

# Ganges and Brahmaputra River System: Need for a Multi-Country Plan for Cleaning, Mitigation, Restoration and Protection

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## Abstract

The Ganges and Brahmaputra River system is in the plains of the northern Indian subcontinent. The river is a wide sluggish stream flowing through densely populated and fertile agricultural regions of the world. The Ganges is known as the Hinduism holy river. In Bangladesh, the Brahmaputra is joined by the Teesta River. The western branch of the Brahmaputra confluences with the Ganges and contains most of the river flow. The eastern branch joins the Meghna River near Dhaka. The basin covers parts of four countries including India, Nepal, China, and Bangladesh. Of greater concern, however, has been the degradation in quality of the river water itself. The primary objective of this research is to encourage the development of a multi-country clean-up, mitigation, and protection plan for the Ganges-Brahmaputra rivers. This article constitutes a real tool for the restoration, enhancement and protection of the Ganges-Brahmaputra River system and its environment. The Ganges and Brahmaputra rivers are known for stream bank erosion, shifting channels, and sandbars that continually emerge in their course. The Ganges and Brahmaputra watershed is home to hundreds of millions of people, with the result that the river's water over much of its course is highly polluted. Arsenic contamination of groundwater in Bangladesh continues to be the largest case of human poisoning in history. Catastrophic floods have prompted the World Bank to prepare a long-term flood-control plan for the region. Scores of cities and towns contribute to treated sewage into the river and its main tributaries, and dozens of manufacturing facilities contribute industrial waste. Also contributing to high pollution levels are agricultural runoff, the remnants of partially burned or unburned bodies from funeral pyres, and animal carcasses. High levels of disease-causing bacteria, as well as such toxic substances as chromium, cadmium, and arsenic, have been found in the Ganges and Brahmaputra. External research and funding of adsorptive media systems to help mitigate

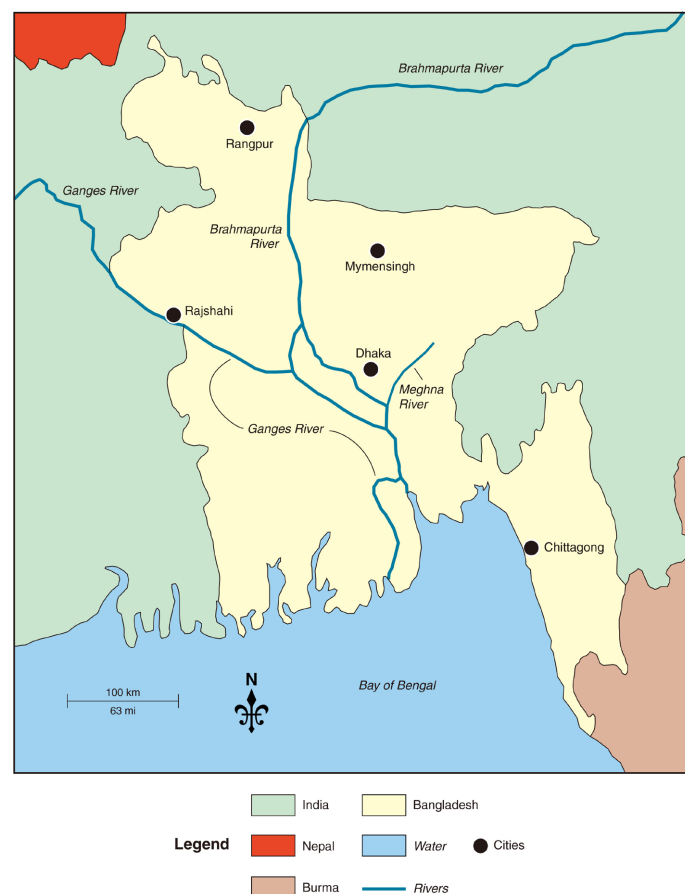
the high arsenic levels in drinking water (river and groundwater) is needed. The Ganges-Brahmaputra River system is of colossal importance to its entire environment. Restoration and protection measures must be adopted appropriately and at the scale of the concerned countries.

## Keywords

Ganges, Brahmaputra River, India, Bangladesh, Pollution, Flooding, Subsidence

## 1. Introduction

The 2510 km long Ganges headwaters are in the southern Great Himalayas on the Indian side of the border with China's Tibet Autonomous Region [1]. In Bangladesh, the Brahmaputra [2] splits into two distributary branches. The western branch confluences with the Ganges and contains most of the river flow (Figure 1). The eastern branch joins the Meghna River near Dhaka. The basin extends into parts of four countries, India, Nepal, China, and Bangladesh (Figure 2).



**Figure 1.** The location of the Ganges and Brahmaputra Rivers and Delta in Bangladesh and India. Map by Mic Greenberg. Published with permission of the Editor of Open Journal of Soil Science.



