International Journal of Ecological Economics & Statistics (IJEES)
Winter 2009, Vol. 13, No. W09; Int. J. Ecol. Econ. Stat.; 64-78
ISSN 0973-1385 (Print), ISSN 0973-7537 (Online)

Threats to the Sundarbans Mangrove Wetland Ecosystems from Transboundary Water Allocation in the Ganges Basin: A Preliminary Problem Analysis

M. Shafi N. Islam[1] and **Albrecht Gnauck**[2]

[1]Department of Ecosystems and Environmental Informatics, Study Course Environmental and Resource Management, Brandenburg University of Technology at Cottbus, P.O. Box -101344, D - 03013 Cottbus, Germany
shafinoor@yahoo.com

[2]Department of Ecosystems and Environmental Informatics, Brandenburg University of Technology at Cottbus, P.O. Box -101344, D - 03013, Germany
albrecht.gnauck@tu-cottbus.de

ABSTRACT

Through their complex network of river channels, the Ganges, Brahmaputra and Meghna Rivers cover an area of about 1.76 million km^2, their boundaries extend across different countries such as Bangladesh, Bhutan, China, India, and Nepal. The Sundarbans are found at the coast of the Ganges River and are known as the world's single largest mangrove forest with 3.5 percent of the world's mangroves covering an area of 6017 km^2. The Sundarbans wetlands act as a natural shield that protects the coastal area from storm surges and cyclones in pre and post monsoon periods. However, due to increased in irrigation of agriculture, industrial activity and the diversion of Ganges water at Farakka Barrage (India) in early 1975, both siltation and salinity have increased in the Sundarbans which is threatening the Sundarbans ecosystems. Consequently the dominant Sundari (Heritiera fomes) and Goran (Ceriops decendra) are affected by top-dying disease which is recognized as a key management concern. The Ganges water sharing is not just a geo-techno-political problem; it is also a humanitarian problem. So, interaction and educational awareness between concerned states are of great significant. The objective of this paper is to make a contribution towards the development and implementation of management plan for mangrove wetlands resources and to ensure that fresh water is supplied to the Sundarbans by the Ganges. Water salinity simulation and modeling would be a proper tool for decision making and allow planners to protect the Sundarbans ecosystems in future.

Keywords: Sundarbans, Mangroves, Wetlands, Ganges River, Ecosystem, Water salinity.

Mathematics Subject Classification: 62P30, 62P12

JEL Classification: Q25, Q57

1 INTRODUCTION

Productive wetlands are valuable component of the environment, which support biodiversity and ecosystems. Globally, wetlands are amongst the most fertile and productive ecosystems and important breeding grounds for fish and game, they regulate water quality, quantity, nutrient cycling, and act as a buffer between terrestrial and aquatic systems (Versfeld and Wassen, 2005). Wetlands constitute part of natural heritage and for thousands of years wetlands have played significant role in the development of human society. Wetlands are valuable resource; it´s destruction has resulted in serious economic, ecological as well as aesthetic consequences for global communities (Khan et al., 1994). It is understood that wetlands provide many vital services within the environment. The

Sundarbans region include the world‘s largest contiguous mangrove wetlands and the world’s largest tiger reserve. The Sundarbans are located in the estuary of the Ganges River and span an area of about one million hectares in southwest Bangladesh and southeastern portion of the state of West Bengal in India. The Sundarbans landscape consists of a large number of fluvial and tidal lands, features created by not only the Ganges but also the Brahmaputra and Meghna Rivers. The Sundarbans reserve forest covers 6017 km^2 of forest, wildlife sanctuaries, sand bars, rivers, creeks and canals (Siddiqi, 1994). Mangrove vegetation stabilizes the coastline, enhances land building and enriches both soil and aquatic environments. The Sundarbans biodiversty is high with about 334 species of plants, 282 species of birds, 49 species of mammals, 210 species of fishes, 63 species of reptiles, and 10 each of amphibians and molluscs (Rashid et al.,1994; Amin and Khan, 2001). In the Bangladesh Sundarbans, there are 36 mangrove species and 30 mangrove-obligate plant species. Comparatively, there are only 7- 9 obligatory mangrove plant species found in the America´s and Africa, while 20-40 species are typically found in the indo-west pacific region. The Sundarbans forest constitutes about 51% of the forest area of Bangladesh and contributes about 50% of the revenue earned by the forestry sector. It is estimated that over 6 million people are benefiting either directly or indirectly on the Sundarbans mangrove resources in the coastal region (Anon, 1995). The Sundarbans natural resources play an important role in supporting the local economy and maintaining conditions for supporting other ecosystems in the coastal region. An area of about 121000 hectares of the Sundarbans mangrove wetlands has experienced catastrophic losses over the past 100 years. On the other hand, human influences on the Sundarban’s natural resources are indelible and have become the main force in this dynamic system. Since the diversion of upstream freshwater salinity has penetrated up to 240 km north from the coast. The change in salinity affected both mangrove plants and animals in a variety of ways (Karim, 1995). This study has indicated that high salinity increase has affected the growth and regeneration of mangrove plants as well as the Sundarbans mangrove wetlands. Intergovernmental dialogue and bilateral agreements are needed between Bangladesh and India to solve this environmental problem. It is essential to know about the presently increasing salinity trends and developing a methodology for making an adequate management plan. In this situation, the water salinity simulation and modelling would be an appropriate tool for making the management plan.

