Assessment of Environmental Parameters in Relation to Different Agro-Water Management Practices in South-West Coastal Region of Bangladesh

by

Nazia Hassan

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

Institute of Water and Flood Management
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

February, 2011

Dedicated to

My Well-wishers

Assessment of Environmental Parameters in Relation to Different Agro-Water Management Practices in South-West Coastal Region of Bangladesh

A Thesis by

Nazia Hassan

In partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

Institute of Water and Flood Management

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

February, 2011

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Institute of Water and Flood Management

The thesis titled '**An Assessment of Environmental Parameters in Relation to Different Agro-Water Management Practices in South-West Coastal Region of Bangladesh**' submitted by Nazia Hassan, Roll No. M10072810P, Session: October 2007, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Development on 27 February, 2011.

BOARD OF EXAMINERS

.... Dr. M. Shahjahan Mondal Associate Professor Institute of Water and Flood Management Bangladesh University of Engineering and Technology, Dhaka	Chairman (Supervisor)
.... Dr. M. Shah Alam Khan Professor and Director Institute of Water and Flood Management Bangladesh University of Engineering and Technology, Dhaka	Member (Ex-officio)
.... Dr. Abul Fazal M. Saleh Professor Institute of Water and Flood Management Bangladesh University of Engineering and Technology, Dhaka	Member
.... Dr. Subrota Kumar Saha Associate Professor Department of Geology University of Dhaka, Dhaka	Member (External)

CANDIDATE'S DECLARATION

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

………………………..

Nazia Hassan

Roll No. 10072810 P

Session: October, 2007

ACKNOWLEDGEMENT

At the onset, I would like to thank the Almighty Allah for giving me the ability to complete this research work.

Foremost I gratefully acknowledge the explicit and effective direction and supervision of Dr. M. Shahjahan Mondal, Associate Professor, Institute of Water and Flood Management (IWFM), Bangladesh University of Engineering and Technology (BUET).

I am profoundly indebt to Dr. Abul Fazal M. Saleh, Professor, IWFM, for providing me valuable advice and guidance. I am also deeply grateful to Dr. M. Shah Alam Khan, Professor and Director, IWFM, for providing me important suggestion and direction. I would like to express my heartfelt gratitude to Dr. Subrota Kumar Saha, Associate Professor, Department of Geology, University of Dhaka, for his fruitful advice and comments.

I am deeply grateful to Crossing Boundary (CB) Project of IWFM, BUET collaborated with SaciWATERs, for their facilitation and for providing total financial support for the research work. In addition, I acknowledge Professor Dr. Dilip Kumar Datta, Head of the Environmental Science Discipline, Professor Dr. Mahmood Hossain, Forestry and Wood Technology Discipline, and Md. Ashkar Bin Sayeed, Assistant Professor, Fisheries and Marine Resource Technology Discipline, Khulna University, for their consultation and facilitation to analyses soil and water parameters.

I also diligently acknowledge Shangkar Kumar Sarkar and Mrs. Morjina Akhter, Khondakar Arifuzzaman from Environmental Science Discipline, Khulna University, for their help in analysis of soil and water.

I greatly acknowledge the farmers of Ranoi, Bhadradia, Jialtoli and Badurgachi villages, for their cooperation and feedback in the research process through specific data assembling of different agro-water management practices (AWMPs).

Lastly but not least, I thankfully acknowledge all the faculties of IWFM, BUET for their motivations and encouragements in the research process.

ABSTRACT

Salinization of productive agricultural lands in southwestern coastal Bangladesh and their reclamation are getting distinct importance to the local people as well as policy makers. Salinization has been established as the prime cause of environmental degradation in the region and there is an urgency to find out a water management practice which is economically beneficial, socially acceptable and environmentally sustainable. Keeping these viewpoints, this study was undertaken to evaluate the present statuses of different agro-water management practices in Dumuria Upazila, to carry out laboratory analyses of selected soil and water quality parameters of agricultural fields, and to assess the environmental consequences of those farming practices. Four different types of agro-water management practices (AWMPs) with three ghers under each practice were selected for investigation. Several important soil and water quality parameters (temperature, salinity, pH, EC, TDS, DO, HCO_3^-, Ca^{2+}, Mg^{2+}, Cl^-, Na^+, K^+, SO_4^{2-}, NO_3^-, etc.) during the pre- and post-boro season of 2009-10 were analyzed to calculate the mean soil and water quality change indicators (MSQI, MWQI). Besides these, management parameters, such as cropping pattern, irrigation, water exchange, use of fertilizer, use of pesticide, number of years of boro cultivation, vegetation on gher dykes, etc., and economics of production were considered for evaluation of best practices among different AWMPs using multi-criteria analysis (MCA). The highest deterioration of soil quality was found in the Type-3 AWMP and the lowest in the Type-2 AWMP. In case of water quality, the order of deterioration was found to be: Type-3 AWMP > Type-4 AWMP > Type-2 AWMP > Type-1 AWMP. The degree of correlation of economic parameters with quality and management parameters was used to give weightage of parameters in MCA – a strong relation ($P < 0.01$) was given a high weightage and a moderate relation ($0.01 < P < 0.10$) was given a low weightage. Thus the Type-2 AWMP got the highest total average score and appeared to be the best AWMP. This was due to the community management approach for controlling saline water into the ghers, use of more organic fertilizer, use of IPM techniques, less cropping intensity, less deterioration of soil and water quality, higher economic return, etc. So, from this study it can be said that the communal approach in water management for HYV boro rice cultivation with a crop rotation of golda-bagda-white fish is the best AWMP among the current practices in the study area

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

ABBREVIATIONS and ACRONYMS

µg/g	microgram per gram
AFI	Aquaculture Foundation of India
AWMPs	Agro-Water Management Practices
BARC	Bangladesh Agricultural Research Council
BADC	Bangladesh Agricultural Development Corporation
BRRI	Bangladesh Rice Research Institute
DAT	Days after Transplantation
DO	Dissolve Oxygen
dS/m	desiSimens per meter
CEC	Cation Exchange Capacity
CEP	Coastal Embankment Project
CM	Community Management
EC	Electrical Conductivity
ESP	Exchangable Sodium Percentage
FAO	Food and Agricultural Organization
GW	Groundwater
ha/kg	hactor/kilogram
HYV	High Yield Variety
IM	Individual management
IPM	Integrated Pest Management
KU	Khulna University
MCA	Multi Criteria Analysis
meq/gm	miliequivalent per gram
meq/ml	miliequivalent per mililiter
mg/kg	milligram per kilogram
MOP	Murate of Potash
MS	Management Status
MSQI	Mean Soil Quality Change Indicator
MV	Modern Variety
MWQI	Mean Water Quality Change Indicator
NACA	Network of Aquaculture Centre in Asia Pacific

NC	Number of Crop
OM	Organic Matter
ppm	parts per million
RPG	Rice Prawn Gher
RSC	Residual Sodium Carbonate
RY	Rice Yield
SAR	Sodium Absorption Ratio
SIC	Silty Clay
SRDI	Soil Resource Development Institute
STW	Shallow Tubewell
SWD	Standing Water Depth
SW	Surface water
Tk.	Taka
TOC	Total Organic Carbon
TSP	Triple Super Phosphate
UCP	Use of Chemical Pesticide
UFO	Use of Organic Fertilizer
UIF	Use of Inorganic Fertilizer
VD	Vegetation on Dyke
WEx	Water Exchange
YBC	Year of Boro Cultivation

CHAPTER ONE
INTRODUCTION

1.1 Background of The Study

The south-west coastal region of Bangladesh is characterized by the Sunderban (world's largest mangrove forest), shrimp cultivation and salinity. The coastal environment has undergone rapid changes in recent years. Such changes in the state of the environment have been multifaceted with the destruction of mangrove forests, and conversion and encroachment of agricultural land to shrimp farming and other uses. Transformation of rice fields into shrimp farms has changed the land use/ cover of the densely populated coastal areas in tropical Asia and Latin America in the world (Flaherty *et al.*, 1999). While the cost of shrimp production in Bangladesh (Tk. 280/ kg) is one of the highest in Asia, the net profit from shrimp is 12 times higher than that of high yielding variety (HYV) rice (Shang *et al.*, 1998). Because of its high profit, shrimp farming has emerged as the most attractive land use practice that contributes to the economic development of the coastal districts of the country (Hossain *et al.*, 2004). The south-west coastal districts, especially Satkhira, Khulna and Bagerhat, are the most promising areas for shrimp cultivation in Bangladesh.

The unplanned and rapid expansion of shrimp farms during the last two decades has provoked conflicts among the three dominant resource-dependent livelihoods of the coastal neighborhood – the agriculture, the shrimp farming and the fishing. Salinization and loss of soil fertility could have been traced from a drastic declination of rice production from around 40,000 ton to only 36 ton in Satkhira within a span of ten years from 1976 to 1986 as saltwater canals from shrimp ponds cut across paddy fields (Shiva, 2000). This can be termed as, according to the local villagers, prawn revolution at the cost of the rice. This conversion sometimes induced environmental degradation and social unrest, and it might not deliver sustainable benefits to small farm-holders (Majid and Gupta, 1997). Thus there is an urgency of advocating or prescribing alternative agro-water management practices for sustainable production system(s) for food security and livelihood of the marginal coastal farmers.

Nandy *et al.* (2007) reported a trend of traditional and improved traditional shrimp farming practices since 1980s at Paikgachha, Koyra, Dacope, Dumuria, and Batiaghata Upazilas of Khulna district. The high profit from shrimp production has overridden all positive impacts of the green revolution planned through Coastal Embankment Project (CEP) of 1960s in these regions. Shrimp farming, whether extensive, semi-intensive or intensive, thrives well in saline ecosystem and exerts wide range of adverse impacts on another crop when conjugates with rice cultivation. As for example, Shang *et al.* (1998) reported a rapid depletion of the organic matter content of the soil due to extensive shrimp farming. Prolonged saline water logging in shrimp ponds accelerates leaching of base minerals, and increases salinity and acidity of soil (Douglas, 1994; Flaherty *et al.*, 1999; Landon, 1991).

Rice plants cannot tolerate excessive salinity (EC> 47 dS/m) and acidity (pH≤ 4) as they reduce its vegetative growth and yield (Mass and Hoffman, 1977; Kyuma, 2004; Ponnamperuma *et al.*, 1973). Highly saline and acidic soil and water also adversely affect the aquatic species living in rice ecosystem (Flaherty *et al.*, 1999; Greenland, 1997; Khatun and Flowers, 1995; Welfare *et al.*, 1996). Most of the shrimp farmers of these regions are found to disregard the significant relation of soil-water environment to crop growth either intentionally or ignorantly. Depletion of organic C, Ca^{2+}, Mg^{2+} and K^{+} and enrichment of N and P are attributed to prolonged waterlogged conditions. Effluent from aquaculture ponds are typically enriched with suspended organic solids, C, N, and P. This may contribute significantly to elevated nutrient loadings in coastal environments and, in particular, to change in soil and water environment (Paez-Osuna *et al.*, 1997; Dierberg and Kiattisimkul, 1996; Chua *et al.*, 1989). As an effect of these, anoxic sediments can be built up, benthic diversity can be impaired, and eutrophication of coastal waters can occur (Folke and Kautsky, 1992). To address healthy water condition in shrimp ghers, several physico-chemical parameters viz., pH, transparency, temperature, dissolved oxygen, biological oxygen demand, phosphate, bicarbonate, chloride, salinity, total dissolved solid, and electrical conductivity, etc., should be within the optimum range fixed by the analysts. Wahab *et al.* (2003) found that low pH and low salinity in water were mostly accompanied with low growth performance of shrimp. Whatever, there are substantial evidences which indicate that shrimp farming has resulted in environmental degradation; restoration costs have conservatively been estimated at 30% of the total revenues derived from shrimp aquaculture. The real cost might be much higher than the prediction, and some of the environmental impacts that have been attributed to shrimp culture, such as biodiversity loss, are irreversible.

On the other hand, farmers of Batiaghata and Dacop Upazilas in Khulna District are trying to get rid of the bare land curse by cultivating paddy and ignoring bagda cultivation. Although the study areas are in geographical vicinity of the aforementioned areas and the livelihood patterns are almost the same, the land use patterns were found to mismatch to some extent, especially in case of shrimp cultivation. The patterns of agro-water management are different in Sobhana and Kharnia Unions of Dumuria Upazila, though the source of water is the same Bhadra River. The river has a diurnal tidal regime. During flood tide, the water level could be 1–3 m high from the mean level, provided that a smooth hyposaline condition is maintained in the monsoon season with an average electrical conductivity < 1.0 dS/m during July-December and < 4.0 dS/m during January-February (SRDI, 2003). According to SRDI (2003), outrange (EC of 5-13 dS/m) of that salinity level in other months is highly harmful for the soil fertility in the neighborhood agro-production areas of the Bhadra River which flows across Dumuria Upazila and falls into the Poshur River; and to say, the level of salinity is favorable for shrimp cultivation in these two unions. The saline water utilization is simply controlled by the sluice gates built in the interface of the river and the canal. Inlets and outlets built into the earthen dykes of the ghers control the entry or exit of saline water into the ghers, otherwise pumped as needed. The entry of saline water is generally restricted during the dry season as because the high salinity level makes the water unsuitable for irrigation. Then golda and rice dominated farm cultivators find convenient to use Shallow Tubewell (STW) water.

The shrimp cultivation implies golda (freshwater prawn) or bagda (brackish water tiger shrimp) cultivation or the both. In the study area, integration of different farming components is a usual phenomenon, like golda—mixed bagda and white fish, rice—mixed golda, bagda and white fish, rice—mixed golda and white fish, and rice—mixed bagda and white fish, etc., in a sequential fashion of farming. Different farming practices have different management measures which have significant impact on the production as well as on the environment. The major concern is that the overlying conflicts among these groups are making the production system unstable in the locality as well as in the southwestern Bangladesh as a whole.

Initially, most of the farmers did welcome the saline water in the coastal agro-production lands from a viewpoint to metamorphose those lands into shrimp ghers. Long-term retention of this saline water into the enclosed ghers posed a threat to soil fertility and crop production at a time when everyone has already to pay much of it. Furthermore, in recent times, frequent disease problem and low quality hatchery-produced seeds following low production of shrimp and economic loss have discouraged the local farmers in shrimp farming. Thus interest in HYV rice production is being backed due to the price hike of rice. As a result, such practices have made the total environment now-a-days favorable for crop production and the economic and social status of the villagers are expected to be in line with the sustainable environment.

Hence, the community management approaches to control the river water access into the ghers, which has already been started in the said areas, is a powerful social tool to resolve the problems related to the sustainability issues in those saline-prone areas. Experiences elsewhere proved that the use of short-duration, high-yielding rice varieties, the effective use of rainwater and proper crop scheduling that matches crop water requirements with the water supply and quality dynamics can increase the cropping intensity and productivity of rice lands in coastal areas (Tuong *et al.*, 1991; My *et al.*, 1995). Mondal (1997) successfully grew HYV rice in the wet season in the coastal zone areas of Bangladesh. Afterwards, he revealed that the river water in Khulna District remained suitable for irrigation far into the dry season until mid-February. Storing river water in the on-farm reservoir canals in the monsoon to ensure available freshwater supply for irrigating the HYV rice fields in the subsequent dry season could create an avenue for resolving the existing resource utilization conflicts and confusions in the coastal lands.

The precise extent of the environmental deterioration associated with shrimp aquaculture development remains largely unquantified due to the lack of reliable data over time. Although diversified works on the consequences of horizontal expansion of shrimp culture in southwest coastal region have been reported in many literatures, very few systematic analyses of environmental parameters following scientific methodology have ever been made to reckon the impairment. Several studies on shrimp farming in Bangladesh have recognized it as highly profitable land use practice, in turn, it destroys the mangrove forest, increases soil acidity, salinity and water pollution, affects rice cultivation, and increases rural unemployment, inequality and social violence; and that there is a great need for multi-disciplinary empirical research to explore its further impacts and development prospects (Deb, 1998; Guimaraes and de Campos, 1989; Hossain *et al.*, 2004; Rahman, 1994). Even though the investigations on the impact of shrimp farming on soil properties, water properties, rice production, and piscine and non-piscine species inherent in rice ecosystem are very important to ensure the nation's future food security in the face of rapid population growth, but those have not yet been covered to a great extent in the past studies.

At present the farmers of the study area are trying to cope with environmental sustainability by practicing rice–mixed shrimp and white fish farming in shrimp ghers. From the present agro-water management practices (AWMPs), farmers are getting benefit environmentally, economically and socially in Dumuria Upazila of Khulna district. This research is undertaken to assess the environmental consequences of different agro-water management practices in Dumuria Upazila using soil and water quality indicators**.** The study was conducted to find out the best suitable AWMP, which can be taken as the first step towards sustainability.

1.2 Objectives of the Study and Possible Outcome

The specific objectives of the study are as follows:

a) To evaluate the present statuses of different agro-water management practices in Dumuria Upazila;
b) To carry out laboratory analyses of selected soil and water quality parameters of agricultural fields; and
c) To assess the environmental consequences of those farming practices.

This study sought to find out such a farming practice which will adopt, to cope with the better farming practices, to achieve sustainability of land use in the south-west coastal region of Bangladesh.

1.3 Limitations of the Study

Some limitations were noted while conducting this research and they are listed below:

I. It was not possible to measure the changes of soil and water quality of V-3, R-1, B-1, and B-2 ghers. These ghers were shifted from the cultivation of HYV boro rice to shrimp cultivation at 45 to 60 days after transplanting of paddy.

II. Two sample ghers (R-1 and V-3) were excluded from multi-criteria analysis (MCA) of different AWMPs because of the above limitations.

III. In this study, only HYV boro rice yield of each gher was taken as economic criteria in evaluating the best farming practice.

1.4 Organization of the Thesis

This thesis contains five chapters. The organization of different chapters is described below:

Chapter One: This chapter contains the background of the study, objectives and limitations.

Chapter Two: A vast literature review has been completed with the shrimp-rice sustainability trends. The negative and positive impacts of shrimp and rice-shrimp cultivation practices on soil and water environment are reviewed in this chapter.

Chapter Three: This chapter is structured with a general description of the study area, the method of water and soil sampling, and the social survey techique. The methods and materials used in the research are clearly described.

Chapter Four: This chapter is structured with the results and discussions of the research. The results and discussion cover existing agro-water management practices (AWMPs) in the study area, environmental quality parameters (soil and water), and the sustainability of different AWMPs.

Chapter Five: The conclusions of the study are made in this chapter and a set of recommendations for further study is also presented.

CHAPTER TWO
LITERATURE REVIEW

2.1 Shrimp Cultivation in South Western Coastal Region of Bangladesh

Land use in coastal Bangladesh is diverse, competitive and conflicting. Agriculture, shrimp farming, salt production, forestry, ship-breaking yards, ports, industry, settlements and wetlands are some of the uses. Land uses have gone through major changes. Land use in the 1950s had been mainly for paddy cultivation, but salinity intrusion and tidal flooding prevented further intensification. Hence, in the 1960s–1980s, the World Bank and others helped with large-scale polderization in order to boost rice production in southwestern Bangladesh. A decade later, drainage congestion inside and heavy siltation outside the polders made the southwestern area unsuitable both for agriculture, and, in extreme cases, even for human habitation. However, as the region has a history of traditional shrimp farming, polders provided an opportunity for intensive shrimp farming. Crop land and mangroves were transformed to shrimp farming (Islam, 2007). Undoubtedly, the shrimp culture industry earns valuable foreign exchange for developing countries and generates jobs across the industry from fry gatherers to growers and processors (Primavera, 1994). In 1995 more than 7,00,000 tones of marine shrimp were farmed worldwide, with around 80% from Asia (Rosenberry, 1995).The contribution of farming to global shrimp production has risen from a mere 6% in 1970 to 26% in 1990. Farmed shrimp contributed 27% of total world shrimp production in 1995 with a volume of 712000 tones (FAO, 1997).

Shrimp culture, nowadays, plays a central part in the fisheries sub-sector in Bangladesh by creating a substantial employment on shrimp farms as well as increasing in activities such as trade and commerce, processing and marketing and export. Shrimp cultivation experienced a spectacular boost from next to nothing in the early 1970s to become a major export earning industry by the mid 1980s (Datta *et a*l., 2009). Analysis of the last decade's export items of Bangladesh reveals that, shrimp has replaced raw jute as the dominant export item in the primary goods category recently, and now shrimp export contributes nearly half of our primary export items. Alauddin and Tisdel (1997) described this export 'boom' as the effects of various government policies and high demand of shrimp in other countries. Despite of this 'so-called' importance of shrimp aquaculture in the country; debates, disparities and criticisms have been following this sector since its very birth. First of all, the profits generated from shrimp exports are not broadly shared throughout the chain—as there are marked differences in the benefits middlemen and farmers accrue in contrast to the surplus acquired by fry catchers. Secondly, shrimp culture is characterized by social inequality, disparity, rice versus shrimp conflicts, inadequate and ill implementation of policies, conflicts of power and privilege, ecological threats and damages, insufficient structure, lack of clarity in understanding, peoples' protest and blood shade, conflicts on saline water breach and so on. Furthermore, gender disparities permeate the chain leading to occupational segmentation, wage inequality, and increased job insecurity for women.

Table 2.1 Shrimp Culture Scenario in Southwest Bangladesh

District	Number of Ghers	Area (Hector)	Bagda		Golda	
			Number of Ghers	Area (Hector)	Number of Ghers	Area (Hector)
Satkhira	15,848	52,399	15,820	51,638	828	761
Bagerhat	52,311	59,424	18,050	43,208	34,261	16,216
Khulna	37,908	51,667	4,606	38,906	33,302	12,761
Total	1,06,067	1,63,490	38,476	133,752	68,391	29,738

(Source: DoF, 2003)

Shrimp is cultured in the southwest of Bangladesh, mainly in the Khulna-Satkhira-Bagerhat region (KSB region). It is also cultured in the districts of Chittagong and Cox's Bazaar in the southeast. The organization of production is quite different in the two regions. In the latter the land use trade-off is between shrimp and salt and in the KSB region the trade off is generally between rice (mainly Aman) and shrimp. A large part of the KSB region is semi-saline. According to the studies by fishery researchers (MoF, 1996; Xan, 1996 and Arlo, 1992) main forms of shrimp farming in the world are extensive, semi-intensive, intensive and super-intensive. These forms of farming are selected based on natural conditions, soil properties, water source, weather, climate, hydrological conditions, socio-economic conditions, local level of education, technical skills, capital investment, etc.

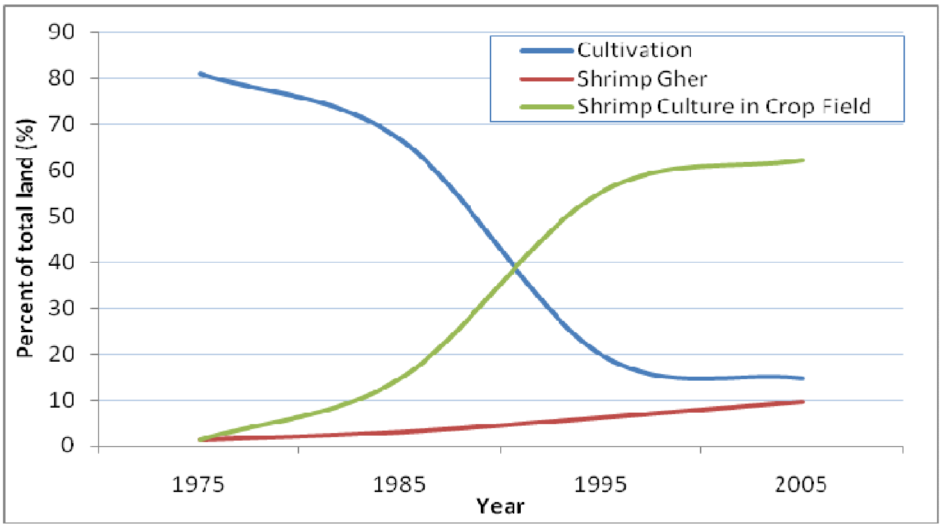
Presently, the total number of these brackish-water shrimp aquaculture farms is 16028, covering an area of 130654 ha of coastal Bangladesh land (DoF, 2002). Rapid conversion of dry season pasture land into shrimp farming is contributing to the adverse effect on our coastal ecosystem. In the Chokoria Sunderbans the shrimp culture at the cost of mangrove forest not only causing loss of bio-diversity but has undermined the very basis of shrimp culture by disturbing the natural nutrient cycle. Decreasing rice production from around 40000 ton in 1976 to only 36 ton in 1986 in Among several species available in the coastal regions, *Penaeus monodon* (locally known as *bagda chingri*) is the preferred species for brackish-water shrimp farming and attracts a very high price in international markets. In Bangladesh, *P. monodon* comprises 60% of farmed shrimp production, followed by the giant freshwater prawn, *Macrobrachium rosenbergii* (*galda chingri*) which accounts for 25% of production (Rosenberry, 1995; Ahmed, 1996). A detail of the area coverage may be seen below in Table 2.2.