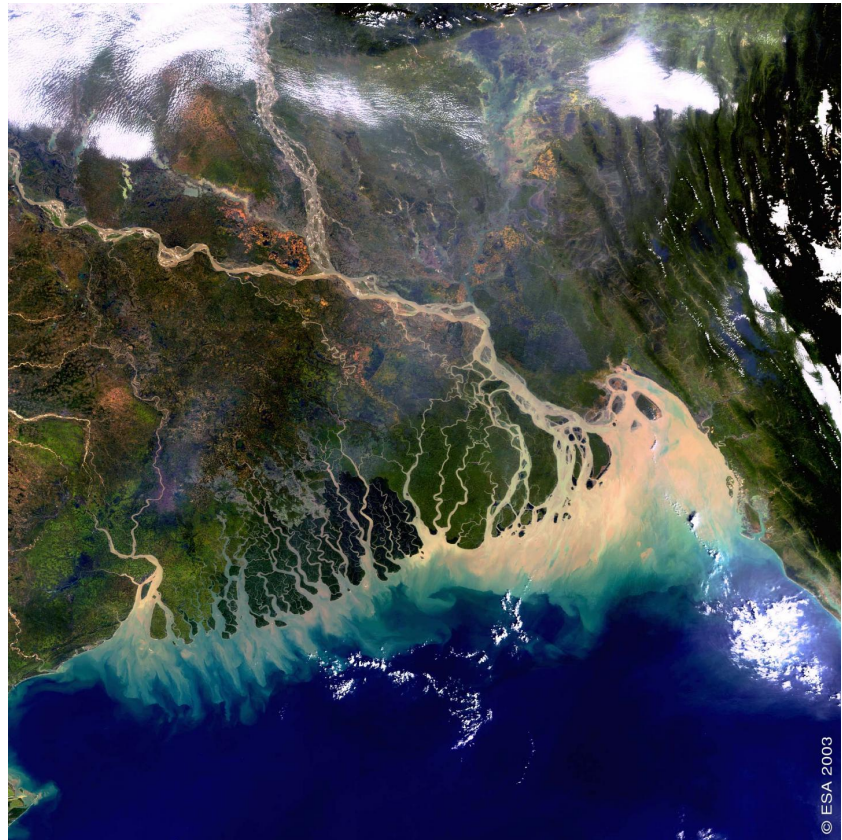
**Figure 2.** Location of the Ganges and Brahmaputra Rivers and Delta in East Asia. Photo Credit: Public Domain.

The Ganges has five headstreams including the Alaknanda, the Mandakini, the Bhagirathi, the Pindar and the Dhauliganag [3]. The Bhagirathi originates 3000 meters above sea level, in a subglacial meltwater cave at the base of the Himalayan glacier called Gangotri. The real source of the Ganges is Gaumukh which is 21 km southeast of Gangotri. The Ganges has a discharge rate of 11,000 m<sup>3</sup> per second.

The basin of the Brahmaputra River watershed covers an area of 651,334 km<sup>2</sup> (Figure 3). It is a good example of a braided river (Figure 4) and meanders quite a bit and frequently forms temporary sand bars. A region of significant tectonic activity has developed with the Himalayan uplift and development of the Bengal foredeep. Huge accumulations of sediment that have been fed from Himalayan erosion have been produced due to the deepening of the Bengal Basin (Figure 3), with the thickness of sediments above the Precambrian basement increasing from a few hundred meters in the shelf region to over 18 km in the Bengal foredeep to the south [4].

The combined Ganges-Brahmaputra system [4] has a suspended sediment load of about 1.84 billion tons per year which is the world's highest (Figure 3). The Ganges-Brahmaputra and their tributaries and distributaries are constantly vulnerable to stream bank erosion (Figure 5) and course changes (Figure 6) in the

delta region. In 1785, the Brahmaputra flowed near the city of Mymensingh and now flows more than 65 km west of the city before joining the Granges. The delta is 355 km wide along the coast which covers an area of some 60,000 km<sup>2</sup> [1].



**Figure 3.** Satellite image ESA 2003. Shows the sediment deposition (light brown color) in the sea. Photo Credit: In the public domain.



**Figure 4.** High altitude photograph of the Ganges-Brahmaputra Delta with islands. Photo Credit: Public domain.



**Figure 5.** Channel erosion on the Ganges. Photo Credit: CNN.



**Figure 6.** A road in Bangladesh cut by flood water. Photo Credit: Public domain.

The Ganges-Brahmaputra delta consists of layers of alternating clays, sands, and marls with some layers of lignite, peat, and beds of previous forests. Some sections of the delta have layers of peat, composed of the remains of forest vegetation and rice plants. In many depressions, known as bils, the peat is still being formed [3]. Peat is often used as a soil amendment by local farmers and can be dried and used as domestic and industrial fuel. To the seaward side of the delta, there is a vast stretch of tidal mangrove forests (Figure 7) and swampland [4]. The region, called the Sundarbans, is protected by India and Bangladesh for conservation purposes. Each country's portion of the Sundarbans has been designated a UNESCO World Heritage site [1].

