БИОЛОГИЧЕСКИЕ НАУКИ И ЭКОЛОГИЧЕСКАЯ ХИМИЯ

Hasan FARUQUE[1]
Dewan A. AHSAN[2]
Maminul H. SARKER[3]
Elena F. GLADUN[4]

EFFECT OF GANGES RIVER MORPHOLOGICAL DYNAMICS AND FARAKKA BARRAGE ON UPWARD MIGRATION AND CATCH OF INDIAN SHAD (*TENUALOSA ILISHA*) IN BANGLADESH

[1] MSc in Fisheries, Assistant Professor,
Department of Fisheries, University of Dhaka, Bangladesh
hasanfaruque28@du.ac.bd

[2] PhD, Assistant Professor, Department of Fisheries,
University of Dhaka, Bangladesh
dah@sam.sdu.dk

[3] PhD, Deputy Executive Director, CEGIS, Dhaka,
Bangladesh Center for Environmental and Geographic Information Services
msarker@cegisbd.com

[4] Cand. Sci. (Law), Associate Professor, Department
of Administrative and Finance Law, Tyumen State University
efgladun@yandex.ru

Abstract

Tenualosa ilisha, the largest and single most valuable fishery, considered as the flag-ship species of Bangladesh, also commonly known as Indian Shad in South-East-Asia, is now

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becoming a threatened species due to human intervention and climatic factors. This study is aimed to assess the impact of the Farakka barrage and the Ganges River morphological dynamics on the Indian shad migration and catch in Bangladesh. Results have indicated that the average water level of the river Ganges during the breeding season of Hilsa has significantly decreased over time. This situation is even worse in some particular points like Satbaria of the Pabna district, Dadpur and Kalyanpur of the Kushtia district, Ruppur and Samadia of the Rajshahi district, where the water level (6.5-8 m) is much lower than the threshold (10 m). The findings of the study have also revealed that the Ganges River is very much dynamic because of the changes in width of the river, and the shifting of river bends is quite frequent over the period of time and is more diverse in the upstream region than downstream. The decreased water level and the frequent shifting of the river bends might force the Hilsa fish to restrict their migration towards the upper Ganges. As a result, CPUE (catch per unit effort) of Hilsa in the Ganges River has significantly decreased (about 50 kg boat-1 day-1 in 1960s to about 1.0 kg boat-1 day-1 in 2012), and in some areas there is almost zero catch.

Keywords

Ganges River morphology, Hilsa migration, Catch, Sinuosity Ratio, Braiding Index.

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Introduction

Bangladesh is called the country of hundred rivers. About 700 rivers including 57 common rivers (54 rivers with India and other 3 rivers with Myanmar) flow through the country constituting a waterway of total length around 24,140 km [9]. The Ganges, one of the largest riverine systems of the world, originated from the combined flow of the Bhagirathi and Alaknanda and runs towards the Bay of Bengal over India and Bangladesh, also shared by China (Tibet) and Nepal [14]. The lowermost reach of the Ganges flows through the Northeastern India to the Bangladesh border, east-southeast 212 km to its confluence with Brahmaputra (known as Jamuna in Bangladesh), and continues as the name of Padma River in Bangladesh for another 100 km to its confluence with the Meghna River at Chandpur. In Bangladesh, the river Ganges is locally known as the Padma River. The basin area of the Ganges River is highly populated [5], and in Bangladesh it is extremely dependent on a regular water supply from upstream to meet requirements for agriculture, fisheries, navigation, salinity control, and domestic and industrial sectors [32: 613-631].

