



CASE STUDY: BANGLADESH

Water Resources and Population Pressures in the Ganges River Basin

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Introduction

There are many links between population growth and environmental degradation, in part because an ever-increasing number of people depend on a fixed natural resource base in order to live. However, it would be too simplistic to suggest that the classical Malthusian view be followed with its implied solution of simply controlling the number of people. Demographic influences are one of many factors that affect water resource management and increase the pressure on the global water resource base.

Linkages of population and water are particularly strong in countries like Bangladesh, with growing population pressure aggravating the ability of the resource base to adequately provide for the current population at the prevailing level of technological development. This in turn also reinforces poverty and leads to further deterioration in socioeconomic conditions.

This study investigates the dynamics of the linkages between population growth and water in the Ganges Flood Plains within the territory of Bangladesh. The dynamics and impacts of the Ganges would be better understood in the Lower Ganges Basin, so that particular area has been studied and described at length herein. This study suggests actions that should be considered in the light of the linkages between growing population pressure and water resources. It identifies the key demographic and water resource concerns, and establishes the current state of understanding as to the linkages between population pressure and water use. Overall, it is important to understand the nature and strength of the linkages because of their implications for effective intervention.

Overview of the Ganges River Basin

The Ganges River Basin is the most populous river basin in the world. Within its 750,000 square kilometers (km²) live 400 million people. The Ganges River (known as the Ganges-Padma River in Bangladesh) begins in the central Himalayas and flows 2,500 kilometers to the Bay of Bengal. Over the course of millennia, this grand river and its tributaries have formed one of the largest flood plains in the world with the sediments from the erosion of mountainous areas. The Ganges Basin is formed by a 200 to 300 kilometer-wide plain, bordered by the mountains and highlands on three sides.

The Yamuna River flows to the west and south of the Ganges and joins it almost halfway down its

course. The Yamuna receives a number of rivers of central India. To the north of the Ganges, the large tributaries are Ramganga, Gomati, Ghagra, Gandak, Saptkosi, and the Mahananda. Beyond the Mahananda the river enters its own delta, formed by its distributaries, and then merges into the combined delta of the Ganges, Brahmaputra, and Meghna rivers.

The Ganges River and its tributaries and distributaries flow through three countries: India, Nepal, and Bangladesh. The Ganges Basin River system remains the main source of freshwater for half the population of India and Bangladesh and nearly the entire population of Nepal. The importance of the Ganges can hardly be exaggerated, particularly in its lower stretch, where it is the only river from which freshwater supplies are obtained for the distributaries (small rivers that distribute waters through a flood plain during peak flows). Freshwater is now a highly prized commodity. As the development of South Asia picks up momentum and populations increase, the Ganges River system rapidly appreciates in importance.

The Lower Ganges Basin contains both an active delta and a moribund delta, both of which are affected by enormous flood flows in the Ganges, relentless tidal pressures from the sea, and occasional severe cyclonic storms capable of disrupting environmental systems. The balance of environmental factors is extremely delicate and complicated, so small changes in one factor affect all the others. The major environmental issues which are associated with population factors include:

- increasing demands on natural resources from development activities;
- the inward penetration of higher salinity levels;
- the spread of waterborne diseases due to the extensive embankment of former bodies of water;
- water and soil pollution;
- decline in fisheries due to human interventions; and
- the excessive felling of the Sunderbans forest.

Bangladesh, being the downstream and deltaic portion of a huge watershed, is naturally vulnerable to the water quality and quantity that flows into it from upstream. All major rivers flowing through Bangladesh have their origins outside its borders, and, therefore, any interventions in the upper riparian regions have a significant impact on Bangladesh. Through its complex network of river systems, Bangladesh drains roughly 1.76 million km² of catchment areas of the Ganges, Brahmaputra, and Meghna rivers, of which only 7 percent lies in Bangladesh. This physical characteristic severely limits the degree of control and management of the inflow water in the monsoon and dry season. The extreme variation of the temporal and spatial occurrence of rainfall is a major constraint to the development of agriculture, which dominates the economy.

Although still a point of controversy, one of the causes of increased flooding in Bangladesh can be traced to Nepal and India (Assam), where the majority of the rivers originate. Massive deforestation of the mountainsides has significantly reduced the Himalaya's capacity to absorb the monsoon rains, and it has greatly increased the amount of eroded soil that is carried by the flood waters.