Previous studies by Kwak *et al.* [5] found “*along the banks of the tidal Meghna River of the Ganges-Brahmaputra-Meghna Delta demonstrated the active sequestration of dissolved arsenic (As) on newly formed iron oxide minerals (Fe(III)-oxides) within riverbank sands. The sand with high solid-phase arsenic (>500 mg/kg) was located within the intertidal zone where robust mixing occurs with oxygen-rich river water. Here we present new evidence that upwelling groundwater through a buried silt layer generates the dissolved products of reductive*

*dissolution of Fe(III)-oxides, including arsenic, while mobilization of DOC by upwelling groundwater prevents their reconstitution in the intertidal zone by lowering the redox state. A three end-member conservative mixing model demonstrated mixing between riverbank groundwater above the silt layer, upwelling groundwater through the silt layer, and river water. An electrochemical mass balance model confirmed that Fe(III)-oxides were the primary electron acceptor driving the oxidation of DOC sourced from sediment organic carbon in the silt. Thus, the presence of an intercalating silt layer in the riverbanks of tidal rivers can represent a biogeochemical hotspot of arsenic release while preventing its retention in the hyporheic zone.”*



**Figure 7.** Mangroves along the shoreline. Photo Credit: Ashley Cooper.

Ahmad and Lodrick [3] [4] reported “*the Indian subcontinent lies atop the Indian tectonic plate [3], a minor plate within the Indo-Australian Plate [6]. Its defining geological processes commenced seventy-five million years ago, when, as a part of the southern supercontinent Gondwana, it began a northeastwards drift—lasting fifty million years—across the then unformed Indian Ocean [6]. The subcontinent’s subsequent collision with the Eurasian Plate and subduction under it, gave rise to the Himalayas, the planet’s highest mountain ranges. In the former seabed immediately south of the emerging Himalayas, plate movement created a vast trough, which, having gradually been filled with sediment borne by the Indus and its tributaries and the Ganges and its tributaries [7] now forms the Indo-Gangetic Plain [8]. The Indo-Gangetic Plain [9] is geologically known as a foredeep or foreland basin” [3] [4].*

### 1.1. Climate and Hydrology

The Ganges-Brahmaputra watershed (**Figure 2**) is the largest river system on the subcontinent. It encompasses 1,086,000 km<sup>2</sup> [10]. The flow depends on the flow from melting Himalayan snows in the hot season from April to June and on the rains brought by the southwesterly monsoon winds from July to October. Tropical

cyclones can originate in the Bay of Bengal, between June and October and bring additional precipitation [11]. These cyclonic storms can result in significant loss of life and destruction of crops, livestock, and homes. The average annual rainfall in the west end of the delta is 76 cm and the east end is 230 cm. There is very little rainfall in December and January.

It is important to note that irrigation is one of the main uses of the Ganges-Brahmaputra River system. The impacts of irrigation cannot be overlooked when studying the hydrology of Ganges-Brahmaputra River system. In fact, one of the most important effects of heavy irrigation is the reduction of the amount of existing groundwater which seriously jeopardizes the river system. Typically, the stream flows of the mentioned river system tend to be mainly diminished. As groundwater gradually decreases, the trend of reduced stream flows in the river system progressively strengthens. During dry seasons, when precipitation is lacking, the reduction of groundwater is accelerated due to the practice of massive irrigation. In such seasons, the impacts of groundwater reduction are very serious. Thereby, as pointed out by Asoka and Mishra [12], in such conditions, drought conditions are triggered and are not disappeared rapidly. This situation can be more pronounced with the effects of climate change. The latter generally causes alteration of temperature and precipitation and makes considerable variation of the river hydrology. Details related to irrigation of this river system are presented in subsection 2.2.1.

## 1.2. Plant and Animal Life

The Ganges watershed was once densely forested. In the 16<sup>th</sup> and 17<sup>th</sup> centuries, buffalo, bison, elephants, rhinoceroses, tigers, and lions were hunted there. Most of the original natural vegetation has disappeared from the Ganges watershed. The land use has changed to agriculture to meet the needs of a growing population. Fish in the rivers and delta are an important part of the diet. The Ganges River dolphin (Figure 8) is now considered an endangered species because of human activity.

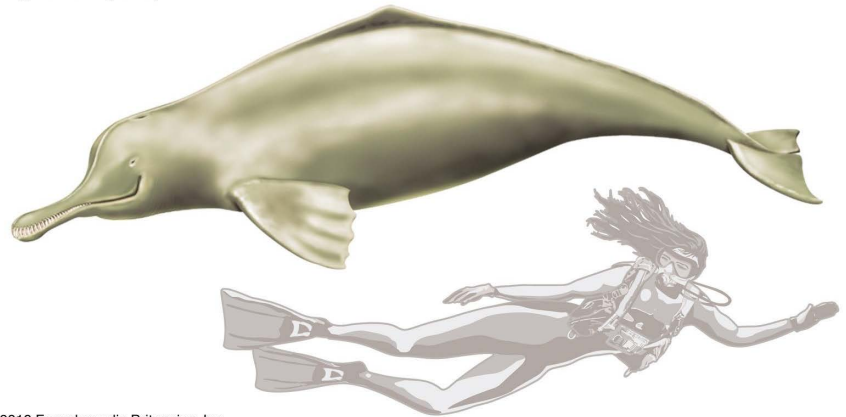
Historically the Gangetic Plain was the heartland of Hindustan and its successive civilizations. The religious importance of the Ganges (Figure 9) may exceed that of any other river in the world. It has been revered from the earliest times and today is regarded as the holiest of rivers (Figure 10) by Hindus. While places of Hindu pilgrimage, called tirthas, are located throughout the subcontinent, those that are situated on the Ganges have particular significance. Among those are the confluence of the Ganges and the Yamuna near Prayagraj, where a bathing festival (Figure 10), or *mela*, is held in January and February; during the ceremony hundreds of thousands of pilgrims immerse themselves in the river.