2 GEOGRAPHICAL LOCATION AND PHYSICAL CHARACTERISTICS

The Sundarbans stretches over 10,000 km^2 and are located at the southwest extremity of Bangladesh and the southeast of the state of West Bengal in India (Hussain and Acharya 1994). Almost 62% of the land areas lies between latitudes 21° 31`N and 22° 30`N and between longitudes 89° 18`E and 90° 18`E (Fig. 1) (Katebi, 2001). The Bangladesh portion of the Sundarbans includes forest area of about 6,017 Km^2 that is spread over the districts of Khulna, Bagerhat and Satkhira. The total land area of Sundarbans is 401,600 hectares of which 395,500 hectares are non-forested area. The area covered by rivers and khals (or canals) is 175,600 hectares (Katebi, 2001). The Sundarbans wetlands consist of a large number of fluvial and tidal landscapes, features created by the Ganges, Brahmaputra, and the Meghna Rivers (Fig. 1).

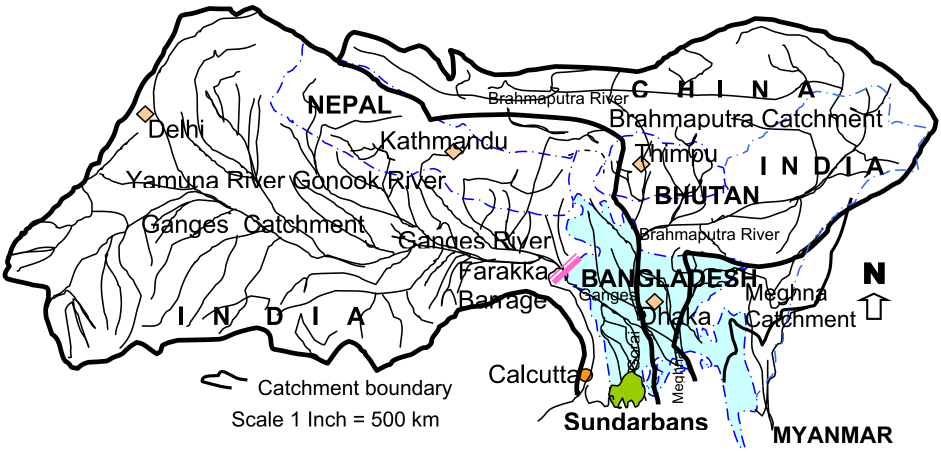

Figure 1. Geographical location of the Sundarbans study area *(the above figure is for academic purpose only and does not represent any accurate political or geographical area of any country).*

Annually 2.4 billion tons of sediment is transported by the major rivers of Bangladesh. This situation is having a profound effect on the floodplains and the coastal region. Silt deposition in the northeastern part of the forest poses a threat to the existence and vigorous growth of mangrove vegetation. Silt deposition causes a rise in the forest floor and due to irregular flow of tidal water, mangroves are not properly regenerated. Historically the boarder of the Sundarbans mangrove was closed to Calcutta city in India and Khulna city in Bangladesh. In 1776, the Sundarbans size was 17,000 km², at present it is almost half of the total area. The Chokoria Sundarbans in the southeastern part of Bangladesh was once 21,000 hectares of reserve mangrove wetlands in 1976, but now only the land bears the memory of a mangrove forest of hundred years ago (Philip, 1999). The Sundarbans mangrove wetlands are divided into three ecological zones (see Fig. 2) where the elements of physical characteristics are carrying the different values.

Table 1 demonstrates the physical characteristics of three ecological zones including soil texture, water and soil salinity rate, soil pH, annual inundation time, forest canopy closure, landscape character, tree heights and ecosystem condition. The environment and ecosystems of the coastal region are characterised by geophysical phenomena, such as sea surges and waves, upland discharge and sedimentation, erosion and accretion, storms and cyclones. The mangrove forest spreads across the flat, level alluvial plain of the Ganges delta at between 0.9 to 2.1 meters above mean-sea level. A close network of interconnected tidal rivers and creeks dissect the Sundarbans in a north-south direction and the water in these rivers is saline.

Table 1. The physical characteristics of three ecological zones in the Sundarbans

Characteristics	*Miohaline Zone*	*Mesohaline Zone*	*Polyhaline Zone*
Soil texture	Silt clay loam	Silt clay	Silt clay
Soil salinity	1- 3.5 dS/m	3.5 -15 dS/m	15 - 40 dS/m
Water salinity	5 -23.4 dS/m	23.4 - 39 dS/m	39 - 52.8 dS/m
Soil pH	7.7- 8.2	6.7- 8.1	7.7 - 8.2
Inundation per year	75 -120 times	105 -135 times	135 -150 times
Canopy closure	60-100 %	40- 80 %	30- 70 %
Cultural landscapes	Changes due to tourism development	Tourism, shrimp cultivation and fry collection etc	Changes due to salinity and shrimp cultivation
Ecosystems	Changing	Vulnerable	Threatened
Tree height	15 - 20 m	10 -15 m	3 - 5 m

2.1 The Sundarbans as Ramsar wetlands and natural heritage site

Bangladesh's principal remaining forest is the Sundarbans; it has mangrove wetlands, 62 percent of which lies in Bangladesh and 38 percent in India. In 1992, the Sundarbans were declared a Ramsar site wetland, enlarging its area from 596,000 to 601,700 hectares of forest reserve. Part of its area was alocated to wildlife sanctuaries (Fig. 2). The Sundarbans are by far the largest estuarine wetlands covering some 1,000,000 hectares of land formed from sediments deposited by the Ganges, Brahmaputra and Meghna Rivers (Fig.1). The coastal mangrove wetlands are dynamic and the ecosystems are in a delicate balance with the factors of soil water and environment. The coastal mangrove resources play an important role in the socio-economic development of the coastal region.