Country and Study Site Profile

With an area of only 144,000 km² and a population of 118 million, Bangladesh at 832 persons per km² is one of the most densely populated countries in the world (UNDP, 1995) (Table 1). In this semi-tropical, predominantly rural country, roughly 48 percent of the rural population and 44 percent of the urban population live below the poverty line (BBS, 1995). Per capita gross national product in 1991 was US\$ 220. Households spend 59 percent of their income on food, and 60 percent of children under 5 years of age are malnourished.

Table 1. KEY INDICATORS FOR BANGLADESH	
Population (1995 adjusted)	118 million
Annual Growth in Population (1994)	1.88%
GNP per Capita (1995)	\$220
Annual growth in GNP per Capita (1965-1987)	0.3%
Area of Forest and Woodland	2 million hectares
Population Density	832 persons / km ²
Source: Bangladesh Bureau of Statistics (BBS), 1995	

The annual growth of the gross domestic product (GDP) in the 1980-91 period exceeded the population growth rate and averaged 4.3 percent, an increase from 2.3 percent in the previous decade. Agricultural production averaged 2.6 percent growth annually during that period. However, its share shrank from 55 percent to 36 percent of GDP, while industry grew from 9 percent to 16 percent and services from 37 percent to 48 percent.

The Lower Ganges Basin comes under the jurisdiction of the greater districts of Kushtia, Jessore, Faridpur, Khulna, Barisal, and Patuakhali. It comprises an area of approximately 40,450 km², or 27 percent of Bangladesh's total area. It is bordered by India to the west, by the Ganges (Padma) and Lower Meghna rivers to the north and east, and by the Bay of Bengal to the south. Sixty-two percent of the region is cultivated. Roughly 10 percent, or 4,000 km², is covered with a coastal mangrove forest known as the Sunderbans. Approximately 13 percent is covered by surface water areas, including rivers and natural land depressions known as beels. The northern part of the area is comparatively high to medium-high land with a rolling topography. Farther south, the topography starts off as gently sloping but soon becomes very flat. This southern part has a large number of beels and low-lying areas. In addition, the coastal areas, which include the Sunderbans, are criss-crossed by a number of tidal rivers and creeks.

The area has a typical monsoon climate with a warm and dry season from March to May. A rainy season from June to October follows as does a cool period from November to February. The mean annual rainfall is 2,000 millimeters (mm), of which approximately 70 percent occurs during the monsoon season. Rainfall generally varies in a northwest to southeasterly direction, increasing from a mean annual rainfall of 1,500 mm in the northeast to 2,900 mm in the southeastern corner. Potential evapotranspiration rates are of the order of 1,500 mm and exceed the rainfall rates from November to May. The relative humidity is high, varying from 70 percent in March to 89 percent in July.

The area experiences moderate to high duration of sunshine hours, and durations in excess of 8.5 hours outside the monsoon season are not uncommon. The mean annual temperature is 26o Celsius (C) with peaks of over 30o C in May. Winter temperatures can fall to 10o C in January.

The southern region of the area and in particular the southeastern coastline is vulnerable to cyclones during the monsoon season. Storm surges can cause dramatic increases in the water level of up to 4 meters above tide and seasonal levels. The southwest coastline is protected to some extent by the dampening effects of the Sunderbans, although surges do progress up the major

rivers.

The coastal zone consists of the extensive flat, coastal and deltaic land of the Ganges Delta, which is crossed by large tidal rivers discharging into the Bay of Bengal. The Lower Ganges Basin coastal zone is in a state of transition. It is changing from an actively developing delta of the Ganges to a semi-moribund delta partially sustained by local rivers.

The coastal area is subjected to coastal processes, which include tides causing periodic variations in water levels and currents, consequential saline intrusion, wave attack on the coastal fringe, surges and extreme wave attacks due to cyclones, and possible long-term sea-level rise due to global warming.

As a consequence of the flat topography, coastal processes have a major impact on the freshwater resources of the area. Tidal propagation into the delta system carries saline water inland, which mixes with the fresh water to create different levels of salinity in the river system, depending on the upland freshwater discharges.

