriculture across 12 different fields from head, middle and tail parts in the irrigation area was 44.36% similar.

4.3.2 Assessment of Distributional Equity of West Togori Deep Tubewell

The computation results of equity in West Togori Deep Tubewell irrigation area are shown in Table 4.3. West Togori (WT) Deep Tubewell irrigated area was also divided into twelve (12) different points as like as East Togori deep tubewell irrigated area. The calculations of total water received per fields are shown in Appendix C.

Table 4.3 shows that head ends of Deep Tubewell irrigated area (point WT2) received the highest quantity of water i.e. 749.30 mm, whereas the middle end point WT8 received 647.70 mm and tail end point WT12 received 482.60 mm which means that middle and tail ends received less water than the head ends.

Table 4.3: Equity computations for West Togori Deep Tubewell irrigated area

Different parts of Irrigated area	Sampling fields	Total Irrigation Water Received (in mm)	Average Irrigation Water Received	No. of Data, n	n/(n-1)(n-2)	Mean, –	Xj-‾	Standard Deviation, S	$X_j - \bar{X}$	Skewness	Equity coefficient (·)
Head	WTI	673.10	711.20	3	1.5	621.24	89.96	93.88	0.8798	-0.3529	0.7027
	WT2	749.30									
	WT3	749.30									
	WT4	673.10									
Middle	WT5	647.70	628.65				7.41		0.0005		
	WT6	571.50									
	WT7	647.70									
	WT8	647.70									
Tail	WT9	527.05	523.88				-97.37		-1.1155		
	WT10	603.25									
	WT11	482.60									
	WT12	482.60									
								Total	-0.2353		

Note: n = number of data, Xj= individual data value

The average water received in terms of depth of head part (points WT1 to WT4) was 711.20 mm, which was the highest than average depth of irrigation water received by middle and tail parts. The average irrigation of water received by middle and tail parts in terms of depth were 628.65 mm and 523.88 mm respectively. The obtained results indicate that the equity coefficient of West Togori Deep Tubewell irrigated area was 0.7027, less than the highest possible equity coefficient of 1, implying that there is much scope for improving equity conditions in the irrigated area.

4.3.3 Assessment of Distributional Equity of Bhavanipur Deep Tubewell

Bhavanipur (BP) Deep Tubewell irrigated area was also divided into twelve (12) different points as like as East Togori and West Togori Deep Tubewell irrigated area. Table 4.4 shows that the average irrigation water received in terms of depth by BP1 to

BP4 fields of head part was 901.70 mm and it was the highest. On the other hand, the lowest average irrigation water received by the tail part and i.e. 690.56 mm. The calculations of total water received per fields are shown in Appendix D.

Table 4.4: Equity computations for Bhavanipur Deep Tubewell irrigated area

Different parts of Irrigated area	Sampling fields	Total Irrigation Water Received (in mm)	Average Irrigation Water Received	No. of Data, n	n/(n-1)(n-2)	Mean,	Xj-	Standard Deviation, S	Xj − X̄	Skewness	Equity coefficient (·)
Head	BPI	863.60	901.70	3	1.5	799.57	102.13	105.74	0.9011	-0.2915	0.7471
	BP2	863.60									
	BP3	863.60									
	BP4	1016.00									
Middle	BP5	863.60	806.45				6.88		0.0003		
	BP6	889.00									
	BP7	736.60									
	BP8	736.60									
Tail	BP9	692.15	690.56				-109.01		-1.0957		
	BP10	800.10									
	BP11	692.15									
	BP12	577.85									
								Total	-0.1944		

Note: n = number of data, Xj= individual data value

The computation result in above table indicates that the equity coefficients of Bhavanipur Deep Tubewell irrigated area was 0.7471, in terms of water received per fields, which indicates the presence of inequity in this irrigated area.

The value 0.7471 for the Bhavanipur Deep Tubewell irrigated area implies that the prevailing pattern of water received for agriculture across the 12 different fields from head, middle and tail parts in the irrigated area was 74.71% similar. If all the canal fields (i.e. 12 points) received the same amount of water per unit area for agriculture; the value would have been 1. From the above table, it can be seen that BP4 points from the head end received the highest depth of irrigation water (1016 mm), whereas BP12 from the tail end received the lowest, i.e, 577.85 mm.

4.4 Equity Co-efficient of Three Deep Tubewells

Figure 4.1 shows that the equity coefficient of Bhavanipur Deep Tubewell irrigated area was the highest i.e., 0.7471, while for West Togori it was 0.7027 and East Togori it was 0.4436. This indicates that among the three irrigated area, the spatial distribution of irrigation water was most equitable (least skewed) in the Bhavanipur compared to the same in other areas. The highest inequity (i.e., the least equity coefficient of 0.4436) across the three irrigated area was observed in East Togori deep tubewell irrigated area which indicates the worst condition of the irrigation water distribution. Values of equity coefficients for Deep Tubewell irrigated areas were more or less vary widely. Irrigation water distribution in Bhavanipur and West Togori Deep Tubewells were almost the same and they performed the better condition in irrigation water distribution.

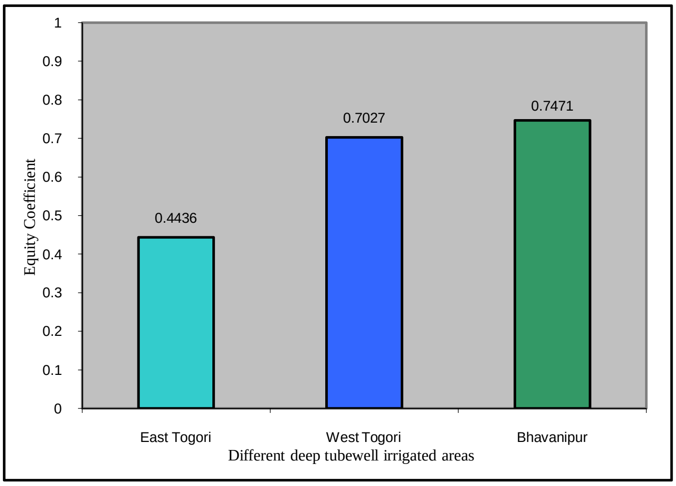

Figure 4.1: Equity Coefficients of different Deep Tubewell irrigated areas

Bhavanipur Deep Tubewell irrigated area received the highest quantity of water (i.e. 1016 mm). As the deep tubewell command area was the smallest and the performance compare with others was almost the same (shown on table 4.1), it received the highest quantity of water. That’s why the rotation period of getting water per field was short and fields of Bhavanipur deep tubewell irrigated area received the water with the maximum no. of times i.e. 20th times whereas West Togori and East Togori received 18th times and 16th times accordingly (Appendices B, C & D).