Dams or barrages have been considered an integral part of the economic development, especially in the last century. USA, Europe, and many other developed nations have constructed hundreds of dams and barrages for the purpose of electricity generation, irrigation, and flood control to reserve water for the lean period. The number of large dams stood at 5,000 in 1950, whereas now the number of large dams exceeds up to 50,000 [10]. However, there is a huge debate on river damming, as the research of several scholars has established that dams, besides blocking the free-flowing river system, also act as a direct barrier to the movement of the anadromous, catadromous, potadromous, and migratory fish species. Dams hamper the flow of nutrients and escalate the deposition of sediments in river beds, blockading, thus, the migratory route of fish and wildlife [17; 20; 28; 30; 45: 160-172]. Dams are obstacles for migratory fishes that require movement from one ecosystem to another (like sea to freshwater and vice versa) for the completion of their life cycle, and dams can reduce the catch per unit effort for migratory species [21: 669-680; 45]. Therefore, dams and barrages have not only considerable negative impact on the livelihoods of people living downstream, but also on those, who live upstream of the river.

In 1960s, India constructed the Farakka barrage (16 km from the Indian side of the border between India and Bangladesh) at West Bengal of India to regulate the flow of Ganga towards Bangladesh. India started to operate the Farakka barrage by regulating the flow of Ganges to feed the Baghirati River through a 40 km long man-made canal in 1975. The river Ganges is rich of many aquatic species specially fishes. However, the Indian shad (*Tenualosa ilisha*) is the most important economically important species of this river.

Tenualosa ilisha (commonly known as Hilsa) is an important migratory species in the Indo-Pacific region. Hilsa is found in Bay of Bengal, Persian Gulf, Red Sea, Arabian Sea, Vietnam Sea, and China Sea. The riverine habitat covers the Satil Arab, the Tigris and Euphrates in Iran and Iraq, the Indus of Pakistan, the rivers of the Eastern and Western India, the Irrawaddy in Myanmar, and Ganges (Padma in Bangladesh), Jamuna, Meghna, and other rivers in Bangladesh, and West Bengal in India [12]. However, the Ganges River (and its tributaries) is famous as the greatest Hilsa producing system in the world. About 95% of Hilsa (locally known as Ilish in Bangladesh and the Eastern part of India) is caught by Bangladesh, India, and Myanmar. Yet, about 75% of world's total catch of Hilsa comes from Bangladesh alone. The flag-ship species of Hilsa (*Tenualosa ilisha*) in Bangladesh alone contributed 10.62% of the total fish production of the country of 3.26 million tons in 2011-2012 [23]. The contribution of Hilsa to GDP is around 1.25%. About 2% of the country's total population is directly or indirectly involved in the Hilsa fishery for their livelihoods [25]. Hilsa is also an important fishery in West Bengal, India, and Hilsa, as it alone contributes about 20-25% of the total fish landing of Hoogh1y-Bhagirathi River system. The total average catch of Hilsa from Hooghly-Bhagirathi River was about 77,000 mt in 2011 [12].

The economic growth of Bangladesh is praiseworthy where fisheries play quite an important role in terms of protein supply, generation of employment, and earning of foreign currency [34]. Indian shad, *Tenualosa ilisha*, or Ilish fish of Bangladesh, is the largest and single most valuable fishery, and it is considered as the flag-ship species of Bangladesh [3]. It has been observed that Hilsa move on the surface in the foreshore region, whereas in the river they move in deeper zones [11: 66-81].

Historically Ganges and its tributaries (specially the part of Bangladesh) are the main spawning and nursery places of Hilsa. The taste and odor of the Hilsa in the Padma River (the part of Ganges in Bangladesh) are very unique, appetizing, and very much popular to the Bengali people both of Bangladesh and West Bengal of India. Therefore, Hilsa is the most important fish species that links not only the transboundary ecosystem of India and Bangladesh, but also the life and the culture of the two neighboring countries. During the period of undivided Bengal, i.e. until 1947, bulk of fish produced by the East Bengal (now Bangladesh) used to be sent to Kolkata fish markets [4] as well as other markets of West Bengal and Assam in India.