The Sundarbans were declared as the world's 560th Ramsar Wetlands site and includes the following wetland types: F (Estuarine waters), G (Intertidal mud, sand, or salt flats), I (Intertidal forested wetlands), and M (Permanent rivers/ streams/-creeks). The international importance and inclusion of the Sundarbans as a Ramsar wetlands site was based on Ramsar wetlands selection criteria 1c, 2a, 2b, 2c, 3b, and 4b. Based on the policies of Ramsar Convention 1971, some specific steps of management and conservation are taken by the Government of Bangladesh which is now at the implementation stage. In 1997, the Indian portion of the Sundarbans was identified as a UNESCO Man and Biosphere (MAB) reserve area. The Bangladesh portion is under consideration as an MAB reserve. The Sundarbans which have outstanding universal value to humanity are diminishing on a global scale. Almost 45% mangrove wetlands destroyed due to shrimp cultivation, construction and other developmental activities in Bangladesh; thus at UNESCO's 21st conference of the World Heritage Committee in 1997 the Sundarbans were declared a natural World Heritage Site and the only natural World Heritage Site in Bangladesh. The area of the Sundarbans east wildlife sanctuary with 31,226 hectares, Sundarbans south wildlife sanctuary with 36,970 hectares and Sundarbans west wildlife sanctuary with 71,502 hectares all together total 139,700 hectares or 1400 km^2 of which part is declared as natural World Heritage site. This includes 910 km^2 of land and 490 km² of water bodies, and 23% of the total area is forested (Fig. 2). The Heritage site area may be extended in the near future. The Bangladesh Government marked a milestone in the establishment of the Sundarbans natural World Heritage site by officially opening at the Park Nilkamal in the Sundarbans in 1999.

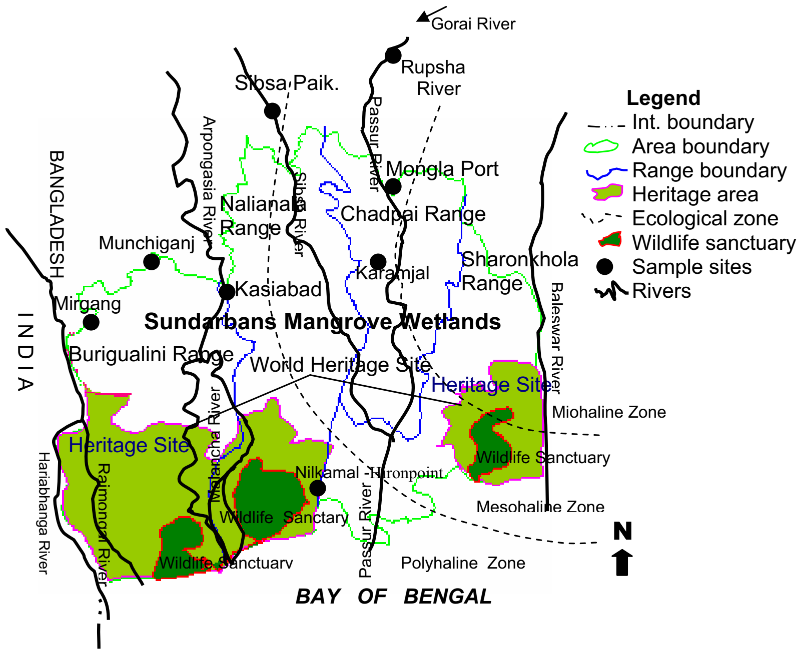

Figure 2. The Sundarbans mangrove wetlands ecosystems *(the above figure is for academic purpose only and does not represent any accurate political or geographical area of any country).*

3 OBJECTIVES OF THIS STUDY

The purpose of this paper is to analyze siltation and salinity problems associated with current situation of the Sundarbans mangrove wetlands ecosystems. A contribution towards the development and implementation of management plan for mangrove wetlands resources to ensure that fresh water is supplied to the Sundarbans by the Ganges have been proposed. In this situation, water salinity simulation and modeling would be an appropriate tool for decision making and aid planners to protect the Sundarbans ecosystems in future.

Analysis of problems from ecological perspective as well as socio-economic and transboundary water allocation and governance analysis could be a better understanding of Sundarbans coastal mangrove wetlands and a means for improving management policies to protect these globally significant natural resources.