Bhavanipur Deep Tubewell irrigated area was better in irrigation water distribution. It happens mainly because of better maintenance of irrigation canal. Bhavanipur Deep Tubewell irrigation canals were regularly cleaned from weeds before carrying out irrigation water. Polyethylene was used in canal bed to reduce water loss along the water path. On the other hand, irrigation canals of East Togori deep tubewell command area were filled with grass and weeds which inhibited the flow of irrigation water. Management of Bhavanipur deep tubewell irrigated area showed less interest to clean up their irrigation canal for smooth water flows (see Photographs 4.1, 4.2 and 4.3). So, it is important to take some measures for achieving equal distribution of irrigation water.

Photograph 4.1: Secondary canal of Bhavanipur Deep Tubewell irrigated area

Photograph 4.2: Secondary canal of West Togori Deep Tubewell irrigated area

Photograph 4.3: Secondary canal of East Togori Deep Tubewell irrigated area

4.5 Assessment of Equity Using Gini Coefficient

The Gini Coefficient is one of the most commonly used indicators for measuring distribution. It is traditionally applied to the measurement of income inequity, but has also been applied to measure water inequity.

4.5.1 Assessment of Equity Using Gini Coefficient of East Togori Deep Tubewell

Calculation of Gini Coefficient for East Togori Deep Tubewell irrigated area is shown in Table 4.5. The Lorenz Curve was constructed as per methodology described in Chapter Three. It is seen from the Figure 4.2 and the Table 4.5 that 55 percent of total irrigation water applied in fields is received by only 20 percent of the total irrigated length at head part, while the 20 percent of total irrigation water applied in fields is received by 50 percent of the total irrigated length at tail part of East Togori Deep Tubewell irrigated area. So, it is clear that in East Togori Deep Tubewell command area, water distributional inequity exists from head to tail end fields.

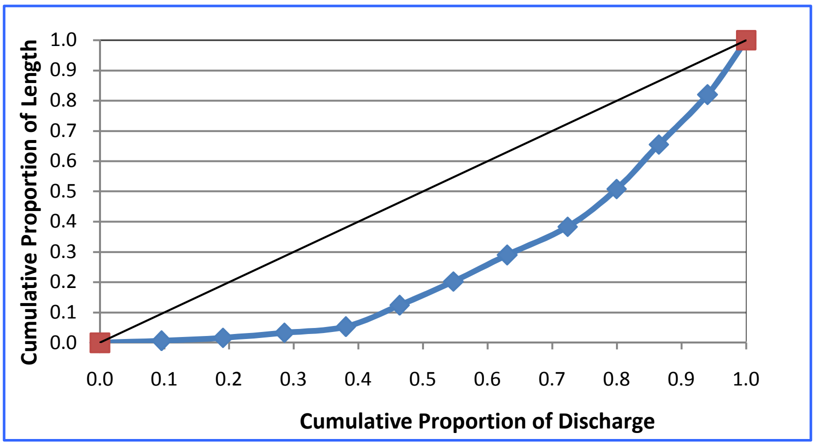

Figure 4.2: Lorenz Curve for water distribution of East Togori Deep Tubewell

The Gini Coefficient of East Togori Deep Tubewell command area was found 0.4754. It indicates the presence of inequity in the irrigated area. Ideally, if all the canal fields (i.e. 12 fields) along the head, middle and tail parts received the same quantity of water per unit area for agriculture, the Gini Coefficient value would have been 0 indicating 100% equal irrigation water distribution. The Gini Coefficient value 0.4754 for the East Togori deep tubewell irrigation area implies that the prevailing pattern of per unit water use for agriculture across the 12 different fields from head, middle and tail parts in the irrigation area was 47.5 % similar.

Table 4.5: Calculation of Gini Coefficient for East Togori Deep Tubewell Irrigated Area

Sampling Point	**Irrigation Water Depth** (mm)	**Length** (m)	**Cumulative Water Depth**	**Cumulative Length**	**Cumulative Proportion of Water Depth**	**Cumulative Proportion of length**	**Lorenz Curve Area**
ETI	711.20	30	711.20	30	0.0952	0.0062	0.0003
ET2	711.20	50	1422.40	80	0.1903	0.0166	0.0011
ET3	711.20	80	2133.60	160	0.2855	0.0332	0.0024
ET4	711.20	95	2844.80	255	0.3806	0.0530	0.0041
ET5	622.30	340	3467.10	595	0.4639	0.1236	0.0073
ET6	622.30	380	4089.40	975	0.5472	0.2025	0.0136
ET7	622.30	420	4711.70	1395	0.6304	0.2897	0.0205
ET8	698.50	450	5410.20	1845	0.7239	0.3832	0.0314
ET9	565.15	600	5975.35	2445	0.7995	0.5078	0.0337
ET10	488.95	710	6464.30	3155	0.8649	0.6552	0.0380
ET11	565.15	790	7029.45	3945	0.9405	0.8193	0.0558
ET12	444.50	870	7473.95	4815	1.0000	1.0000	0.0541
Total	**7473.95**	**4815**				**B =**	**0.2623**
						Gini Coefficient, G (1-2B) =	**0.4754**

4.5.2 Assessment of Equity Using Gini Coefficient of West Togori Deep Tubewell

The Gini Coefficient of West Togori Deep Tubewell command area was found 0.4427. It indicates the presence of inequity in the irrigated area. Table 4.6 and Figure 4.3 demonstrate the unequal distribution of irrigation water through Gini Coefficient. They show that 55 percent of total irrigation water applied in fields is received by only 21 percent of the total irrigated length at head part, while the 21 percent of total irrigation water applied in fields is received by 45 percent of the total irrigated length at tail part of West Togori Deep Tubewell irrigated area. It clearly shows the distributional inequity of irrigation water from head to tail ends.

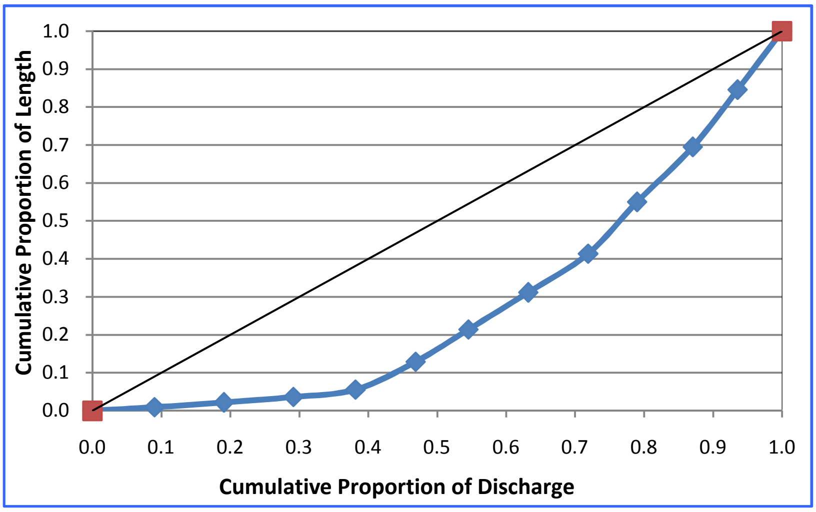

Figure 4.3: Lorenz Curve for water distribution of West Togori Deep Tubewell

The Gini Coefficient 0.4427 means that irrigation water distribution should be improved for achieving better performance as well as elimination of inequity in water distribution for the irrigation area.