Like Pacific salmon, *Tenualosa ilisha,* is a highly migratory transboundary fish, which originates at sea and migrates to freshwater river during spawning period as the eggs and juvenile cannot survive in salt water [163]. Hilsa needs at least 10 m water depth for upward migration [15] and migrate up to 2,000 km (till Delhi, India) from the Bay of Bengal in the pre-Farakka period (before the migration blockage) [11]. It is known to be a fast swimmer [38: 11-12], capable of migrating long distances from marine habitat to up-stream freshwater for breeding purposes. In Bangladesh, the upstream spawning migration of 1 y. o. mature Hilsa takes place during October as the peak season, and there is also a lower peak breeding season in January-February [3; 25], though the date of spawning migration of Hilsa varies from region to region [16: 4-8]. After spawning, the Hilsa starts its seaward journey, and the juveniles (locally known as Jatka Hilsa) finally migrate to the sea after 5-6 months of foraging in the inland riverine system [26: 7-10].

The migration of fish vastly depends on the nature of rivers, as they are a dynamic and increasingly important part of the physical environment [44: 669-675]. Alluvial river channels can be categorized as straight, braided and meandering [35; 44: 217-239], and they vary greatly from river to river [22] and even from reach to reach and along the course of particular rivers under different flow stages [19; 27: 181-182]. Some anthropogenic factors as well as the morphological dynamics of the rivers cause the distortion of its course form previous path and are well measured by the sinuosity ratio [24: 49-57]. Straight and meandering channels are described by sinuosity, which is the ratio of channel length to valley length or the ratio of valley slope or channel gradient as measured over the same length of valley [37]. Rivers having a sinuosity of 1.5 or greater refers meandering, and below 1.5 straight or sinuous [44]. Braiding intensity greatly affected the planform properties of a river [13] as intensity of braiding varies river to river [22; 27].

The transboundary Ganges River of Bangladesh is considered as a dynamic river for its shifting pattern, and the formation of bars in the main channel is immensely caused by natural factors along with anthropogenic factors including the operation of the Farakka barrage [34], river siltation, closure of migratory routes, over-fishing, and hydrological changes [33]. Consequently, this changing pattern of Ganges imposes a negative impact on Hilsa migration and catch in the Ganges River. The magnitude of Hilsa migration in the Hooghly-Bhagirathi system in India is also significantly low [12]. However, it was the most abundant in fish in the Ganges River system in the pre-Farakka barrage period until the mid-1970s in Bangladesh [34]. Therefore, the poor professional fishermen, whose livelihood merely depends on the Hilsa catch, are now facing a great problem due to the declination of the Hilsa fishery in the upstream region, mostly in the Ganges River of Bangladesh. Though the fisheries sector is considered as the second largest export earner for Bangladesh after ready-made garment, in which Hilsa along contributes 1.25% of the GDP, unfortunately, no study has yet been carried out to address the causes of the Hilsa migration route destruction, the declination of its migration and catch in the upstream rivers mainly in Ganges, which are very important for sustainable management of Hilsa fishery.

Our overall aim is to ascertain how the Farakka dam affects Hilsa (migratory species) fisheries in the Ganges River. To fulfill this aim, this paper has following specific objectives: (i) to assess changes of width and bends development of the Ganges River over the period of time; (ii) to know the Sinuosity Ratio and Braiding Index of the Ganges River; (iii) to assess the average water level of the Ganges River during the breeding season of Hilsa over the period of time; (iv) the impact of the morphological changes of the Ganges River and Farakka barrage on the Hilsa migration and catch in Bangladesh. Unfortunately, there are no available long-term fisheries databases on Hilsa catch in Ganges. Furthermore, there is no available quantitative information on the impact of the Farakka barrage on migratory route of Hilsa (especially in Bangladesh). Therefore in this paper we have used fisheries observations and perception to ascertain the impact of barrage on migratory route and catch of Hilsa.