Table 2.2 Shrimp Culture Coverage in Southwestern Region of Bangladesh

Type of Shrimp	District	Upazila
Bagda (saline water shrimp)	Satkhira	Tala, Satkhira, Debhata, Kaligonj, Assasuni and Shayamnagar
	Khulna	Koyra, Paikgacha, Rupsha, Batiagahta, Dacope and some parts of Dumuria
	Bagerhat	Mongla, Rampal and Southern parts of Fakirhat, Bagerhat and Morelganj
Golda (fresh water prawn)	Jessore	Keshabpur, Monirampur and Abhoynagar
	Khulna	Terokhada and parts of Dumuria
	Bagerhat	Mollahat, Chitolmari and the northern portions of Bagerhat, Fakirhat and Morelganj

(Source: Tutu, 2001)

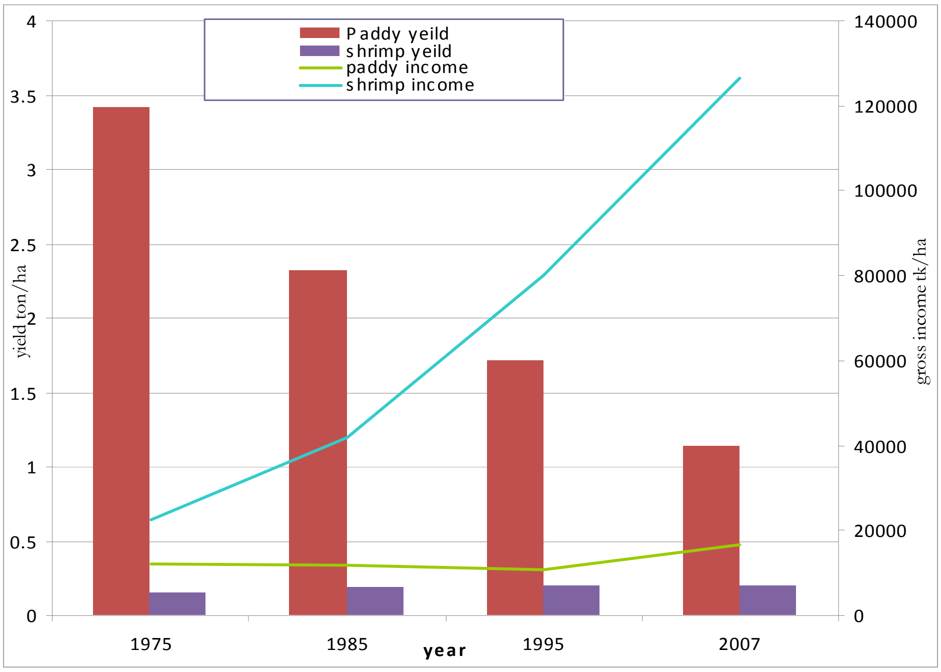
Over the recent decades, transformation of rice field into shrimp farms has been a major land use/land cover change in coastal areas of Bangladesh (Ali, 2006). On the one hand, high population pressure induced smallholders to intensify rice production by shifting from low yielding variety to HYVs of rice (Ali, 1987; Turner and Ali, 1996). On the other hand, increased global market demand for cultured shrimp and its high profit has induced tropical farmers to transform part of their rice fields into shrimp ponds and thus transformed into dual farmers (Pingali *et al*., 1997). Although the environmental consequences of such transformation is to some extent understood by the local communities and shrimp farmers, the deteriorating conditions of the environment is one of the key role players in provoking shrimp farming in the region along with the most important catalyst called 'quick profit'. Hence, it is important to understand the environmental consequences of such land transformation: whether this would disrupt the ecological conditions and sustainability of rice production; and how that would affect the farmers mixed production behavior (Ali, 2006).



(Source: Islam, 2007)

Figure 2.1 Land Use Change during 1975-2005 in a Southwestern Region

Field studies from Islam (2007) and Karim (2006) reveals, most of the lands under agriculture were double cropped, and to some extent triple cropped in Khulna, Satkhira and Bagerhat districts, i.e. southwestern belt of Bangladesh. The cropping pattern started to change gradually from mixed Boro and Aman cultivation to monoculture of *Boro* in this area since the introduction of the shrimp culture in 1980s. Local varieties of rice like *Ratna*, *Hirra* were traditionally used for the rice cultivation in Boro season. Nowadays, high yielding varieties like BR-11, 28, 34 and some other varieties have replaced the traditional varieties. This transformation is mainly provoked by some facts like: the yield reduction of local traditional varieties due to salinity and water logging, continuously hike of price of fertilizer and pesticides and low price of rice, quick profit from shrimp etc. Saline water round the year also shows a negative impact on grain size filling locally called as "*chitta para*" which frequently appears in the *Boro* harvesting season most of the time. Despite of the negative environmental impacts of shrimp '*gher*' on agricultural land, which according to the local farmers are due to salinity mainly (Islam, 2007) for a case study in Dumuria, Khulna), factors like quick profit and cash flow has mainly evolved as the main stay behind the wide spread practice of shrimp culture.

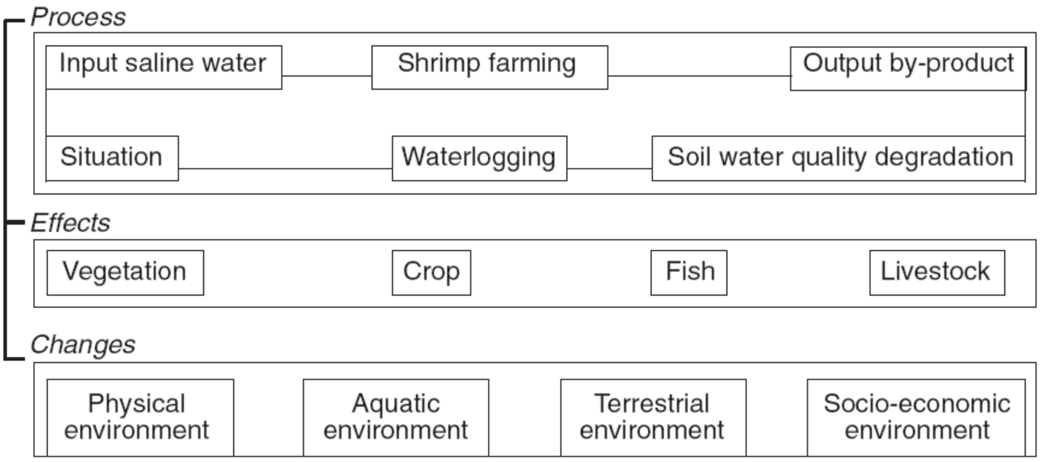


(Source: Islam, 2007)

Figure 2.2 State of Paddy versus Shrimp Yield and Income in a Southwestern Region of Bangladesh

Ali (2006) documented how the coastal saline landscape of the country became transformed from a rice dominated region to a shrimp dominated area. During 1 975–2000, the country's shrimp *gher* area has increased from 20,000 to 141, 000 ha; and shrimp export revenue has grown from US$4.0 million to US$360 million (BBS, 2002). Because of its high profit, shrimp farming has emerged as the most attractive land use practice that contributes to the economic development of the coastal districts of the country (Hossain *et al*., 2004).

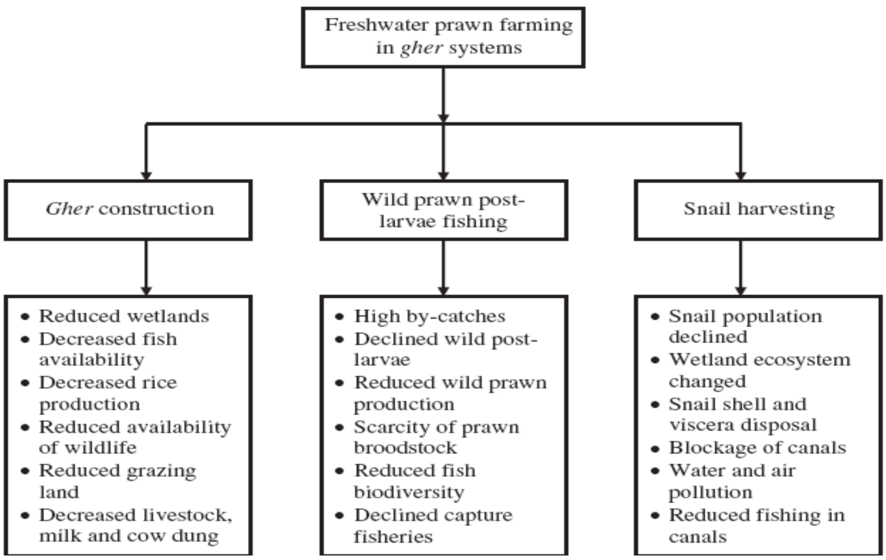
The cropping pattern has changed from YRMV paddy farming to RPG farming system after the introduction of gher farming (Toufique, 2002). In Bangladesh, freshwater prawn farming first started in the southwest region in the early 1970s (Mazid, 1994). Finally a few pioneers, some time between the late1970s and the mid 1980s, developed the first prawn cultivation in rice yields in low lying agricultural land. In the late1980s, this farming practice began to be adopted widely in the original location in the Fakirhat area, where prawns were grown along with carps and rice (Kamp and Brand, 1994). The expansion of prawn cultivation has been dramatic, and since1990 adoption has accelerated, spreading to other southwest districts such as Khulna and Satkhira. Brackish-water shrimp farming has altered the physical, ecological (aquatic and terrestrial) and socio-economic environment. A schematic flow diagram (Figure 2.3) describes the various functions and interrelationships among the processes, effects and changes of each subcomponent.



(Source: Karim, 2006).

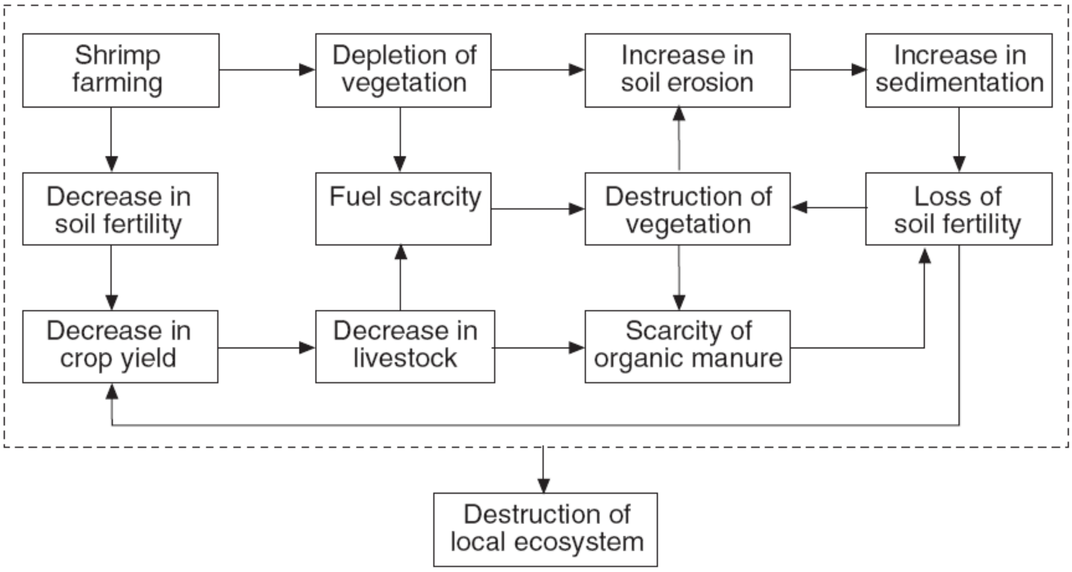
Figure 2.3 A Diagrammatic Model of Overall Function and Implications of Bagda Farming in Rampal Upazila

Freshwater prawn farming in Bangladesh had not been associated with any of the negative environmental consequences for which marine shrimp production has received so much criticism (Csavas, 1993; Phillips, Lin and Beveridge, 1993). The development of prawn farming has brought about several environmental impacts due to ghers construction, wild post larvae collection and snail harvesting (Figure 2.4).



(Source: Ahmed, 2001).

Figure 2.4 Environmental Impacts of Freshwater Prawn Farming in Gher Systems



(Source: Karim, 2006).

Figure 2.5 A Diagrammatic Model of Direct And Indirect Effects of Shrimp Farming in Khulna

Figure 2.5 was showed that the interrelationship of the direct and indirect effects of shrimp farming on physical, ecological, socio-economic and environmental conditions in Khulna. The conversion of agriculture to shrimp farming created a physical and ecological imbalance, which has largely destroyed the natural ecosystem of the study area (Karim, 2006).

However, shrimp farming in the world has faced many difficulties due to impacts of environmental pollution, and shrimp epidemics, resulting in great damage; for example, in China in 1991, shrimp yield reached 145,000 ton reducing to only 50,000 ton in 1993, in Indonesia from 140,000 ton in 1991 to 50,000 ton in 1998, in Taiwan from 90,000 ton in 1987 to 9,000 ton in 1990 (ACIAR, 1999). Poernomo (1989) identified reasons for failures of shrimp culture as: Improper site selection, poor design and lay outs of ponds. Improper planning resulted in a poor irrigation system, and many shrimp farmers faced problems in obtaining the right quantity and quality of seawater and freshwater (Hanafi, 2004).

The general impression is that the pre-shrimp environment was static and pristine. This is false. Pre-shrimp agri-environment changed from time to time and from place to place. There are two things that come up sharply from this literature review undertaken by BCAS (2001). *First*, there were changes before shrimp farming was introduced in this region. A pristine picture of an environmental harmony in a pre-shrimp state of nature is a myth. The complex interactions between the nature and the community have always been there. Shrimp came to the community as a new dimension at a time while they were already exposed to changes and interacted with the local elites, bureaucracy and the like. *Second*, shrimp is just one component of the rural system although it has wider impact on land ownership, property rights, livelihoods, consumption, exchange and the like. Without shrimp, the community had to address other environmental problems associated with managing commons, demographic pressure on natural resources and so on. In fact before shrimp aquaculture started in Chakoria in the southeast of Bangladesh, expansion of agriculture and demographic pressure resulted in rapid depletion of the forests.

2.1.1 Environmental impact

An array of environmental concerns have been documented that range from salt water intrusion, alteration of drainage patterns, mangrove deforestation, loss of barrier services, changes in nutrient recycling, and contamination from runoff associated with feeding and fertilization practices (Datta *et al.*, 2009). The following illustrates some of the major issues concerning environmental impacts of the shrimp aquaculture.

Shrimp farming has been expanding here and there in an unplanned way in the entire coastal belt without considering whether the area is high saline zone, medium saline zone or low saline zone by nature. This has increased the salinity in areas where the salinity usually is low (Islam *et al.*, 1998). Non saline soils have been turned into slightly saline (2-4 dS/m) or moderate saline (4-8 dS/m) and are not suitable for crop cultivation anymore. Some parts even are left fallow (Islam, 1999). During the months of May and June the salinity rises to 16125 ppm in most of the rivers in Khulna zone, water is used for the shrimp cultivation. In the months of December and January when the ghers dry up, a layer of white salt becomes visible on the soil. The layer contains salt up to 12900 ppm, which is badly harmful for the production of paddy and other crops (Saha *et al.*, 2000). The predominant soil texture is clay and silty clay, with mostly slightly acid to alkaline conditions (pH 5.4-8.0). Clay dominates over silt (36%) and sand (2%). There is less variation in soil pH in agricultural areas than there is in shrimp farming areas. Conversely there is a greater variation in soil salinity (up to 13 ppt) in shrimp farming areas than in agricultural areas (2.8-4 ppt). Organic matter contents are higher in agricultural areas, and lower (about 2.7%) in shrimp farming areas. The N, P, K and Ca levels are low to moderate in shrimp farming areas, whereas Mg, S, and B are moderate to high. In agricultural areas the overall soil fertility is low and soil salinity is the major hazard to be overcome (Alam and Phillips, 2004).

Islam (1999) studied on soils and water in some areas under Khulna division some changes in the physical condition can be indentified which may affect the ecology in the area. The air and water temperature in the shrimp farming areas was found to be slightly higher than non–shrimp farming areas. This is not favorable for the fresh water fish. Some changes in the plankton can also be seen according to the study. In the saline area the fresh water plankton were not found anymore, but marine phytoplankton though. Further on the density of zooplankton was lower in the shrimp farming areas than in the non–shrimp farming areas.

Ali (2004) examined the impact of shrimp farming on rice ecosystem in a village in Southwestern Bangladesh. The village Damarpota has experienced transformation of 274 ha (79%) of its prime quality rice fields into shrimp farms during the period between 1985 and 2003. Prolonged shrimp farming for 5-, 10-, and 15-year period has increased soil salinity, acidity, and depleted soil Ca, K, Mg, and organic C content of all three types of soils in the villages to a variable degree and caused soil degradation that significantly affected the rice yield. Declined yield and acreage of rice jointly reduced the total production of rice and animal fodder. Soil degradation and loss of acreage under rice have threatened the sustainability of the village rice ecosystem.

One of the major problems caused by shrimp farming development and faced by not only shrimp farmers themselves but also local people living in and around the farming areas are water pollution (Doa *et al.,* 2006). The quality and quantity of available water are major factors controlling shrimp production. Water quality is critical during the early life stages in the hatchery and during grow out in ponds. In general water for shrimp culture should be free from agricultural and industrial pollution and be within the necessary salinity and temperature range for the shrimp species being cultured. The water quality requirements for shrimp culture have been broadly defined in several publications (Boyd, 1989). There is evidence that shrimp culture itself is threatened by growing water pollution in Asia and Latin America (Chua *et al*., 1989; Aiken, 1990).

The amount of water required for shrimp culture depends on the nature of the culture system. Extensive pond culture relies largely on tidal flow and sites are usually selected such that there is adequate in flowing water and the ponds are drainable during periods of low tide (Csavas, 1989). The requirement of water increases with intensification because intensive culture need to remove substantially more waste metabolites and supply oxygen at high stocking and feeding rates (Phillips *et al*., 1993). Shrimp farming expansion has changed the process of flowing of clean river water into sea and reduced the self-cleaning ability of waters. But most seriously, due attention has not yet been paid to waste water/effluent treatment. Some farming areas are in lack of appropriate water exchange system or water treatment system, deteriorating water quality in farming ponds. In many areas, effluents from disease infection ponds become a water supply source of other adjacent ponds, leading to disease outbreak and water pollution of the whole farming area. Bad water quality is mainly responsible for shrimp epidemics (Doa *et al*, 2006). In the first six months of 2003, in the coastal areas of Thai Binh and Nam Dinh Provinces in Northern Vietnam, on *Meretrix meretrix* culture sites (normally outside shrimp farming areas), many *Meretrix meretrix* have been found dead, leading to great capital loss of farmers, some even can not pay their bank loans. The reason is that this species and some other molluscs have been poisoned by effluents with toxic chemicals from shrimp pond nearby (Hong, 2003).

There is a noticeable lack of variation in the water quality over the study area, with a high degree of uniformity of salinity, water temperature, transparency, ammonia, nitrite and dissolved oxygen content. The low level of oxygen at 1.5 mg/l is due to the shallow depth of the water and deteriorating bottom conditions. Water salinity is lowest in the agricultural areas and highest in the shrimp farming areas and ponds. The average pH level at 6.5 to 7.8 is observed throughout the different salinity areas, but the carbon dioxide content increases from highly saline (16.67 ppt) to lower saline (21.67 ppt) areas. Nitrite content also decreases from highly saline (0.103 ppt) to lower saline (0.071 ppt) areas. A variation in salinity is also noticeable throughout the year, with the highest salinity at 24 ppt in May and the lowest at 6 ppt in October in the study of Alam and Philips (2004).

Salinity intrusion has become one of the most significant ecological and socio-economic problems to the coastal communities. The process of salinity intrusion in the coastal areas under shrimp culture is more a management related issue rather than scientific. Initially the socially empowered and thus privileged persons try to grab lands from marginal farmers for shrimp culture. They floods the whole area with saline water when fails. This process forced the marginal farmers to either give his/her land for shrimp culture or make a shrimp farm of his/her own as rice cultivation becomes a impossibility under such conditions; thus with the introduction of shrimp the environment become saline. This causes fodder and fuel crisis and crisis of seedlings as rice and plants start dying in saline conditions. As a consequence, communities need to import fodder, fuel wood, fresh water, seedlings etc. from outside the locality that implies extra money to pay. Ali (2006) observed that low-lift irrigation pump also responsible for significant salinity increase.

It has been observed that 10-40% of the *gher* water is exchanged every day to remove waste metabolites - direct discharge of which creates water and soil pollution (Deb, 1998). Kongkeo (1990) estimated that one metric ton of shrimp at a semi-intensive farm requires between 50 and 60 million liters of water to raise them. The waste contains dissolved metabolites, particulate matters, unused fish feed, various forms of chemical, microorganism, fertilizer, faeces etc (Deb, 1998). The amount of pollutant discharge increases while preparing the *ghers* for next crops. Phillips *et al.,* (1993) reported that the traditional shrimp culture is not expected to represent any significant load of nutrients to the surroundings as such culture relies on natural feed, moderately stimulated by input of manure and fertilizers. Such culture might significantly removes of nutrient from coastal environment (Beveridge and Philips, 1993). However, in an extensive mixed shrimp – mangrove forestry farm in Vietnam, Alongi *et al*. (2000) estimated a higher nutrient output than input.

Unlike the significant effluent load from artificial feed-supplied intensive and semi-intensive shrimp *ghers* with high water exchange rate (Hopkins *et al*., 1993), the extensive shrimp culture in Bangladesh seems to act as a sink for particulates and nutrients. However, semi-intensive systems are evolving rapidly in recent years in Bangladesh (Islam *et al.*, 2004) because of the little available room for further horizontal expansion. Farm intensification without basic understandings of the system might lead to adverse consequences such as higher mortality from disease outbreak associated with increased ammonia concentrations as already reported (Wahab *et al.*, 2003).

Impact of intensification of shrimp culture on the surrounding environment is an important concern for sustainability of the system as a whole. A partial mass budget in selected semi-intensive shrimp farms indicates that the system discharging about 1000 kg/ ha/cycle of pollutants to the surrounding waters. There are concerns that semi-intensive shrimp aquaculture may contribute to eutrophication with increased nitrogen loading as has been observed by Jackson *et al*. (2003). They found that 22% of the N input was converted to harvested shrimp, 14% remained in the sediment while most of the remainder (57%) was discharged to the environment. Only 3% of N input was unaccounted for, and assumed to be lost to the atmosphere via denitrification or volatilization of ammonia.

2.1.2 Sustainability of shrimp cultivation

Over the last two decades, shrimp farming has emerged as a major industry in Bangladesh. The impact of the process has economic, social and environmental dimensions. All of these may have serious implications for sustainability, not only of shrimp farming itself, but of the rural community in the coastal areas of Bangladesh.
The relationship between shrimp aquaculture and the environment in Bangladesh needs to be systematically addressed as the sustainable development of the industry becomes a priority. Sustainable coastal aquaculture requires adequate consideration of the interactions among social, economic and ecological changes, which accompany development. This can be achieved through an integrated approach or planning and management of coastal aquaculture within the coastal systems (Das, 1992). In many areas of Asia, traditional culturing involves a poly culture of fish and shrimp intimately linked to harmonious use of the coastal ecosystem. Existence of such integrated ecosystems for several hundred years testifies their sustainability (Bailey, 1988). For the sustainability of shrimp culture the best option is to follow rotational

cropping of shrimp and fish culture or a poly culture of both, depending on the suitability of the area. This culture will maintain ecological balance by serving as ideal habitat, media for propagation and growth of food organism and recycling of nutrients from decomposed compounds. Characteristics of such integrated farming include:

- Control to maintain full vertical utilization of the water column,
- A rational proportion of those organisms that occupy different trophic levels and parts of water column,
- Full utilization of various kinds of foods including wastes,
- Maintenance of high productivity of cultivated specie in ponds during most part of the year
- Preserving appropriate living conditions in pond management (Li, 1987).

Adoption of such cropping pattern will help to reduce the scale and magnitude of environmental impacts. Government agencies and non-government organizations must come forward to demonstrate the utility of such environmentally friendly farming system (Deb, 1998)

But the picture is somewhere divergence with the above characteristics in shrimp cultivation in Bangladesh (Alauddin and Tisdell, 1998). The process of shrimp cultivation epitomizes conflicting resource-use patterns. Extensive shrimp farming systems require more land than intensive ones. Given the extreme scarcity of arable land in Bangladesh, this threatens Bangladesh's ability to expand and sustain rice supply as well as salt productions. Increased salinity and soil acidification as a result of shrimp culture are believed to have led to decreased rice yields. Furthermore, declining shrimp yields due to continuous use of the same land and use of chemicals are impediments to sustainable land-use in the shrimp belt with potentially serious implications on the sustainability of rural communities and their livelihoods. Where sustainability is defined as "development that meets the needs of the present without compromising their own needs…" (WCED, 1987). The process of agricultural development has led to environmental changes which has undermined the sustainable livelihood of people in many less developed countries (LDCs), including Bangladesh (Ahmed and Doelemean 1995; Alauddin et al. 1995; Alauddin and Tisdell 1997).