4 SOCIO-ECONOMICS ASPECTS OF THE SUNDARBANS WETLANDS

The Sundarbans plays an important role in the economic development of southwestern region of Bangladesh as well as in the national economy. The Sundarbans mangrove forest is exploited for a range of forest products, including lumber, thatching materials, and wood for fuel. Transportation and retailing activities are the main sources of income for a large number of people in the southwestern part of the country (Hasan and Rahman, 2001). The forest also provides livelihood and employment to woodcutters, fishermen, honey and wax collectors, shell collectors, timber traders and other workers. The total number of people directly employed in the Sundarbans is estimated to be about 500,000 to 600,000 people for about 6 months per year (UN/ESCAP, 1988). Besides these 120,000 tourists visit the Sundarbans heritage site and about 50,000 fishermen and other stakeholders work daily in the Sundarbans (Chaves, 2002). Shrimp culture and tourism will be the main economic activities in the near future in the Sundarbans (Islam, 2003). The heritage area is very attractive because of its natural beauty and indigenous cultural treasures. The Sundarbans provide ideal habits for a variety of unique plants and animals. One of the most important non-wood forest products is the *Nypa fruticans* leaf that is used for posts and frames of walls of homes in coastal settlements. This information elaborates on the socio-economic aspects of the Sundarbans and its linkages with different communities. Wood is an important source of forest revenue and contributes over 80% of the income generated in the Sundarbans. The mangrove forests are an important source of fuel wood for the local population as well as other markets of Bangladesh (Alam, 2001). As demand increases, there is often a progression of social and economic changes from subsistence use to commercial exploitation. A number of important ecological and social factors can be identified and vulnerability assessment can be an important tool in planning biodiversity conservation and management of the Sundarbans. The annual value of the wood products removed from the Sundarbans reserve forest is 100 million United States dollars. The value of standing timber has been calculated at 2.09 billion United States dollars. The annual value of fish caught is 304 million United States dollars, which is three times larger than the annual value of forest products. The wildlife in the Sundarbans has a significant socio-economic and ecological importance.

5 VEGETATION DYNAMICS AND IMPACTS IN THE SUNDARBANS

The mangrove species in the Sundarbans have been classified into three categories based on their salinity tolerances. Fresh water loving species have a narrow ecological range (*Heritiera fomes, Bruguiera species*); moderate saline water tolerating species have a relatively wide ecological range (*Excoecaria agallocha*, *Ceriops decandra, Sonneratia apetala, Xylocarpus species)* and saline water loving species have a narrow ecological range (*Avicennia species, Agialitis rotundifolia, Rrhizophora apiculata*) (Karim, 1994). Due to increased salinity, the salt tolerant species are expanding and gradually displacing other species and the amount of barren areas are also increasing. *Heritiera fomes* is the single most dominant and important species because its timber value is very high rather compared to other species in the Sundarbans. The demand of Sundari plant (*Heritiera fomes)* for furniture making and local house construction is popular in the coastal community and other parts of the country. Marginal vegetation on the Sundarbans ecosystem is very diverse. The composition of the common marginal vegetation types that are found throughout the forest include Sundari (*Heritiera fomes*-21%), Sundari-Gewa (*Heritiera fomes - Excoecaria agallocha* -29%), Sundari-Passur (*Heritiera fomes- X. mekongensis*-1%), Sundari- Passur- keora (*H.fomes-X. mekongesis -S. apetala*-2%), Gewa (*Excoecaria agallocha*-5%), Gewa-Sundari (*E.agallocha-H.fomes*-15%), Goran-Gewa (*Cerops decandra- E.agallocha*-14%), Gewa-Goran (*E. agallocha- C.decandra*-9%), keora (*Sonneratia apetala*-1%), Goran (*Ceriops deceandra*-2%), and others 1%. *Heritiera fomes* covers 52.7 % of the area and constitutes about 63.8% of the standing volume. Top dying of *H.fomes* in the Sundarbans is considered as the most serious of all of the diseases and disorder of three species in Bangladesh (Rahman, 2001).

As a pure crop and in mixture with *Excoecaria agallocha, H.fomes* occupies about 18.2% and 62.4% of the Sundarbans respectively. Dominant of Heritiera type is decreasing at the rate of 0.38 % per year, this effect can cause the forest type to disappear within 47 years (Iftekhar and Islam, 2002). In Sundarbans, the number of obligatory mangrove plants is relatively small. Contiguous areas such as the Sundarbans can be expected to harbour many plant and animal species, with sizeable viable populations. The Sundarbans are however of significant importance for many species that currently have populations elsewhere, but are likely to disappear in these other sites within the next few decades (Gonzalo, 1998).

6 IMPACTS OF FRESH WATER FLOWS

The Sundarbans ecosystem depends on the availability of adequate fresh water. However, the landscapes began to change during the early 19th century when part of the Sundarbans began to lose the saline fresh water balance. Salinity levels increased in the Sundarbans when intake-mouths of the Mathabhanga, Kobadak and other rivers that used to bring fresh water from the Ganges to the south were silted up and thus lost their connection with the Ganges. As a result, the regeneration of Sundari, the dominant timber species in the forest was reduced in the southwestern part of the Sundarbans. The already degraded environment became further imbalanced when India constructed the Farakka Barrage on the Ganges which is 17km upstream of Bangladesh boarder. The placement of the dam resulted in the diversion of more than half of the Ganges discharge to the Hooghly River via a feeder canal to improve navigation to the port city of Calcutta. With the commissioning of Farakka Barrage, the downstream discharge was drastically reduced; the water flows data (Series1) show a polynomial behavior (Fig. 3).