The primary objective of this research is to encourage the development of a multi-country clean-up, mitigation, and protection plan for the Ganges-Brahmaputra rivers. Previously plans were not able to overcome the lack of will and funding support from India, Bangladesh, Nepal, and China governments. Poor technical expertise, corruption, poor environmental planning, and lack of religious authority support were contributing factors to the lack of success. This paper aims

to strongly encourage a multi-country clean-up, mitigation, and protection plan for the Ganges-Brahmaputra rivers.

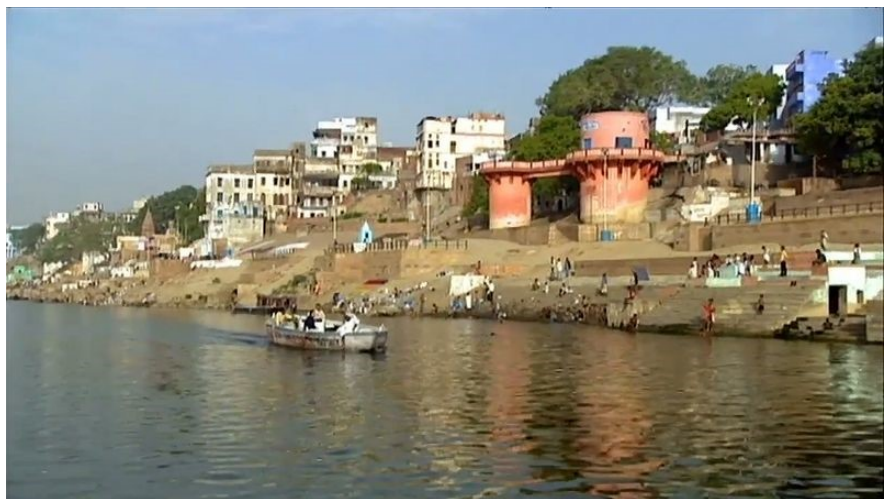
Ganges river dolphin, or *susu*  
(*Platanista gangetica*)  
length 2.5 m (8.2 ft)

1 metre  
3 feet



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**Figure 8.** Drawing of the Ganges dolphin (*susu*). Photo Credit: Encyclopaedia Britannica.



**Figure 9.** Banks of the bedrock-controlled Ganges. Photo Credit: Encyclopaedia Britannica.



**Figure 10.** People bathing on the banks of the Ganges River. Photo Credit: In public domain.

## 2. Findings

### 2.1. Ganges-Brahmaputra Delta: Flooding and Subsidence

Olson [13] reported “*The Ganges-Brahmaputra delta southwest Bangladesh (Figure 11) was flooded in 2009 because of Cyclone Aila which displaced more than 100,000 people (Figure 12). The storm inundated the island’s polders and deposited fresh silt that reached depths up to 70 cm in thickness. This demonstrated the natural system still had the ability to replenish the delta and revealed the downside of sea walls (Figure 13) and diking huge stretches of the delta shoreline to prevent flooding. Further, dikes must be regularly raised to protect subsiding land and to keep pace with steadily rising sea levels. A delta’s elevation above seas level depends on vertical movement resulting from plate tectonics and other geophysical processes, aggradation, sediment compaction and the global volume of the ocean. Sea levels are rising because of natural and human induced climate change. As oceans warm, the ice sheets near the poles melt, increasing the volume of available water and resulting in sea level rise. Dams, levees, polders, dikes (Figure 14) and embankments that trap silt and starve deltas of new sediment severely limit aggradation. Extraction of groundwater and hydrocarbons increases sediment compaction. The total weight of urban infrastructure contributes to compaction. Groundwater recharge is reduced when pavements and nonporous structure roofs prevent surface water from percolating into the soil and underlying sediments*” [13].



**Figure 11.** Flooding of an urban area. Published with permission of the Editor of Open Journal of Soil Science.

Reduced aggradation and increasing compaction have put most of the world’s mega deltas in danger, especially in Southeast Asia [13]. Delta areas are sinking

below sea level and the tributary and sea flooding is worsening. The possibility that a mega delta collapse is the biggest threat. The Ganges-Brahmaputra Delta with 170 million people is sinking and could collapse. Dams and levees [14] have reduced sediment delivery to Ganges-Brahmaputra Delta. The worst subsidence (Figure 15) has occurred in tens of thousands of square kilometers of river islands southwest of Bangladesh. Concrete and earthen embankments were built to hold back the sea [15]. Polders were built after 1960 around lower lying plots of land. The embankments blocked replenishment of the delta with river sediments carried downstream by annual monsoon floods. These islands have lost 1 - 1.5 m of elevation. Storm surges can breach or damage the walls around the polders and create crater lakes that can last for years [16].