The western half of the Ganges delta contains the Sunderbans, which is the largest single block of natural mangrove forest in the world. It covers 5,892 km², and contains a continuing, dynamic, and changing mosaic of plant communities. The Sunderbans house many species of flora and fauna, and part of it is being considered as a World Heritage Site. At present, the Sunderbans is under considerable threat, which may be attributed to the reduction in the freshwater flushing action caused by upstream extraction at the Farakka Barrage, increasing shrimp cultivation, over-exploitation of wood resources, increased agriculture, and increased silt deposits.

The Sunderbans Reserve Forests encompass 580,000 hectares of land, of which 410,000 hectares is mangrove forest and 170,000 hectares is open water areas in rivers, channels, and creeks. The Sunderbans comprises approximately 45 percent of the natural productive forest and provides livelihoods for at least 500,000 people, mainly wood cutters (Bawalies); fishermen; honey collectors (Mowalies); and *Nypa*-leaf collectors. Besides being a forest resource, the Sunderbans is extremely important for fish production and wildlife conservation. It also serves as a protective barrier against coastal erosion, cyclonic storms, and tidal surges. The mangrove forests and mud flats of the Sunderbans serves as a vital breeding and nursery ground for fauna, consisting of fishes, crustaceans, and mollusks.

Based upon salinity and species composition, three ecological zones have been recognized within the Sunderbans, the Freshwater, Moderately Saltwater, and Saltwater Zones. The zonation of the Sunderbans is defined by the distribution of the three mangrove species, the Sundri, Gewa and Goran. All three occur throughout the Sunderbans but in different proportions, depending on salinity. Sundri is the characteristic species of the Freshwater Zone, Gewa of the Moderately Saltwater Zone, and Goran of the Saltwater Zone.

The natural vegetation of the Sunderbans forest is composed of the holophytic tree species, or mangrove. The forest canopy is seldom more than about 10 meters above ground level. Much of the forest is two-stories high, with scattered trees attaining heights above 20 meters. Epiphytes are common and woody parasitic species are also common on tree crowns.

The faunal ecology of the Sunderbans' mangrove habitat is an extremely complex subject of study. The complexity is due to assemblages of several species of macrofauna and countless species of microfauna and their action and interactions with other biota in a complex and dynamic environment. Being a very specialized environment, the Sunderbans supports a wide assemblage of animal communities. For some species it is permanent habitat, for others it is a temporary place to feed or breed. This unique habitat depends to a great extent on freshwater flows from upstream to maintain its present character.

Human Population Profile

The population of Bangladesh in 1995 was 119.7 million, with 832 persons per km², making it the most densely populated country in the world. The male-to-female ratio was 100:104 in 1995. The population was 87.12 million in 1981, and the annual rate of increase in population was 2.17 percent in 1991, having declined from 2.8 percent in 1981 (BBS, 1994). The 1995 rate of population growth was 1.88 percent (MOHFW, 1994).

From 1970 to 1989, the total fertility rate fell from 7.2 to 4.9. It continued to fall in 1990 to 4.33, and in 1995 to 3.67. However, both birth rates and infant mortality were still high in 1995, at 27.8 and 81.8 per 1,000, respectively. Bangladesh has a relatively low life expectancy of 58.1 years for men and 57.6 years for women. Average life expectancy is 57.9 years (MOHFW, 1994).

Although contraceptive use increased from 25 percent in 1985 to 35.5 percent in 1990, and to 44.6 percent in 1994, a further decline in fertility will be needed to significantly slow the growth in population. If the current population growth rate continues, the population of Bangladesh is expected to double by the year 2032 to 238 million (Table 2). The present age structure of the population is 51 million people or 42.7 percent of the population currently under the age of 15.

Table 2. Projection of Population Growth in Bangladesh, 1950-2050 (in thousands)

Year	Actual	Population (Both Sexes)		
		Low Estimate	Medium Estimate	High Estimate
1950	41,783	-	-	-
1955	45,486	-	-	-
1960	51,419	-	-	-
1965	58,312	-	-	-
1970	66,671	-	-	-
1975	76,582	-	-	-
1980	88,221	-	-	-
1985	98,556	-	-	-
1990	108,118	-	-	-
1995	-	120,093	120,433	120,741
2000	-	133,324	134,417	135,479
2005	-	146,399	148,786	151,137
2010	-	158,162	162,501	166,800
2015	-	167,728	174,837	181,936
2020	-	174,338	185,190	196,148
2025	-	181,036	196,128	211,589
2030	-	187,126	206,954	227,636
2035	-	191,939	216,965	243,647
2040	-	194,835	225,491	259,023
2045	-	195,827	232,573	273,889
2050	-	195,189	238,512	288,574

Source: United Nations, *The Sex and Age Distribution of World Populations, 1994 revision, 1995*

In general women have poorer health than men in Bangladesh. In spite of this, however, and

although the gap between life expectancies of men and women has narrowed recently, women live longer than men. Childhood mortality among girls is higher than that among boys.