Table 4.6: Calculation of Gini Coefficient for West Togori DTW Irrigated Area

Sampling Point	**Irrigation Water Depth** (mm)	**Length** (m)	**Cumulative Water Depth**	**Cumulative Length**	**Cumulative Proportion of Water Depth**	**Cumulative Proportion of length**	**Lorenz Curve Area**
WTI	673.10	40	673.10	40	0.0903	0.0097	0.0004
WT2	749.30	50	1422.40	90	0.1908	0.0219	0.0016
WT3	749.30	60	2171.70	150	0.2913	0.0365	0.0029
WT4	673.10	80	2844.80	230	0.3816	0.0560	0.0042
WT5	647.70	300	3492.50	530	0.4685	0.1290	0.0080
WT6	571.50	350	4064.00	880	0.5451	0.2141	0.0131
WT7	647.70	400	4711.70	1280	0.6320	0.3114	0.0228
WT8	647.70	420	5359.40	1700	0.7189	0.4136	0.0315
WT9	527.05	560	5886.45	2260	0.7896	0.5499	0.0341
WT10	603.25	595	6489.70	2855	0.8705	0.6946	0.0504
WT11	482.60	620	6972.30	3475	0.9353	0.8455	0.0499
WT12	482.60	635	7454.90	4110	1.0000	1.0000	0.0597
Total	**7454.90**	**4110**				**B =**	**0.2786**
						Gini Coefficient, G (1-2B) =	**0.4427**

4.5.3 Assessment of Equity Using Gini Coefficient of Bhavanipur Deep Tubewell

It is found from the Lorenz Curve (Figure 4.4) that Bhavanipur Deep Tubewell command area has the distributional water inequity like other Deep Tubewell areas. The Gini Coefficient of Bhavanipur Deep Tubewell command area was found 0.4370 (Table 4.7) which was the lowest than the other two deep tubewell irrigated area.

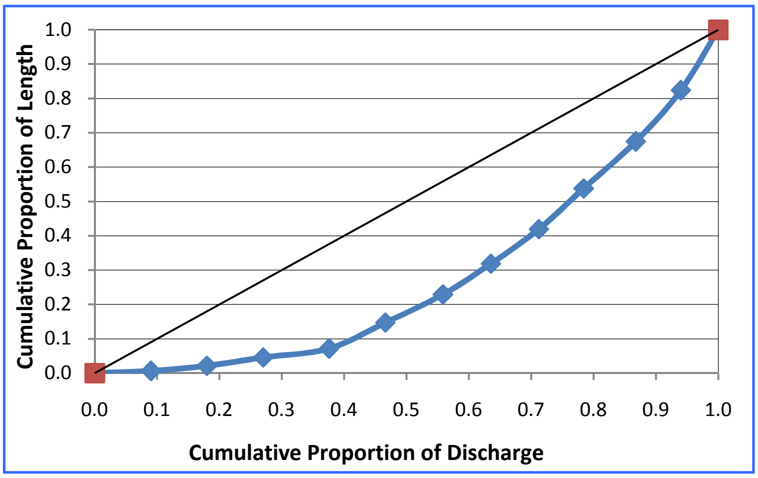

Figure 4.4: Lorenz Curve for water distribution of Bhavanipur Deep Tubewell

Similar to other two deep tubewell irrigated areas, 56 percent of total irrigation water applied in fields is received by only 23 percent of the total irrigated length at head part, while the 22 percent of total irrigation water applied in fields is received by 46 percent of the total irrigated length at tail part of Bhavanipur Deep Tubewell irrigated area.

The finding of Gini Coefficient of Bhavanipur Deep Tubewell irrigated area resembles the same trend like other two deep tubewells under study.

Table 4.7: Calculation of Gini Coefficient for Bhavanipur DTW Irrigated Area

Sampling Point	**Irrigation Water Depth** (mm)	**Length** (m)	**Cumulative Water Depth**	**Cumulative Length**	**Cumulative Proportion of Water Depth**	**Cumulative Proportion of length**	**Lorenz Curve Area**
BPI	863.60	20	863.60	20	0.0900	0.0061	0.0003
BP2	863.60	50	1727.20	70	0.1800	0.0213	0.0012
BP3	863.60	80	2590.80	150	0.2700	0.0456	0.0030
BP4	1016.00	85	3606.80	235	0.3759	0.0714	0.0062
BP5	863.60	250	4470.40	485	0.4659	0.1474	0.0098
BP6	889.00	270	5359.40	755	0.5586	0.2295	0.0175
BP7	736.60	295	6096.00	1050	0.6353	0.3191	0.0211
BP8	736.60	330	6832.60	1380	0.7121	0.4195	0.0284
BP9	692.15	390	7524.75	1770	0.7842	0.5380	0.0345
BP10	800.10	450	8324.85	2220	0.8676	0.6748	0.0506
BP11	692.15	490	9017.00	2710	0.9398	0.8237	0.0540
BP12	577.85	580	9594.85	3290	1.0000	1.0000	0.0549
Total	**9594.85**	**3290**				**B =**	**0.2815**
						Gini Coefficient, G (1-2B) =	**0.4370**

4.6 Gini Coefficient of Three Deep Tubewells

The Gini Coefficient is a useful tool to measure the level of inequality of income, property distribution, water distribution etc. in an area, to compare the inequality in one area with that of another area, or of the same area with a different time. The Gini Coefficients for determining of unequal irrigation water distribution has been calculated for three deep tubewells in this study. The Lorenz Curves in Figure 4.5 show the distribution of irrigation water for three deep tubewell command areas of East Togori, West Togori and Bhavanipur. The computed Gini Coefficients of the irrigation water distribution are 0.4754, 0.4427, and 0.4370 for East Togori, West Togori and Bhavanipur respectively. A low Gini coefficient indicates more equal water distribution, while a high Gini coefficient indicates more unequal distribution. So, from the calculation it is found that, East Togori deep tubewell irrigated area shows the highest Gini coefficient whereas Bhavanipur shows the lowest.