**Figure 12.** Flooding of streets in Bangladesh. Photo Credit: CBS.



**Figure 13.** Jakarta floodwall. Published with permission of the Editor of Open Journal of Soil Science.



**Figure 14.** Close-up of Jakarta floodwall insert. Published with permission of the Editor of Open Journal of Soil Science.



**Figure 15.** Evidence of subsidence. The land surface has dropped 45 cm. Published with permission of the Editor of Open Journal of Soil Science.

## 2.2. Ganges River Economy

### 2.2.1. Irrigation

Ganges and Brahmaputra water is used for irrigation via flooding or via gravity canals. Irrigation has been used for more than 2000 years. Irrigation was highly developed in the 12<sup>th</sup> century during Muslim rule. Mughal kings later constructed several canals which were extended by the British [10]. The Upper Ganga canal and its branches have a combined length of 9575 km and the Lower Ganga Canal with its branches has a combined length of 8240 km. The system of irrigation utilizes both gravity canals and electrically powered lifting devices. The irrigation water is used for production of cotton, rice (Figure 16), oil seeds, and sugarcane.



**Figure 16.** Hand seeding rice in SE Asia. Published with permission of the Editor of Open Journal of Soil Science.

### 2.2.2. Navigation

In ancient times, the Ganges and Brahmaputra and some of their tributaries, especially in the east, were important transportation routes [3]. The advent of paddle steamers revolutionized inland transport, stimulating the growth of indigo production in Bihar and Bengal. Regular steamer services ran from Kolkata up the Ganges and Brahmaputra River.

### 2.2.3. Railroads

With the construction of railroads in the mid-19<sup>th</sup> century, water transport began to decline. The increased use of river water for irrigation also adversely affected navigation. British India was partitioned into India and Pakistan in 1947 [3] [4]. The eastern Bengal became East Pakistan until 1971 when it declared its independence as Bangladesh. Large-scale river traffic was insignificant, and traffic was mostly rural rivercraft. However, Bangladesh continued to rely on waterways to transport tea, jute, grain, and other agricultural products [4].

In India, the Inland Waterways Authority of India formulated policy for maintenance of extensive system of national waterways. The publicly owned Central Inland Water Transport Corporation, Ltd., is responsible for transporting cargo in the waterway system and maintaining the transport vessels as well as the facilities at several ports. Approximately 1600 km of waterways in the Ganges basin are included in the system. In Bangladesh inland water transport is the responsibility of the Bangladesh Inland Water Transport Authority [4].

### 2.2.4. Farakka Barrage

Just inside Indian territory in West Bengal, the Farakka Barrage at the head of the delta, began diverting Ganges waters south into India in 1976 [3]. The Indian government argued that hydrological changes had diverted Ganges water from the port of Kolkata over the preceding century and resulted in the deposition of silt and the intrusion of saline seawater. India constructed the dam to mitigate the condition of Kolkata by flushing away the seawater and raising the water level.

The Bangladeshi government maintained that the Farakka Barrage deprived southwestern Bangladesh of a needed source of water. In 1996 both countries signed an agreement resolving the dispute by apportioning the waters of the Ganges between the two countries. Catastrophic floods in Bangladesh (**Figure 12**) (**Figure 17**) (**Figure 18**) in 1987 and 1988—the latter being among the most severe in the country's history—prompted the World Bank to prepare a long-term flood-control plan for the region.



**Figure 17.** Bangladesh flooding of streets which required a boat to travel. Photo Credit: Xinhua net.



**Figure 18.** Ganges flooding homes in Bangladesh. Photo Credit: Washington Post.

### 2.3. Environmental Hydroelectric Power Issues

The estimates of the hydroelectric potential (**Figure 19**) of the Ganges and Brahmaputra and their tributaries range from some 51,700 to 128,700 megawatts—of which about two-fifths lies within India and the rest in Nepal [3]. Some of that potential has been exploited in India, including hydroelectric developments on headwater tributaries of the Ganges and its tributaries. Only a tiny fraction of Nepal's hydroelectric generating capacity has been exploited.



**Figure 19.** A dam constructed by China on the Brahmaputra River. Photo Credit: Public Domain.

Ahmad and Lodrick [3] [4] reported “*growing concern over the environmental impact of hydroelectric dams, including habitat destruction for wildlife (terrestrial and aquatic), forced relocation of people living in the paths of dams and reservoirs, loss of agricultural land, and disruption of water supplies for inhabitants near the completed dams. Some have called for reductions in the amount of power generated, redesigning dams to make them and their impounded reservoirs less intrusive, and even moratoriums on future dam construction in some areas*”.

“*Of greater concern, however, has been the degradation in quality of the river water itself. The Ganges basin is one of the most intensely inhabited regions on earth, home to hundreds of millions of people, with the result that the river's water over much of its course is highly polluted (Figure 20). Scores of cities and towns (Figure 21) dump untreated sewage into the river and its main tributaries, and dozens of manufacturing facilities contribute to industrial waste (Figure 22). Also contributing to high pollution levels are agricultural runoff, the remnants of partially burned or unburned bodies from funeral pyres, and animal carcasses. High levels of disease-causing bacteria, as well as such toxic substances as chromium, cadmium, and toxic arsenic, have been found in the Ganges*” [3] [4].