Bangladesh's rate of population growth is 1.88 percent. Five children are born in Bangladesh every minute, two of whom are born in the Lower Ganges Basin. On an annual basis, the population increases by 2.2 million persons, who are and will continue to exert additional pressure on the available but limited water resources, agriculture, and other environmental facilities.

There are government policies which aim to stabilize the population. They include:

- Undertaking efforts to delay marriage;
- Promoting population planning as an integral part of the total development process and integrate population issues into all development programs; and
- Building up the national commitment to a one-child family norm.

To achieve the last of these goals, the availability of family planning would have to become less complicated and more community-oriented. Various options for intervention should be introduced. Rising population growth could be discouraged through economic disincentives directed toward large families.

Population and Water

The large size of the Bangladeshi population and the high rate of its growth, in addition to the poverty and other related social problems, place a tremendous strain on the country's natural resources and on the socioeconomic fabric of the society, and pressure on the land, forests, and fisheries. The situation is compounded by inequalities in wealth distribution and access to productive resources. The youthfulness of the country's population, with increasing numbers entering labor force age also places a tremendous burden on the government to try and create employment opportunities.

With its growing population, Bangladesh has more and more difficulty managing its limited water resources. An average Bangladeshi uses roughly 40 liters per day of water for household use, and the demand for irrigation water is gradually increasing. The growing population causes an increase in the demand for food. This has led Bangladesh to irrigate more crops which in turn means the need for more water. Rice production for every individual requires over 800 m³ of water. Multiplied by the population of Bangladesh, water demands can become enormous. To reduce pressure on Bangladesh's already limited water resources, it is important to consider ways to manage population growth

One of the other major concerns in water resource management related to increasing population is the problem faced by the poor in gaining access to water. The problem is further aggravated by pollution of existing water bodies by industries, runoff from the indiscriminate use of fertilizer and pesticides, and poor drainage. In terms of income generation, water has been found to be the second most important resource after land. The role of women and children in supplementing household incomes is affected largely by difficulties in accessing water sources, particularly during the dry season. These environmental changes have put the rural poor in disadvantaged positions.

Major health-related environmental concerns also include the fact that the rate of population increase in urban areas outstrips attempts to improve provisions for water supply and sanitation. High population densities in rural areas leads to encroachment and degradation of natural habitats as well as over-exploitation of fisheries and other natural resources. Inadequacies in the institutional framework for population planning (such as the absence of birth/death registration and the non-integration of health and family planning services) make it difficult to monitor the success of specific interventions.

Water-related diseases also remain a common occurrence in Bangladesh. Infant mortality rates persist at a high level with 103 deaths per 1,000 live births in 1991, down from 140 in 1970 (World Bank, 1993). In 40 of the 50 common diseases prevalent in Bangladesh, including diarrhea, dysentery, typhoid, worm infestation, measles, and poliomyelitis, unsafe water and human excreta are the main elements in transmission. Gastroenteritis and diarrheal diseases kill 250,000 children under five years of age annually and sap the vitality of young and old. In 1989 alone 79 million episodes of diarrheal diseases were reported.

Women's role in the gathering and use of water is critical in Bangladesh. Understanding women's needs as the country's primary water managers and users is important to program success. However, gaining this understanding requires conscious effort to reach women and involve them in projects from the first step, as women operate under constraints not shared by men.

Women invest their time and labor to bring water to the household. Projects that increase their time and labor requirements, such as projects in which fetching tubewell water is more costly in time and labor than scooping up water from a nearby surface water source, will succeed only to the extent that women see a compelling reason.