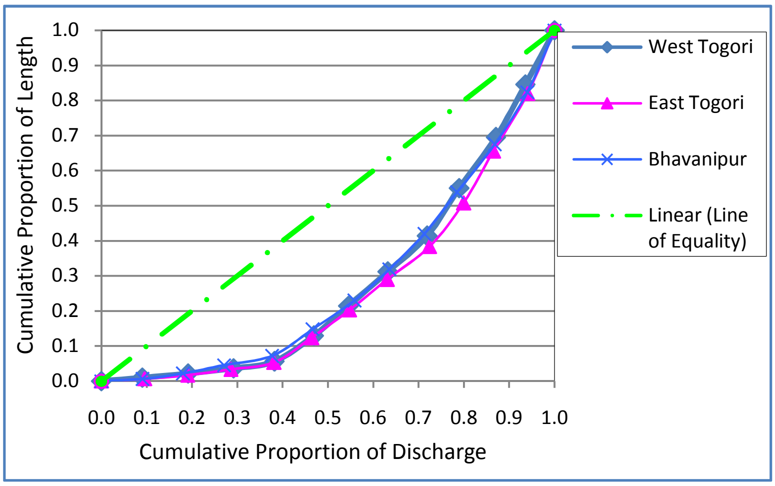

Figure 4.5: Gini Coefficients of three deep tubewells for distribution of irrigation water

The Figure 4.5 shows that the irrigation water distribution bears the same pattern and is much more similar in irrigated areas of East Togori, West Togori and Bhavanipur Deep Tubewells. The inequality of distribution of irrigation water by Gini Coefficient are less than 50% for each case i.e., head and tail end difference of irrigation water consumption by fields is substantial. The Gini Coefficient of Bhavanipur Deep Tubewell irrigated area is found the lowest than the other two deep tubewell irrigated area. It means that Bhavanipur Deep Tubewell irrigated area was better in irrigation water distribution than the other two deep tubewell irrigation areas.

4.7 Water Distribution and Crop Yield of East Togori Deep Tubewell

The length of one of the farthest field from tubewell along the irrigation canals of East Togori Deep Tubewell under study was found 870 m. Total applied Irrigation water measurements were carried out at twelve fields at different distances (Head to Tail ends) along the 870 m irrigation canal. The rice yield data for the Boro 2011-12 season of twelve fields were collected from farmers through questionnaire survey. Water distribution (mm) and productivity in terms of irrigation as crop yield (kg/ha) are graphically plotted against 12 fields along the 870 m canal under study and are shown in Figure 4.6. They represent water productivity in different fields of East Togori Deep Tubewell irrigated area under study. The results indicate that the depth of irrigation water bear higher values when the fields lie more or less close to the deep tubewell or at head ends. The farther the fields or at tail ends, the lower the depth of irrigation water received by the fields.

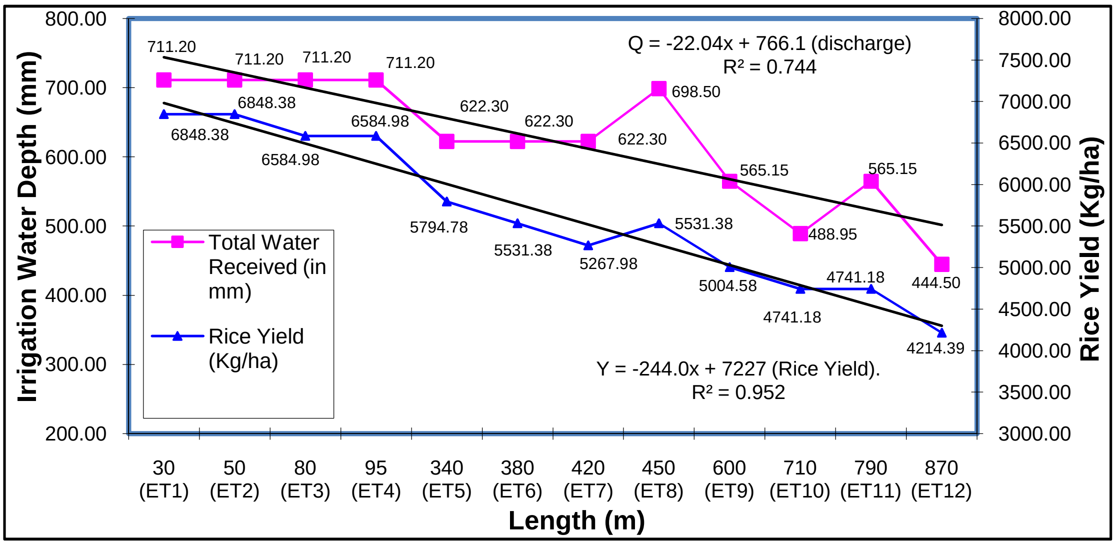

Figure 4.6: Water distribution and crop yield of East Togori Deep Tubewell

From the above figure it is found that when the total applied irrigation water was 711.20 mm – the maximum at head end, the crop yield was also attained maximum i.e. 6848.38 kg/ha . The lowest crop yield of East Togori Deep Tubewell irrigated area was 4214.39 kg/ha, which was found at tail end of the canal with minimum depth of irrigation water received by the field i.e. 444.50 mm. It is also seen in the figure that production curve is almost horizontal with depth of irrigation water curve. It means that the depth of irrigation water received by fields and the related productivities of the fields along the canal bear strong correlation. They are the following:

$$Q = -22.04X + 766.1, r^2 = 0.744 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

where, Q is total applied irrigation water in field, mm and X is length of canal, m

$$Y = -244.0X + 7227, r^2 = 0.952 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

where, Y is crop yield of field, kg/ha and X is length of canal, m

4.8 Water Distribution and Crop Yield of West Togori Deep Tubewell

The length of one of the farthest field from tubewell along the irrigation canals of West Togori Deep Tubewell under study was found 635 m. Total applied Irrigation water measurements were carried out at twelve fields at different distances (Head to Tail ends) along the 635 m irrigation canal. The crop yield data of the twelve fields were collected from farmers through questionnaire survey. Water distribution (mm) and productivity in terms of irrigation as yield (kg/ha) are graphically plotted against 12 fields along the 635 m canal under study and are shown in Figure 4.7. They represent water productivity in different fields of West Togori Deep Tubewell irrigated area under study. The results indicate that the depth of irrigation water bear higher values when the fields lie more or less close to the deep tubewell or at head ends. The farther the fields or at tail ends, the lower the depth of irrigation water received by the fields.