The Ganges water flows at Harding Bridge (in Bangladesh) before and after construction of Farakka Barrage shows a reduction in discharge in the dry season from February to June (Fig. 3). The water

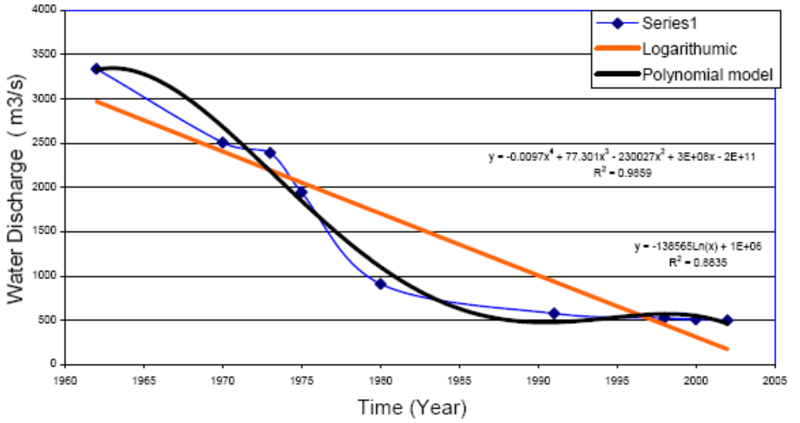

Figure 3. Ganges water flows in the dry season (Feb.-June).

(Data source: Jabbar, 1995; Nishat, 2006)

flow in 1962 was 3338 m³/sec whereas it was 500 m³/sec in 2003. In Figure 3, the polynomial model shows a reduction in discharge over a period of time, and the regression value (R^2=0.986) was observed in the early 1970's when the discharge was greater. On the other hand, the regression value (R^2=0.8835) was observed in 1980 when water flow rates started reducing drastically. An extreme variation of availability of water in the dry and wet seasons is being observed. Since the diversion of Ganges water at Farakka Barrage in India from early 1975, salinity levels have increased drastically in the Sundarbans region (Fig. 4). Analysis of the time series salinity data of Passur River-Mongla point (this river is connected with Ganges through the Gorai tributary) shows that before and after withdrawal of fresh water, the salinity trends changes from year to year, and it depends on availability of fresh water supply from upstream. The salinity rate was less than 10 dS/m (in 1968) in the dry season, whereas in 2003 the highest salinity rate was 25 dS/m. So the salinity values show a large variation before and after diversion of fresh water from the Ganges basin.

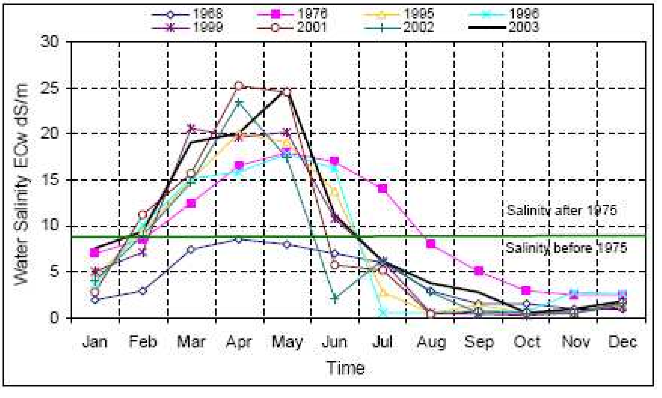

Figure 4. Water salinity density at Passur- Mongla River site (1968 – 2003)

The salinity trends in the Sundarbans are not fixed from both soil and water perspective. They vary from year to year and season to season. The uncertain and unstable nature of soil and water salinity in the Sundarbans causes a serious negative impact on the local and national economies. High salinity also affects the growth of mangrove vegetation which brining about changes in species composition. The recent increase in water and soil salinity has upset the natural equilibrium of the delicate ecological balance required for the healthy growth and existence of the rich flora and fauna (Khan et al., 1994). Consequently, scarcity of water during the dry season (Feb-June) and widespread flowing of excess water in the wet season damages the crops and the ecosystems (Hoque and Alam, 1995). The water maintains the environment and the ecology of the region and constitutes the main potential for development. The impact of commissioning the Farakka Barrage on agricultural production was severe and so the impacts were on river morphology, groundwater, salinity, fisheries, forestry, ecology, navigation, industry and drinking water that is a risk factor for sound health (Fig. 5).

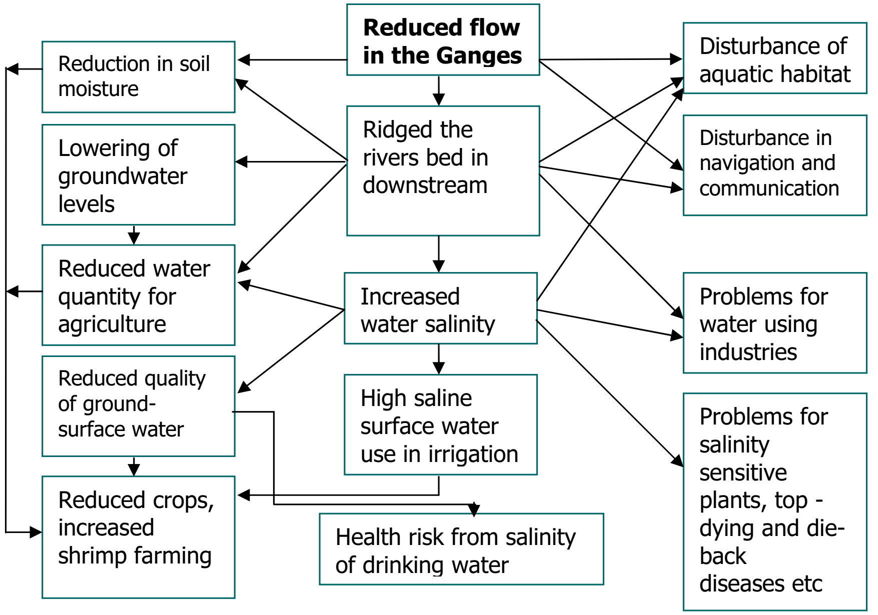

Figure 5. Reduced fresh water flow and impacts on ecosystems (after Ben, 1995).