A recent study (Nijera Kori, 1996) documents displacement of small and marginal farmers, increasing landlessness and gross human rights violations as problems resulting from the process of shrimp farming. However, there has been little discussion of the effects of environmental changes using rigorous analytical techniques [e.g. Ali, 1991; Chowdhury, 1988]. Rahman (1995) correctly identified important environmental problems associated with shrimp cultivation but, like many earlier studies, did not analyze their effects on the sustainability of shrimp farming. While suffering from limitations mentioned above, the available literature dose identify (1) uneven gains between gher owners and land owners; (2) the environmental effects of shrimp culture resulting in decline rice yields; (3) loss of green vegetation; (4) increased salinity; and (5) decline and loss of indigenous species of fish.

The issues of environmental sustainability of prawn cultivation, while clearly not as negative as those of marine shrimp culture in Bangladesh, are nevertheless poorly understood. Therefore research would be required as quantitative and qualitative environmental impacts for sustainable prawn farming (Ahmed *et al.*, 2008). In the study of Alauddin and Hamid (1996) it was argued that sustainable development of the shrimp industry could be achieved by explicitly taking into account the long-term and cumulative effects of the factors embedded in the integrated shrimp–rice farming system. This paper suggests two research strategies: (1) a robust approach to the complicated and interlocking issues of integrated shrimp–rice farming, which develops indicators for measuring the sustainability of shrimp farming and could be used by shrimp producers at the farm level; and (2) an approach that offers policy guidelines to respond effectively to changes in different variables that determine and affect shrimp farming.

While there is a great potential for rice-shrimp and fish farming, a number of issues were identified affecting its sustainability including the lack of technical knowledge of farmers, high production costs and natural disasters (flood and drought). Moreover, rice-fish farming technology has not yet contributed substantially to food security in Bangladesh due to its low level of adoption. The lower levels of rice-shrimp farming adoption were found among poorer households. It seems that the benefit of rice-fish farming technology accumulate to better-off farmers unless institutional and organizational support is provided to resource-poor farmers. Intervention to improve agricultural water management affect poverty through several pathways; improved productivity and production, employment generations, keeping food prices within the affordable range for the rural and urban poor, multiplier effects, reducing vulnerability, nutritional effects, equity impacts, multiple uses, and effects on the environment and human health.

It is therefore worthwhile to find means of providing institutional and organizational support to poorer farmers, in terms of training facilities and extension services for sustainable rice-shrimp and fish farming. Training and technical support would help to improve profitability and reduce risks.

2.2 Present Agro-Water Management Practices and its Sustainability

In Bangladesh two types of ghers farming are operated; one is bagda and another is rice-golda culture. Bagda ghers farming is large in size and scale, and needs saline water, whereas golda ghers farming is comparatively small in size and scale, and need fresh water (Barmon, 2006). In alternate shrimp-rice farming one crop Aman rice (e.g local varieties and HYV) is grown between August / September to December, which is followed by crop of shrimp in between February to July/August. Under this system shrimp is completely harvested by August or September before the water salinity drops below the tolerant limit of *Penaeus monodon*. After the transplantation of T. Aman, rain water is allowed to accumulate inside the gher to flood the land, whrer the fin-fishes are allowed to grow until harvest (Islam *et al*., 2003).

Interesting land use like agro-fisheries (rice-fish culture) is gaining popularity in Khulna district (Saheed, 2003). A new cropping system with a rainfed rice crop during the wet season and an additional irrigated rice crop during the dry season (from mid-November to mid- April) was conceptualized and implemented by Mondal *et al*., (2006) in Khulan region. In other areas of KSB region under the Satkhira district, shrimp farming continued almost year round due to the presence of moderate to high salinity in the water (Alam, 2002). There are a few studies that focus on the impacts of RPG farming on labor demand and household income (Barmon *et al*., 2004), and the impact of shrimp gher farming on the environment (Asaduzamman *et al*., 1998; Nijera Kori, 1996; and Bhattacharya *et al*., 1999) and ecology (Datta and Sannamat,

2001) in the coastal region in Bangladesh. Thus from these studies it is found that a large number of gher owners are also involved in rice agriculture in KSB region.

After the introduction of rice- prawn (golda) gher (RPG) farming system, the cropping patterns have changed in southwestern coastal region of Bangladesh. Rice-prawn gher (RPG) farming is an indigenous technology which is a combined form of aquaculture and agriculture. The term **"***rice-prawn gher***"** refers to a modification of paddy field that has been used for prawn and MV paddy cultivation. The whole land of gher is filled up with rain-water from June to December and resemble to a pond and during this time, farmers cultivate prawn (*Macrobrachium rosenbergii*) and fishes. The entire land becomes dry naturally from January to April except canals. The canals retain sufficient water for MV *Boro* paddy during this time. Rice-prawn gher (RPG) farming system is an indigenous agricultural technology solely developed by farmers since mid 1980s. Now the farmers are producing prawn and MV paddy in the RPG farming system (Barmon *et al*., 2007). Prior to the RPG farming, the southwest region experienced a period of severe environmental change during 1960s and 1980s because of the construction of embankments and polders that caused permanent waterlog and increased saline intrusion and the farmers were not able to produce any agricultural crops (Kendrick, 1994).

In fact the gher owners did not altogether moved away from rice agriculture. Following this pattern, one crop of transplanted Aman is grown between September and November during monsoon season when the water of the river becomes fresh and sweet. From February to August a crop of shrimp is cultured, when the water of the surrounding rivers becomes saline. Though the yield performance of the local variety was less (1.9 ton/ha) than the HYV (2.5 ton/ha) in Khulna region , farmers preferred to cultivate local variety in Aman season for its indigenous characters like taller plant height, insect, disease, water logging and salt tolerance capacity, more tasty as well as less production cost (Miah *et al*., 2004). This is possible because it is a semi-saline zone and Aman is still cultivated in a large tract of land. But more important is the fact that the conflict between Aman and shrimp production has been avoided at the cost of lower Aman productivity (Toufique, 2002). If managed properly there should not be any conflict between rice and shrimp.

In Bangladesh about 80% of aquaculture production of marine shrimp (*P. monodon*) comes from the southwest inter-tidal coastal flatlands, where shrimp is grown in the dry season (February to mid-August), in rotation with rice, which is grown in the wet season (mid-August to December) when water salinity is lowered by rainfall (Islam *et al.*, 2005). In the dry season, salinity is high and rice cultivation is hardly possible. It is the right time for raising shrimp. Attempts to grow rice in this season have been a failure in this region. In the wet season (excessive rain) salinity of water is too low for raising shrimp. This is the right time to grow rice – Aman (Toufique, 2002). The current farming practice was characterized by extensive culture systems with low input use, leading to low productivity levels. The different farm management practices were noticed among the different categories of farm ownership (Alam and Philips, 2004).

According to Barmon *et al.* (2006) estimation of land productivity of modern varieties (MV) paddy production under RPG and year-round modern varieties (YRMV) paddy farming systems in the southwest Bangladesh showed that the RPG farming system has significant impacts on inputs used in MV *Boro* paddy production. The findings of the study indicate that more chemical fertilizers were used in per ha MV *Boro* paddy production under YRMV paddy farming in comparison with RPG farming. Similarly, per ha cost of irrigation, pesticides and land preparation were also higher in MV *Boro* paddy production under YRMV paddy farming system compared to RPG farming system. The inputs usage for MV *Boro* paddy production under two farming systems showed statistically significant difference with each others. Although fewer inputs were being used in MV *Boro* paddy production under RPG farming system, yield was higher (statistically significant) than YRP MV paddy farming system. Therefore, it could be concluded that land productivity of MV paddy production under RPG farming system was significantly higher than YRMV paddy farming system.

Though alternate rice-shrimp system is one of the more ecologically sustainable approaches to shrimp farming, production of shrimp in the rice-shrimp system in Bangladesh is low, from 29 to 277 kg/ha (Islam *et al.*, 2004), with a threat of frequent shrimp crop failures due to disease outbreaks. The rice production in this system is also low, ranging from 1.0 to 3.0 t/ha (Karim, 2006), which is considerably lower than the potential (Mondal *et al.*, 2006). But Chowdhury *et al.* (2006) concluded in his study that the integrated shrimp-rice farming is more sustainable than only shrimp farming. He developed a triangular model of sustainability where he remarks shrimp-rice mixed culture rather than newly adopting semi-intensive shrimp culture as more environmentally sound (Figure 2.6).

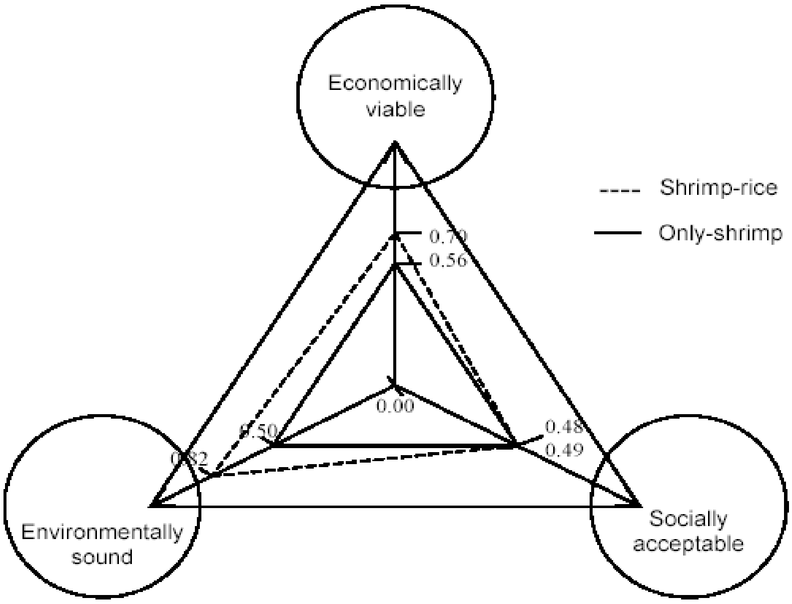


Figure 2.6 Triangular models of shrimp culture and its sustainability (Chowdhury, 2006)

Islam *et al.* (2003) found that the shrimp-salt farming is more profitable compared to shrimp-rice farming. There are two ways to increase shrimp production, such as either by constructing new farms or improving the existing farm to intensive ways or doing the both. Islam *et al.,* (2003) found the decision of choosing between these options depends on economic considerations. A study conducting by Islam (2007) concluded that, the decision function of choosing among shrimp, shrimp-rice or rice depends on economic benefits. However, nowadays some marginal farmers from the farthest corners of south west Bangladesh are frequently reported to be demonstrating on 'back to rice farming' (Nandy *et al.*, 2007) because food security has become the decisive factor in those areas.

The relationship between economic return from shrimp culture and international market demand could be established by analyzing the history of the evolution of the shrimp sector industry in Bangladesh. Bangladesh shrimp sector is an export-oriented sector; therefore depends on international market demand for its survival. A backup plan must be needed to survive if the international market fails.

Sustainability of the shrimp sector depends on mainly two functional questions: how much the coastal environment would support shrimp culture? And how long the international market demand would be active? Up till now we have not observed any research articles – however both these are researchable problems!

So saline water proofing by structural management like coastal embankment projects, dams, sluices, and coastal area zoning, as well as non-structural management strategies could change the land use and other activities, which would be vision of a sustainable livelihood and environment for Bangladesh (Rahman and Bhattacharya, 2006). Finally, not only a positive government policy can help to promote sustainable development of rice-shrimp & fish farming throughout the country, but also technological and institutional help should be needed.

CHAPTER THREE
MATERIALS AND METHODS

3.1 General Description of the Study Area

In Bangladesh the south-western coastal region is an important place for shrimp cultivation especially the Khulna district. Shrimp culture always had a special place in the people's traditional livelihood practices in this region simply because of the high level of salinity and availability of low inundated lands. In the early stages of development, shrimp farming was restricted to the peripheral land between flood embankments and the main river systems. At first, bagda cultivation was started outside the embankments. After a few years, it entered into the embankments, and gradually shrimp culture started on the mainland in a large scale. The expansion was rapid. As there is an international market for it and the shrimp cultivation requires less labor, and a huge profit is possible against a very low investment.

Dumuria Upazila of Khulna district was selected as the study area in the research. From this Upazila two unions were selected such as Kharnia and Sobhana, which were encircled by polder number 25 (west) and 26, respectively. These two unions are situated on the bank of the Bhadra River. The criteria for selection of Kharnia and Sobhana unions were: (i) this area was vulnerable to salinity intrusion because of extensive and improved extensive shrimp culture, and (ii) the area was situated very close to the Bhadra River and the same river water was used in both the areas though the agro-water management approaches were different. The present major identified agricultural land uses of these areas are: Shrimp—transplanted Boro / Boro—integrated shrimp and transplanted Aman. Boro rice cultivation became the common land use pattern in Dumuria Upazila since last 3 years. Several agricultural constraints are identified in this area. The dominant soil, land and water related constraints are – slight to moderate salinity, scarcity of quality irrigation water during dry season, limited scope of ground water and river water upliftment for irrigation, prolonged artificial water logging with saline water for aquaculture, late draining condition in early dry season, moderately deep flooding in monsoon season in some areas, relatively high flooding depth during monsoon season for HYV transplanted Aman crop (SRDI, 2003).

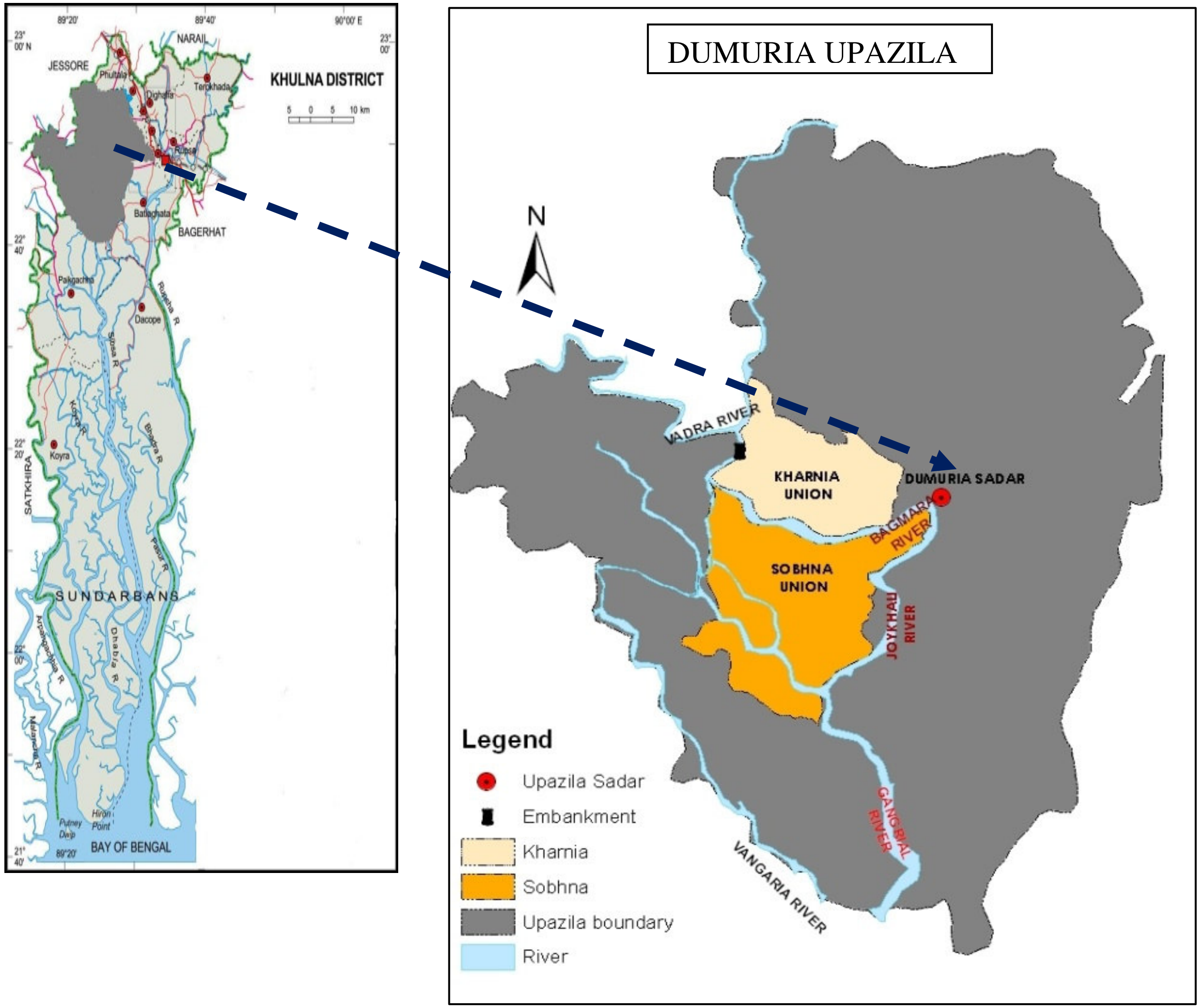


Figure3.1 Geographical Location of the Study Area

Figure 3.1 shows the geographical location of the study area. The study was conducted in two unions – Kharnia and Sobhana (Figure 3.1). The two unions are well known for cultivation of shrimp as an agricultural crop, cultivation of Boro rice in the Rabi season consecutively. From each of these two unions, two villages were selected by purposive sampling. The villages were Ranai and Bhadradia from Kharnia Union, and Jialtali and Badurgachi from Sobhana Union. The Mouza No.31, No.40, No.89 and No.101 which are comprise the four villages respectively Ranai, Bhadradia, Jioltoli and Badurgachi (SRDI, 2008). There were four sluice gates in four villages. These are used to check the entry of water from the Bhadra River to *Shingar beel* at Ranai village, *Muchikata khal* at Jialtoli village, *Badurgachi khal* at Badurgachi and *Vadradia khal* at Bhadradia village.

All agricultural lands in Dumuria Upazila became ghers (shrimp culture pond) to produce short term economic return since 1980s. As a result, most of the agricultural lands became fallow lands over time. At present, the small farmers of the selected villages are not interested in bagda cultivation and want to control the saline water intrusion from the Bhadra River into rice fields. Farmers had been trying to cultivate paddy though the production level was low last year. Here the soil quality of this region had great impact on rice yield. The soil of the area is dominated by salinity. The salinity of the soil is mainly due to shrimp cultivation with saline water of flooding depth of 60-120 cm. In Dumuria Upazila, the soil is kept flooded for 5-8 months with saline water for shrimp cultivation (SRDI, 2008). Most of the lands of the study area (about 61%) are medium high lands. About 17% of the area has highly saline soil. Only about 5% of the area has non-saline soil. The soil classification of the study area goes under the Ganges Floodplain and the Ganges Tidal Floodplain which are medium low lands. The Ganges Floodplain is characterized by silty-clay soil with no salinity to moderate salinity, low content of nitrogen, phosphorus and potassium and high content of magnesium and sulfur, whereas the Ganges Tidal Floodplain is also characterized by silty-clay soil, but with low to high salinity, very low nitrogen, low phosphorus and potassium, and very high calcium, magnesium and iron content (SRDI, 2008). The following Table 3.1 provides the general soil characteristics of the study area.

Table 3.1 Physico-Chemical Characteristic and Nutrient Status of Soil in Dumuria Upazila

Soil Depth (cm)	Particle Size Distribution (%)			Texture	Macro Nutrient			Micro Nutrient						CEC	OM	pH
	Sand	Silt	Clay		N	K	S	P	Cu	Fe	Zn	Mn	B	meq/100 gm soil	(%)	
					(%)	meq/100 gm soil		ppm								
0-11	1	57	42	SiC	0.17	0.21	319	3.16	5.4	69	0.6	21.7	1.6	18.4	3.82	7.4

(Source: SRDI, 2003)

Table 3.2 Chemical Composition of Irrigation Water Used in Dumuria and the adjacent Upazilas of Khulna District

Sources of Water	pH	ECw dS/m	HCO^-	$SO4^{--}$	Cl^-	TSS	Ca^{2+}	Mg^{2+}	Na^+	K^+	SAR
			ppm				meq/100ml				
The Bhadra River Water	7.6	13	201.4	716.9	4005.9	7800	0.52	1.83	12.4	0.24	12
Shallow Tubewell Water *	8.1	1.3	591.9	0.7	124.1	608	0.27	0.26	0.20	0.017	0.4
Deep Tubewell water **	8.5	1.7	469.9	44.6	330.8	778	0.06	0.10	1.25	0.002	6.2
Gher Water***	7.6	20.5	250.2	983.5	7178.6	14614	0.78	4.3	12.4	0.4	7.8

(Source: SRDI, 2003)

Note: *Paikgacha,**Batiaghata,***Dacope

Table 3.2 shows the quality (chemical composition) of irrigation water of the study area. Irrigation waters quality would have the effect on rice yield in these four villages because salinity was a big concern. During Shrimp cultivation river water, canal water or STW were used which also had impact on the following Boro rice cultivation. Irrigation from STWs and canals were provided over three months in dry season for HYV Boro rice cultivation.

The increasing trend of salinity in the study area is reducing the farmers' interest of cultivating various agricultural crops. But they need to continue their cultivation practices, as the farmers have no better alternative to their livelihood. In the study area, it was found that most of the farmers were not able to cultivate crops round the year due to salinity. The salinity levels were higher during the months of March to June and lower during the months of August to October.

The practices of shrimp cultivation were different in different areas. Significant differences in soil and water quality are recently being observed in the areas (Table 3.1 and Table 3.2). In Kharnia union, fresh water shrimp (golda) was cultured with white fish and HYV Boro rice (Rabi crop) for the last 12 years. On the other hand, in Sobhana union transplanted Aman rice is the major crop for farmers with shrimp (bagda) and Boro as the minor one. Golda is a freshwater shrimp and in adverse situation it can tolerate 12-15 ppt salinity. Though the production of golda was lower than that of bagda, the price of golda (Tk. 1100-1300/ kg) was higher than that of bagda (Tk. 600-800/ kg). The price of rice was also high and it added to the total benefit from agricultural production. Whereas integrated rice-shrimp culture was practiced in Kharnia and Sobhana unions.

The area, which in total is approximately 19.5 km^2, is surrounded by many rivers (Figure 3.1). The Upazila is surrounded by Soilmari River in the east, by Soilmari, Bagmara and Joykhali rivers in the middle, Hori and Bhadra Rivers in the south-west and Dangaria River in the north-west (SRDI, 2008). The main Bhadra River is flowing from north to south along the western portion of the study area. Besides these, Baleshwar and Boalkhali rivers flow through the eastern portion of the area. These rivers all have tidal reaches in their lower stretches which affect their hydrology due to damming of back water during each high tide. In the rainy season, the river water is free from saline but the salinity increases from the start of the dry season. In the month of April, the salinity is the maximum (SRDI, 2008).

The area has a subtropical monsoon climate with a moderate rainfall that has significant effects on the fluctuating level of salinity and hydrology, and these in turn are critical for shrimp and paddy cultivation. The three main seasons are the pre-monsoon (March-April), monsoon (May-October), and winter (November-February) (SRDI, 2008). The pre-monsoon is characterized by southerly winds, high temperatures and evapotranspiration rates, and by occasional thunderstorms and northwesterly winds. The monsoon brings heavy rainfall, high humidity and cloud cover. The post-monsoon is hot and humid, with occasional thunderstorms, cyclones and storm surges. The dry winter season is characterized by cool, dry and sunny weather. Rainfall is an important factor that has a much influence on tidal river water chemistry. Due to the variation in rainfall pattern, the water chemistry of a tidal river and surface water of the area fluctuates significantly. No rainfall was found during Boro rice cultivation and also the frequency of the rainfall was less in 2009-2010 agro-years. The meteorological data of the study area are described in the following Table 3.3 to show the climatic condition.

Table 3.3 Meteorological Data of the Study Area during the Year of 2008 to 2010 *

Month	Average Temperature (^0C)			Total Precipitation (mm)			Average Humidity (%)		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
January	20	20.7	18	67	1	0	80	81	80
February	21.1	23.4	22.3	36	6	2	74	74	73
March	27.4	27	30.6	48	10	14	77	71	71
April	30	31.3	31.5	36	23	21	75	70	73
May	30.6	31	30.7	151	137	146	75	72	75
June	29.5	29.4	30.3	187	233	287	81	81	80
July	28.9	29.3	30	301	347	181	89	87	84
August	29.5	29.5	30.2	203	570	205	86	85	83
September	29.5	29.8	29.9	379	357	157	86	86	85
October	27.8	28	28.9	187	111	332	84	80	82
November	24.6	25.4	25.9	0	20	0	79	79	78
December	21.3	20.2	20.2	0	0	0	85	79	76

Note: *Meteorological Station of Khulna, 2011.

3.2 Soil and Water Sampling

In the study area, mainly shrimps were cultivated in ghers. A gher is an enclosed area characterized by an encirclement of land along the banks of tidal rivers. Samples were mainly collected from extensive and improved extensive integrated shrimp farms.