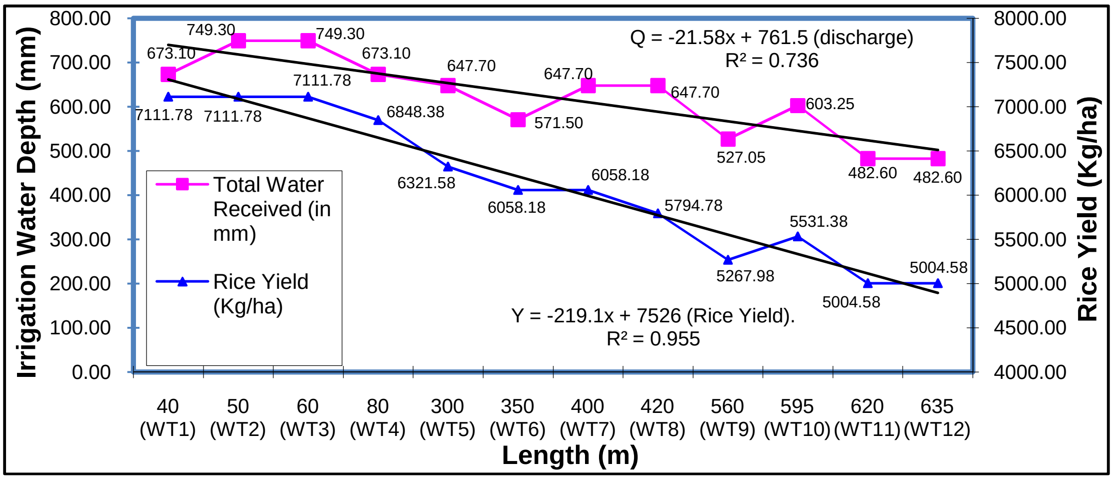

Figure 4.7: Water distribution and crop yield in West Togori Deep Tubewell

In the above figure the water productivity shows the downward trends with the reduction of depth of irrigation water along the canal. When the total applied irrigation water was 749.30 mm – the maximum at head end (only 50 m away from Deep Tubewell), the crop yield was also attained maximum i.e. 7111.78 kg/ha. The lowest crop yield of West Togori Deep Tubewell irrigated area was 5004.58 kg/ha, which was found at tail end of the canal with minimum depth of irrigation water received by the field i.e. 482.60 mm. It is seen in the figure that production curve is almost horizontal with depth of irrigation water curve. It again means that the depth of irrigation water received by fields and the related productivities of the fields along the canal bear strong correlation. They are the following:

$$Q = -21.58X + 761.5, r^2 = 0.736 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

where, Q is total applied irrigation water in field, mm and X is length of canal, m

$$Y = -219.1X + 7526, r^2 = 0.955 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

where, Y is crop yield of field, kg/ha and X is length of canal, m

4.9 Water Distribution and Crop Yield of Bhavanipur Deep Tubewell

The length of one of the farthest field from tubewell along the irrigation canals of Bhavanipur Deep Tubewell under study was found 580 m. Total applied Irrigation water measurements were carried out at twelve fields at different distances (Head to Tail ends) along the 580 m irrigation canal. The crop yield data of the twelve fields were collected from farmers through questionnaire survey. Water distribution (mm) and productivity in terms of irrigation as yield (kg/ha) are graphically plotted against 12 points along the 580 m canal under study and are shown in Figure 4.8. They represent water productivity in different fields of Bhavanipur Deep Tubewell irrigated area under study. The results also indicate that the depth of irrigation water bear higher values when the fields lie more or less close to the deep tubewell or at head ends. The farther the fields or at tail ends, the lower the depth of irrigation water received by the fields.

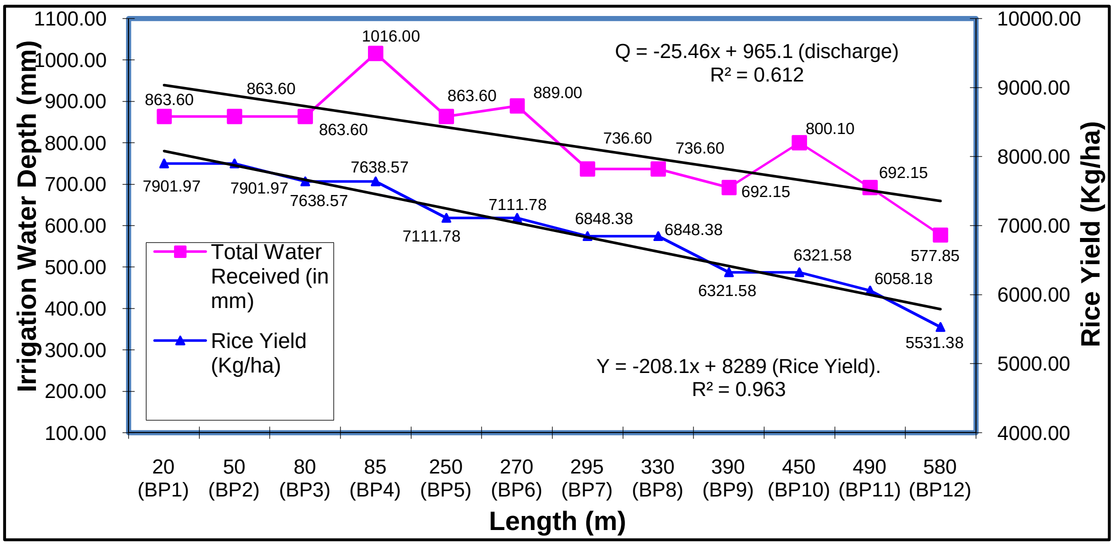

Figure 4.8: Water distribution and crop yield in Bhavanipur Deep Tubewell

In the above figure the crop yield curve shows the downward trends with the reduction of depth of irrigation water along the canal. When the total applied Irrigation water was 1016 mm – the maximum at head end, the crop production was 7638.57 kg/ha. The lowest crop production of Bhavanipur Deep Tubewell irrigated area was 5531.38 kg/ha, which was found at tail end of the canal with minimum discharge received by the field i.e. 577.85 mm. It is also seen in the figure that production curve is almost horizontal with the depth of irrigation water curve. It again means that the depth of irrigation water received by fields and the related productivities of the fields along the canal bear strong correlation.

They are the following:

$$Q = -25.46X + 965.1, r^2 = 0.612 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.5)}$$

where, Q is total applied irrigation water in field, mm and X is length of canal, m

$$Y = -208.1X + 8289, r^2 = 0.963 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.6)}$$

where, Y is crop yield of field, kg/ha and X is length of canal, m

4.10 Factors affecting the inequity of irrigation water distribution

In total 36 nos. of farmers were selected for carrying out social survey, where focus was given to water distribution and its impact upon their life. It was tried to find out the causes of unequal distribution of irrigation water through survey among the selected farmers. There are many causes which were mentioned by the farmers related with irrigation water management. The main causes are summarized in the Table 4.8, as a percentage of respondents focusing upon the main causes. The table shows the total percentage of respondents from the selected field areas mentioning the factors affecting the unequal distribution of water.