The Ganges fresh water withdrawal in the upstream area in India resulted in three types of negative impacts in the downstream catchment. The problems are fresh water reduction, increase of salinity and disturbance of growth and habitat have been identified. As a result, the major environmental agents are affected which are rearranged in the structure (Fig. 5). After field investigation and from observations, it can be concluded that a deteriorating environment in the downstream including the Sundarbans region of the coastal mangrove wetland ecosystems are being threatened.

7 THREATENED MANGROVE WETLAND ECOSYSTEMS IN BANGLADESH

The increasing salinity and pollution have also threatened the health of the forest. This is evident from the top-dying of sundari (*Heritiera fomes*) trees. In addition to changes caused by the construction of the Farraka Barrage, the landscapes around the Sundarbans have further been altered by massive shrimp cultivating operations and the vegetation is vanishing due to high salinity and chemical fertilizer used in the shrimp farms. The southwestern part of Bangladesh is now a productive shrimp cultivation zone. Shrimp farming requires that landscapes are modified, resulting in threats to ecosystems in the coastal region. There are fifty thousand fishermen and local stakeholders that enter the Sundarbans for fishing and the collection of natural resources on a daily basis. The picture (see Fig. 6) shows evidence for one of these substantial natural resource used in the mangrove wetlands. In addition to these developments, construction, urbanization and tourism activities inside the forest are also helping to change the mangrove landscapes in Sundarbans areas.

Figure 6. A wetland landscape in the Sundarbans (Picture: Author, 2003)

The Sundarbans mangrove ecosystems are delicate, dynamic and complex and their principal parameters are the environment, the flora, the fauna and human interference (Choudhury, 1984). The forest land is highly influenced by tidal interactions because of the presence of these water bodies. The forest receives freshwater and sediment from a number of distributaries of the Ganges. It hosts one of the richest natural genepools for forest flora and fauna species in the world, including the Bengal tiger (Huq, Karim, Assaduzzaman and Mahtab, 1999). Each one of the following elements of the ecosystem, namely climate, salinity, fresh water, siltation, erosion, substrate and nutrients have first order reaction on flora and fauna. The upper regions of the Sundarbans are primarily influenced by the upstream stress conditions. To some extent, the decomposing litter and detritua do affect the particular tension zone. The factors in the cycles of transported materials include daily tides, run-off, rainfall, decomposition, mineral intake, and activities of the fauna in general, fish and wildlife in particular. A survey of water and soil salinity was conducted at eight sites in the Sundarbans in April 2003. The findings of this survey are shown in Figures 7 and 8.

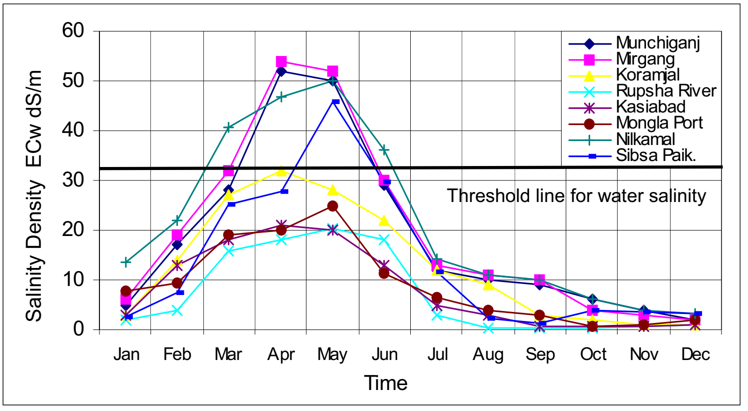

Figure 7. Water salinity at 8 sites in the Sundarbans in 2003

The survey samples were collected from 8 different sites in the Sundarbans region including Munchiganj, Mirgang, Koramjal, Rupsha River, Kasiabad, Mongla Port, Nilkamal, and Sibsa Paikgacha location (Fig. 2). These findings have shown that in general water and soil salinity in the Sundarbans increases from north toward the southwest depending on salinity levels of inundating water. Similarly water salinity increased rapidly and varied from east to west and north to south. The increasing rate is gradually higher in the dry season (February to June).

The results shown in Figure 7 indicate that until February, water salinity levels were less than 20 ECw dS/m and a highest density of over 50 ECw dS/m was found in Mirgang, Munchiganj and Nilkamal points, which are situated in the North West and south middle of the study area. The soil samples were also collected from the same eight sites (Fig. 2) and soil salinity levels show trends similar to the water data (see Fig. 8).