Table 3.4 General Description of Sample Number

Name of Union	Name of Villages	Sample Name	Sample ID
Kharnia	Ranai	Ranoi-1	R-1
		Ranoi-2	R-2
		Ranoi-3	R-3
	Bhadradia	Bhadradia-1	V-1
		Bhadradia-2	V-2
		Bhadradia-3	V-3
Sobhana	Badurgachi	Badurgachi-1	B-1
		Badurgachi-2	B-2
		Badurgachi-3	B-3
	Jialtala	Jialtoli-1	J-1
		Jialtoli-2	J-2
		Jialtoli-3	J-3

Twelve samples were collected from different types of farming systems by purposive sampling. At first, ghers were selected based on different farming systems and water sources criteria. The samples were collected from the main land of the gher which was locally known as gher chatal. Soil samples were taken from the top-soil of a gher chatal and water samples were collected from the canal of a gher (Figure 3.2).

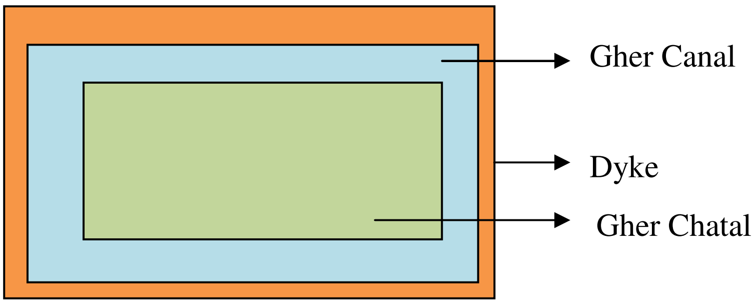


Figure 3.2 Schematic Diagram of a Typical Gher

For the Study the sample size was 12 numbers of ghers. Figure 3.2 shows the sampling location and Table 3.4 describes the twelve sample plots of the study area.

Soil and water samples were collected during the Boro season of 2009/10 at pre-Boro season (late December, day before fertilization of rice field) and post-Boro season (mid April, day after harvesting of HYV Boro rice) of rice-bagda, rice-golda or rice-golda-bagda cropping patterns. Twelve soil and twelve water samples were collected in each of the two seasons from each union.

3.2.1 Soil sampling

For soil sample collection, BARC (2005) guidelines were followed. At first soil samples were collected from nine points between depths of 0-15 cm of each sample area and then they were mixed thoroughly. Preparing these soils for laboratory analysis by removing the moisture by sun-dry and packed in plastic packet for carrying samples to the laboratory.

3.2.1.1 Soil quality parameters

Bottom soils are the primary source of nutrients in an aquatic system (Datta and Sannamat, 2000). With the increase of temperature, the pH and salinity increase. EC values represent the status of organic loading and metabolic waste generation in an aquatic system. Nitrogen content in soil is a limiting factor in plant growth. Phosphorus in the bottom soil is mostly of organic origin. Potassium is a macronutrient for plants and its major source in the cultured system is K-rich fertilizer, e.g., potash. Calcium source in a gher is from regular liming and it has correlation with magnesium (NACA, 1994). For soil quality, the following parameters were analyzed: Temperature, pH, EC, Salinity, Organic Matter (OM), Bicarbonate, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Chloride (Cl^{-}), available Nitrogen (N), available Phosphorus (P), Potassium (K), Sulfur (S) and Iron (Fe). For chemical analysis of soil parameters, number methods were used according to Allen (1974). All instruments and methods were used, which were shown in the following Table 3.5.

Table 3.5 Methods for Determination of Different Parameters of Soil

Sl. No	Parameter	Determination Method
1	pH	Portable pH meter-model HI 98107, HANNA
2	Electrical Conductivity (EC)	Portable water proof Multi-range Conductivity meter
3	Temperature	Thermometer
4	Sodium (Na^+)	Flame Emission Photometer (Flame photometer- models PEP 7 and PEP 7/C)
5	Potassium (K^+)	Flame emission photometric method (Flame photometer- models PEP 7/C)
6	Salinity	Refractometer, Extraction method
7	Sulfur	Turbidimetric method (Thermo spectronic, UV-visible Spectrophotometers, Helios 9499230 45811)
8	Organic Carbon	Walkely and Black's wet oxidation method
9	Soil organic matter	Ignition method
10	Available Nitrogen	Digestion, Alkali Distillation and Titration method
11	Available Phosphorus	Turbidimetric method (Thermo spectronic, UV-visible Spectrophotometers, Helios 9499230 45811)
12	Iron	Colorimetric method
13	Calcium and Magnesium	Titrimetric method
14	Bicarbonate	Titrimetric method

3.2.2 Water sampling

The water sample collection methods were followed by grabbing or catch sample method Ramesh and Anbu (1996). Water samples were collected by using plastic bottles from the sampling point. All the samples were collected in plastic bottles by following the standard technique. Each sample size was approximately 1000 ml.

3.2.2.1 Water quality parameters

Wistrand (2001) found that shrimp farming in Khulna region affects the physico-chemical and biological qualities of water and increases soil salinity which make certain soil nutrients unavailable for plants and thereby make the soil unproductive. The most important water quality parameters for rice-shrimp farming are: temperature, DO, pH, transparency, and salinity (New and Singholka, 1985). Some other water quality parameters such as EC, NO_3^-, Cl^-, Na^+, K^+, HCO_3^- and SO_4^{2-} have important bearing on the culture and production of shrimp farming (Wistrand, 2001). Temperature, pH, EC, TDS, turbidity, DO, TOC, salinity, bicarbonate, Chloride (Cl^-), Sodium (Na^+), Potassium (K^+), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), etc. were the quality parameters of gher water. For chemical analysis of water parameters a number of methods were used according to Standard methods (1992).

3.2.2.2 Field measurement of water quality parameters

Some physical parameters, such as, temperature, pH, TDS, DO, EC and turbidity, were measured directly in the field (Photo 3.1).

Photo 3.1 Mobile Field Laboratory at Jialtoli Village

3.2.2.3 Laboratory analysis of water quality parameters

The remaining parameters, such as, salinity, hardness, Chlorine, Sodium, Potassium, TOC, Sulfate and Nitrate, were analyzed in the laboratory of Environmental Science Discipline of Khulna University (KU) (Photo 3.2). Table 3.6 shows the list of instruments and methods which are used to measure gher canal water chemistry.

Photo 3.2 TOC Analysis in Environmental Science Discipline Laboratory, KU

Table 3.6 Analytical Methods for Determining the Gher Canal Water Chemistry

Sl No	Parameters	Unit	Methods /Instruments
1	Temperature	(^{0}C)	TDS meter (H1-9635, portable water proof Multi-range Conductivity/TDS meter).
2	pH		Microprocessor pH meter (HANNA instruments, pH 211)
3	EC (Electrical Conductivity)	µS/cm	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter, HANNA)
4	Salinity	ppt	Refractometer
5	TDS (Total Dissolved Solid)	ppm	TDS meter (H1-9635, portable water proof Multirange Conductivity/TDS meter, HANNA)
6	Transparency	cm	Secchi disk
7	DO (Dissolve Oxigen)	ppm	Winkler's method (APHA, 1992)
8	Sodium (Na^{+})	ppm	Flame photometric method (Flame photometer- models PEP 7/C)
9	Potassium (K^{+})	ppm	Flame photometric method (Flame photometer- models PEP 7/C)
10	Calcium (Ca^{2+})	ppm	Titrimetric method
11	Magnesium (Mg^{2+})	ppm	Titrimetric method
12	Chloride (Cl^{-})	ppm	Ion Electrode method (Cole-parmer R 27502-12, -13)
13	Sulfate (SO_4^{2-})	ppm	Turbidimetric method (Thermo spectronic, UV-visible Spectrophotometers, Helios 9499230 45811)
14	TOC	ppm	TOC analyzer
15	Nitrate (NO_3^{2-})	ppm	Turbidimetric method (Thermo spectronic, UV-visible Spectrophotometers, Helios 9499230 45811)
16	Bicarbonate	ppm	Potential methods

3.3 Collection of Data on Agro-Water Management Practices

Primary data on AWMPs were collected by semi-structured interviews with the farmers of the sampled ghers (Photo 3.3). The interview was structured based on the reconnaissance survey findings in order to collect necessary agro-water management input and production data. The data were collected on cultivation pattern, cultivated crops/fishes (rice, fish and shrimp), cultivation pattern in the surrounding area, type of cultivation on dyke, golda/bagda/fish production, type of cultivation in previous years of 2008 and 2007, sources of water in wet and dry seasons, application of irrigation, water exchange for shifting cultivation type in a year, fertilizer management, pesticide management, etc. The key informant interview was used to collect data from the relevant persons of the Upazila agriculture office and Upazila fisheries office.

Photo 3.3 Data Collection through Semi-Structured Interviews with the Farmers

3.4 Data Analysis

All information and data gathered from the field were combined and summarized in tabular form and classified according to gher type arrangement. The observations for each parameter were divided into pre-Boro season and post-Boro season of HYV Boro rice cultivation. The pre-Boro season data was collected for the day before fertilization during land preparation for Boro rice and the post-Boro season data for the day after HYV Boro rice harvesting.

In the study, data were analyzed using correlation analysis. ANOVA was done using standard statistical package to observe season's variance of soil and water chemistry between four types of farming in the study area. MSQI and MWQI were calculated using the concept of Ali (2006) to measure the soil and water quality degradation in four types of farms. SPSS was used in the evaluation of the significant impact of different management inputs of each farm type on rice production. Multi-criteria analysis (MCA) was used to evaluate best AWMPs towards sustainability among different agro-water management practices.

3.4.1 Calculation of MSQI and MWQI

First, for each farming type, the average value for each of fourteen soil quality parameters and sixteen water quality parameters was computed for both the pre-Boro season and post-Boro season (12 plots). Second, percentage change in average value of each soil property and water property during pre- to post-Boro season of HYV Boro rice cultivation was computed; and percent change values of all fourteen soil properties were averaged to obtain the mean soil quality change indicator (MSQI), and percent change values of all sixteen water properties were averaged to obtain the mean water quality change indicator (MWQI) for each farming type. A larger negative value of MSQI or MWQI of a farm type would indicate the degradation in soil or water quality due to the particular agro-water management practice (AWMP).

3.4.2 Multicriteria analysis

From an operational point of view, the major strength of multicriteria analysis (MCA) method is its ability to resolve questions characterized by various conflicting issues, thus allowing an integrated assessment of the problem at hand. All effects need not be translated into a common unit of value or significance with the process of standardization. Evaluations of selected strategies were performed in a following order.

Scoring ⟶ Standardizations ⟶ Weights

After scoring (performance with respect to criteria) with real data, management inputs data (qualitative and quantitative) were standardized with the following equation for reducing scores to same type of unit:

$$\text{Standardization} = \frac{\text{Actual} - \text{Worst}}{\text{Best} - \text{Worst}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.1)}$$

where,
'0' for the worst score and '1' for the best score

All data in a standerdized form had been executed before relative importance of different criteria were used to evaluate best strategy. The Pearson's correlation coefficient was used to set relative importance of each criteria. In order to establish a linear relationship between two variables x_1(management input) and y_1 (rice yield) the Pearson's correlation coefficient r was used.

$$r = \frac{n\sum x_1 y_1 - \sum x_1 \sum y_1}{\sqrt{\left[n\sum x_1^2 - \left(\sum x_1\right)^2\right]\left[n\sum y_1^2 - \left(\sum y_1\right)^2\right]}} \quad \ldots\ldots\ldots\ldots\ldots (3.2)$$

Where n was the number of data points. The value of r must lie between +1 and -1: the nearer it is to -1 or in the case of negative correlation to 1, then the greater the probability that a definite linear relationship exists between the variables x and y. Values of r that tend towards zero indicate that x and y are not linearly related. The degree of weight was given to the criteria following the order of significance level. For a higher degree of significant correlation, the given weight was high (weight = 6) and for a lower degree of significant correlation, the given weight was low (weight =1).

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Current Status of AWMPs in Dumuria Upazila

The study found four types of agro-water management practices (AWMPs) in Dumuria Upazila (Figure 4.1). These types were mainly based on the dominant crops and irrigation water sources. Two types (Type-1 and Type-2) were found in Kharnia Union and the other two (Type-3 and Type-4) in Sobhana Union.

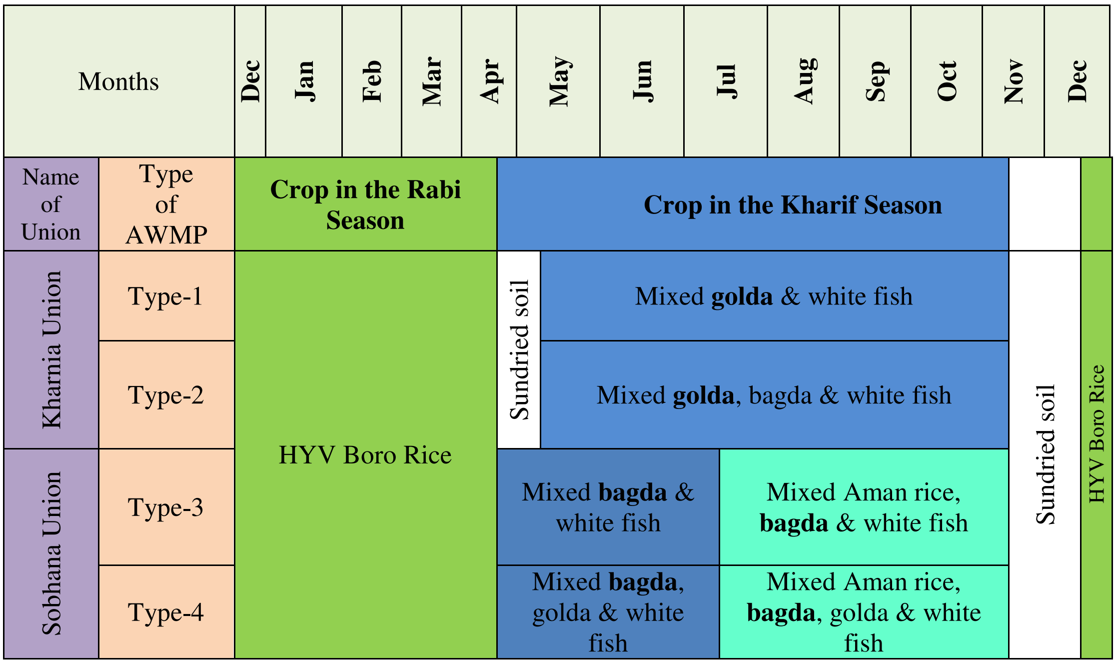


Figure 4.1 Land Use Pattern and Different AWMPs in the Study Area

In Type-1 AWMP, BRRI Dhan 28 and Hira rice were found to be cultivated in gher R-2, R-3 and V-3 during the Rabi season (from late December to mid April). Mixed cultivation of golda & white fish were found in the following the Kharif season (mid May to early November). Irrigation water was used from shallow tube-wells (STWs) and adjacent *Shingerbeel* canal. The dyke vegetations in Type-1 AWMP were composed of neem, banana, datetree, brinjal, turnip and other vegetables (Photo 4.1).

In Type-2 AWMP, the same rice varieties were grown in the Rabi season, but in the Kharif season mixed golda, bagda and white fish were cultivated in ghers of V-1, V-2 and R-1. In both seasons in Type-2 AWMP, the sources of irrigation water were STWs and adjacent canal water. Due to being golda as a freshwater and bagda as a saline water shrimp, the water was managed and controlled by both STWs and canal water in ghers. In the monsoon season (June to October), the Bhadra River water salinity became low at a range which made bagda culture suitable without hampering golda. Vegetation on dykes was found to be less than that of Type-1 AWMP and these were brinjal, cauliflower and red turnip (Annex-I).

Type-1

Type-2

Type-3

Type-4

Photo 4.1 Different Types of AWMPs in Kharnia and Sobhana Unions

In Type-3 AWMP, BRRI Dhan 28 and Hassan were found to be cultivated in the Rabi season. Mixed Aman rice, bagda and white fish were cultivated during mid July to early November. Mixed bagda and white fish were cultivated during the period from mid April to mid July (Figure 4.1). Boro rice cultivation was done using the Bhadra River water during December to mid February followed by irrigation with STW water. But in the Kharif season, the Bhadra River water was directly used as irrigation in ghers. No vegetation was found on gher dykes (Photo 4.1).

In Type-4 AWMP, salinity tolerant rice varieties BRRI Dhan 28 and BRRI Dhan 47 were cultivated in ghers of J-1, J-2 and J-3 with less dyke vegetation (banana, kolakashia) using STW water and *Muchikata* canal water. Mixed bagda, golda and white fish were cultivated during the period from mid April to mid July (Figure 4.1). In the Kharif season, only the water from *Muchikata* canal was used for irrigation.

A one-month interval between aqua-product harvesting and HYV Boro rice bed preparation was maintained for drying of gher soil. The above cropping patterns were mainly governed by the seasonal salinity variation in the Bhadra River. In some of the past studies, only two types of AWMPs such as Type-1 and Type-3 were studied in the Khulna region (Bramon, 2004; Ali, 2006). However, the current research added two more new AWMPs such as Type-2 and Type-4 for investigation.

4.1.1 Rice cultivation

The irrigated HYV Boro rice cultivation has been found to be common in the study area over the last three years. In Kharnia Union, HYV Boro rice cultivation started about twelve years back. The reasons behind the starting of HYV Boro cultivation in Sobhana union were the decrease of bagda and golda yield and price hike of rice in local and global markets. During the rabi season in all types of AWMPs, BRRI Dhan 28 or BRRI Dhan 47 were cultivated. The farmers were used to cultivate traditional rain-fed transplanted Aman paddy in the Kharif season and high yield salinity tolerant rice varieties in the Boro season where soil salinity was a main constraint.

Table 4.1 HYV Boro Rice Yields in different AWMPs during 2009/10

Yield kg/ha	Types of AWMPs										
	Type-1		Type-2			Type-3			Type-4		
	R-2	R-3	V-1	V-2	R-1	B-1	B-2	B-3	J-1	J-2	J-3
Rice	6531	5587	6296	6519	NY	NY	NY	778	2473	1992	395

Note: NY=No yield

The average yields of HYV rice in the study area ranged from 778 kg/ha to 6531 kg/ha (Table 4.1). In Kharnia union, the yield ranged from 6049 kg/ha to 6507 kg/ha and from 778 kg/ha to 2473 kg/ha in Sobhana union (Table 4.1). It was found from Table 4.1 that in Type-1 and Type-2 AWMPs, the yield of BRR Dhan 28 rice varieties were high compared to BRRI (1999) where the required rice yield was 5000 kg /ha. The highest rice yield (6407 kg/ha) was found in Type-1 and the lowest (778 kg/ha) in Type-3 AWMP. Thus brackish water shrimp cultivation might affect the soil salinity which retarded the growth of rice plants and resulted in lower yields in Sobhana union.

4.1.2 Crop cultivation in the Kharif season

Two types of shrimps were cultivated in the study area in the Kharif season (Photo 4.2). These were fresh water shrimp known as ‘golda’ (*Macrobrachium rosenbergii*) and brackish water shrimp known as ‘bagda’ (*Penaeus monodon*).

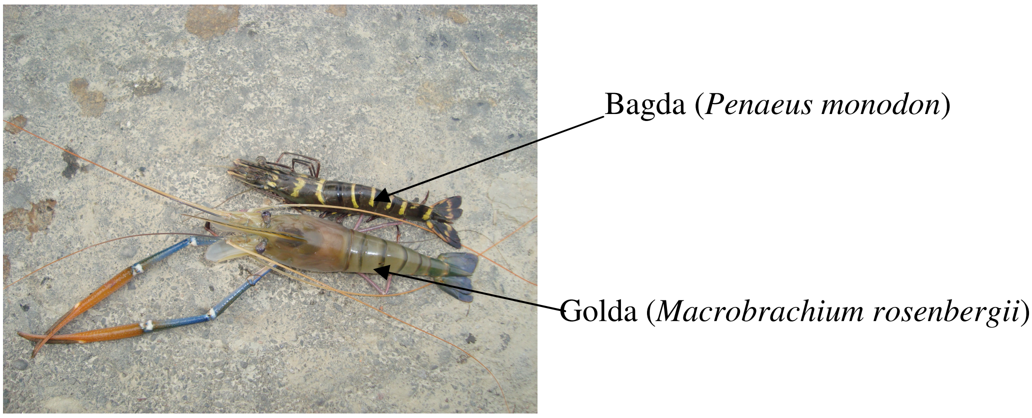


Photo 4.2 Shrimp in Kharnia and Sobhana Unions of Dumuria Upazila

In Type-2 and Type-4 AWMPs, golda was cultivated with bagda in a mixed water condition (Photo 4.2). However, in Type-2 AWMP, golda was dominant, and in Type-4 AWMP, bagda was dominant in the Kharif season (mid-May to mid-November). Improved extensive (Type-1 and Type-2) and extensive (Type-3 and Type-4) gher systems were found in Kharnia and Sobhana unions, respectively (Figure 4.1).Gher systems were defined by the gher sizes and the management practices. Improved extensive gher size is smaller than extensive farming systems (Phillips et al. 1993)

Surveyed farms were varied between 0.20 ha and 1.66 ha in size in the study area (Table 4.2). Golda farms were typically smaller than bagda farms (Table 4.2). Average size of golda gher was 3.5 ha which varied from 0.20 ha to 0.49 ha in Kharnia union and the average size of bagda farms was 0.85 ha which varied from 0.28 ha to 1.66 ha in Sobhana union. DOF (2002a) and Muir (2003a) were made a similar comparison between golda and bagda gher size, which was 0.28 ha and 4.0 ha in Khulna region. More than a decade ago Rutherford (1994) observed that 0.35 ha was average golda gher size in Bagerhat district.

Table 4.2 Crop Yield in Different AWMPs in the Kharif Season 2009

Types of AWMPs	Type-1			Type-2			Type-3			Type-4		
Area (ha)	0.49	0.36	0.41	0.27	0.41	0.20	1.47	0.70	0.52	0.28	1.66	0.51
Golda (kg/ha)	408	559	370	704	370	892	---	---	---	72	10	15
Bagda (kg/ha)	---	---	---	370	198	446	543	650	195	182	65	98
White Fish (kg/ha)	327	279	294	296	257	371	407	448	389	436	251	277

However, Ahmed (2001) reported that the average golda farm size was 0.23 ha in the Bagerhat area, with thousands of tiny farms and only a few large units; the largest farm size was 1.01 ha and the smallest was 0.06 ha. So from the Table4.2 it is clear that the size of golda and bagda ghers were bigger in Dumuria Upazila of Khulna district than other parts of the Khulna-Satkhira-Bagerhat region.

Table 4.2 shows the yield of golda and bagda and white fish in four Types of AWMPs in the study area in the Kharif season (mid-May to mid-November). The highest yield of golda was 892 kg/ha and the highest yield of bagda was 650 kg/ha. The production of golda was higher in Type-2 than Type-1 AWMP. Thus, the mixed water (fresh water + low saline water) could be ascribed as good for the high production of golda rather than fresh water in Kharnia union. But the high yield of bagda (650 kg/ha) was influenced by mixed water in Sobhana union, where the yield in Type-3 AWMP was greater than that of Type-4 AWMP. The high yield of white fish (407 to 448 kg/ha) was also found along with the bagda cultivation in Type-3 AWMP. The individual and the group farmers preferred to produce shrimp (22% and 21% respectively) and finfish (32% and 30% respectively) to increase total biomass and to avert risk of diseases (Mohanthy, 1994) in this region.

Changing of water in ghers mainly depended upon the high and low tides. Occasionally, a pump was used for exchanging water during bagda cultivation in extensive ghers of Type-3 and Type-4 AWMPs. After a three-month cultivation, bagda was harvested in every *gon* (ebb tide and flood tide), whereas golda took almost one year for cultivation (Figure 4.1). During golda cultivation, the ghers were irrigated with the water from adjacent canal or STW to maintain available depth of water. In golda cultivation water depth was higher in ghers than in bagda cultivation ghers

In gher systems the peak season of golda harvesting was from November to January. Farmers grade all head-on golda by size and weight and sold them to golda traders (Photo 4.3). The size of golda smaller than grade 50 restocked rather than harvested in homestead pond when water was unavailable in gher-canals. During HYV Boro cultivation the sufficient water were retained in gher-canals at the first quarter of February. But from mid-February to mid-April, water quality degraded much to make fish cultivation hard in gher canals. It was found that at the post harvest (mid-April) season, the water volume and quality in gher-canals became too poor to sustain any shrimp or fish or both.