Women's productivity is underestimated, which consequently undervalues the labor-saving benefits of water projects. Their participation in projects and their utilization of water and sanitation facilities must take into account the value of women's time and the opportunity costs of participation. Much of women's labor is not reflected in national income accounts because it is largely unpriced and uncompensated home-based labor (UNDP, 1995). Their tasks include cooking; cleaning; washing; collecting fuel and water; rearing children; caring for the sick; growing fruits and vegetables and raising livestock; and processing field crop production. In 25 percent of rural landless families, female earnings are responsible for food security. Among male-headed households with female wage earners, female earnings contribute 25 percent to 50 percent of family income. Not recognizing their myriad contributions to the economy and household impedes informed decision making about resource allocation in development planning

Water Needs in the Lower Basin

Bangladesh is a fertile deltaic region criss-crossed by numerous rivers and subject to periodic and occasionally catastrophic flooding. The hydrology of Bangladesh is characterized by three major international rivers: the Brahmaputra, the Ganges, and the tributaries forming the Meghna. Surface water availability varies by region according to rainfall and storage capacity in streams, ponds, and lakes. About 37 percent of the country is permanently or intermittently inundated during the monsoon season, up to a depth of 30 centimeters or more.

Rainfall is abundant but seasonal. About two thirds of the annual rainfall evaporates and 15 percent percolates into the ground, raising the water table close to ground level. In the dry season, flood water recedes, and ponds and water tables fall. The general availability of water, however, remains high in most of the country. Despite this fact, irrigated agriculture during the dry season draws heavily on groundwater resources. Every year new areas are added to those affected by low water tables, which render shallow wells dry.

Sand and clay soils, which predominate in the country, provide a natural filter that rapidly attenuates bacterial contaminants and creates a vast reservoir of potable groundwater for relatively cheap extraction. Although well water is favored for drinking, surface water is the traditional and more convenient source of supply for other uses. Much of it is polluted with human waste (World Bank, 1990).

Water is used for a variety of purposes within the Lower Ganges Basin, including irrigation, potable and industrial water supply, navigation, and agriculture. The quality of surface water outside the

areas of saline intrusion is generally good, with no significant limitation upon use for irrigation. The critical issue is the extent of saline intrusion.

In some instances and mainly in the irrigation and water supply sectors, water is consumed. In other sectors, such as navigation, water is not consumed but its presence is required. For aquaculture and forestry, notably within the Sunderbans, the quality of the water rather than quantity is the key issue. The ability of the rivers to transport sediment in a favorable manner is also a vital issue that has impact upon the overall allocation of water.

For the main consumptive sectors of irrigation and water supply, the critical factors are the availability of water in the dry season, both within the rivers and the groundwater table. In general, no constraints exist within the monsoon season. Dry-season surface flows also have a major impact upon the maximum extent to which the saline front moves inland each year and upon the depths of channels used for navigation purposes.

In the wet season, while it is true to a large extent that the problem is too much water, it needs to be recognized that wet-season freshwater flows are important for two main reasons. First, high river flows flush out the saline front virtually to the coast each year, thus counterbalancing the net inward movement each year during the dry season. Second, these peak flows contribute to the maintenance of channel sizes, thus keeping the surface water conveyance system in place in the non-tidal areas.

Groundwater quality is generally good. Since the area includes the coast, however, a saline-freshwater interface takes place. A risk is always present in such circumstances that groundwater development will cause the inland movement of the saline front. Evidence exists that this process is occurring in the water supply wells at Khulna.

The key to understanding the water availability problems of the Ganges Basin is appreciating the summer monsoon climate that prevails in this region. The summer monsoon climate is characterized by wet summers, with very little rain the rest of the year. As a result, all ecosystems are adapted to this very marked seasonal pattern. The southwest monsoon winds begin to blow in from the Southern Indian Ocean soon after the Spring Equinox. They bring in an abundance of moisture-laden clouds after roughly two months. The heavy monsoon showers begin in the south of India and a part of Southeast Bangladesh on or about the first of June; they gradually spread inland. In approximately ten more days, the whole Lower Ganges Basin receives heavy showers.

In the Middle Ganges Basin, the onset of the summer monsoon season is in the middle of June. In the Upper Ganges Basin, the heavy rains begin some 10 days later. The city of Khulna in the Lower Basin receives most of its rainfall from June to October. The plains in the Middle Basin receive 800 to 1,200 mm of rain, and the plains in the Upper Basin get 400 to 800 mm.