**Figure 20.** Pollution in river with two boys on a boat collecting recyclable trash. Photo Credit: World Atlas.



**Figure 21.** Buildings on the Ganges Riverbank. Photo Credit: Wikipedia.



**Figure 22.** Man collecting trash for recycling on the edge of the Ganges River. A bridge across the Ganges is in the background. Photo Credit: Wikipedia.

Coordinated efforts to clean up the river began in 1986 with the establishment of the Ganga Action Plan (GAP) agency by Indian Prime Minister Rajiv Gandhi [3]. Although the agency did initiate and complete several projects aimed at reducing pollution levels, its efforts were generally deemed inadequate and failures. In 2009 a new government organization, the National Ganga River Basin Authority (NGRBA), was launched as a successor to the GAP. The NGRBA also faced criticism for inaction in its early years of existence.

Ghosh [2] noted “*the main channel of the greater Ganges River is called Padma River in Bangladesh. For some 145 km the Ganges River forms the western boundary between India and Bangladesh before it enters Bangladesh as the upper segment of the Padma River. The upper Padma flows southeastward to receive the mighty Jamuna River (the name of the Brahmaputra in Bangladesh). The combined flow of those two rivers constitutes the lower segment of the Padma, to empty into the Bay of Bengal. The Padma River is known for heavy bank erosion, shifting channels, and sandbars that continually emerge in its course. The flow of the Padma is controlled seasonally by the Farakka Barrage, located a few miles upstream in West Bengal, India. The river forms a busy waterway and is a rich source of fish*” [2].

Padma is a trans-boundary river of Asia which flows through both Bangladesh and India. The 2525 km river rises in the western Himalayas. It flows east and south through the Gangetic plain of North India. The Ganges-Brahmaputra is the second-largest river based on discharge rate. The Ganges is a lifeline to millions of people who live in the watershed. The Ganges is home to 140 species of fish, 90 amphibians, reptiles, and mammals such as the endangered South Asian River dolphin (Figure 8). The Ganges is the most sacred river (Figure 23) to Hindus [17].



**Figure 23.** A ship with a sail on the Ganges used to spread human remain ashes in the river to expedite travel to heaven. Photo Credit: World Atlas.

The Ganges is threatened by severe pollution. The danger is to both animals and humans. The levels of fecal coliform bacteria from human waste in the river near Varanasi are more than a hundred times the Indian government’s official

limit [18]. The Ganga Action Plan, an environmental initiative to clean up the river, has been considered a failure [19]. The failure is attributed to lack of will in the government, poor technical expertise, corruption, poor environmental planning, and lack of religious authority support.

#### 2.4. Impacts of Arsenic in the East Asia Environment

Many East Asia countries including India and Bangladesh have geological environments that produce a high arsenic (As) content in groundwater. Arsenic in groundwater poses a growing health threat in the deltas of Southeast, East and South Asia through human consumption of naturally and anthropically contaminated groundwater. Exploitation of both shallow and deep aquifers in East Asia caused interbedded clays to release dissolved As or As-mobilizing solutes. As a result, deep, untreated groundwater will likely become contaminated with As [20].

Arsenic is naturally present in the environment and comprises 99% of human exposure to As, through ingestion of small concentrations in water and the food supply (Figure 16). It accumulates in the body and takes decades before any physical symptoms of As poisoning show. Due to the proliferation of India and Bangladesh government-subsidized shallow tube-wells (Figure 24) in past 30 years, shallow groundwater has become the primary source for drinking and irrigation water in Ganges-Brahmaputra Delta. Another pathway for human exposure is inhalation of atmospheric gases and dusts. Over the past 60 years, disturbance of As contaminated soil by industrial development has maintained bio-available arsenicals in the human environment. People often begin showing symptoms of having been poisoned, decades after chronic exposure.



**Figure 24.** Tube wells used to bring arsenic rich water back to the soil surface. Published with permission of the Editor of Open Journal of Soil Science.

The biogeochemical processes that regulate As mobility within sandy shallow riverbank aquifers with an intercalating silt layer has not previously been characterized. Kwak *et al.* [5] findings suggest “*that the presence of buried silt layers can significantly alter the dynamics of As mobility. The intercalating silt layer prevents As accumulation within the HZ on Fe(III)-oxides across intertidal zones, and instead generates a biogeochemical hotspot for As release within the HZ. In the presence of buried silt layers, riverbank aquifers within intertidal zones may therefore be susceptible to production of dissolved As in porewaters that adds to the mass flux of dissolved As advected from shallow Holocene aquifers toward the river. These findings modify the previous conceptual model in which permeable riverbank aquifers accumulate the As discharging to rivers. These findings expand our understanding of the fate of As discharging to rivers and the cycle of As across the broader shallow alluvial aquifers*”.