Table 4.8: Main factors related to inequity of three deep tubewell irrigated areas

Parameter	**Percentage of respondent (%)**			**Total Average %**
	East Togori	**West Togori**	**Bhavanipur**	
Load shedding	33.33	25.00	33.34	30.56
Manager’s t partiality / Power relationship	25.00	33.33	25.00	27.78
Absence of active management committee/Management weakness	8.33	25.00	25.00	19.44
Faulty irrigation canal	25.00	8.34	8.33	13.89
Unmeasured water supply	8.34	8.33	8.33	8.33
Total	100	100	100	100

According to selected respondents the main reason for the inequity of irrigation water distribution was Load shedding. Load shedding or disruption of electricity supply was the factor responsible for the inequity of irrigation water distribution (Table 4.8). In total of 30.56 % respondents blame electricity supply as their problem riser. Frequent load shedding makes the irrigation rotation period lengthier than the usual time. The calendar of irrigation water distribution in fields gets upset. It becomes extremely difficult for a manager to provide irrigation water to remote fields. During such an event, water availability is greatly hampered and ultimate victim is the farmers at tail end. The condition becomes worst when water requirement in rice field attains the peak. The tail end farmers cannot get ample water for their rice fields. The respondents of Bhavanipur deep tubewell irrigation area suffered mostly for load shedding or disruption of electricity supply. 33.34% of respondents of Bhavanipur, 25% of respondents of West Togori and 33.33% of East Togori confirmed it.

About 27.78% of the respondents from three deep tubewell command areas blame their manager for the unequal distribution of irrigation water. As per their opinion, manager or lineman provides opportunity in receiving water giving priority to rich people or the farmers with good relation to him. The maximum numbers of respondent (33.33%) of West Togori blames the managers for their partial behavior in case of distribution of irrigation water. The respondents from other two Deep Tubewell areas also keep the same opinion (25% of respondents for each area). Power relation plays an important role in decision making of water providing opportunity to farmers.

Poor irrigation water management committee in each Deep Tubewell area was a major factor for enhancing the problem of inequity in irrigation water distribution. In total 19.44% of all respondents opined that if there was active management committee, then the command area under each Deep Tubewell could function quite well. As per opinion of 25% of respondents from West Togori and Bhavanipur, the poor management committee is to be blamed directly for the inequity of water distribution in each deep tubewell irrigated area.

Faulty irrigation canal is also one of the main causes for unequal distribution of irrigation water. Leaky irrigation canal with grown up grasses in canal bed, accumulated polythene or pesticides packets in the canal retard water flow enhancing seepage loss at head end diverting water through spilling to the other directions. The irrigation water cannot reach up to the tail end of canal. It is the most common scenario for the tail end part of all deep tubewell irrigation area. In total, 13.89% of respondents blame faulty irrigation canal for the inequity in water distribution. The maximum respondents i.e. 25% of respondents from East Togori Deep Tubewell irrigation area blame the faulty irrigation canal responsible for the unequal distribution of water.

Mangers of Deep Tubewells cannot supply water in field with a precision measured way and volume of water applied in field is done on assumptions as per time allocation. As a result, the farmers suffer mostly especially having fields at tail ends. But water pricing is the same for all. Usually water pricing is fixed as 800 taka per bigha (0.1417 hectare) in a season. So, tail end farmers pay the fixed amount of taka but in fact, they get much lower amount of water for their fields. In total 8.33 % of respondents opined for less amount of water they received in fields and the water price they were to pay for that less amount of water. If there has been fixed water pricing for head ends and tail ends, then the disparity could be averted. Sometimes water conflicts arise there due to disparity in water pricing and non-availability of necessary irrigation water in due time. There is no water user association or cooperative society in the irrigated area under study. So, the farmers do not have any platform of their own to raise their demands and needs.

4.11 Impact on yield for unequal irrigation water distribution

Water equity (mm) and productivity in terms of irrigation as crop yield (kg/ha) are directly related with each other. Lower water equity leaded to lower crop yield in each Deep Tubewell irrigated area under study. Accordingly, higher water equity provided higher yield in the fields. And the crop yield was also reversed with the reversed condition of equity that means when the water equity for the deep tubewell irrigated areas was good; the total crop yield for the whole irrigated areas was also good. Crop yield decreased from head ends to tail ends due to unequal water distribution. Table 4.9 shows the difference in crop yield between the head and tail ends for all Deep Tubewell irrigated areas under study.

Table 4.9: Difference of crop yield (kg/ha and %) from head end to tail end due to unequal irrigation water distribution

Crop Yield	Deep Tubewells under Study		
	East Togori	West Togori	Bhavanipur
Head End crop yield, kg/ha	6848.38	7111.78	7901.97
Tail End crop yield, kg/ha	4214.39	5004.58	5531.38
Difference in crop yield between head and tail ends, kg/ha	2633.99	2107.2	2370.59
Difference in crop yield between head and tail ends, in %	38.46	29.63	30.00

Difference in crop yield of East Togori deep tubewell irrigated areas at tail end was almost 38.46% less than the head end in 2011-12 Boro season. For both West Togori and Bhavanipur Deep Tubewell irrigated areas, crop yield decreased from head ends to tail ends by 29.63% and 30% respectively. But as a whole, Bhavanipur Deep Tubewell irrigated area received more water and has the lowest inequity in irrigation water distribution (equity coefficient 0.7471& Gini Coefficient 0.4370) and consequently crop yield was also higher in Bhavanipur than the other two irrigated areas (see Table 4.10). So, it might be concluded that with the better equity of water distribution, crop yield can be increased.

Table 4.10: Depth of Irrigation water differs from head end to tail end due to inequity

Depth of Irrigation Water, in mm	Deep Tubewells under Study		
	East Togori	West Togori	Bhavanipur
Head End water depth, in mm	711.20	749.30	1016.00
Tail End water depth, in mm	444.5	482.6	577.85
Difference in water depth between head and tail ends, in mm	266.7	266.7	438.15
Difference in water depth between head and tail ends, in %	37.50	35.59	43.13

From the figure 4.9, it is found that in case of East Togori Deep Tubewell irrigated area, tail ends received 37.50 % of less irrigation water than the head ends and tail end crop yield was also 38.46 % less than the head ends.

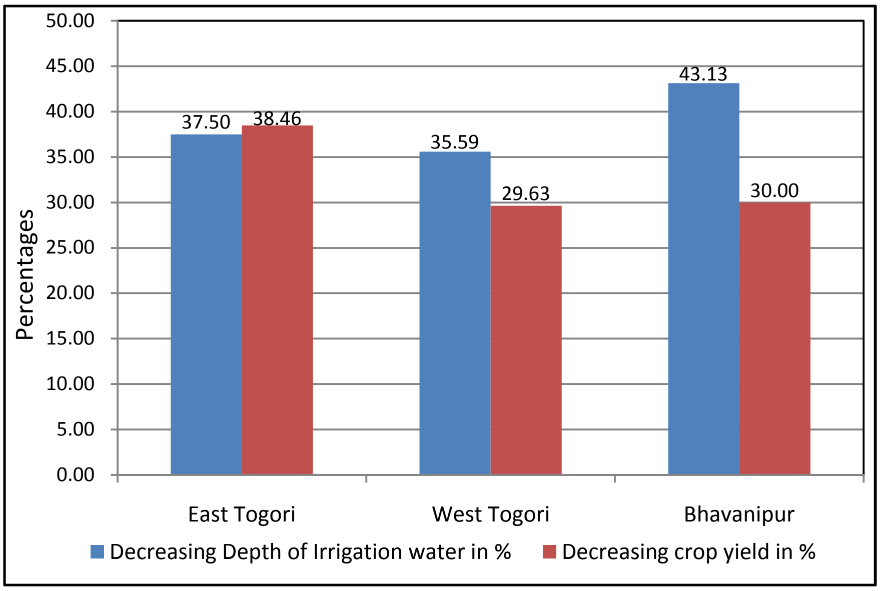

Figure 4.9: Crop yield scenario of three deep tubewell irrigated areas in terms of difference of irrigation water received by tail ends than the head ends.