The primary source of the water resources of the Ganges River system lies in the Himalaya Mountains in Nepal and in Western Uttar Pradesh of India. The southern flanks of this vast mountain belt receive from 1,200 to 2,400 mm of rain, and even the inner ranges do not receive less than 800 mm rainfall in only 4 months. This high rainfall in a relatively short period of time causes heavy erosion in the mountains, frequent flooding in the plains, extensive waterlogging, and the creation of a vast wetland in the Lower Basin.

In the Lower Basin, three seasons are generally recognized: monsoon (June-October); winter (November-February); and summer (March-May). Whereas the monsoon months are remarkably wet, the winter months are suddenly very dry. Rainfall in these 4 months averages only about 100 mm. Winter rainfall in the Ganges Basin is due to the retreat of the Southwest Monsoon. This retreat is gradual in the Upper Basin, a striking contrast to the sudden burst with which it arrives. By early September, the monsoon season is over in the Delhi Area (Upper Basin), and by late

September it is over even in Patna in the Middle Basin. While the last of the Southwest (summer) Monsoon is still bringing showers in the Lower Basin, the drier Northeast (winter) Monsoon winds begin to blow in the Upper Basin. By the middle of October, the Lower Basin is subject to dry continental air and the Summer Monsoon rains have ceased.

Winter in this tropical area means much lowered humidity, temperatures that fall to 10^f C or lower in the plains, plenty of snowfall in the Upper Himalayas, and occasional showers from depressions that can originate in the Mediterranean area. Due to relatively low temperatures, evaporation is reduced for three months. In February, however, the temperature begins to rise and so does evaporation.

In the dry summer months (March to May), the heat is intense, potential evapotranspiration is very high, and total rainfall is low. There are occasional thundershowers, but they bring very little relief. This season is the time of the killing droughts. Small rivers may dry up, wetlands shrink, and the water table drops. Ocean tides penetrate further and further inland and salinize the soil. Agriculture is impossible without irrigation. The contrast between the dry summer and the wet summer is extreme.

After assessing the environmental situation in this area, a major study concludes that the "repercussions of reduced water levels in the Ganges river, and its principal distributaries such as the Gorai, Arial Khan, etc., has disrupted fishing and navigation, brought unwanted salt deposits into rich farming soil, allowed greater saline intrusion northwards, affected agricultural and industrial productions, changed the hydraulic characteristics of the river, and caused changes in the ecology of the delta" (FPCO, 1993).

The Lower Ganges Basin is experiencing an increase in human-induced interventions. This is due to the decrease of dry season flows in the Ganges, which in turn has allowed salinity levels to increase inland. The combined effect of these factors could be the following:

- the deterioration of distributary rivers from the Ganges;
- the northward movement of the saline front in the dry season as tidal movements meet lesser resistance from freshwater flows;
- the increased sedimentation of wetlands; and
- the increased monsoon flooding from inundation and poor drainage in sedimented channels.

Bangladesh possesses an extensive system of wetlands, which have been estimated at nearly 50 percent of the total land surface (Ali, 1991; Green, 1990). All the rivers of Bangladesh have extensive flood plains along both banks of their courses. The flood plains remain inundated with flood water to various depths during the monsoon season. There are a number of water-logged areas throughout the country, either permanently or semi-permanently inundated with water, natural or human-made. Within the flood plains, deep depressions exist, known locally as beels. Some beels retain water throughout the year. The depressed flooded basins in the northeast of the country are known as haors. The Baors or Oxbow lakes are found in the districts of Jessore and Kushtia.

These water types support multitudes of species of plants, fish, prawn and other types of organisms. Of all these living organisms, fish are the most important element in the freshwater ecosystem. They are a major source of employment for the poor and the main dietary source of protein for the rural population.

The relatively high level of fish production is attributed to the nutrient rich delta of the three-river system. An estimated 260 species of freshwater fish can be found in Bangladesh. However, only three species provide the major catches from the open freshwater and estuarine ecosystems: the hilsa, rohu, and catla (DANIDA, 1989).

The reduced flow of river water has reduced the major carp habitats in the Ganges River Basin in Bangladesh (Ali, 1991). The construction of the Farakka Barrage in India in 1974 has drastically reduced the natural flow of the Ganges water downstream in Padma, Bangladesh. This condition merits concern because the reduced water flow, especially during the dry season and in hill regions such as the Barind Tract, causes drought and the drying of ponds as a result of the drop in groundwater levels.