The Ganges-Brahmaputra delta groundwater has As concentrations above the World Health Organization (WHO) guidelines. The safe concentration of As in drinking water is 10 ug/L. The toxicity of As is related to its solubility which is affected by the pH of the environment in which it occurs. Arsenite (+3 oxidation state) is more soluble than arsenate (+5 oxidation state) at lower pH and are the most readily bioavailable oxidation states. At lower pH arsenite is more mobile and toxic.

High concentrations of As in groundwater, which is often the primary source of drinking water and for agricultural production in the Ganges-Brahmaputra need remediation. Developing optimal treatment processes for Ganges-Brahmaputra groundwater for drinking water and irrigation water is needed to reduce the As ingestion by the India and Bangladesh people who consume fish, rice (**Figure 16**) and vegetables produced with contaminated water and soils. The continued success of the Ganges-Brahmaputra economy is dependent on agriculture.

### 3. Discussion

#### 3.1. Bioremediation

The As in the groundwater is primarily of natural origin. As is released from sediment into groundwater and is mainly caused by *anoxic conditions* of the water-logged subsurface sediments. In the Ganges-Brahmaputra Delta, the Bangladesh and India governments undertook a massive shallow tube well drinking water program in the 1970s. This program was designed to prevent drinking of bacteria – contaminated surface waters but failed to test for As in the groundwater [21] was [20]. Increased levels of As exposure increase skin cancer. Epidemiological studies suggest inorganic As exposure can increase the risk of bladder cancer [20]. Epidemiological studies also suggest a correlation between the leading causes of mortality [22] and chronic consumption of As-rich water [23] is causative in the pathogenesis of diabetes.

Olson and Chau [20] found “*remediation of groundwater contaminated with As aims to convert arsenite, the toxic form of arsenic to humans, to arsenate.*

*Arsenate (+5 oxidation state) is the dominant form in surface water while arsenite (+3 oxidation state) is the dominant form in hypoxic to 'anoxic' environments. Arsenite is more soluble and mobile than arsenate. Many species of bacteria can be used to transform As during groundwater remediation”.*

*“Another bioremediation strategy is to use plants that accumulate As in their tissues via phytoremediation, but the disposal of contaminated plant materials needs to be considered. Bio-remediation requires an evaluation of existing conditions. Some sites require addition of substances containing an electron acceptor while others require microbial supplementation (bio-augmentation)” [20].*

### 3.2. Water Treatment

A successful process for removing arsenic from drinking water is to co-precipitate the dissolved As with iron or aluminum oxides. United States Environmental Protection Agency (USEPA) and National Science Foundation (NSF) have funded several adsorptive media systems. European and Indian scientists and engineers have set up six As treatment plants in West Bengal (**Figure 25**). The technology does not use any chemicals and As is left in the insoluble form (+5 oxidation state) in subterranean zone by recharging aerated water into the aquifer and developing an oxidation zone that supports microorganisms that oxidize As. The process does not produce any waste stream or sludge and is relatively inexpensive [24] [25].



**Figure 25.** A water treatment plant in SE Asia. Published with permission of the Editor of Open Journal of Soil Science.

Another approach in the Ganges-Brahmaputra Delta is to drill 150 m or more into aquifers which have low As levels, but this approach is now contaminating the lower aquifers [26]. Klassen *et al.* [27] found deep sediment could remove As and take it out of circulation. This process is called adsorption. Arsenic adheres

or bonds to the surface of deep sediment (clays and silt) particles and is naturally removed from groundwater.

Magnetic separation of As at very low magnetic field gradients with high-surface area and monodisperse magnetite ( $\text{Fe}_3\text{O}_4$ ) nanocrystals have been used in water purification.  $\text{Fe}_3\text{O}_4$  nanocrystals have a high specific surface area and reduce the mass waste associated with As removal from water. Chaff-based filters have been shown to reduce the As content of water to 3 ug/L. This may have applications in areas where portable water is extracted from an under Removing or decreasing As in water is one of the best ways to improve the health of any aquatic environment. In fact, As is very toxic for water and its surroundings. When it is present in water, it causes various harmful effects, namely stunted growth, delay of relevant biological processes and death as the worst consequence. Thus, compared to normal water, very few species are generally encountered in water polluted with arsenic. It is therefore an urgent need to opt for effective removal of As into the Ganges-Brahmaputra River system ground aquifer [24] [25].

Removing or decreasing As in water is one of the best ways to improve the health of any aquatic environment. In fact, As is very toxic for water and its surroundings. When it is present in water, it causes various harmful effects, namely stunted growth, delay of relevant biological processes and death as the worst consequence. Thus, compared to normal water, very few species are generally encountered in water polluted with arsenic. It is therefore an urgent need to opt for effective removal of As into the Ganges-Brahmaputra River system.

### 3.3. Remediation of Arsenic in Rice

Management of contaminated water can reduce concentration of As in food supplies. Recent experiments show that rice (**Figure 26**) grown in soil with high As concentrations had elevated levels of As in the roots, leaves, grain, cooked rice, hulls, and straw [24] [28] [29]. The flooded or wet rice production system traditionally transplants seedlings into puddled paddy fields. In this planting system, anaerobic As contaminated soil promotes increased As availability and uptake by the plant, resulting in high As concentration in rice straw and grain [24]. Many of Ganges-Brahmaputra Delta soils are high in iron oxides. Under anaerobic conditions such as flooded rice paddies, iron oxides are reduced and release inorganic As from sediments and soils, making the As more available for plant use.