Materials and Methods

For the present analysis, BIWTA (Bangladesh Inland Water Transport Authority) hydrographic survey chart of the Ganges River of 2003 and 2010 from Gualanda transit to Hardinge bridge and Hardinge bridge to Rampur Boalia respectively were collected to analyze the long profile of the river bed. These charts were geo-referenced and the data have been extracted. Average water level data (January-February and October-November) from 1960s, 1980s, and 2000s of different stations (Fig. 1) along the Ganges River have been collected from BIWTA to show the actual scenario of changes of the Ganges River water level during the last couple of decades, and its impact on the Hilsa migration and catch during the spawning season.

The primary data have been collected with the help of a questionnaire survey, which included the information about Hilsa migration and catch. Total 150 fishermen from six different villages (Kathatlbaria, Horisonkorpur, Chock Muktarpur, and Yousufpur in the Rajshahi district; Dhuplia and Roghunatpur in the Manikganj district) along the Ganges River have been personally interviewed during the study period.

A substantial portion of the geo-statistical database for this study has been derived from a time series of Landsat images. The Landsat images consist of 10 images frames for 1973, 1980, 1985, 1989, 1993, 1995, 2002, 2005, 2008, and 2010. The Landsat images have been obtained from CEGIS (Centre for Environmental and Geographic Information Services).

Stream length and valley length have also been measured by using ArcView GIS software with satellite images of the Ganges River for calculating Sinuosity Ratio of Ganges from the Farakka barrage to the Gualanda transit in two different segments

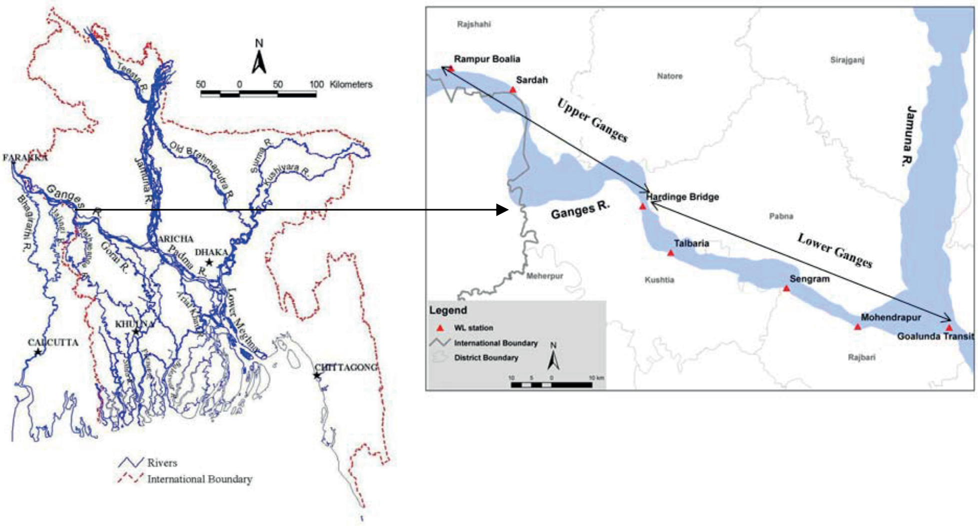

Fig. 1. Map showing the Ganges River of Bangladesh and sample stations along the Ganges River

Рис. 1. Карта р. Ганг в Бангладеше, а также станции отбора проб вдоль р. Ганг

(upper reach-Hardinge bridge to the Farakka barrage and lower reach-Hardinge bridge to the Gualanda transit).

The following formula was used for calculating Sinuosity Ratio of the Ganger River in the present study:

Sinuosity Ratio = Stream length/Valley length [37];

Braiding Index of the Ganges River was calculated using Brice's formula [13]:

$$\text{Braiding Index (BI)} = 2\sum(Li)/Lr,$$

where ΣLi is the total length of bars and (or) islands in the reach, and Lr is the length of the reach measured mid-way between the banks. A total braiding index of 1.50 was selected by Brice to differentiate braided from non-braided reaches. Simple descriptive statistical methods are used to analyze the catch data.