In Bangladesh the reproduction, breeding, and multiplication of open inland water fish and prawn species are very finely tuned and adjusted to the rhythm and amplitude of monsoon flooding. At this time, rivers, estuaries, beels, haors, and flood plains become inter-connected and integrated into a single biological production system. This cycle enables brood stocks and newborn young fish and prawn species to undertake upstream and downstream migrations in the rivers and laterally into and out of the flood plains. The flood plains provide landing and feeding habitats for many species. Fries of river-breeding fishes and also of estuarine or saltwater breeding prawn thrive in the flood plain (Ali, 1991).

The Present Situation

Salinity is a factor of unusual importance in Bangladesh. The coastal zone is extensive and in most areas heavily populated. This area is directly affected by salinity. This zone includes large cities, such as Khulna (population over two million), which are also industrial centers. Salinity affects the normal functioning of these cities. Any increase in salinity has severe repercussions on their economic functioning.

The coastal aquifers have high salinity, and water supply wells must penetrate more than 250 meters to find water of acceptable quality. Therefore, any increase in salinity means incurring more expense exploring deeper tubewells and sharply increased pumping costs. Often, a suitable layer of freshwater is not available, which renders development virtually impossible.

The recharge zone for these deep coastal aquifers is located far from the coast along the Ganges. Activities in these inland areas that decrease recharge, such as river diversion or flood prevention works, would affect the dynamic balance within these aquifers between the saltwater and freshwater interface. This balance is of critical importance to Bangladesh. Any change in the quantity, timing, or direction of flows in inland areas can affect surface and sub-surface salinity in the coastal zone. Activities in the Ganges Basin that decrease freshwater flow into the estuary are bound to increase the penetration of salinity inland and impair water quality.

Diversion of low flows at Farakka has increased the inland penetration of salinity. Salinity levels increase rapidly and curve northwards in the area affected by the withdrawal of Ganges water in the low-flow season.

The urban center of Khulna is severely affected in the dry summer months by increasing levels of salinity. They are caused primarily by the decrease of flows down the Ganges distributaries. It may be due in part to the growth of brackish, water shrimp aquaculture on three sides of the urban area. The problem is most acute in the month of April when flow in the Rupsha River is low.

The direct linkage between the dry season flows in the rivers and the ingress of salinity is a matter of great concern in the Lower Ganges Basin. Salination of soils in lower riparian areas due to reduction of flows by upstream diversion is an issue not yet fully appreciated in discussions about water sharing. If, for example, river flow was reduced to nil in the dry summer months, half of the Lower Ganges Basin would be salinized. This condition would lead to a massive loss of agricultural production, which would trigger the migration of at least 20 million people and the collapse of a quarter of Bangladesh's urban and industrial infrastructure.

The river system in Bangladesh is now dying. This is partly due to the follies of human interventions in its catchment areas and river beds and partly due to nature's consequent readjustment of its dynamic equilibrium. Reduction of the Ganges flow through the Farakka Barrage has severely affected the downstream river regime of the Ganges-Padma. For the Ganges-Padma River at Hardinge bridge, the ratio of maximum and minimum discharge during pre-Farakka days and post-Farakka days are roughly 70 percent and 27 percent respectively, which is far greater than the ratio of ten percent of maximum discharge required for maintaining a stable river regime. After the commissioning of the Farakka Barrage, Ganges-Padma River velocities during post-monsoon and dry season are not adequate to transport the sediment load discharged downstream. Consequently, maintenance of the river regime has become almost impossible.

The Ganges dry season flows have been notably reduced since the construction of Farakka (Table 3). Consequently, saline intrusion has moved farther inland within the coastal areas, and the opportunity to expand irrigation is much lower. In addition, the natural and progressively deteriorating cycles of dry season flows in the Gorai--a major spill river from the Ganges--will go into irreversible decline unless preventive steps are taken.