Photo 4.3 Graded Golda after Harvesting in Kharnia and Sobhana Unions

A range of carp species were cultured with the golda and bagda which is locally named as white fish (Photo 4.4). Farmers were found to stock Bhetki (*Lates calcarifer*), Catla (*Catla catla*), Mrigal (*Cirrhinus cirrhosus*), rohu (*Labeo rohita*), Tilapia (*Oreochromis mossambicus*), Grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), Tengra (*Glyptothorax cavia*), Koi (*Anabas testudineus*), Parshe (*Liza parsia*), etc. (Photo 4.4). The white fish yield ranged from 237 to 493 kg/ha in the shrimp culture season of 2009, which added extra financial aid and support nutrient supply to farmers' family in Kharnia and Sobhana unions (Table 4.2). Also the yield of white fish was found to be the highest (407 to 448 kg/ha) in Type-3 AWMP, and yields in different AWMPs in the study area was of the following orders: in Type-3 (an average 415 kg/ha) > Type-4 (an average 321 kg/ha) > Type-2 (an average 308 kg/ha) > Type-1 (an average 300 kg/ha) (Table 4.2). Thus, to some extent, yields of white fishes were related to salinity of water in different AWMPs in south-western coastal region of Bangladesh.

Photo 4.4 Harvested White Fish in Different AWMPs

Fish larva in improved extensive system (Type-1 and Type-2 AWMPs) was sourced from the natural habitat with an addition of 5-10 larvae/m^2 from a hatchery (NACA 1994). In Type-1 and Type-2 AWMPs, feeding was supplemented occasionally in ghers. The supplemented fish feed contained chita gur of 5 kg, salt of 1 kg, pulse of 15 kg, mustard cake of 20 kg, rice polish of 20 kg, flour of 20 kg, wheat polish of 10 kg, pila globosa of 8-10 kg and provita of 20 kg per ha. 50 kg lime with 100 gm formalin was sprayed in golda dominated gher in Kharnia union. Extensive system of shrimp cultivation in Type-3 and Type-4 AWMPs took 3-4 months with occasional feeding. Feeding mostly depended upon natural food, such as residue of Aman rice plants and planktons in Type-3 and Type-4 AWMPs in Sobhana union.

4.1.3 Management inputs in different AWMPs

4.1.3.1 Management status

Two Types of water source management existed in Kharnia and Sobhana unions within different AWMPs; one was community management approach (Photo 4.5) and the other was individual management approach (Photo 4.6). In Type-1 AWMP water was used from STW and in Type-2 AWMP water was used from the canal connected to the Bhadra River and STW in the dry season. Retained water in *Singerbeel* canal was stored during the rainy season. Saline water intrusion into *Singeerbeel* canal and *Bhadradia* canal were prevented during winter season by controlling sluice gate at the river-canal interface. Community management approach influenced the operation of the sluice gate (Photo 4.5). The opening and closing of sluice gate was done by consensus decisions of the people in Ranoi and Bhadradia villages at Kharnia union. Here, uniform AWMPs were found for rice-golda, bagda & white fish cultivation around R-2, R-3, V-3, V-1, V-2 and R-1 ghers due to community management of water sources.

Photo 4.5 Community Managed Sluice Gate Operation in Kharnia Union

Retained water of the *Muchikata* canal and STW water were used for HYV Boro rice cultivation in Type-4 AWMP from January to mid-April in Jialtoli village of Sobhana Union. Community management approach was established for sluice gate operation at the interconnection of river and canal and had been practicing for the last three years like Kharnia Union (Photo 4.5). So uniform agro-water management practice such as rice-mixed bagda, golda & white fish cultivation was found around J-1, J-2, J-3 ghers of Type-4 AWMP in Sobhana Union.

Photo 4.6 Individual Management of Water Source in Type-3 AWMP

In Type-3 AWMP, water was used from STW in the Rabi season, but in earlier Kharif season, the Bhadra River water was used directly through individual management approach in Sobhana union (Photo 4.6). There were pocket gates in each gher connected to the Bhadra River, to draw water by gravitational force (Photo 4.6). There was no unified decision or choice to operate sluice gate or control of pocket gates operation to prevent saline water intrusion into ghers. The choice of crop cultivation in Rabi season fully depended on farmer's individual crop selection as whether it could be bagda or HYV Boro rice. Thus there was no uniform cultivation practice around Type-3 AWMP. So the individual management of water sources such as river water or STW depending on crop selection was created adverse impact on HYV Boro rice cultivation. Ghers of B-1, B-2 and B-3 were surrounded by bagda cultivation and the saline water was used in surrounded gher from the Bhadra River, which affected B-1 and B-2 ghers fully and B-3 gher partially by increasing salinity in soil and water through leaching.

4.1.3.2 Water management in different AWMPs

4.1.3.2.1 *Water exchange*

For gher preparation, dewatering for sun drying of soil and subsequent watering in ghers were done at the starting of shrimp cultivation in different Types of AWMPs in Kharnia and Sobhana unions. Generally, the water of the old shrimp pond was drained out by the end of November and left for sun drying for a month (Alam and Philips, 2004). But the gher was fully dewatered at the first quarter of December except the gher canal in the study area. The frequency of water exchange differed in each AWMP based on golda or bagda cultivation in the shrimp cultivation season. In Type-1 and Type-2 AWMPs, the water was exchanged once in a year. In Type-3 and Type-4 AWMPs, the frequency of water exchange was related to the number of low tides and flood tides of the Bhadra River. Because of bagda cultivation the water exchange rate was high in Type-3 and Type-4 AWMPs, and because of golda cultivation it was low in Type-1 and Type-2 AWMPs. The wooden pocket gate in water exchange system was used for drainage and flushing purposes. Due to being elevated than the source of water, most of the farms of Type-1, Type-2 and Type-4 AWMPs were found to have water pumping facilities which were similar to the findings of Alam and Philips (2004).

4.1.3.2.2 *Irrigation*

In different AWMPs, sources of irrigation water and frequency of irrigation acted as a factor for the changing cropping pattern in the study area. In Type-1 AWMP, only shallow tube-well (STW) water and rain water were used for shrimp and rice cultivation. In Type-2, during the Rabi season STW and *Singairbeel* canal water, and during shrimp culture season only the water of the canal connected to the Bhadra River were used. The frequency of irrigation in Type-1 AWMP was estimated to be an average of 10 times, whereas that in Type-2 AWMP of 17 times for HYV Boro rice cultivation per season. In Type-3, during the Kharif season, water for irrigation was sourced from the river only, whereas during the Rabi season, that was sourced from the river till mid-February followed by STW water in the later part. In B-1 and B-2 ghers, irrigation was provided 6 times, whereas in B-3 gher it was 14 times per season. In Type-4 AWMP, the paddy fields were irrigated by the water from nearby *Muchikata* canal and STW waters with an average of 12 times in J-1 and J-2 ghers, and 10 times in J-3 ghers per season. During the Kharif season in Type-4, irrigation water was used only from *Muchikata* canal.

4.1.3.3 Fertilizer management

The rate of fertilizer used was found to be high in improved extensive ghers of Type-1 and Type-2 AWMPs in Kharnia union than in extensive ghers of Type-3 and Type-4 AWMPs in Sobhna Union. Urea, TSP, MP, mixed N-P-K, Zink, Gypsum, etc. were used as inorganic fertilizers, and cow dung and mastered oil cake as organic fertilizer (Annex-I). But generally golda farmers used mainly cow dung, urea and TSP (Ahmed 2008). The practices of organic fertilizer were found to be infrequent in all types of AWMPs. Among 12 ghers of the study, organic fertilizers were used only in 5 ghers; most of the farm's production depended on natural feed (Annex-I). The rate of organic fertilizer were 380 kg/ha in Type-1, 340 kg/ha in Type-2, 123 kg/ha in Type-3, and 55 kg/ha in Type-4. According to Ahmed (2001), the general rate of fertilization for cow dung is 1467 kg/ha, for urea is 403 kg/ha and for TSP is 217 kg/ha, and compared with these rates, the annual fertilization rate found in the study area was lower (Annex-I) at varying frequency. Farmers were also found to use lime in golda ghers (Annex-I). Varying rates of application of fertilizer, according to the farmers, were also due to their differential financial conditions.

4.1.3.4 Pesticide management

Pesticides with lower rates of application and lower toxicity were used in the ghers under the study (Annex-3) and the use of IPM techniques was rarely found in different types of AWPMs. Some of those pesticides were Belt, Josh, Alfatap, Kartap-50sp, Lancer-Acephet-75sp, Sunfuran-Carbofuran and Furadan. There was a tendency among the individual and group farmers to spray thiodan (endosulfan 35% and emulsifiers 65%) at the first intake of water to kill unwanted organisms at 70-100 gm per ha rate. There were five types of IPM techniques used in Kharnia union (Annex-3). Spraying water with crushed tobacco leaf (300 gm/10 L) in the soil and plantation of *Neem* on gher dike was found at R-2 gher, and only the later technique (*Neem* tree plantation) at R-3 gher. A very local IPM technique was found to be used in V-1 gher where a structure was made over and across the paddy field to allow birds to land on and to grab insects. In V-2 farm, hand netting and ash spraying were used. Most of the farmers in the study area reported of being interested on IPM which failed at the execution level due to lack of training, financial facilities and institutional help.

4.2 Environmental Parameters

There were two environmental quality parameters of ghers such as soil quality and gher canal water quality which control the productivity of HYV Boro rice cultivation in different AWMPs. Also the degradation of soil quality and water quality during HYV Boro rice cultivation could be used as parameters for sustainability indicator for an AWMP in the study area.

4.2.1 Soil quality

The study involved examining the impacts of HYV Boro rice cultivation on sixteen soil properties, and comparing of those parameters between the different types of AWMPs. Mean soil quality change indicator (MSQI), which has been calculated from the laboratory data, was used for the assessment of soil quality degradation in different AWMPs. The term 'soil degradation' refers to temporal changes in a group of soil properties as they deteriorate the soil capability to sustain higher yields (Dumanski and Pieri, 1997). Soil degradation is generally measured by comparing variations in certain physical, chemical, and biological properties under different land uses / land covers at a single point in time (Adejuwon and Ekande, 1988; Islam and Weil, 2000). In the study soil quality degradation was measured by comparing with the critical limit and nutrient availability of loamy to clay wetland soil recommended in BARC (2005) for rice.

4.2.1.1 Soil physical properties

Temperature, pH, EC and salinity were taken as the physical parameters of soil in the study**.** Soil temperature was found increased from pre-Boro season (17- 22 ^{o}C) to post season (30-33 ^{o}C) in different types of AWMPs of HYV Boro rice cultivation because of seasonal change. The increase in temperature and consequent microbial decomposition might cause high organic acidity in soil of the ghers. Different physical parameters of the soil of the farms during pre- and post-Boro season under the study were analyzed and the results are summarized in Table 4.3. Soil pH is the most important factor for nutrient availability in soil for rice.

Table 4.4 Pre- and Post-Boro Season Soil Quality in Different AWMPs

Soil Quality Parameter		Types Of AWMPs								(BARC, 2005)		
		Type-1		Type-2		Type-3		Type-4		Critical limit	Availability	Remarks
		Pre	Post	Pre	Post	Pre	Post	Pre	Post			
pH		7.26	6.43	7.31	6.41	7.41	6.61	6.6	5.64	<4	5.6 to 6.5	Slightly acidic
EC	**dS/m**	0.91	1.93	2.21	2.74	1.43	2.66	1.3	4.6	<0.2	<2 to 2-4	Non saline to Slightly saline
OM	**%**	2.86	1.86	2.18	2.15	2.59	1.99	2.3	1.96	2	1.8-3.4	Medium
Ca^{2+}	**meq / 100 gm soil**	10.26	9.6	9.2	12.4	15.87	10.26	7.46	14.66	2	>7.5	Very High
Mg^{2+}		16.53	13.22	11.5	11.63	8.86	7.54	8.99	6.61	0.5	>1.875	Very High
Na^{+}		2.33	2.85	2.73	3.03	1.66	1.22	3.11	3.03	1	----	----
K^{+}		0.072	0.071	0.107	0.105	0.097	0.155	0.09	0.095	0.12	0.076-0.15	Low
CEC		29.19	25.75	23.55	27.17	26.48	19.18	19.66	24.40	----	16-30	High
ESP	**%**	7.97	11.07	11.61	11.14	6.26	6.36	15.84	12.40	<5	6-15	High
N		0.1307	0.1302	0.1423	0.1265	0.1297	0.1265	0.1227	0.1279	0.12	0.091-0.18	Low
P	**µg/gm**	1.26	0.87	0.94	1.3	0.98	0.73	0.82	0.74	8	<6	Low
S		11.43	32.71	44.85	87.032	13.82	65.75	30.14	66.28	10	>30	Very High
Fe		23.73	10.07	29.65	22.84	14.03	24.28	37.46	14.32	4	>15	Very High
Cl	mg/kg	798.75	2958	2367	3313	1479	5147	1331	7100	----	----	----

In most causes, the pH of 6-7 is optimum for adequate availability of nutrients in soil for plant. From pre-Boro to post-Boro season, pH ranged from 7.26 to 6.43 in Type-1, from 7.31 to 6.41 in Type-2, from 7.41 to 6.66 in Type-3 and from 6.6 to 5.64 in Type-4 AWMPs. During HYV Boro rice cultivation soil pH value was decreased in ghers which indicates slightly acidic soil according to soil classification BARC (2005). Datta and Sannamat (2000) reported that the pH value of the extensive ghers (Type-3 AWMP) was higher than the improved extensive ghers (Type-1, Type-2) at pre-Boro season which coincide with the current findings.

Electrical conductivity (EC) values represent the status of organic loading and metabolic waste generation in an AWMP. In comparison with BARC (2005) it was found from Table 4.3 that a slight increment in soil EC values were indicated non-saline soil in Type-1 AWMP and slightly saline soil in Type-2, Type-3 and Type-4 AWMPs. These might be, according to Datta and Sannamat (2000), due to the addition of Mg and K-rich fertilizers. In Type-3 and Type-4 AWMPs, soil EC increased from 1.43 to 2.66 dS/m and 1.3 to 4.6 dS/m respectively. The higher increments of EC were found in Type-4 AWMP, which were directly served by *Muchikata* canal water in the Kharif season. The shrimp producers of Jialtoli village were found to keep on adding extra salt into the water to ensure required salinity level. This extra salt accumulated and contributed in eventual increase of soil salinity. The higher increase of EC (> 4 dS/m) might create stress to rice plant growth and influence low yield in Type-4 AWMP compared to other AWMPs.

4.2.1.2 Soil nutrients

Soil nutrient status is mainly governed by OM, N, P and K in a crop field. Organic matter (OM) was found medium high in gher soil at pre-Boro season in four types of AWMPs, but most of the OM content in soil might be immature (partial decomposition) (Table 4.3). During the Kharif season, unconsumed fish feed, shrimp metabolites, aquatic weed, fish excreta, etc. contributed significantly to the organic matter of the soil during December 2009. From the Table 4.3, in comparison with BARC (2005) the soil OM content of four types of AWMPs were profiled as moderate as it were found to be less than 5% and ranged between 1.8 to 3.4 % . The less variation in soil OM content (2.18%-2.15 %) was observed in Type-2 AWMP due to the supply of cow dung during rice cultivation (Table 4.3). The higher soil OM content of Type-2 AWMP could be related with the higher yield of rice (6405 kg/ha) than others (Table 4.1).

From the Table 4.3, it is seen that available nitrogen (N) content in four types of AWMPs, soil ranged from 0.12 to 0.14 % which was shown the low content of N during 2009-10 Boro rice season. But available N content in gher soils of AWMPs did not vary much from the pre- to post-Boro season of HYV Boro rice cultivation (Table 4.3). Nitrogen fertilizer application such as urea in rice fields influenced the low differences of nitrogen content in soil between pre-Boro season and post-Boro season. But this low content of N (0.12%) was found almost equal with the critical limit of N content for rice plant growth. So use of N fertilizer should be increased to attain higher rice production. This result does match with Datta and Sannamat (2000), where the authors reported that the traditional ghers relatively contained low N. From the Table 4.3 it is also found that available N content is more in Type-1 and Type-2 than in Type-3 and Type-4 AWMPs, and it can be related to cropping patterns of these AWMPs. Aman rice was cultivated during mid July to mid November before HYV Boro rice farming (January to mid April) which could affect the available N of the soil in Type-3 and Type-4 AWMPs.

In comparison with BARC (2005) the available phosphorus (P) in ghers soil ranged from 0.73 to 1.3 (µg/g) in four types of AWMPs which could be classified as very low P content soil in Tables 4.3. The available phosphorus content in soil at pre and post-Boro season in four types of AWMPs were found to be low. NACA (1994) found high available P in pre-Boro season because of shrimp cultivation in earlier season, but the available phosphorus content in gher soil was found very low in SRDI (2003) observation. Table 4.3 shows that the available P content of soil in four AWMPs are so poor to meet the critical limit (8 µg/g) for rice plant growth. So increase of organic fertilizer/ TSP use would be beneficial for the rice growth during Boro season.

Potassium (K) content in soil was found to be low ranging from 0.076 to 1.3 meq/100gm soil in three types of AWMPs (Type-2, Type-3 and Type-4) compared to BARC (2005), except Type-1 AWMP where the K content found very low (Table 4.3). In Type-2, Type-3, Type-4 ghers, high potassium content was found compared to Type-1 and this might be related to slightly saline soil (Table 4.3). Bandyopadhya et al. (1990) reported that the coastal saline soil had high potassium-supplying capacity. But K content of different AWMPs, soil found below ranged of the critical limit for rice plant growth. The reason might be supply of frequent irrigation in these ghers.

4.2.1.3 Major cations

Ca^{2+}, Mg^{2+}, Na^{+} and Fe^{3+} were found as the major cations of the soil in the study area. Tables 4.3 shows that from pre-Boro season to post-Boro season the calcium (Ca^{2+}) content of Type-1 and Type-3 AWMPs soil were decreased where the sodium (Na^{+}) content were increased. Which is represented the phenomena where Na^{+} replaced Ca^{2+} from the soil, and made the soil structure potential to dispersion. High concentrations of sodium in a soil create a state of easy dispersion, leading to poor soil physical conditions (Rengasamy and Olsson 1993) such as: low hydraulic conductivity, conceivably due to blockage of pores by dispersed colloid, the downward movement of dispersed material, leading to the formation of a clay pan, which can limit root development and drainage, unfavorable soil consistency: hard when dry and plastic-sticky when moist; such soils are difficult to work, a low resistance to slaking, easily leading to the formation of surface crusts, which hamper water infiltration and plant emergence, and water logging resulting from the general deterioration of soil drainage associated with the above effects. From Table 4.3 it is also found that four types of different AWMPs, soils contain very high Ca^{2+}, Mg^{2+} and Na^{+} which lead to Very high CEC of the soil compared with BARC (2005). Magnesium content (from 11.5 to 16.53 meq /100 gm soil) was found in Type-1 and Type-2 where is Mg^{2+} in soil with the pattern Ca < Mg. This pattern shows the increment of salinity during HYV Boro season cultivation. However, Ca > Mg trend was found in in Type-3 and Type-4 AWMP. Increase of calcium content in the soil of the ghers, other than Type-1 and Type-2, would be related to liming during land drying and fertilization by gypsum. In some similar studies in Khulna, Datta (2000), Haque (1995) and Ali (2006) found Ca and Mg rich soil in rice-shrimp ghers which was, according to them, an effect of liming.

Table 4.3 show that sodium content in soil in Type-1, Type-2 and Type-3 AWMPs ranging from 2.33 to 2.85, 2.73 to 3.03 and 3.11 to3.03 meq/100gm soil respectively were higher than that in Type-3 ranging from 1.66 to 1.22 meq/100 gm soil. This variation might take place by regular tidal water exchange in Type-3 at pre-Boro season, and water logged condition in Type-1, Type-2 and Type-4 AWMPs during Kharif season. At post-Boro season, the same trend of pre-Boro season was observed, but sodium content became higher ranging from in Type-1, Type-2 and Type-3 AWMPs (Table 4.3). Also the high sodium content was contributed to higher the exchangeable sodium percentage (ESP) (ranged from 6 to 11%), which is categorized as sodic soil to highly sodic soil in comparison with BARC (2005). High ESP frequently causes poor drainage in soil, inherent poor drainage characteristics of the soil may also lead to high soil salinity and high ESP values (Rengasamy and Olsson 1993). Effects of high soil sodicity on plants growth can also materialise in the form of toxicity or a nutritional imbalance. The effects of specific solutes, or their proportions, especially chloride, sodium and Boron, can reduce plant growth.

From Tables 4.3 it is found that the iron (Fe^{3+}) content was found to be very high(>15 µg/g) in four types of AWMPs. From pre- to post-Boro season, the iron content became very high due to the exposure of soil in the air. Also the tidal effect increased the iron content in soils under different AWMPs in the study area.

4.2.1.4 Major anions

During HYV Boro rice cultivation, an increase in major anions such as chloride (Cl^-) and sulfur (SO_4^{2-}-S) contents in soil were found very high in the study area (Tables 4.3). In comparison with BARC(2005) it was found that high salinity in the soil of different AWMPs was reflected from the very high chloride (>700 to <7500 mg/kg) and sulfur (>30 µg/g) contents of the gher soil(Table 4.3). The research findings found a trend of Cl > Na type in soil at post-Boro season in four types of AWMPs, which caused chloride ion toxicity in the paddy field and hampered the yield. Generally, the accumulation of excessive Cl^- reduces the stomatal conductance and inhibits photosynthetic mechanism (Kurban *et al*., 1999). If the chloride concentration in the leaves exceeds the tolerance of the crop, injury symptoms such as marginal leaf burn and intervenial chlorosis develop (Ayers and Westcot, 1994). The farmers of the Type-3 and Type-4 informed that marginal leaf burn of rice plant at 45-55 DAT, which might be due to the excessive accumulation of Cl ion.

Table 4.4 One-way ANOVA of Soil Quality Parameters between Different Types of AWMPs

Farming Types		Dependent Variables							
		pH	Ca	Mg	Na	Cl	N	K	S
(I) Type	(J) Type	Mean Difference (I-J)							
T1	T2	.020	-560	192	-40.18	-355.00	-116.66	-13.37	-54.32*
	T3	-0.17	-133.	688	375.01*	-2189.17	9.333	-32.80	-33.04***
	T4	0.79***	-1013*	800	-40.18	-4141.67*	79.333	-9.45	-33.57***
T2	T1	-0.02	560	-192	40.18	355.00	116.667	13.37	54.32*
	T3	-0.19*	427	496	415.19*	-1834.17	126.000	-19.43	21.28
	T4	0.77	-453	608	0.00	-3786.66**	196.000	3.92	20.74
T3	T1	0.17	133	-688	-375.01*	2189.17	-9.333	32.80	33.04***
	T2	0.19*	-427	-496	-415.19*	1834.17	-126.00	19.43	-21.28
	T4	0.97***	-880**	112	-415.19*	-1952.50	70.000	23.35*	-0.54
T4	T1	-0.79***	1013*	-800	40.18	4141.67*	-79.333	9.45	33.57***
	T2	-0.77	453	-608	0.00	3786.67**	-196.00	-3.92	-20.745
	T3	-0.97***	880**	-112	415.193*	1952.50	-70.000	-23.35*	0.54

Note: * The mean difference is significant at the 0.05 level; **the mean difference is significant at the 0.10 level; ***The mean difference is significant at the 0.15 level.

4.2.1.5 Comparison of Soil Chemistry of Different AWMPs

Statistical analysis of post season soil parameters among AWMPs of Type-1, Type-2, Type-3 and Type-4 are shown in Table 4.4. One-way ANOVA was done where soil pH, Na, Cl^-, Ca^{2+}, Mg^{2+}, available N, K^+ and S content varied among the existing AWMPs.

During post season of HYV Boro rice cultivation, sulfur content of soil was significantly ($p < 0.15$) higher in Type-3 and Type-2 than in Type-1 AWMPs. This higher sulfur content in soil indicated the brackish water in Type-3 and mixed water in Type-2 AWMPs influenced soil by the previous Kharif season. But sodium was significantly ($p < 0.05$) higher in Type-1 than that of Type-3. This was due to the long term water logging in gher and the absence of soil flushing which created high sodium deposition in Type-1 farm. The similar scenario for sodium content in soil was found in Type-2 and Type-3 farming. Though the influence of brackish water could be high on sodium content in Type-3, but regular soil flushing by flood tide and ebb tide diminished that influence leading to the lower level of sodium in soil.

The pH, calcium, chloride and sulfur content in Type-1 farm were significantly higher than those in Type-4 AWMP. It was found that the number of years of Boro cultivation (3 years in Type-4 and 12 years in Type-1) and flushing of soil during the Kharif season in Type-4 could have an effect on lower content of calcium, chloride and sulfur than in Type-1 gher soil.

The soil of bagda dominated salinity rich Type-4 AWMP had significantly ($P < 0.15$) high chloride content and the soil of Type-3 AWMP contained significantly ($P < 0.15$) high pH, calcium, sodium, potassium and bicarbonate, which indicated a regular tidal flushing in Type-3 and more use of fertilizer, liming and fish feed in Type-4 (Table-4.4).