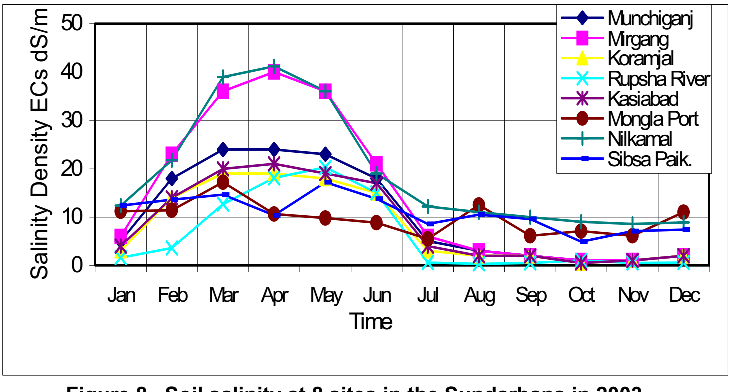

Figure 8. Soil salinity at 8 sites in the Sundarbans in 2003

The highest soil salinity levels measured were ECs 41.2 dS/m at Nilkamal, ECs 40 dS/m at Mirgang and third highest rate of soil salinity is ECs 24 dS/m at Munchiganj point in the northwestern Sundarbans (Fig 8). The increasing salinity levels are major threats for both biotic and abiotic factors of mangrove wetland ecosystems in the region. In the Sundarbans mangrove ecosystems, there are flora that adapt to water-logged areas, breathing by means of outgrowths of roots around the tree. The best environment for mangroves to flourish is that, there should be adequate fresh water, on the other hand, all types of mangrove vegetation, trees, shrubs, small plants and chippers are very sensitive to saline water. Some species flourish in a highly saline environment, while others prefer a less saline one. The present study focuses on water salinity modelling for up to 13 rivers in the Sundarbans. After completion of this study, it would be possible to assess the salinity and to estimate the future negative impacts in the coastal areas. The Fourier polynomial models using a time series approach would be an important tool for making policies and developing an adequate management plan for the ecosystems protection in the Sundarbans region.

8 MANGROVE WETLAND ECOSYSTEMS MANAGEMENT PLAN

The Sundarbans mangrove forest was declared as a reserve forest in 1875 and its overall administration was vested by law to the hands of the Forest Department (FD), which created Sundarbans division, with Headquarters at Khulna in 1879. The present mangrove resource management plan was prepared by Chowdhury in 1968, which was prepared before the Farakka Barrage construction in 1975. The modified management plan has been redeveloped in 1980 and is still active. The management plan divides the forest into Gewa (Excoecaria agallocha) Sundri (Heritiera fomes) and Keora (Sonneratia apetala) working circles. The felling cycle is 20 years and the yield is regulated by area. The Sundarbans mangrove wetlands ecosystems are managed, maintained and preserved by the forest department under the Ministry of Environment and Forests (MoEF) by application of the Forest Act 1927 and the Forest Amendment Act in 1960. The Divisional Forest Officer (DFO) is responsible for all basic administration of the forest act, silvicultural norms, sales of forest products, industrial and liaison. The DFO is assisted by one Additional Divisional Forest Officer (ADFO), four range-based persons headquartered at Khulna are designated as Assistant Conservator of Forests (ACF) of the environment and forest division. They are exclusively responsible for the conservation and management of wildlife sanctuaries of the Sundarbans. The Ministry of Environment and Forest with the Co-operation of IUCN has drafted a national wetlands policy framework, which has not yet been implemented. The objectives and the main features of this policy include the following issues;

- Maintenance of biodiversity in the reserve forest
- Maintenance of ecosystems functions in the coastal wetlands
- Promotion of economical development through stakeholders participation and
- Principles for sustainable natural resources utilisation and management.

Summing up, it appears that a number of physio-chemical factors are involved in mangrove growth and its ecosystems development. Considering the present environmental condition, an integrated resource management and development approach will be appropriate for improving the existing management situation. Water salinity modelling (can be done by IWM) would be an appropriate tool for designing an interdisciplinary management plan for decision making by the government.

9 CONCLUSIONS

The Sundarbans mangrove wetland serves as economic, social, political and ecological importance, because local people increasingly want to use its natural resources and tourists want to visit this world heritage sites. Increasing salinity is the major threat to the Sundarbans mangrove ecosystems. In addition, wildlife preservation, protection of cultural landscapes and establishment of adequate management policy have become issues in Bangladesh. The Ganges River has an influential role in the economy and ecosystems of both Bangladesh and India. Water availability has been an important factor shaping the economic and environmental developments of the southwestern part of the Sundarbans region in Bangladesh. Fresh water resource issues are also a high priority concerning biodiversity conservation and mangrove wetland ecosystems in the coastal region. Bangladesh needs water from the Ganges basin in the dry season (February-June) to protect the world's largest mangrove wetland ecosystems in the Sundarbans. Top-dying and die-back diseases of *Heritiera fomes* and *Cariops decandra* is associated with water salinity. If water salinity was reduced then the soil salinity would also be reduced, and as a result, it can be expected that the rate of top-dying and die-back diseases in the Sundarbans would decrease. Water allocation policy is therefore, an issue of strategic and political importance between Bangladesh and India. A bilateral monitoring strategy should be developed and implemented to ensure fresh water is supplied to the Sundarbans thereby protecting the economic, cultural and environmental resources of mangrove ecosystems.

REFERENCES

Alam, K.M., 2001, *Integration of Socio-economic and Ecological Data in Conservation and Management of Floral Diversity in the Sundarbans*. In Siddiqi, N.A., and Baksha, M.W. (eds.), Mangrove Research and Development, Proceedings of the National Workshop on Mangrove Research and Development at Bangladesh Forest Research Institute, Chittagong.

Amin, M.A., and Khan, N.A., 2001, *A Primer on the Nature and Management of Resources of the Sundarbans,* Grassroots Voice: A Journal of Indigenous Knowledge and Development, Vol.IV Issue 1, Dhaka, pp 85-101.