Water management experiments show that growing rice on raised beds with irrigated furrows between the beds rather than flooding the entire field reduces As concentration in rice primarily because of aerobic conditions. As is bound to iron oxides and unavailable for plant uptake in the soils of the raised beds [24]. These alternating wet and dry soil zones reduce water logging and hence the amount of As released from the soil, thereby lowering As bioaccumulation in plants. Other mitigation strategies to reduce the arsenic loads in the food supply include selection of the rice cultivar and rotations with other non-rice crops having low As uptake [25]. Screening for rice cultivars that do not easily take up As

and translocate into the grain revealed that root traits with higher porosity and capacity to form iron plaques bind more As. These rice cultivars have lower levels of As translocation throughout the plant [27] [28]. Other species that generate reactive oxygen and produce antioxidant enzymes have been found to reduce As toxicity and enhance plant resistance to bioaccumulation [29]. Much more research in this area is needed to identify and test crops that are relatively tolerant to As toxicity. The different farming methods and rice cultivars used in California, Pakistan, Texas, Louisiana, and Arkansas rice production could provide useful technical guidance to help mitigate the Ganges-Brahmaputra Delta rice-arsenic problem.



**Figure 26.** Rice growing in SE Asia. Published with permission of the Editor of Open Journal of Soil Science.

### 3.4. Protection of Ganges-Brahmaputra River System

It is widely known that river pollution is among the biggest environmental issues. Identifying sources of pollution and developing effective remediation strategies are of paramount importance. However, to maintain any remediation measures in a given river system, realistic protection plans are highly needed. In fact, relevant protection plans will ensure good ecological indicators at the Ganges-Brahmaputra River system. They will allow a reasonable water quality of the river system, and the proper development of aquatic communities without disturbance. This protection can be seen in terms of sustainable and integrated conservation of river ecosystems. In this sense, water and associated terrestrial ecosystems must be adequately taken into account and ensure that they are in healthy ecological conditions [30]. Moreover, anthropogenic activities should be strictly controlled upstream and around the Ganges-Brahmaputra River system. It is

strongly encouraged to reduce these activities, especially upstream of the river system. Furthermore, opting for the conservation of free flows of the Ganges-Brahmaputra River system is extremely important to avoid flooding and other serious environmental impacts. This will effectively protect the natural flows of the Ganges-Brahmaputra River. Indeed, this protection manner provides excellent results in terms of river protection [31]. To maintain the integrity of the Ganges-Brahmaputra River system, suitable monitoring system should be adopted. Continuous monitoring of the overall ecological quality and flows of the studied rivers should be taken into consideration.

#### 4. Summary

The Ganges and Brahmaputra watershed is home to hundreds of millions of people, with the result that the river's water over much of its course is highly polluted. Catastrophic floods have suggested the need to prepare a long-term flood-control plan for the region. Scores of cities and towns dump untreated and treated (Figure 27) sewage into the river and its main tributaries, and dozens of manufacturing facilities contribute to industrial waste. Also contributing to high pollution levels are agricultural runoff, the remnants of partially burned or unburned bodies from funeral pyres, and animal carcasses. High levels of disease-causing bacteria, as well as toxic substances such as chromium, cadmium, and toxic arsenic, have been found in the Ganges and Brahmaputra.



**Figure 27.** The largest sewage treatment plant on the Ganges-Brahmaputra rivers in Bangladesh.

Arsenic levels are naturally high in the Ganges-Brahmaputra Delta environment of India and Bangladesh. Human exposure to arsenic is primarily (99%) through ingestion. Arsenic is known as the “king of poisons” and is mutagenic, teratogenic, and carcinogenic. According to the World Health Organization (WHO), the safe concentration level of arsenic in drinking water is 10 ug/L. The current legal arsenic concentration limit is 50 ug/L or five times the WHO guidelines.

## 5. Conclusions

The wetlands and land masses are subsiding because of groundwater extraction, dam construction, level construction, population growth, infrastructure development, saltwater intrusion, consolidations, reduced sediment loads in the lower Ganges River and reduction in the current plumes into the Bay of Bengal which takes the fresh water and sediment out into the sea.

Successful processes for removing arsenic from drinking water such as co-precipitation of dissolved arsenic with iron or aluminum oxides are being developed. USEPA and NSF have funded several adsorptive media systems to help mitigate the high arsenic levels in drinking water. A multi-country development, mitigation, restoration, and protection plan is needed to clean up the Ganges-Brahmaputra rivers. Previously, plans were not able to overcome the lack of will and funding support from India, Bangladesh, Nepal and China governments, poor technical expertise, corruption, poor environmental planning, and lack of religious authority support. The Ganges-Brahmaputra River system is of colossal importance to its entire environment. Restoration and protection measures must be adopted appropriately and at the scale of the concerned countries.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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