4.2.1.6 Mean Soil Quality Change Indicator

Mean soil quality change indicator (MSQI) for each type of AWMP in the Dumuria Upazila was calculated and is shown in Table 4.5. Table 4.5 shows that the average percentage change in soil quality parameters was the highest (MSQI = -452.26) in the

Type-4 and the lowest in Type-2 (MSQI = -133.4) AWMP. During the HYV Boro rice cultivation (late December to mid April), nutrients uptake by rice plants, fertilizer and pesticide application in soil, and irrigation changed the soil quality in the study area. These findings could be simply defined by the impact of golda and bagda cultivation in the previous Kharif season and management impact on soil during HYV Boro rice season. The higher the MSQI was the higher the soil degradation occurred and it followed the ranking of Type-3 > Type-4 > Type-1 > Type-2 (Table 4.5).

Table 4.5 MSQI of different AWMPs in Kharnia and Sobhana Unions

Soil Quality Parameters	Changes in Parameter (%) of Different AWMPs			
	Type-1	Type-2	Type-3	Type-4
pH	-11.43	-12.22	-10.88	-14.6
EC	-111.8	-23.98	-87.56	-253.55
Ca	6.43	-34.783	35.33	-96.515
Mg	20.024	-1.13	14.9	26.474
Na	-22	-11	26.5	2.57
K	-1.39	-1.87	59.79	5.556
N	2.17	1.05	7.14	-12
P	-31	20.21	-25.5	-9.76
S	-186.2	-94.05	-375.8	-119.9
Fe	57.564	22.968	-73.06	61.773
OM	53.76	1.395	-23.17	17.35
MSQI	**-224.107**	**-133.4**	**-452.26**	**-392.24**

4.2.2 Water quality

Different water quality parameters of gher canal water were analyzed and the results are summarized in Table 4.6 for the pre-Boro season and the post-Boro season. These water, were retained for the shrimp and white fish rearing, and were not used for irrigation purpose. Though the water had no direct effect on rice yield or soil, but the changes of water quality might have effect on soil quality change. A distinct environment was found for rice cultivation which was surrounded by water in different AWMPs. Also the quality of post-Boro season water is a great concern because it discharges as effluent into surrounding water bodies such as canal or river, which lead to an ecological degradation.

Table 4.6 Pre- and Post-Boro Season Gher Canal Water Quality of Different AWMPs

Types of AWMPs	Physico- Chemical Parameter of Gher Canal Water														
	Temp[1]	pH	EC	Salinity	Trans[2]	DO	TOC	Ca^{2+}	Mg^{2+}	K^+	Na^+	SAR	Cl^-	NO_3^-	SO_4^{2-}
	°C		dS/m	ppt	cm	ppm	Ppm	ppm	ppm	ppm	ppm		ppm	ppm	Ppm
Pre- Type-1	21.97	7.66	3.38	3.25	8.573	4.9	3.9	88.172	73.73	20.1	6310.2	51.1	1119.63	8.33	107.6
Post-Type-1	34.1	7.49	5.12	5	13.84	4	8.19	120.23	199.3	8.19	655.2	116.93	1107.81	8.41	23.387
PreType-2	21.2	7.78	8.29	7	6.817	4.5	8.6	158.98	171.8	28.1	12059	136.86	2652.84	9.38	110.52
Post Type-2	33.83	7.39	13.71	8.5	9.948	4.13	25.9	179.02	243.1	59.6	6943.5	157.87	4354.44	12.6	860.85
Pre- Type-3	22.77	7.49	4.67	5.17	12.6	5.85	3.95	192.37	209.8	30.1	858.49	10.15	711.954	13.8	165.5
Post-Type-3	31.93	7.48	27.71	15.7	11.8	5.88	11	344.67	621.4	147	6563.2	276.66	9335.17	7.81	1296.2
Pre-Type-4	23.83	7.19	3.48	3.5	9.51	3.97	6.56	154.97	76.97	18.2	682.2	11.38	649.917	14.9	155.46
Post-Type-4	31.63	7.45	19.78	10.7	11.51	3.7	27.5	303.26	388.9	82.5	3451	197.46	6735.5	13.5	854.65
FAO[3](Golda)	**28-33**	**7-8.5**		**<4**	**25-40**	**3-7**		**4-160**	**<15**		**75**		**< 800**	**10**	
NACA[4]	**28-34**	**7-8.5**		**10-20**	**<40**	**4**	**7.03**		**120**	**81**			**1200**	**<300**	
Bangladesh[5]		**6-8.5**	**2.25**			**>5**					**1000**	**23**	**600**		

Note: [1]Temperature; [2] Transparency; [3] FAO water quality standard for golda adopted from Datta and Sannamat (2000); [4]NACA (1994) ; [5]Irrigation water quality standard for Bangladesh adopted from BADC (2007)

4.2.2.1 Physico-Chemical Parameters of Gher Canal Water

Temperature ranged between 20.9 and 25 ^{0}C in the pre-Boro season in different types of AWMPs (Table 4.6). The lowest to highest values of temperature followed the pattern of Type-1 < Type-2 < Type-3 < Type-4. It would be due to the shallower water depths in the bagda ghers. In the post-Boro season, typical temperature ranged between 33 and 34 ^{0}C at Kharnia union and 29.9 and 32.8 ^{0}C at Sobhana union which was within the Standard of FAO, NACA and irrigation water quality Standard of Bangladesh (Table 4.6).

It is seen from the Table 4.6 that the pH value of water changed from average 7.66 to 7.49 to be less alkaline in Type-1 during Boro rice cultivation. High fluctuation of electrical conductivity (EC) was found in Type-3 AWMP (from 4.67 to 27.71 dS/m), in Type-3 AWMP (from 3.48 to 19.78dS/m). Whereas in Type-1 AWMP (from 3.38 to 5.12 dS/m) and in Type-2 (from 8.29 to 13.71 dS/m) EC value changes slightly but they cross the standard limit during HYV Boro rice cultivation (Table 4.6). Ali (2006) reported a relationship among high temperature, low volume of water and leaching of base minerals from frequently irrigated soil. This was ascribed in the present study to cause high concentration of anions and cations in the gher canal water at the post-Boro season. The above relationship could influence the high alkalinity in water of all types of AWMPs. In comparison with FAO standard for golda cultivation and Bangladesh Irrigation water quality standard, the pH value were ranged within this standard but EC value were over ranged and not suitable for shrimp cultivation or irrigation (Table 4.6).On an average, salinity was found to be higher in the pre-Boro season (3.25 to 7 ppt) (Table 4.7). The lesser increase of salinity in gher canals of Type-1 and Type-2 than Type-3 and Type-4 were more evident at the post-Boro season, because the irrigation water from STWs was used in Type-1 and Type-2 areas rather than *Singerbeel* canal and *Bhadradia* canal (Table 4.6).

DO level was found in a range of 4.9 to 4 ppm at Type-1, 4.5 to 4.13 ppm at Type-2, 5.85 to 5.88 ppm at Type-3 and 3.97 to 3.7 ppm in Type-4 during the pre-Boro season to post-Boro season (Table 4.6). In Type-3 at the post-Boro season, DO was ranged from 5.85 to 5.88 ppm which was slightly high in the study area and within the standard limit of AFI (Table 4.6). Water which is containing DO level of less than 4 ppm is considered fatal for shrimp culture or less than 3.8 causes stress to shrimp and fish (NACA, 1994). The optimum level of transparency is 30-40 cm, but in most of the ghers transparency level was observed in the range of 6.5 to 13 cm at pre-Boro season and 11 to 17 cm at post-Boro season which were below the standard value of FAO and NACA (Table 4.6). Higher phytoplankton density during pre-Boro season and higher TDS (1480-15600 ppm) concentration during post-Boro season might be the reasons for low *secci* disk readings as reported in Datta and Sannamat (2000). Considering transparency of these waters, the gher canal waters were not suitable for shrimp/fish rearing.

The Total Organic Carbon (TOC) observed (from 3.9 to 6.57 ppm) in different ghers in pre-Boro season was positively correlated with TDS and OM concentration. TOC content in four types of AWMPs at post-Boro season ranged to be high (9.95 to 13.84 ppm) and observed average concentrations of TOC among four types of farming were Type-4 > Type-2 > Type-3 > Type-1 (Table 4.6). High organic loads would have increased the oxygen demand in water bodies and it would have eventually reduced the dissolved oxygen levels. Finally, this would have increased the anaerobic condition inducing the ecological stress to the organisms (Senarath, 1998).

Calcium ion (Ca^{2+}) and magnesium ion (Mg^{2+}) concentration represents the total hardness of the gher canal water in four types of AWMPs. Calcium ion concentration was greater than the magnesium ion in pre-Boro season and vice-versa in post-Boro season in different types of AWMPs (Tables 4.6). These observations were justified by Hounslow (1995) that the increase in salinity might cause a change which would be unsatisfactory for any type of aquatic life sustenance in gher canal at post-Boro season. Thus all the canal waters were not within the FAO and NACA standard of Calcium ion (Ca^{2+}) and magnesium ion (Mg^{2+}) for shrimp growth (Table 4.6).

Sodium ion concentration at pre-Boro season was higher than the chloride ion and vice-versa at post-Boro season in all types of ghers (Tables 4.6). Sodium ion concentration ranged between 6310.2 to 655.2 ppm, 12059 to 6943 ppm, 858.49 to 6563.2 ppm and 682.2 to 3451 ppm in Type-1, Type-2, Type-3, and Type-4 ghers respectively during HYV Boro rice cultivation (Table 4.6). Also in Table 4.6 it was found that sodium ion and chloride ion concentration were found to be higher than the FAO and AFI water quality standard for shrimp cultivation (Na < 75ppm and Cl <

800 for golda and Cl < 1200 ppm for bagda) in different AWMPs . The high concentration of sodium ion (>1000 ppm) were found in four types of AWMPs which were not suitable for irrigation purpose according to Bangladesh irrigation wter quality standard. The gher canal water became hazardous based on the chloride ion concentration exceeding all standards value (Table 4.6). Also high sodium ion concentrations would have developed alkaline conditions and might have been destructive to soil structure (El-Swaify, 2000). The post-Boro season water quality of four AWMPs in respect to SAR (>23) is too poor to act as an aquatic ecosystem and highly toxic to aquatic organisms (Table 4.6).

Nitrate is generally regarded as non-toxic to shrimp, even at concentrations of 300 ppm, shrimp can be grown normally (NACA, 1994). However, FAO water quality standard for shrimp cultivation has recommended 10 ppm nitrate for golda and AFI recommended 1.1 ppm for bagda. So, Type-2, Type-3 and Type-4 AWMPs the ghers canal water at pre-Boro season and post season containing more than 10 ppm nitrate might have created stress to shrimp and fish, whereas Type-1 gher canal water containing less than 10 ppm nitrate could be used for shrimp farming and Irrigation (Table 4.8).

Sulfate concentration was found to be high in the study area (Table 4.6). Sulfate concentration was related with increased salinity from pre-Boro season to post-Boro season in Type-2, Type-3 and Type-4 (Tables 4.6). The influence of the brackish water environment and tidal influences are also evident from the Table 4.6. Sulfate is a dominant anion after chloride ion concentration in coastal water. Sulfate concentration was found to be low compared to other types in Type-1 because of irrigation from STW and use of rainwater during HYV Boro rice cultivation.

4.2.2.2 Comparison of Gher Canal Water Quality of Different AWMPs

Statistical analysis of post-Boro season water parameters was done among groups of Type-1, Type-2, Type-3 and Type-4 and the results are shown in Table 4.7. ANOVA of water data for HYV Boro rice cultivation (the Rabi season) suggests that water temperature, salinity, EC, TDS, DO, TOC, Na, HCO_3^-, Cl^-, Mg^{2+} and K^+ contents varied among different types of AWMPs (Table 4.9).

Table 4.7 Multiple Comparisons of Different AWMPs by One-way ANOVA

Farming Types		Dependent Variables										
		Temp	Salinity	EC	TDS	DO	TOC	Na^+	K^+	Cl^-	HCO_3^-	Mg^{2+}
(I) Type	(J) Type	Mean Difference (I-J)										
T1	T2	0.267	-3.7	-5497.8	-5015	-0.13	-17.*	-6288.3*	-51.448	-3246.6	195.8	-43.7
	T3	2.2**	-12.4**	-14459**	-12135*	-1.9*	-2.8	-5907.9*	-138.635*	-8227.3*	290.8	-422.1
	T4	2.467	-7.4	-9382.4	-8161.7	0.3	-19.*	-2795.8	-74.325	-5627.6	215.2	-189.5
T2	T1	-0.267	3.7	5497.8	5015	0.1	17*	6288.3*	51.448	3246.6	-195.8	43.7
	T3	2***	-8.7	-8961.5	-7120.0	-1.7*	14*	380.3	-87.187	-4980.7	95***	-378.3***
	T4	2.200	-3.7	-3884.6	-3146.6	0.4	-1.6	3492.5	-22.877	-2381.1	19.3	-145.8
T3	T1	-2**	12.4**	14459**	12135*	1.9*	2.8	5907.9*	138.635*	8227.3*	-290.8	422.0
	T2	-2***	8.7	8961.5	7120	1.7*	-14*	-380.3	87.187	4980.7	-95***	378.3***
	T4	0.300	5.0	5076.9	3973.3	2.2*	-16*	3112***	64.309	2599.6	-75.8	232.5
T4	T1	-2.467	7.4	9382.5	8161.6	-0.3	19*	2795.8	74.325	5627.6	-215.2	189.5
	T2	-2.200	3.6	3884.6	3146.6	-0.4	2	-3492.4	22.877	2381.1	-19.3	145.8
	T3	-0.300	-5.000	-5076.9	-3973.3	-2.1*	17*	-3112***	-64.309	-2599.6	75.6	-232.5

Note: * The mean difference is significant at the 0.05 level; **the mean difference is significant at the 0.10 level; ***The mean difference is significant at the 0.15 level.

From Table 4.7 it is found that temperature is significantly ($p < 0.15$) high in Type-1 because of longer water logging period and use of more inorganic and organic fertilizers than Type-3. Total Organic Carbon and sodium were significantly ($p < 0.05$) higher in mixed water golda dominated ghers in Type-2 than fresh water ghers in Type-1. Sodium was high because of low saline water mixing from canal, which is connected to the Bhadra River during mid-July to mid-November. Though both types of AWMP systems were golda dominated and extra feeds (organic manure, mustard cake, snail, rice-husk, rice, etc.) were served for golda shrimp cultivation, but TOC was significantly ($p < 0.15$) high in Type-2 and Type-4 ghers than Type-1 ghers because of bagda shrimp shell deposition at gher bottom.

In Type-3 ghers, salinity, EC, TDS, DO, Na^+, K^+ and Cl^- were high in post-Boro season than in Type-1 ghers, whereas most of these parameters were interrelated. Significantly ($p < 0.15$) high concentration of these parameters in Type-3 was found because of saline water entry into rice–shrimp and white fish ghers directly from the Bhadra River since February 2010 to cultivate bagda. In Type-3, the transplanted HYV Boro rice was fully damaged at 30 DAT, because there was individual management at water sources. So leaching from surrounded ghers caused severe salinity increase in Type-3 farming and impeded the growth of rice and lastly totally damaged rice production.

The farming types of Type-2 and Type-3 were different from the management approach and cropping system. Temp, TOC and HCO_3^- were significantly ($p < 0.15$) high at post-Boro season in Type-2 because of mixed water of STW and canal water (stored during the rainy season) and bagda shell deposition. Magnesium ion concentration and DO were significantly ($p < 0.05$) high in Type-3 because of saline water exchange at each ebb tide and flood tide in ghers for bagda cultivation. Only one time water has exchanged before the land preparation of Boro rice cultivation which lead to high concentration of Na and DO ($p < 0.15$) in Type-1. In gher canal water of Type-3 high TOC ($p < 0.15$) concentration has found due to bagda shell deposition and regular water exchange in ghers. However, no significant differences were found in Type-2 and Type-4 ghers because of the existence of the same type of agro-water management practice though one was golda dominant and the other was bagda dominant but in HYV Boro cultivation season both types used only STW and canal water.

4.2.2.3 Suitability of Gher Canal Water Based on SAR

During the pre-Boro season, Type-1 and Type-2 ghers contained high sodium and salinity because of single time water exchange in a year, and inorganic and organic fertilization over the year. SAR value were found greater than 10 and RSC were nil with high EC (> 2 dS/m) in four types of AWMPs compared with BARC (2005) (Annex-II). The high evaporation might be a reason for the high salinity of gher canal during the dry season and it may also be due to more intensive use of freshwater sources.

The higher degrees of SAR (Annex- II) led to replace Ca and Mg ions from soil clays and thus damaged soil structure. In Type-3 and Type-4, water volume of the gher was routinely exchange every 4-6 days at every lunar cycle. Sodium ion concentration was low in Type-3 and Type-4 compared to Type-1 and Type-2 AWMPs, where salinity was high because of water exchanged pattern. During the post-Boro season, high SAR was found in all types of ghers. This was because of the presence of water in gher canal over the cultivation period. During the post-harvest period, the volume of water became very low with highly diluted concentration of Na, Cl^-, SO_4^{2-}, Mg and chloride as shown in Table 4.6, which has shown increased salinity unsuitable for golda-white fish, golda-bagda-white fish, or bagda-white fish in gher-canals, and also unsuitable for irrigation purpose. High Na and Mg would have affected soil structure. Na is antagonist to K, and Ca and Mg create crust on soil and hamper plant growth.

4.2.2.4 Mean Water Quality Change Indicator

Mean water quality change indicator (MWQI) for each type of AWMP in the Dumuria Upazila was calculated and is shown in Table 4.8. It is seen from the table that the higher the MWQI, the higher the water quality degradation in gher canals. The water quality degradation from pre-Boro season to post-Boro season of HYV Boro rice cultivation was found to follow the pattern of Type-3 > Type-4 > Type-2 > Type-1. There was a strong relationship between the quality of the water in the gher canals and that in the surrounding environment. It is expected that the degradation of surrounding water quality will be faster unless proper water quality management techniques are implemented in the existing rice-shrimp cultivation system in Dumuria Upazila.

Table 4.8 MWQI of Gher Canal Water in Different AWMPs

Water Quality Parameters	Changes in Parameter (%) in Different AWMPs			
	Type-1	Type-2	Type-3	Type-4
Temperature	55.23	59.59	40.26	32.73
pH	-2.24	0.135	-0.04	3.52
Transparency	61.47	45.94	-6.33	21.08
Salinity	35	6.67	-203.22	-204.76
EC	-51.48	-65.3	-493.71	-468.52
DO	18.367	8.15	-0.57	-6.72
TOC	-110.18	-200.81	-178.5	-319.77
Ca^{2+}	-36.36	-12.605	-79.17	-95.69
Mg^{2+}	-170.33	-41.51	-196.14	-405.26
Na^{+}	89.62	42.42	-664.5	-405.87
K^{+}	59.133	-112.16	-387.24	-352.86
Cl^{-}	1.06	-64.14	-1211.2	-936.36
NO_3^{-}	-1.04	-34.2	43.3	9.35
SO_4^{2-}	78.26	-678.9	-683.23	-449.75
MWQI	**26.5**	**-1046.7**	**-4020.3**	**-3578.9**

4.3 Evaluation of Different Agro-Water Management Practices

In four AWMPs, soil and water quality changes were considered as environmental factors and rice yield during HYV Boro rice cultivation as economic factor. According to Ahmed and Loung-Van (2009), all management practices in ghers can be considered as social factor, so in the present study community management or individual management of water source control, use of chemical pesticides, IPM, irrigation, fish feed application during the previous Kharif season, status of vegetation on ghers dykes, water inflow, stocked shrimp and any organic matter or inorganic fertilizer added to ghers were part of management practice and considered as social factors in multi criteria analysis (MCA). Integration of environmental, social/management and economic factors would lead to a sustainable agro-water management practice (AWMP). The best type of AWPM among different types of AWMPs in the study area was assessed by MCA.

4.3.1 Environmental consequences

Mean soil quality change indicator (MSQI) and mean water quality change indicator (MWQI) in ghers of different AWMPs indicated (Table 4.5 and Table 4.8) the environmental quality degradation in the study area. The MSQI and MWQI of Type-1 AWMP show that the soil quality change was greater than the water quality change. But in other three types of AWMPs, these were the opposite. The degradation of soil quality can be obtained from MSQI (Ali, 2006). The highest soil degradation had occurred in Type-3 AWMP and the lowest in Type-2. The MSQI and MWQI (Table 4.5 and Table 4.8 respectively) of the gher environment might play a key role in putting mixed shrimp and white fish in a stressful condition in the study area during HYV Boro rice cultivation. The farmers of all types of AWMPs were found to drain out the waste water from the gher canal to the surrounding canal or to the Bhadra River at post-harvest period (mid-April). Thus, a slight increase in organic matter, salinity, alkalinity and NPK parameters leading to the nutrient enrichment or eutrophication was a regular phenomenon of the receiving water bodies. The degradation of water quality can be obtained from MWQI. The highest water quality degradation in gher canals was found in Type-3. From the view point of waste water quality which depends on quantity and quality of feed, rate of water exchange, and rearing period (NACA 1994), it can be said that water management of Type-3 and Type-4 were superior to that of Type-1 and Type-2. But considering water quality degradation the phenomenon was vice-versa (Table 4.8). As an ecological impact, excessive primary productions might cause a highly imbalance trophic structure of the biota in the Bhadra River or canal waters which might be threatening for those ecosystems. According to USAID (2006), the improved extensive / semi-intensive shrimp ghers could be contributed to higher eutrophication with the discharge or seepage of nutrients and feeds added to the ghers than extensive shrimp ghers. The poor gher management practices also influenced the afore-mentioned soil and water quality changes and affected the surrounding water environment during HYV Boro rice cultivation.

4.3.2 Multicriteria analysis to evaluate four types of AWMPs

Multicriteria analysis (MCA) was used to evaluate four types of AWMPs and to find out suitability of HYV Boro rice cultivation as common seasonal crop cultivated sequentially with mixed golda-white fish/ mixed golda-bagda- white fish/ mixed bagda-white fish in Dumuria Upazila. MCA was done with social criteria [eleven inputs of management practices, such as, management status (MS) (community management (CM), individual management (IM)), water exchange rate (WEx), Number of irrigation (Irri), Use of inorganic fertilizer (UIF), Use of organic fertilizer (UFO), Integrated Pest Management (IPM), Use of chemical pesticide (UCP), status of fish feed (Fishfd) in the Kharif season**,** Number of crops (NC), vegetation on gher dykes (VD), and number of years of Boro cultivation(YBC)], environmental criteria (MSQI and MWQI) and economic criteria [rice yield (RY)]. Table 4.9 shows the original data obtained from field survey on management practices, laboratory analysis of soil and water quality change, and Boro rice yield in different AWMPs.

.

Table 4.9 Scorecard of Different AWMPs with Different Units of Criteria

Criteria	Type-1	Type-2	Type-3	Type-4
Management Status (CM/ IM)	CM	CM	IM	CM
Number of Crops	3	4	3	4
Years of Boro Cultivation	12	12	3	3
Water Exchange Rate Over Year	Low	Medium	High	High
Status of Fish Feed Application	Low	Medium	Absent	Low
Vegetation on Dyke	High	High	Absent	Medium
Number of Irrigations	10	17	14	12
Standing Water Depth the Rabi Season (cm)	8	8	9	9
Use of Chemical Fertilizer in the Rabi Season (kg/ha)	252	572	356	289
Use of Organic Fertilizer in the Rabi Season (kg/ha)	1300	1400	467	727
Use of Chemical Pesticides in the Rabi Season (kg/ha)	0	10	7.50	4.55
No. of IPM Techniques	3	2	0	0
MSQI	-224.107	-133.4	-452.26	-392.24
MWQI	26.5	-1046.7	-4020.3	-3578.9
Rice Yield (kg/ha)	6059	6407	778	2233

For the evaluation of four types of AWMPs by MCA, all qualitative and quantitative data from Table 4.9 were standardized by Equation No.3.1 and summarized in Table 4.10.

Table 4.10 Standardized Scores of MCA of Different Types of AWMPs

Criteria	Type-1	Type-2	Type-3	Type-4
Management Status	1	1	0	1
Number of Crops	0	1	0	1
Years of Boro Cultivation	1	1	0	0
Water Exchange Rate Over year	0	0.5	1	1
Status of Fish Feed Application	1	0 .5	0	0
Vegetation on Dyke	1	1	0	0.5
Number of Irrigation during the Rabi Season	1	0	0.43	0.71
Use of Chemical Fertilizer in the Rabi Season	1	0	0.68	0.9
Use of Organic Fertilizer in the Rabi Season	0.89	1	0	0.28
Use of Chemical Pesticides in the Rabi Season	1	0	0.25	0.55
No. of IPM Techniques	1	0.66	0	0
MSQI	0.72	1	0	0.19
MWQI	1	0.74	0	0.11
Rice Yield	0.91	1	0	0.25

The correlation Table 4.11 shows that the management inputs of the Kharif season and the HYV Boro rice season influenced the yield of rice in rice-shrimp and white fish ghers. But the significant ($p < 0.10$) correlation with rice yield was found with five management inputs out of eleven management inputs in different AWMPs (Table 4.12).