East Togori suffered from the higher unequal distribution of water (equity coefficient 0.4436 & Gini Coefficient 0.4754) and head ends to tail ends difference in crop yield was also the highest (38.46%), so it is clear that East Togori Deep tubewell irrigated area gets less quantity of irrigation water than the other two deep tubewell irrigated areas. The inequity of distribution of irrigation water might be reduced only through the elimination of the factors affecting the inequity of irrigation water distribution between head and tail ends.

West Togori Deep Tubewell irrigated area, at tail ends received 35.59 % of less irrigation water than head ends that leaded to tail end crop yield 29.63 % less than the head ends. If excess water at head ends could be distributed to the tail ends decreasing inequity, then higher crop yield might be achieved from all irrigated fields.

In case of Bhavanipur Deep Tubewell irrigated area, tail end fields received 43.13 % of less irrigation water than head ends and tail end crop yield was also 30% less than the head ends. As Bhavanipur also suffered from unequal distribution of irrigation water (equity coefficient 0.7471& Gini Coefficient 0.4370) and head ends to tail ends difference in crop yield was almost the same as West Togori, i.e. 30%), so it is clear that head ends of Bhavanipur Deep tubewell irrigated area gets more irrigation water than they need to produce same crop yield. So, there is much scope to minimize the inequity in water distribution by proper distribution of excess water from head ends to tail ends.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. The Equity Coefficients of irrigation water distribution for East Togori, West Togori and Bhavanipur Deep Tubewell irrigated area under study were found 0.4436, 0.7027 and 0.7471 respectively.

2. Similarly, the Gini Coefficients of irrigation water distribution for East Togori, West Togori and Bhavanipur Deep Tubewell irrigated area under study were found 0.4754, 0.4427 and 0.4370 respectively.

3. Both Equity and Gini Coefficients prove the inequity in irrigation water distribution prevalent in the study area.

4. The highest crop yield (7901.97 kg/ha) was found at head ends of Bhavanipur Deep Tubewell irrigated area applying 863.60 mm of irrigation water, while the lowest crop yield (4214.39 kg/ha) was found at tail ends of East Togori Deep Tubewell irrigated area applying 444.50 mm of irrigation water in 2011-12 Boro season.

5. The water productivity diminishes from head ends to tail ends with the reduction of irrigation water. If more equal water distribution could be achieved along the canal i.e. inequity between head and tail ends is reduced, difference of crop yields between head and tail ends might be reduced.

6. Bhavanipur deep tubewell irrigated area received more water and has the better inequity in irrigation water distribution (equity coefficient 0.7471& Gini Coefficient 0.4370) and consequently crop yield was also higher than the other two irrigated areas. Difference in crop yield between head ends and tail ends in Bhavanipur was found 30%. There is much scope to minimize the inequity in water distribution by proper distribution of excess water from head ends to tail ends.

6. East Togori deep tubewell irrigated area received less water and has the worst inequity in irrigation water distribution (equity coefficient 0.4436 & Gini Coefficient 0.4754) and difference in crop yield between head and tail ends was also the highest (38.46%). So, it is clear that East Togori Deep tubewell irrigated areas get less quantity of irrigation water than the other two deep tubewell irrigated areas.

5.2 Recommendations

1. Equitable water distribution is to be ensured for achieving better crop production. The difference of amount of water delivered at head and tail ends must be reduced to minimum.

2. Establishment of Water User Group or Farmer's Association might be good option for ensuring transparency as well as elimination of manager's partiality.

3. The inequity of distribution of irrigation water might be reduced only through the elimination of the factors affecting the inequity of irrigation water distribution between head and tail ends.

4. Removal of inequity in irrigation water distribution is a good option for attaining higher food production as well as food security increasing the water productivity.

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APPENDIX-A

Questionnaire Survey for Water Equity & Productivity Assessment

জেলাঃ গাজীপুর, উপজেলা: গাজীপুর সদর

ফিল্ড নংঃ

সাক্ষাৎকারের তারিখঃ

(ক) কৃষকের তথ্যাদিঃ

১) কৃষকের নামঃ

২) পিতার নামঃ

৩) গ্রামের নামঃ

৪) ইউনিয়নঃ

(খ) জমির তথ্যাদিঃ

১) প্রকল্পে আপনার মোট কত দাগ জমি আছে? উহাদের মোট পরিমান কত? ---------শতক।

২) যে জমির জন্য আপনার সাক্ষাৎকার গ্রহণ করা হচ্ছে তার পরিমান কত?--------শতক।

৩) এ জমির প্রকৃতি কি (নিজ জমি/ বর্গা নেয়া/ গীরপি নেয়া/ লীজ নেয়া)?

(গ) সেচ বিষয়ক তথ্যদিঃ

১) আপনার জমিতে পানি সরবরাহের পরিস্থিতি কি?

নিয়মিত এবং যথেষ্ট

অনিয়মিত তবে যথেষ্ট

কদাচিৎ পাওয়া যায়

নিয়মিত তবে যথেষ্ট নয়

অনিয়মিত এবং যথেষ্ট নয়

অন্যান্য (বিবরণ দিন)

২) কি কি কারণে পানি সরবরাহ ব্যবস্থা সন্তোষজনক নয় বলে আপনি মনে করেন?

i) পাম্প ঠিকমত কাজ করে না?

ii) সেচখাল কাচাঁ হওয়ার দরুন সমস্যা?

iii) পানি বন্টনে পাম্পের মালিক / লাইনম্যান কোন অনিয়ম করে কিনা (একজনের জমিতে বেশী পানি দেয়া, অন্যজনের জমিতে কম পানি দেয়া, ইত্যাদি)?

iv) বিদ্যুৎ সমস্যা?

v) অন্যান্য সমস্যাঃ

৪) আপনার জানামতে প্রতিদিন গড়ে কত ঘন্টা পাম্প চলে?

৫) দিনের যতটুকু সময় পাম্প চলে এটাকে কি আপনি পর্যাপ্ত বলে মনে করেন?

যদি উত্তর না হয়, তাহলে এই কম সময় চলার কারণ কি কি বলে আপনি মনে করেন?

৬) পাম্প ঠিক ভাবে কাজ করলে সাধারণত আপনার একই জমিতে কতদিন পরে পুনরায় পানি দেওয়া যায়? অর্থাৎ সাধারন রোটেশন পিরিওড কত?