Table 3. MEAN MONTHLY FLOWS IN THE GANGES-PADMA AT HARDINGE RIDGE, AJSHAHI (in m³)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
AVERAGE FLOW													
a	3,090	2,668	2,287	2,031	2,176	4,489	17,290	38,348	36,063	17,870	7,091	4,180	11,685
b	1,932	1,482	1,155	1,063	1,450	3,569	20,111	40,183	39,233	16,685	5,730	2,943	1,1295
c	1,436	788	576	712	1,309	5,016	20,269	32,596	32,243	14,798	4,133	2,151	9,663
MINIMUM FLOW													
a	2,055	1,897	1,576	1,260	1,440	2,344	9,704	23,584	20,907	7,714	4,145	2,869	7,817
b	1,249	884	742	263	706	1,512	11,725	26,574	15,360	7,813	2,864	1,930	6,839
c	1,204	551	517	663	1,187	4,547	11,636	26,650	27,035	8,599	3,519	2,064	8,534
Note:													
a: 1934-1974, pre-Farakka flows													
b: 1974-1988, post-Farakka flows													
c: 1989-1992, post-Agreement flows													
Source: FPCO, Ministry of Irrigation, Government of Bangladesh, FAP 25, 1993.													

Four main factors have been identified as dominating the current trends in this region's changing environment:

1. the diminution of dry season flows through the Ganges distributaries and, thereby, the dying of distributary streams from the Ganges as sediment bars increase at the offtake;
2. the northwest movement of the saline wedge as tidal movements meet less and less resistance from dominant freshwater flows;
3. increased sedimentation; and
4. growing human population.

Lowering water levels in the Ganges and other rivers and streams have seriously affected the groundwater level. The Department of Public Health Engineering conducted a survey in 1992 that

shows the water table has dropped to 23 feet from its pre-diversion level. This drop has affected the greater districts of Rajshahi, Pabna, Faridpur, and Kushtia. Groundwater quality is good. Since the area includes the coast however, a saline-fresh water interface takes place. A risk is always present in such circumstances that groundwater development will cause the inland movement of the saline front. Evidence exists that this process is occurring in the water supply wells at Khulna.

Reports have been received recently regarding the presence of arsenic in groundwater in the western parts of Bangladesh, particularly in the Lower Ganges Basin. The districts affected are Rajshahi, Chapai Nawabganj, Pabna, Kushtia, Chuadanga, and Meherpur. Studies by health and environmental personnel have found arsenic to be present in the groundwater, exceeding World Health Organization permissible limits. The presence of arsenic in groundwater was also found in West Bengal, India, where the problem was studied in great detail. The West Bengal study was used to complement the Bangladesh study, and it was determined that the presence of arsenic in groundwater could be attributed to its over-extraction. Given the scenario that the depletion of surface water systems could be compensated by groundwater, extraction would be hazardous in the case of Bangladesh, especially in the Lower Ganges Basin.

Reduced water flow in the Ganges Basin Rivers has resulted in a severe depletion of fisheries, especially hilsa fish of the Padma River. The reduction of fisheries resources has resulted in a decrease in the nutrition of the regions inhabitants. Due to the decrease in groundwater and surface water, tremendous pressure has been exerted on the wetlands to convert them to agricultural land, resulting in a serious decline in the numbers of water fowls and reptiles. With the reduction of forest and vegetation cover, a wide variety of insect populations have been severely depleted.

Policy Issues and Recommendations for Action

There should be the formulation of regional water management plans based upon hydrological, hydrogeological, and agro-ecological characteristics. These plans must identify areas where exploitation of water should be constrained or prohibited and outline sustainable methods of exploitation.

Bangladesh's requirements for the sustainable management of trans-boundary water resources and the preservation of national ecosystems should be identified and the cooperation of neighboring countries sought through binding agreements.

Efforts must be made to examine the legal implications of unilateral withdrawal from an international river. A binding agreement for regional water sharing should be formulated.

Education is a critical factor. With severe resource limitations in a densely populated country, education becomes the most important determinant in the conservation of material resources, their optimum use, and environmental protection. Education is an important factor for population planning, public hygiene, health, and other environmental issues. It is also a powerful instrument to mobilize community involvement in the process of sustainable socioeconomic development and to ensure a meaningful commitment and accountability for people's welfare.

A working committee should be established on a permanent basis to review the status of environmental education, evaluate options for improvements, and coordinate inter-agency actions regarding environmental education.

Population planning must take a more prominent role. While there is some evidence of fertility decline, much more remains to be achieved in terms of population planning and policy in Bangladesh. The goal of reducing fertility rates should be achieved by improving the quality of family planning services and by influencing the factors that promote high fertility.

The rapid growth of urban populations needs to be checked. This can be done by developing employment opportunities and other incentives for people to move to and remain in rural areas.

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