Table 4.11 Correlation of Management Inputs and Rice Yield in Four Types of AWMPs

		MS	WEx	Irri	UIF	UOF	IPM	UCP	Fishfd	NC	VD	YBC	SWD	RY
MS	Pearson Correlation	1												
	Sig.	.												
WEx	Pearson Correlation	-.522	1											
	Sig.	.478	.											
IrrI	Pearson Correlation	.164	-.323	1										
	Sig.	.836	.677	.										
UIF	Pearson Correlation	-.052	-.050	.958*	1									
	Sig.	.948	.950	.042	.									
UOF	Pearson Correlation	.759	-.832	-.115	-.394	1								
	Sig.	.241	.168	.885	.606	.								
IPM	Pearson Correlation	.555	-.987*	.176	-.105	.900	1							
	Sig.	.445	.013	.824	.895	.100	.							
UCP	Pearson Correlation	.310	-.526	.974*	.867	.111	.393	1						
	Sig.	.690	.474	.026	.133	.889	.607	.						
FIshfd	Pearson Correlation	.522	-1.00**	.323	.050	.832	.987*	.526	1					
	Sig.	.478	.	.677	.950	.168	.013	.474	.					
NC	Pearson Correlation	-.577	.905	.095	.372	-.964*	-.961*	-.134	-.905	1				
	Sig.	.423	.095	.905	.628	.036	.039	.866	.095	.				
VD	Pearson Correlation	.816	-.853	.546	.290	.759	.818	.712	.853	-.707	1			
	Sig.	.184	.147	.454	.710	.241	.182	.288	.147	.293	.			
YBC	Pearson Correlation	.577	-.905	-.095	-.372	.964*	.961*	.134	.905	-1.00**	.707	1		
	Sig.	.423	.095	.905	.628	.036	.039	.866	.095	.	.293	.		
SWD	Pearson Correlation	-.577	.905	.095	.372	-.964*	-.961*	-.134	-.905	1.00**	-.707	-1.00**	1	
	Sig.	.423	.095	.905	.628	.036	.039	.866	.095	.	.293	.	.	
RY	Pearson Correlation	.733	-.850	-.108	-.389	.999**	.922	.119	.850	-.975*	.756	.975*	-.975*	1
	Sig.	.267	.150	.892	.611	.001	.078	.881	.150	.025	.244	.025	.025	.

Note: *Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.001 level.

Table 4.12 Weighted Values of Management Inputs of AWMPs

Variables	Pearson' s Correlation, r	Significance Level	Weight
UOF	0.999	0.001	5
IPM	0.922	0.078	2
NC	-0.975	0.025	3
YBC	0.975	0.025	3
SWD	-0.975	0.025	3

Use of organic fertilizer (UFO) has the highest significant ($P < 0.01$) positive correlation with rice yield (Table 4.14). High organic fertilizer (cow dung and mustard cake) application influenced soil fertility which increased rice yield in different AWMPs. IPM is positively correlated ($P < 0.10$) with rice yield which shows that environmental practice could increase rice yield during HYV Boro rice cultivation. Year of Boro Cultivation (YBC) has significant ($P < 0.05$) positive correlation with rice yield. The relationship between number of Boro rice cultivation year (YBC) and rice yield could be explained by regular rice cultivation and community management approach to control saline water into ghers. Standing water depth (SWD) in rice fields is also negatively correlated ($P < 0.05$) with rice yield which shows that the high volume of water retained in golda ghers reduced the soil nutrients. Number of crops (NC) (double cropped or triple cropped) has significant negative correlation ($P < 0.05$) with the rice yield. The higher the number of crops cultivated, the lower the HYV Boro rice yield due to improper soil nutrient management.

In Table 4.13, management criteria have been assigned with different weights based on their significant correlation level with rice yield. The criteria which have significant level equal or less than 0.001 were weighted as 5, significant level equal or less than 0.01 were weighted as 4, significant level equal or less than 0.025 were weighted as 3, significant level equal or less than 0.05 were weighted as 2, significant level equal or less than 0.10 were weighted as 2, and significant level more than 0.10 were weighted as 1.

In Table 4.13, all criteria have been assigned with different weights based on their impact on total environment of a gher system (AWMP) and significant correlation level with rice yield. Islam *et al.* (2003) found that the decision of choosing between options depends on economic considerations. So rice yield of AWMP was weighted as the highest weight, which was equivalent to 39 percent of the total weight (Table 4.13). In south western coastal region, environmental degradation because of shrimp production has received so much criticism (Karim, 2006; Csavas, 1993; Phillips, Lin and Beveridge, 1993). The conversion of agriculture to shrimp farming created a physical and ecological imbalance, which has largely destroyed the natural ecosystem of the Khulna (Karim, 2006; Datta *et al.*, 2009). So from this point of view, the environmental parameters in an AWMP system (gher system) such as MSQI (weight = 25 %) and MWQI (weight = 13%) were given a total weight of 38 percent. Lastly the management inputs as social criteria of different AWMPs systems were weighted as 23 percent based on their correlation and importance in HYV Boro rice production systems.

Table 4.13 Weighted Sums of Multi Criteria of Different AWMPs

Criteria	Weight	Type-1	Type-2	Type-3	Type-4
Management Status	1	1	1	0	1
Number of Crops	3	0	3	0	3
Years of Boro Cultivation	3	3	3	0	0
Water Exchange Rate Over the Year	1	0	0.5	1	1
Status of Fish Feed Application	1	1	0 .5	0	0
Vegetation on Dyke	1	1	1	0	0.5
Number of Irrigations	1	1	0	0.43	0.71
Standing Water Depth	3	0	0	3	3
Use of Chemical Fertilizer in the Rabi Season	1	1	0	0.68	0.9
Use of Organic Fertilizer in the Rabi Season	5	4.45	5	0	1.4
Use of Chemical Pesticides in the Rabi Season	1	1	0	0.25	0.55
No. of IPM Techniques	2	2	1.32	0	0
Management Criteria	**23**	**15.45**	**14.82**	**5.36**	**12.06**
MSQI	25	18	25	0	2.375
MWQI	13	12.5	9.25	0	1.375
Environmental Criteria	**38**	**30.5**	**34.25**	**0**	**3.75**
Rice Yield	39	35.49	39	0	9.75
Economic Criterion	**39**	**35.49**	**39**	**0**	**9.75**
MCA Total Score	**100**	**81.44**	**88.07**	**5.36**	**25.56**

From the evaluation of MCA of four types of AWMPs, Table 4.13 shows that the Type-2 AWMP (total score of 88) is the best agro-water management practice among different AWMPs in Dumuria Upazila. From Table 4.13, it is found that the golda dominated rice-mixed shrimp, bagda and white fish cultivation in an improved extensive gher system was the preferred AWMP among the four types, by controlling water salinity with different management measures. Also the economic benefit (yield of golda, bagda, white fish and HYV Boro rice) in Type-2 AWMP was the higher among different AWMPs (Tables 4.1 and 4.2). EGIS-II (2001) reported that golda has less social and environmental impact than bagda cultivation, and the better strategy would be maximized the yield of golda.

Type-2 AWMP became an optimum AWMP than any other types because of the lowest soil and water quality change during HYV Boro rice cultivation season and use of IPM techniques, fresh water source, and doubled crop cultivation and the highest economic return. HYV Boro rice—shrimp and white fish not only accommodate crop diversification, enhance productivity and increase income, but also distribute the risk (both biological and economic) over two or more subsystems instead of a single commodity farming system. Ahmed *et al*. (2008) reported that golda dominated rice—mixed golda, bagda and white fish farming was an organic method that maintained best environmental sustainability. Hence HYV Boro—shrimp and white fish rotation can enhance efforts to develop ecological agriculture that generate maximum benefit using available energy and materials.

Table 4.14 Financial Return during the Crop Year 2009-10 of Different AWMPs

Types of AWMPs	Type-1		Type-2		Type-3		Type-4	
Economic Return	kg/ha	Tk/ha	kg/ha	Tk/ha	kg/ha	Tk/ha	kg/ha	Tk/ha
HYV Boro Rice	6059	72708	6407	76884	778	9336	2233	26796
Golda	446	557500	656	820000	0	0	33	41250
Bagda	0	0	338	253500	596	447000	115	86250
White Fish	300	25500	308	26180	415	35275	322	27370
Total	Tk. 655708 /ha		Tk. 1153002 /ha		Tk. 491611 /ha		Tk.181666 /ha	

Note: Price of Boro rice = Tk. 12 /Kg; Price of Golda = Tk. 1250/ Kg; Price of Bagda = Tk. 750/ Kg; Price of White fish = Tk. 85 /Kg

However the decision comes from MCA would not be different if the yield of golda, bagda, and white fish during the Kharif season were considered. From Table 4.14 it is seen that yield of HYV Boro rice was the highest (6,407 kg/ha) in Type-2 AWMP, and the total financial return (Tk. 11, 53,002) was also the highest in Type-2 AWMP. A study conducted by Islam (2007) concluded that, the decision function of choosing among shrimp, shrimp-rice or rice depends on economic benefits. Also Chowdhury *et al.* (2006) concluded in their study that the integrated shrimp-rice farming was more sustainable than only shrimp farming. They developed a triangular model of sustainability where they identified shrimp-rice mixed culture rather than newly adopting semi-intensive shrimp culture as more environmentally sound. In Table 4.13, only HYV Boro rice yield of each gher was taken as economic criterion for the evaluation of AWMPs. Furthermore Type-2 AWMP had the highest financial return in the Kharif and Rabi seasons (Table 4.14).

Mohanty *et al*. (2009) reported that rice—fish and golda was more eco-friendly than golda–fish. This double production system could improve soil fertility, recover lost energy, and adjust energy flow by consuming plankton, weeds, insects, and bacteria that compete with rice for nutrients.

It thus appears that HYV Boro rice—mixed golda-bagda-white fish was the best practice in the study area considering environmental point of view among different AWMPs and could be a sustainable option for diversification of smallholding rice farms in low lands with soil and water conservation structure, and with a reliable source for irrigation (mixed groundwater—surface water).

CHAPTER FIVE
CONCLUSIONS

5.1 Conclusions

The principal farming components of the diverse agro-water management practices (AWMPs) of the south-western Bangladesh are brackish water shrimp, freshwater prawn, white fish and HYV rice. Several combinations of these components are practiced either sequentially or concurrently where bagda-Aman cropping pattern is found to be more common than the golda-Boro pattern. However, in recent years, HYV Boro rice has been integrated with the existing practices as one of the major farming components. To identify the AWMP, which will be resilient to sustainability in southwestern coastal region from environmental, social and economic perspectives, different soil and water quality parameters for gher environment along with several important and relevant social and economic criteria were analyzed.

Community management of water sources generated two AWMPs in the region for HYV Boro rice cultivation, which was followed either by a mixed golda, bagda and white fish cultivation and or by a mixed bagda, golda and white fish – Aman rice cultivation. Such management prevented salinity intrusion into agricultural fields during Boro cultivation. Local people considered shrimp cultivation as their first preferred crop. Recently white fish cultivation became the second important crop in all AWMPs. Boro rice cultivation is considered as the third preferred crop. In golda ghers, HYV Boro rice cultivation reduced the problems of drainage congestion and water logging by frequent irrigation, and in bagda ghers, it lowers the soil salinity with fresh water flushing through irrigation from STWs and/or canals.

Mean soil quality change indicator (MSQI) revealed that among the various AWMPs the cultivation of mixed golda, bagda and white fish after the HYV Boro rice (Type-2 AWMP) had the least impact on soil. Mean water quality change indicator (MWQI) revealed that the cultivation of mixed golda and white fish after the HYV Boro rice (Type-1 AWMP) had the least impact on water environment. Both these AWMPs were community managed. Thus community managed AWMPs had lesser impact on physical environment of the gher ecosystem than the other practices. In the latter cases, water was controlled at the source on an individual basis.

Multicriteria analysis of environmental (MSQI and MWQI), management (Number of crops (NC), irrigation (Irri), water exchange (WEx), use of organic fertilizers (UOF), use of chemical pesticides (UCP), IPM, year of Boro cultivation (YBC), etc.) and economical (yields of HYV Boro rice, golda, bagda and white fish) parameters revealed that the communal approach in water management for HYV Boro rice cultivation with a crop rotation by mixed golda, bagda and white fish is the best AWMP among four types of existing AWPMs in the south-western coastal region of Bangladesh.

5.2 Recommendations for Further Study

The key to effective water resources management is inextricably linked to the understandings of the water cycle and land management. According to Bossio *et al.* (2009), every land use decision is a water use decision. Rehabilitating degraded land to enhance the multi-functionality of agricultural landscapes can improve water management and water productivity, while also improving the livelihoods of the rural poor. So gains in agricultural water productivity will be obtained alongside improvements in land use management. Expected increases in food demands by 2050 insist that agricultural production – and agricultural water use – must increase. So for better agricultural water use, the following recommendations are made for further study:

- In this study, only one HYV Boro rice season was investigated for soil and water quality change in different types of AWMPs. It will be better if such changes are investigated for a few more years and compared with this study.
- The study found that water management had great impact on land productivity, where source of water was found to be the most important factor. Studying the chemistry of river water, groundwater and canal water, this type of study can be more comprehensive and technically sound.
- In this study, soil and water quality was only analyzed for the period of HYV Boro rice cultivation season. Such analysis for other crops and seasons,

including the production information, will be more informative to find out a sustainable AWMP.

Soil erosion, nutrient depletion and other forms of land degradation reduce water productivity and affect water availability, quality and storage. Reversing these trends by better agro-water management practices entails tackling the underlying social, economic, political and institutional drivers of unsustainable land use. Further study can be undertaken to assess the livelihood impacts of different types of AWMPs that are taking place in the south-western coastal region of Bangladesh and to investigate the feasibility of reversing such trends.

REFERENCES

ACIAR (Australian Centre for International Agricultural Research), 1999. Coastal Shrimp Aquaculture in Thailand : Key Issues for Research, Canberra: pp 131.

Adejuwon, J.O., Ekande, O., 1988. A comparison of soil properties under different land use types in a part of the Nigerian cocoa belt. Catena, 15: pp. 319–331.

Ahmed, A.T.A., 1995. Impacts of shrimp culture on the coastal environment of Bangladesh. In: Proceedings of the National Workshop on Coastal Aquaculture and Environmental Management. Institute of Marine Sciences, University of Chittagong/UNESCO, Bangladesh: pp. 77–84.

Ahmed, I. and Doelemean, J. A. (eds.), 1995. Beyond Rio: The Environmental Crisis and Sustainable Livelihoods in the Third World, McMillan Publishing, London.

Ahmed, N., 1996. Commercial Shrimp Cultivation in Khulna, Bangladesh: Its Negative Impact on Women, Their Families, and the Environment. International Center for Research on Women Report in Brief. Washington, D.C., USA.

Ahmed, N., 2001. Socio-Economic Aspects of Freshwater Prawn Culture Development in Bangladesh. PhD Thesis, Institute of Aquaculture, University of Stirling, Scotland, UK.

Ahmed, N., Demaine, H. and Muir, J. F., 2008. Freshwater prawn farming in Bangladesh: history, present status and future prospects. Aquaculture Research, Elsevier, 39: pp. 806-819.

Ahmed, N. and Luong-Van, J., 2009. Can rice-fish farming provide food security in Bangladesh? Aquaculture Asia Magazine, Thailand, XIV (1).

Aiken, D., 1990. Shrimp Farming in Ecuador Whiter the Future ? World Aquaculture, 21(4): pp. 26-30.

Alauddin, M. and Tisdel,C., 1998. Bangladesh's Shrimp Industry and Sustainable Development: Resource Use Conflict and Development. Asian Fisheries Science, 11: pp. 97-110.

Alam, S.M.N., 2002. Shrimp based farming systems in south-western coastal zone of Bangladesh. Integrated Tropical Coastal Zone Management: 102.

Alam, S.M.N. and Phillips, M.J., 2004. Coastal Shrimp Aquaculture Systems in Southwestern Bangladesh. Asian Fisheries Science, Asian Fisheries Society, Manila, Philippines, 17 (2004): pp. 175-189.

Ali, A.M.S., 1987. Changes in near-saturated agro-ecosystems: a comparison of paddy agriculture in six villages in Bangladesh. Unpublished Ph.D.

Dissertation, Graduate School of Geography, Clark University, Worcester, MA.

Ali, A.M.S., 2004. Technological change in agriculture and land degradation in Bangladesh: a case study. Land Degradation & Development, 15: 283–298.

Ali, A. M.S, 2006. Rice to shrimp: Land use/land cover changes and soil degradation in South western Bangladesh". Land use Policy, Elsevier, 23: pp. 421-435.

Ali, M. Y., 1991. Towards sustainable development: Fisheries resources of Bangladesh. Bangladesh Ministry of Environment and Forest and National Conservation Strategy Secretariat, Dhaka, Bangladesh.

Alauddin, M., Mujeri, M. K. and Tisdel, C. M., 1995. Technology-employmentenvironment linkages and rural poor of Bangladesh: Insights from farm level data. In: Ahmed, I. and Doelemean, J. A. (eds.) Beyond Rio: the environmental crisis and sustainable livelihoods in the third world, McMillan publishing, London.

Alauddin, M. and Tisdel, C., 1997. The environment and economic development of South Asia: An overview from Bangladesh. McMillan publishing, London.

Alauddin, M. and Hamid M.A., 1999. Shrimp culture in Bangladesh: key sustainable and research issues. Paper presented during the AClAR Workshop on Key Researchable Issues in Sustainable Coastal Shrimp Aquaculture in Thailand. Songkhla. Thailand : pp. 27.

Allen, S., Grimshaw, H.M., Parkinson, J., and Quarmby, C., 1974. Chemical Analysis of Ecological Materials. Edited by Stewarte Allen, Blackwell Scientific Publication, Oxford London.

Alongi, D.M., Johnson, D.J., Xuan, T. T., 2000. Carbon and nitrogen budgets in shrimp ponds of extensive mixed shrimp – mangrove forestry farms in the Mekong delta, Vietnam. Aquatic Research, 31: pp. 387– 399.

Arlo W. F., 1992. An overview of Asian marine shrimp culture. In marine shrimp culture principle and practies. Elsevier-Amsterdam-London-Newyork-Tokyo: pp. 475-494.

Asaduzamman, M. and Toufique, K.A., 1998. Rice and Fish: "Environmental Dilemmas of Development in Bangladesh" in Growth or Stagnation? A Review of Bangladesh's Development 1996, Center for Policy Dialogue, University presses Ltd. Dhaka.

Ayers, R.S. and Westcot, D.W., 1994. Water Quality for Agriculture, FAO irrigation and Drainage Paper, FAO, Rome, 29(1).

BADC, 2007.Water quality for irrigation: Emphasis on Arsenic Contamination in agriculture, First Edition, Bangladesh Agricultural Development Corporation, Dhaka.

BARC, 2005. Fertilizer Recommendation Guide-2005. Soils Publication No. 45, Bangladesh Agricultural Research Council, Dhaka.

Bailey, C., 1988. The social consequences of tropical shrimp mericulture development. Ocean & Shoreline Management, 11: pp. 31-44.

Bailey, C. and Skladany, M. 1991. Aquaculture development in tropical Asia: A reevaluation, Natural Resources Forum: pp. 66-73.

Bandyopadhyay, B.K., and Maji, B., 1990. Long-term experiment to study the effect of missing P and K treatments on yield of crops. Annual Report,Central Soil Salinity Research Institute, Karala: pp. 180.

Barmon, B.K., Kondo. T., and Osanami, F., 2004. Impacts of Rice-Prawn Gher Farming on Cropping Patterns, Land Tenant System, and Household Income in Bangladesh: A Case Study of Khulna District,14(1): pp. 10-28.

Barmon, B. K, Kondo, T. and Osanami. F., 2006. Economic evaluation of Rice-prawn gher farming system on soil fertility for MV paddy production in Bangladesh. International association of Agricultural Economics Conference, Gold Coast, Australia.

Barmon, B.K, Kondo. T and Osanami. F., 2007. Agricultural Technology Adoption and Land Productivity: Evidence from the Rice-Prawn Gher Farming System in Bangladesh. Paper prepared for presentation at the 104th (joint) EAAE-IAAE Seminar Agricultural Economics and Transition: „What was expected, what we observed, the lessons learned." Corvinus University of Budapest (CUB) Budapest, Hungary.

BBS, 2002. Bangladesh Statistical Year Book, Bangladesh Bureau of Statistics, Dhaka, Bangladesh.

BCAS, 2001.The Coastal Shrimp Sector in Bangladesh: Review of the Literature with Annotated Bibliography, Bangladesh Centre for Advanced Studies, Dhaka,

Beverage, M., Phillips, M., 1993. Environmental impact of tropical inland aquaculture. In: Pullin, R., Rosenthal, H., Maclean, J. (Eds.), Environment and Aquaculture. Center for Tropical Aquaculture Research, Manila: pp. 213–236.

Bhattacharya, D., Rahman, M. and Khatun, F., 1999. Environmental Impact of Structural Adjustment Policies: The Case of Export Oriented Shrimp Culture in Bangladesh, Centre for Policy Dialogue, Dhaka.

Bossio, D., Geheb, K. and Critchley, W., 2010. Managing water by managing land: Addressing land degradation to improve water productivity and rural livelihoods§. Agricultural Water Management, Elsevier, 97: pp. 536–542.

Boyd, C.E., 1989. Water quality management and aeration in shrimp farming. Fisheries and allied aquacultures development series No.2, Auburn University: pp. 88.

Chowdhury, M. A. M., 1988. Socio-economic consequences of shrimp cultivation in Bangladesh: a case study of Satkhira, Chakaria and Maheshkhali. Bangladesh Journal of Public Administration, 2(2): pp. 49-76.

Chowdhury, M. A., Shivakoti, G. P. and Salequzzaman, M., 2006. A conceptual framework for the sustainability assessment procedures of the shrimp aquaculture industry in coastal Bangladesh. Int. J. Agricultural Resources,Governance and Ecology, 29 (3): pp. 198- 201.

Chua T. E., Paw, J.N. and Guarin, F.Y., 1989. The environmental impact of aquaculture and the effects of pollution on coastal aquaculture development in Southeast Asia, Mar poll Bull, 20: pp. 335-343.

Csavas, I., 1989."Problems of inland fisheries and aquaculture",chapter 6, in Fishing Industry in Asia and the Pacific. Asian Productivity Organization, Tokyo: pp. 137-180

Csavas, I., 1993. Aquaculture development and environmental issues in the developing countries of Asia. In: Environment and Aquaculture in Developing Countries, ICLARM Conference Proceedings,Vol. 31 (ed. by R.S.V. Pullin, H. Rosenthal & J.L. Maclean): pp. 74-101..

Dao,Q.T.Q., Thanh, N. K. and Ha, M.V., 2006. Final Report of the Research Project Funded by Mab/Unesco-Assessment of water quality change in shrimp farming ponds in the mangrove area of proposed Biosphere Reserve in the Red River Delta - A case study in Giao Lac Commune, Giao Thuy District, Nam Dinh Province.

Das, R. K., 1992. A Study on Social and Economic Aspects of Shrimp Prawn Cultivation in Bangladesh. Master of Agriculture in Agricultural Economics unpublished Thesis, Mymensingh Agricultural University, Mymensingh.

Datta, D. K. and Sannamat, S., 2000. Draft Report on -Study Of Water Quality In The Prawn Ghers And Its Surrounding Environment In Fakirhat Upzila Of Bagerhat District. Environmental Science Discipline, Khulna University and Golda Project, CARE Bangladesh.

Datta, D. K., Roy, K. and **Hassan, N**., 2009. Shrimp culture: Trend, consequences and sustainability in the south-western coastal region, In: Management and Sustainable Development of Coastal Zone Environment, Ramanathan, A.I.; Bhattachaya, P.; Nepunae, B; Dittmar, T and Prasad M. B. K (eds.). Springer (Germany) jointly with Capital Publishing Company, New Delhi, X: pp. 470.

Deb, A.K., 1998. Fake Blue Revolution: Environmental and Socio-Economic Impacts of Shrimp Culture in the Coastal Areas of Bangladesh, Ocean and Coastal Management, 4: pp. 63–88.

Dierberg, F., and Kiattisimkul, W., 1996. Issues, Impacts, and Implication of Shrimp Aquaculture in Thailand. Environmental Management, 20(5): pp. 649-666.

DoF, 2002. Shrimp Aquaculture in Bangladesh: a Vision for the Future. Department of Fisheries, Dhaka, Bangladesh.

DoF, 2003. Fishery Statistical Yearbook of Bangladesh: 2002–2003. Department of Fisheries, Dhaka, Bangladesh, pp. 41.

Douglas, I., 1994. Land degradation in the humid tropics. In: Roberts, N. (Ed.), The Changing Global Environment. Blackwell, Oxford, UK, pp. 332–350.