Anon, 1995, *Integrated Resource Management Plan of the Sundarbans Reserved Forest*, Vol. 1, Draft Final Report of FAO/UNDP Project BGD/84/056- Integrated Resource Development of the Sundarbans Reserve Forest, Khulna, Bangladesh.

Ben, C., Alan, L., and David, W., 1995, *Sharing the Ganges-The Politics and Technology of River Development*, University Press Limited, Dhaka, Bangladesh.

Chaves, L.G., 2002, *Tourism, Recreation and Ecotourism Management Plan for the Sundarbans Reserve Forest, An Integrated Management Approach to Tourism Development,* Sundarbans

Bio-diversity Conservation Project, Bangladesh., ARCADIS Euroconsult Project no. 417.4463.1, The Netherlands in Association with Winrock International.

Chowdhury, A.M., 1968, Working *Plan of the Sundarbans Forest Division for the Period 1960 – '61 to 1979 –'80*, East Pakistan Government Press, Dhaka.

Choudhury, M. A., 1984, *Integrated Development of the Sundarbans, Bangladesh: Silvicultural Aspects of the Sundarban*s, FAO Report No/TCP/BGD/ 23 09Wf, W/R003.

Gonzalo, C., 1998, *Biodiversity Conservation in the Sundarbans Reserve Forest*- World Bank Technical Report, 16th January 1998.

Hasan, M., and Rahman, M.S., 2001, *Some Facts and Observations Related to Salinity and the River System of the Sundarbans Mangrove Forest*, Paper Presented at 1st National Conference on the Sundarbans at Khulna University, 14-16 February, Khulna, Bangladesh

Hoque, M.A., and Alam, S.M.K., 1995, *Post Farakka dry Season Surface and Ground Water Conditions in the Ganges and Vicinity*. In Hasna, J. M. (ed.), Women for Water Sharing. Academic Publishers, Dhaka, pp 48-64

Huq, S., Karim, Z., Assaduzzaman, M., and Mahtab, F., (eds.), 1999, *Vulnerability and Adaptation to Climate Change for Bangladesh,* Kluwer Academic Publishers, London.

Hussain, Z., and Acharya, G., (eds.), 1994, Mangrove *of the Sundarbans, Volume Two: Bangladesh*. IUCN – Bangkok, Dyna Print, Thailand.

Iftekhar, S. M., and Islam, R. M., 2002, *Vegetation Dynamics in the Sundarbans and its Implications on the Integrated Coastal Zone Management of Bangladesh*, Dhaka.

Islam, S.N., 2003, *Sustainable Eco-tourism As a Practicale Site Management Policy? A Case Study on the Sundarbans World Heritage Site in Bangladesh*. AH Development Publishing House, Dhaka, Bangladesh.

Jabbar, M.A., 1995, *Farakka Barrage and its Impact on the Environment of Southwest Region of Bangladesh*, In Hasna, J.M. (ed.), Women for Water Sharing, Academic Publishers, Dhaka, pp 65-70

Karim, A., 1994, *Vegetation in Mangrove of the Sundarbans Volume Two: Bangladesh,* In Hussain, Z. and Acharya, G., (eds.), IUCN – The World Conservation Union, Dyna Print, Bangkok, Thailand.

Karim, A., 1995, *Ecological Implecation of Changing Natural Flow of Water on the Ganges River Ecosystems*. In Hasna, J.M. (ed.), Women for Water Sharing, Academic Publishers, Dhaka, Bangladesh. pp 35-47

Katebi, M.N.A., 2001, *Sundarbans and Forestry*, In Haider (ed.), Cyclone ´ 91– an Environmental and Perceptional study, BACS, Dhaka, pp 79-100

Khan, M.S., Haq, E., Huq, S., Rahman, A. A., Rashid, S.M.A., and Ahmed, H., (eds.), 1994, *Wetlands of Bangladesh*. BCAS, Dhaka. Bangladesh.

Nishat, A., 2006, *Water at Farakka Barrage* http:// www.ajkerkagoj.com/2006/April 08/ Dhaka

Philip, G., 1999, *A Report on the Chokoria Sundarbans, A Forest Without Trees*. Earth Touch, Dhaka, Bangladesh.

Rahman, A., 2001, *Diseases and Disorders of Tree Species in the Sundarbans and Their Management.* In Siddiqi, N.A. and Baksha, M.W. (eds.), Proceedings of the National Workshop on Mangrove Research and Development at Bangladesh, Forest Research Institute Chittagong, Bangladesh, 15-16 May, pp 86-97

Rashid, S.M.A., Khan, A. and Akonda, A.W., 1994, *Fauna*. In Hussain, Z., and Acharya, G. (eds.), Mangrove of the Sundarbans, IUCN, Bangkok, Thailand. pp 125-132

Siddiqi, N.A., (ed.), 1994, *The Importance of Mangroves to the People in the Coastal Areas of Bangladesh, Proceedings of VII Pacific Science International Congress*, International Society for Mangrove Ecosystems, Tokyo, Japan.

UN/ESCAP, 1988, *Coastal Environmental Management Plan for Bangladesh*. ESCA, Bangkok, Thailand.

Versfeld, N.G., and Wassen, M.J., 2005, *Wetland Management for Nature, What Canada, The Netherlands and Poland Can Learn From Each Other*, In Kotowski, W. (ed.), Anthropogenic Influence on Wetlands biodiversity and Sustainable Management of Wetlands, Warsaw Agricultural University Press, Poland.