৭) বর্তমানে একই জমিতে কতদিন পরে পুনরায় পানি পাওয়া যায় অর্থাৎ বর্তমানে রোটেশন পিরিওড কত?

৮) আপনি সেচের জন্য যে পরিমান টাকা দেন সে রকম সেচ সুবিধা পাচ্ছেন কি?

যদি না হয় তবে তার কারণ কি কি বলে আপনি মনে করেন?

(ঘ) জমির পরিচর্যা বিষয়ক তথ্যাদিঃ

১) আপনি কি সময়মত (যখন দরকার তখন) এবং পরিমানমত (যতটুকু ততটুকু) নিচের জিনিসগুলি দিতে পেরেছেন?

	সময়মত		পরিমানমত		না দিতে পারার প্রধান কারণ
	হ্যাঁ	না	হ্যাঁ	না	
পানি					
সার					
ঔষধ					
নিরানী					
ধানের চারা					
ধান লাগানো					
জমি চাষ					

২) আপনার জমিতে কোন প্রকারের সার কতটুকু ব্যবহার করেছেন?

৩) আপনার কৃষি জমির পরিচর্যার পিছনে আপনি কতটুকু সময় ব্যয় করেছেন?

৪) আগাছা দমনের জন্য কি ব্যবস্থা গ্রহণ করেছেন?

৫) জমিতে যে বীজ ব্যবহার করেছেন, তা কোথা থেকে সংগ্রহ করেছেন? আপনি কি মনে করেন আপনি যে বীজ ব্যবহার করেছেন তার মান ভাল? ভাল না হলে, কেন আপনি তা ব্যবহার করেছেন?

৬) আপনি কি জমির মাটি কখনো বিক্রি করেছেন, যদি করে থাকেন তবে কখন করেছেন?

(ঞ) ফলন সম্পর্কিত তথ্যাদিঃ

১) আপনি কি ধরনের ফলন পান?

সাধারনতঃ------মণ পাখি (-----শতক) প্রতি

গত-----বছরের সর্বোচ্চ ফলনঃ -----মণ, গত-----বছরের সর্বনিম্ন ফলনঃ -----মণ

গত বছরের ফলন-------মণ, এই বছরের ফলন---------মণ।

গত মৌসুমের উৎপাদন-----মণ, এ মৌসুমের উৎপাদন ----মণ।

২) আপনি কি মনে করেন যে আপনি কম ফলন পাচ্ছেন বা অন্যদের তুলনায় কম পাচ্ছেন? কম হলে,কতটুকু কম হয়েছে?

৩) যদি আপনি কম ফলন পান তবে কি কি কারণে আপনার ফলন কম হয় বলে আপনি মনে করেন। প্রধান কারণ বা সমস্যা কি কি? এ সমস্যা কিভাবে দুর করা যায়?

কারণ / সমস্যা ১ঃ

দুরিকরণের উপায়ঃ

কারণ / সমস্যা ২ঃ

দুরিকরণের উপায়ঃ

কারণ / সমস্যা ৩ঃ

দুরিকরণের উপায়ঃ

APPENDIX – B

Total Water Received in Boro season (2011-12) of East Togori Deep Tubewell Irrigation Area

Fields	Distance from tubewell (m)	Field Area (Ha)	Depth of water received per irrigation (in inch)																Total Irrigation Water Received (in inches)	Total Water Received (in mm)
			1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th *	16th *		
ETI	30	0.17	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	28.00	711.20
ET2	50	0.28	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	28.00	711.20
ET3	80	0.14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	28.00	711.20
ET4	95	0.14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	28.00	711.20
ET5	340	0.13	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	24.50	622.30
ET6	380	0.14	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	24.50	622.30
ET7	420	0.11	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	24.50	622.30
ET8	450	0.17	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	27.50	698.50
ET9	600	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.5	1.5	22.25	565.15
ET10	710	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	-	-	19.25	488.95
ET11	790	0.14	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.5	1.5	22.25	565.15
ET12	870	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	1	1	1	1	1	1.5	1.5	17.50	444.50

Where ET1 means East Togori 1, ET2 means East Togori 2 and so on as shown on Chapter 4 Study Methodology.

*** Irrigation only for Rice Variety BRRIdhan29 (where the others are BRRIdhan28).**

APPENDIX – C

Total Water Received in Boro season (2011-12) of West Togori Deep Tubewell Irrigation Area

Fields	Distance from tubewell (m)	Field Area (Ha)	Depth of water received per irrigation (in inch)																		Total Irrigation Water Received (in inches)	Total Water Received (in mm)
			1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th *	18th *		
WTI	40	0.14	2	2	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	26.50	673.10
WT2	50	0.28	2	2	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	29.50	749.30
WT3	60	0.14	2	2	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	29.50	749.30
WT4	80	0.21	2	2	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	26.50	673.10
WT5	300	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	25.50	647.70
WT6	350	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	22.50	571.50
WT7	400	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	25.50	647.70
WT8	420	0.14	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	25.50	647.70
WT9	560	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	-	-	20.75	527.05
WT10	595	0.13	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.5	1.5	23.75	603.25
WT11	620	0.14	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	1	1	1	1	1	-	-	19.00	482.60
WT12	635	0.14	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	1	1	1	1	1	-	-	19.00	482.60

Where WT1 means West Togori 1, WT2 means West Togori 2 and so on as shown on Chapter 4 Study Methodology.

*** Irrigation only for Rice Variety BRRIdhan29 (where the others are BRRIdhan28).**

APPENDIX – D

Total Water Received in Boro season (2011-12) of Bhavanipur Deep Tubewell Irrigation Area

Fields	Distance from tubewell (m)	Field Area (Ha)	Depth of water received per irrigation (in inch)																				Total Irrigation Water Received (in inches)	Total Water Received (in mm)
			1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th *	19th *	20th *		
BPI	20	0.14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	-	34.00	863.60
BP2	50	0.17	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	-	34.00	863.60
BP3	80	0.13	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	-	34.00	863.60
BP4	85	0.14	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	40.00	1016.00
BP5	250	0.17	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	-	-	-	34.00	863.60
BP6	270	0.14	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2	2	2	35.00	889.00
BP7	295	0.13	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	-	29.00	736.60
BP8	330	0.14	2	2	2	2	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	-	29.00	736.60
BP9	390	0.11	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	-	-	-	27.25	692.15
BP10	450	0.13	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.5	1.5	1.5	31.50	800.10
BP11	490	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1	1.5	1.5	1.5	27.25	692.15
BP12	580	0.11	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1	-	-	-	22.75	577.85

Where BP1 means Bhavanipur 1, BP2 means Bhavanipur 2 and so on as shown on Chapter 4 Study Methodology.

*** Irrigation only for Rice Variety BRRIdhan29 (where the others are BRRIdhan28).**