Dumanski, J. and Pieri, C., 1997. Application of the pressure–state–response framework for the land quality indicators (LQI) programme. In: Land Quality Indicators and their use in Sustainable Agriculture and Rural Development. Food and Agricultural Organization (FAO) Land and Water Bulletin #5: pp. 35–56.

EGIS II , 2001. Integrated environmental management -A case study on shrimp-paddy land use strategies in the southwest of Bangladesh, EGIS Technical Note 19. Ministry of Water Resources, Government of Bangladesh Environment and GIS support project for water sector planning, Dhaka. Sponsored by the Netherlands Government executed by resource analysis b.v. Delft, the Netherlands.

El- Swaify, S.A., 2000. Soil and water from Plant Nutrient Management in Hawaii,s Soils, Approaches for tropical and subtropical Agriculture.Chapter-17. , J. A. Silva and R. Uchida,(eds.), College of Tropical Agricultural and Human Resources, University of Hawaii at Manoa.USA

FAO, 1997**.** Aquaculture Development. FAO Technical Guideline for Responsible Fisheries 5 Food and Agriculture Organization of the United Nations (FAO), Rome.

Flaherty, M., Vandergeest, P. and Miller, P., 1999. Rice paddy or shrimp pond: tough decisions in rural Thailand. World Development, 27 (12): pp. 2045–2060.

Folke C. and Kautsky N., 1992. Aquaculture with its environment: prospects for sustainability. Ocean and Coastal Management, 17: pp. 5-24.

Greenland, D.J., 1997.The Sustainability of Rice Farming. CAB International, New York.

Guimaraes, J.P., de Campos, 1989. Shrimp culture and market incorporations: a study of shrimp culture in paddy fields in Southwest Bangladesh. Development and Change, 20 (4): pp. 333.

Hanafi, A., and Ahmed, T., 2004. Shrimp Culture in Indonesia: Key Sustainability and Research Issues.

Haque, M.M., 1995. Fisheries Sector of Bangladesh at a glance. In: Fisheries Fortnight ’95 Bulletin, Department of Fisheries, Dhaka, Bangladesh.

Hong, P.N., 2003. Mangrove forests in Vietnam - Present status and challenges. International Symposium on Conservation and Wise Use of Mangroves in Southeast Asia, 6-8 October 2003, Bandar Seri Begawan, Brunei Darussalam, 15.

Hopkins, J.S., Hamilton, I.I.R.D., Sandifer, P.A., Browdy, C.L., and Stokes, A.D., 1993. Effect of water exchange on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. Journal of the World Aquaculture Society, 24: pp. 304 – 320.

Hossain, S., Alam, S.M.N., Lin, C.K., Demaine, H., Khan, Y.S.A., Das, N.G., and Roup, M.A., 2004. Integrated management approach for shrimp culture development in the coastal environment of Bangladesh. Journal of the World Aquaculture Society, 35 (4): pp. 35–44.

Hounslow, A.W., 1995. Water Quality Data: Analysis and Interpretation. Lewis Publisher, Boca Raton, pp. 24-110.

Islam, K.R. and Weil, R.R., 2000. Land use effects on soil quality in tropical forest ecosystem of Bangladesh. Agriculture, Ecosystem & Environment, 79: pp. 9–16.

Islam, M.S., 1999. Social and institutional aspects of shrimp-rice farming in Bangladesh. Workshop on Economic, social and environmental implications of shrimp-rice integrated farming system in Bangladesh. Dhaka, Bangladesh.

Islam, M.S., Wahab, M.A., Miah, A.A., and Kamal, A.H.M.M., 2003. Impacts of shrimp framing on socio-economic and environmental conditions in the coastal region of Bangladesh. Pakistan Journal of Biological Sciences, 6 (24): pp. 2058-2067.

Islam, M.A., Sattar, M.A., and Alam, M.S., 1998. Impact of Shrimp Farming on Soil and Water Quality of Some Selected Areas in the Greater Khulna District. Research and Development Collective, Dhaka, Bangladesh.

Islam, M.L., Alam, M.J., Rheman, S., Ahmed, S.U., and Mazid, M.A., 2004 .Water quality, nutrient dynamics and sediment profile in shrimp farms of the Sundarbans mangrove forest, Bangladesh. Indian Journal of Marine Science, 33 (2): pp. 170-176.

Islam, M.S., 2003. Socioeconomic Impacts of Alternate Shrimp-Shrimp-Crop Farming in Bangladesh. In: M.A. Wahab (ed.), Environmental and socioeconomic impacts of shrimp aquaculture in Bangladesh, Technical Proc. BAU – NORAD Workshop, BRAC Centre, Dhaka, Bangladesh, pp. 61–78.

Islam, N., 2007. Exploring the Drivers for Conversion of Agricultural Land to Shrimp Farms in South West Region of Bangladesh. MSc Thesis, Environmental Science Discipline, Khulna University, Khulna, Bangladesh.

Jackson, C., Preston, N., Thompson, P. J. and Burford, M., 2003. Nitrogen budget and effluent nitrogen components at an intensive shrimp farm. Aquaculture, 218: pp. 397 – 411.

Kamp, K. & Brand, E., 1994. Greater Options for Local Development Through Aquaculture. CARE-GOLDA Project, Dhaka, Bangladesh.

Karim, M., and Stellwagen, J., 1998. Shrimp Aquaculture. Final Report of the Fourth Fisheries Project (vol. 6), Department of Fisheries, Dhaka, Bangladesh,

Karim, R., 2006. Brackish-water Shrimp Cultivation Threatens Permanent Damage to Coastal Agriculture in Bangladesh. In: C.T. Hoanh, T.P. Tuong, J.W. Gowing and B. Hardy (eds), Environment and Livelihoods in Tropical Coastal Zones, CAB International.

Kendrick, A., 1994. The Gher Revolution and the Social Impacts of Technological Change in Freshwater Prawn Cultivation in Southern Bangladesh. The Report of a Social Impact Assessment prepared for CARE International Bangladesh with support from the Bangladesh Aquaculture and Fisheries Resources Unit.

Khatun, S., Flowers, T., 1995. Effect of salinity on seed set in rice. Plant Cell and Environment, 18 (1): pp. 61–67.

Kongkeo, H., 1990. Pond management and operation. Paper presented at Aquatic conference '90, Kulalumpur, Malaysia.

Kurban, H., Saneoka, H., Nehira, K., Adilla, R., Premachanda, G. S. and Fujita, K., 1999.Effect of Salinity on Growth,Phptosysthesis and Minarale Composition Leguminus Plant Aihagi Pseodohalhagi (Bieb.), Soil Science and Plant Nutrition, 45(4): pp. 851-862.

Kyuma, K., 2004. Paddy Soil Science. Kyoto University Press, p. 222.

Landon, J.R., 1991. Booker Tropical Soil Manual - A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman, London.

Li, K., 1987. Rice-fish culture in China: A review. Aquaculture, 71: pp173-186.

Majid, M.A., and Gupta, M.V., 1997. Research and information needs for fisheries and development and management. In: Proceedings of National Workshop on Fisheries Resources Development and Management in Bangladesh, 29 October – 1 November 1995. MOFL/BOBP/FAO/ODA, pp. 160–177.

Mass, E.V., and Hoffman, G.J., 1977. Crop Salt Tolerance - Current Assessment. Journal of the Irrigation and Drainage Division, pp. 115–135.

Mazid, M.A., 1994. Evaluation of Prawn Farming on Socio-economic Aspects. Fisheries Research Institute, Mymensingh, Bangladesh.

McBride, M.B., 1994. Environmental Chemistry of Soils. Oxford University Press, New York/Oxford

Menasveta, P., 1992. Shrimp culture industry in Thailand. In: Marine shrimp culture principle and practices. Elsevier, pp. 653-674.

Miah, M.Y., Mannan, M.A.,Quddus, K.G., Mahmud, M.A.M. and Baida, T.,2004. Salinity on cultivable land and its effects on crops. Pakistan Journal of Biological Science, 7(8), pp. 1322-1326.

Ministry of Fisheries, 1996. General review of coastal aquaculture. Project of coastal aquaculture development, vol. 2, Ministry of Fisheries, Hanoi, pp. 3- 25.

Mohanty, R.K., Jena, S.K., Thakur, A.K., and Patil, D.U.,1994. Impact of high-density stocking and selective harvesting on yield and water productivity of deepwater rice-fish systems. Agricultural Water Management, 96: 1844-1850.

Mondal, M.K., 1997. Management of soil and water resources for higher productivity of the coastal saline rice lands of Bangladesh. PhD Thesis, University of Los Banos, Philipines.

Mondal, M.K., 2001. Development of Suitable Salinity Management Techniques and their Environmental Impact assessment on the Coastal Ecosystem of Bangladesh. Bangladesh Agricultural Research Council (BARC), Dhaka, Bangladesh.

Mondal, M.K., Tuong, T.P., Ritu, S.P., Chowdhuri, M.H.K., Chasi, A.M., Majumder, P.K., Islam, M.M., and Adhikari, S.K., 2006. Coastal water recourse use for higher productivity: Participatory Research for Increasing cropping intensity in Bangladesh. CBA international, IRRI and IWM.

Muir, J.F., 2003. The future for fisheries: economic performance. Fisheries Sector Review and Future Development Study. Commissioned with the association of the World Bank, DANIDA, USAID, FAO, DFID with the cooperation of the Bangladesh Ministry of Fisheries and Livestock and the Department of Fisheries, Dhaka, pp.172.

My, T.V., Toung, T.P., Xuan, V.T., and Nghiep, N.T., 1995. Dry seeding rice for increased cropping intensity in Long An Province, Vietnam. In: Denning, G.L. and Xuan, V.T. (eds), Vietnam and IRRI: A partnership in Rice Research. International Rice Research Institute, Manila, Philippines, and Ministry of Agriculture and Food Industry, Hanoi, Vietnam, pp. 111-122.

NACA, 1994. Environmental Assessment and Management of Aquaculture Development. Draft report of the workshop of Network of Aquaculture Centre in Asia Pacific, GCM-6/REF 03, Bangkok.

Nandy, G., Ali, S., and Farid, T., 2007. Chingri o jono-orthoniti: Kar lav kar Khoti (in Bangla). Action Aid, Bangladesh.

New, M.B., and Singholka, S., 1985. Fresh water prawn farming: A manual for the culture of Macrobrachium rosenbergii. FAO Fish. Tech. Pap., 225 (1): pp. 118.

Nijera Kori, 1996. The Impact of Shrimp Cultivation on Soils and Environment in Paikgacha Region (Limited to Polders 20, 21, 22, 23 and 24). Khulna.

Ofori, J., Abban, E.K., Otoo, E., and Wakatsuki, T., 2005. Rice-fish culture: an option for smallholder Sawah rice farmers of the West African lowlands. Ecological Engineering, 24: pp. 235-241.

Paez-Osuna, F., Guerreo-Gaval, S.R., Ruiz-Fernandez, A.C., and Espanoza-Angulo, R., 1997. Fluxes and mass balance of nutrients in a semi-intensive shrimp farm in North-western Mexico, Mar Poll Bull, 34: pp. 290-297.

Phillips, M.J., Kweilin, C., and Beveridge, M.C.M., 1993. Shrimp culture and the environment: Lessons from the world's most rapidly expanding warm water aquaculture sector. In: R.S.V. Pullin, H. Rosenthal and J.L. Maclean (eds.), Environment and Aquaculture in Developing Countries. ICLARM Conf. Proc., vol. 312, pp. 171-197.

Poernomo, A.T., 1990. Site Selection for Coastal Shrimp Ponds. Proceedings of the Conference "Shrimp 90", Malaysia.

Ponnamperuma, F.N., Attanandana, T., and Beye, G., 1973. Amelioration of three acid sulfate soils for lowland rice. Proceedings of the International Symposium on Acid Sulfate Soils, vol. II. ILRI Publication 18, Wageningen, pp. 391–406.

Primavera, J.H., 1997. Socio-economic impacts of shrimp culture in Aquaculture Research. South-East Asian Fisheries Development Centre, Ilolio, Philippines, 28, pp. 815-827.

Rahman, A., 1995. Shrimp Culture and Environment in the Coastal Region. Bangladesh Institute of Development Studies, Dhaka.

Rahman, A., Islam, M.A., Roy, I., Azad, L., and Islam, K.S., 1994. Shrimp culture and environment in the coastal region. Bangladesh Institute of Development Studies (E-17), Agargaon, Sher-e-Bangla Nagar, Dhaka, pp. 112.

Rahman, M., and Ahsan, M., 2001. Salinity constraints and agricultural productivity in coastal saline areas of Bangladesh. In: Soil Resources in Bangladesh: Assessment and Utilization. Proceedings of the Annual Workshop on Soil Resources. Soil Resources Development Institute, Dhaka, Bangladesh.

Rahman, M.M., and Bhattacharya, A.K., 2006. Intrusion and Its Management Aspects in Bangladesh. Journal of Environmental Hydrology, 14.

Ramesh, R., and Anbu, M., 1996. Chemical Methods for Environmental Analysis of Water and Sediment. Macmillan India Limited Publications, pp. 15-67.

Rengasamy, P. & K.A. Olsson 1993, 'Irrigation and sodicity', Australian Journal of Soil Research, 31(6)**: pp.** 821-837.

Riquier, J., 1978. A methodology for assessing soil degradation. FAO Background Paper, Rome.

Rosenberry, B., 1995. World shrimp farming 1995. Aquaculture Digest, San Diego, CA.

Rutherford, S., 1994. CARE and Gher: Financing the Small Fry. Report prepared for CARE International in Bangladesh with support from Bangladesh Aquaculture and Fisheries Resource Unit (BAFRU).

Saha, S.B., Bhattacharyya, S.B., and Choudhury, A., 1999. Preliminary observation on culture of Penaeus monodon in low-saline waters. NAGA ICLARM Q. 22: pp. 30– 33.

Saheed, S.M., 2003. The State of Land, Water and Plant Nutrition Resources of Khulna Division of Bangladesh. Soil Resource Development Institute, Dhaka, Bangladesh

Standard Methods for the Examination of Water and Waste Water, 1992. 18th Edition, APHA (American Public Health Association), AWWA (American Water Works Association), WPCF (Water Pollution Control Federation), New York, pp 4.75-4.117

Senarath, R.M.U., 1998. Environmental Management of Brackish-water Aquaculture Systems in Sri Lanka. Masters Thesis, Asian Institute of Technology, School of Environment, Resources and Development, Bangkok, Thailand

.

Shang, Y.C., Leung, P., and Ling, B.H., 1998. Comparative economics of shrimp farming in Asia. Aquaculture, 164 (1-4): pp. 183–200.

Shiva,V., 2000. Stolen harvest: The Hijacking of The Global Foods Supply. South End Press, MA.

SRDI, 2003. Soil Salinity in Bangladesh 2000. Soil Resource Development Institute, Dhaka, Bangladesh.

SRDI, 2008. Upazilla Bhumi O Mrittika Byabohar Nirdeshika (in Bangla), Dumuria Upazila, Khulna District.

Toufique, K.A., 2002. Community Responses to Environmental Degradation due to Shrimp Aquaculture in Bangladesh. 9th Biennial Conference of the International Association for the Study of Common Property on The Commons in an Age of Globalisation, Victoria Falls, Zimbabwe.

Tuong, T.P., Hoanh, C.T. and Khiem, N.T., 1991. Agro-hydrological factors as land qualities in land evaluation for rice cropping patterns in the Mekong Delta. In: Deturk, P. and Ponnamperuma, F.N. (eds), Rice production on Acid Soils of the Tropics. Institute of fundamental Studies, Kandy, Sri Lanka, pp. 23-30.

Turner, I.I.B.L., and Ali, A.M.S., 1996. Induced Intensification: Agricultural change in Bangladesh with implications for Malthus and Boserup. Proceedings of the National Academy of Science, USA, pp. 14984–14991.

Tutu, A.A., 2001. Industrial Shrimp Cultivation and Related Issues in Respect of South-West Coastal Region of Bangladesh. Padma Network.

USAID, 2006. A Pro-Poor Analysis of the Shrimp Sector in Bangladesh. United States Agency for International Development.

Vromant, N., Duong, L.T., and Ollevier, F., 2002. Effect of fish on the yield and yield components of rice in integrated concurrent rice-fish system. J. Agric. Sci., 138: pp. 63–71.

Wahab, M. A., Berghaim, A., and Braaten, B., 2003. Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. Aquaculture, 218: pp. 413 – 423.

Welfare, K., Flowers, T., Taylor, G., and Yeo, A., 1996. Additive and antagonistic effects of ozone and salinity on the growth, ion contents and gas exchange of five rice varieties. Environmental Pollution, 92 (3): pp. 257–266.

.

Wistrand, A., 2001. Country Report on Saline Water Shrimp Aquaculture in Bangladesh.

Xan, L., 1996. Research on some biological features and scientific bases for tiger shrimp (Penaeus monodon) farming technology in some northern provinces of Vietnam. Doctoral Thesis, Hai Phong, Vietnam.

ANNEXURE

ANNEX-I

Agro-Water Management Practices

Table A.1.1 Management Practices and HYV Boro Rice Cultivation at Dry Season 2009/10

Types of AWMPs		Water Source Mgt.	Water Source	No of Water Exchang	No of Irrigation	Standing Water Depth (m)	Fertilizer (Inorgani) (kg/ha)	Fertilizer (Organic) (kg/ha)	No of IPM Techniques	Use of Chemical Pesticides (kg/ha)	Status of Fish feed	No. of Crop	Veget on Dykes	Boro cultivation years	Rice Yield (kg/ha)
Type-1	**R-2**	CM	GW	2	8	0.07	306	0	2	0	1	2	Present	6531	6531
	R-3	CM	GW	2	12	0.09	196	1117	1	0	1	2	Present	5587	5587
	V-3	CM	GW	2	2	0.07	254	1481	0	0	1	2	Absent	0	0
Type-2	**V-1**	CM	GW+SW	2	16	0.07	533	0	1	22.5	0.5	3	Present	2296	6296
	V-2	CM	GW+SW	2	16	0.07	610	1481	2	3.09	0.5	3	Present	6519	6519
	R-1	IM	GW+SW	2	17	0.08	183	0	0	4.95	0.5	3	Present	0	0
Type-3	**B-1**	IM	SW	20	6	0.08	44.8	0	0	0	0	4	Absent	0	0
	B-2	IM	SW	20	6	0.08	373	0	0	7.46	0	4	Absent	0	0
	B-3	IM	SW+GW	20	14	0.10	340	467	0	0	0	4	Absent	778.2	778.2
Type-4	**J-1**	CM	SW+GW	16	12	0.08	200	727	0	8.36	0.5	4	Present	2473	2473
	J-2	CM	SW+GW	16	12	0.08	373	0	0	1.33	0.5	4	Present	1992	1992
	J-3	CM	SW+GW	16	10	0.09	294	0	0	3.95	0.5	4	Present	395.3	395.3

Table A.1. 2 Types of Vegetation on Gher Dykes and Irrigation Sources during Rabi Season 2009/10

Site no	Types	Sample Name	Vegetation on dykes	Irrigation sources during Shrimp seasons
Kharnia Union	Type-1	R-2	Nim, Banana, Date, Brinjal, Turnip	STW+ Shinger beel
		R-3	Nim, Banana	
		V-3	Vegetable	
	Type-2	V-1	Vegetable (Cauliflower, Red Turnip)	Shinger beel canal+STW
		V-2		
		R-1		
Sobhna Union	Type-3	B-1	No vegetation	The Bhadra River+STW
		B-2		
		B-3		
	Type-4	J-1 J-2 J-3	Banana, kalokashia	Muchicata Khal canal+STW

Table A.1.3 Types of Fertilizer Use in Different AWMPs during Rabi season 2009/10

Sl. No	Name of Sample	Total Area ha	Amount of Fertilizer Input							
			Urea kg	TSP kg	Mixed fertilizer kg	MP kg	Zink kg	Cow dung kg	Gypsum /lime kg	Mustard cake kg
1	J-1	0.275	12	22		10	11	200		
2	J-2	1.66	372	124		124				
3	J-3	0.506	72	55		21	1			
4	B-1	1.473	11	55	----	---			---	
5	B-2	0.268	40	20		20			20	
6	B-3	0.514		15		10		240	150	
7	R-1	0.202	8		15				4	10
8	R-2	0.49	80	----	50	20	---		---	---
9	R-3	0.358	45	25		----		400		
10	V-1	0.27	76	24		---			44	
11	V-2	0.405	115	50		18	4.5		60	
12	V-3	0.405	25	50		18		600	10	

Table A.1.4 Pesticide Management in Different AWMPs in Rabi Season

Sample Ghers	**In Organic Pesticide**	**IPM Techniques**
R-2	No Chemical Pesticides Used	Crushed tobacco leaf spray mixed with water (during land preparation) -3 times (12-40 days interval) ; Neem Tree plantation on gher dykes
R-3	Kingfs-48EC Aungkur traders-480gm chloropyris	Parmanent Neem Tree plantation on gher dykes
V-1	Bipolar-25gm, Flaon15-50gm and Theovit -6 kg	‘Ara Deoa’ and Ash Spray
V-2	Belt-25 gm	‘Ara Deoa’
R-1	Kingfs	------
B-2	Sun furan	-----
B-3	Sun furan ,M erin	------
J-1	katap	------
J-2	Bipolar, Kartap	-----
J-3	Theovit, Kartap	------

ANNEX-II

Soil and Water Quality

Table A.2.1 Availability of Major Nutrients Level in Wetland Soil for Rice

Nutrient Element	Very low	Low	Medium	Optimum	High	Very High	Critical Limit
N (%)	≤ 0.09	0.091-0.18	0.181-0.27	0.271-0.36	0.361-0.45	> 0.45	0.12
P (µg/g soil)	≤ 6.0	6.1-12	12.1-18.0	18.1-24	24.1-30.0	> 30.0	8
S (µg/g soil)	≤ 6.0	6.1-12	12.1-18.0	18.1-24	24.1-30.0	> 30.0	10
K (meq /100 g soil)	≤ 0.075	0.076-0.15	0.151-0.225	0.226-0.30	0.31-0.375	> 0.375	0.12
Ca (meq/100 g soil)	≤ 1.5	1.51-3.0	3.1-4.5	4.51-6.0	6.1-7.5	> 7.5	2
Mg (meq/100 g soil)	≤ 0.375	0.376-0.75	0.751-1.125	1.126-1.5	1.51-1.875	> 1.875	0.5
Organic Matter (%)	-	0-1	1.1-4.0	-	4.1-5	>5	-
Fe (mg/kg)	<3	3.1-6	6.1-9	9.1-12	12.1-15	>15	4

(Source: BARC, 2005)

Table A.2.2 Classification of Salinity in Soil and Water of Dumuria Upazila

Soil Salinity Class	Non saline	Slightly Saline	Moderately saline	Saline	Highly saline
EC (dS/m)	<2	2 to 4	4 to 8	8 to 16	12 to 15
Water Salinity Class	Normal		Harmful	Very Harmful	
EC(dS/m)	<0.75		0.75 to 3	>3	

(BARC, 2008)

Table A.2.3 SAR and RSC of Gher Canal Water during 2009/10

Sample Name	EC (meq/l)	SAR	Na hazard (Hunslow, 1995)	RSC
Pre-Season				
Average Value of Type-4	34.73	11.38	C4-S1	
J-1	20.1	5.11		-11.99
J-2	33	18.40		-10.89
J-3	51.1	10.64		-17.29
Average EC Value of Type-3	46.6	10.15	C4-S1	
B-1	36.7	7.96		-21.59
B-2	62.7	11.31		-30.89
B-3	40.4	11.17		-22.49
Average EC Value of Type-1	33.73	116.93	C4-S4	
V-3	59.5	163.23		-9.09
R-2	16.2	88.99		-3.19
R-3	25.5	98.56		-4.99
Average EC value of Type-2	82.8	157.87	C4-S4	
V-1	99.4	172.58		-23.19
V-2	68.7	157.79		-13.19
R-1	80.3	143.23		-15.69
Average EC value of Type-4	197.46	31.52	C4-S4	
J-1	172	41.97		-33.2469
J-2	111.4	22.43		-22.6889
J-3	309	30.12		-74.7142
Average EC Value of Type-3	276.66	48.88	CA-S4	
B-1	291	53.15		-68.44
B-2	276	50.73		-62.62
B-3	263	42.73		-66.87
Average EC value of Type-1	51.1	9.44	C4-S1	
R-2	72.4	12.92		-8.29
R-3	29.8	5.94		-22.29
Average Value of Type-2	136.86	88.14	C4-S4	
V-1	57.3	95.20		-12.77
V-2	84.3	118.55		-16.22
R-1	269	50.69		-46.11

Table A.2.4 Sodium Hazard in Gher Canal Water

Type of farming	Na-hazard in water		Remarks (Reference Hunslow, 1995)
	Pre Season	Post Season	
Type-1	C4-S4	C4-S1	Very High sodium hazard-low salinity
Type-2	C4-S4	C4-S4	Very High sodium and Salinity
Type-3	C4-S1	C4-S4	Very High sodium and Salinity
Type-4	C4-S1	C4-S4	Very High sodium and salinity