Results

Width of the Ganges River

Considering Ganges as two separate reaches demarcated by Hardinge bridge, it was found that the width of both reaches has changed over the period of time. The width of the lower reach (Hardinge bridge to Gualanda transit) has been found to be lower than that of the upper reach (Hardinge bridge to Farakka barrage) (Fig. 2).

During the 1970s the reach-averaged width of the lower reach was reduced, and since the 1990s it maintained a constant width of around 4 km. On the other hand, the reach-averaged width of the upper reach was about 5 km in the 1970s and 1990s,

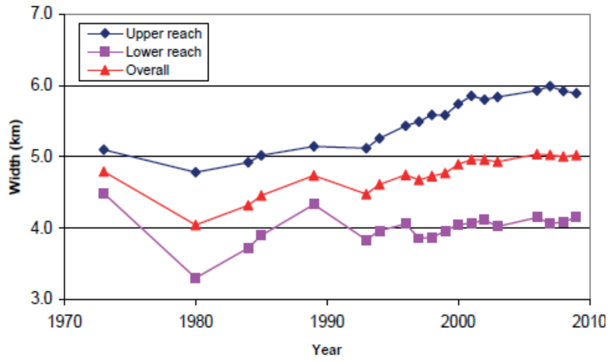

Fig. 2. Change of width of the Ganges River over time

Рис. 2. Изменение ширины р. Ганг с течением времени

and since the mid-1990s the river has shown a very rapid widening trend with the maximum reach-averaged width found to be about 6 km. In the recent past, the widths of both reaches of the river have become stable. The development of meandering bends and chute cut-offs in the recent past indicate that the reach-averaged width of the upper reach might be reduced in the near future.

Meandering bend development

Satellite images from 1973 to 2010 were examined to understand the meandering bend development in the Ganges River. The planform at the downstream of Hardinge bridge has remained straight for a longtime. On the other hand, the meandering bend development was frequent between the Farakka barrage and Hardinge bridge (Fig. 3).

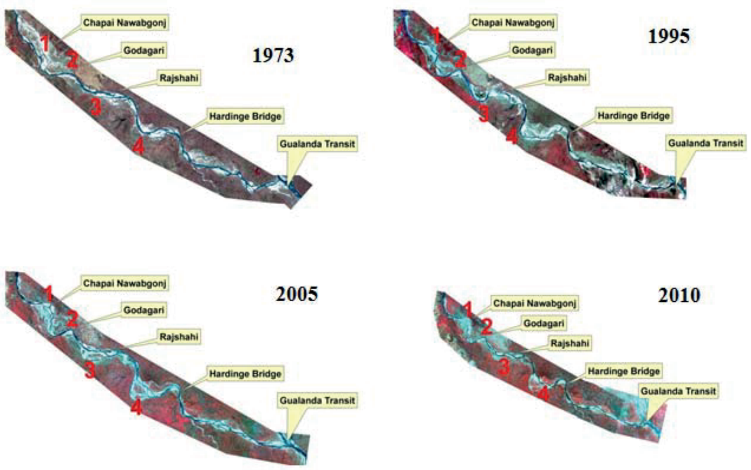

Fig. 3. Satellite images of Ganges River (1973-2010) showing the development of different bends

Рис. 3. Спутниковые снимки р. Ганг (1973-2010 гг.), показывающие развитие различных изгибов

In Fig. 3 satellite images reveal that different bends were formed and migrated in several places through the process of extension or translation in the Ganges River, thus changing the movement of channel in the whole Ganges as well as particular areas over a period of time. Bend 1 is situated along the left bank of the river at Shibganj upazila of Chapai Nawabganj district. Bend 2 is situated along the left bank of the river at Godagari upazila of Rajshahi district, bend 3 is also located near the Rajshahi sadar of Rajshahi district. The most prominent bend 4 is situated along the right bank of the river at Philipnagar of Kushtia district (Fig. 3).

Figs 4-5 indicated that bend 4 is the long sustaining eroding bend of the right bank at Philipnagar of Kushtia district. In 1973 it was a well-defined bend, which

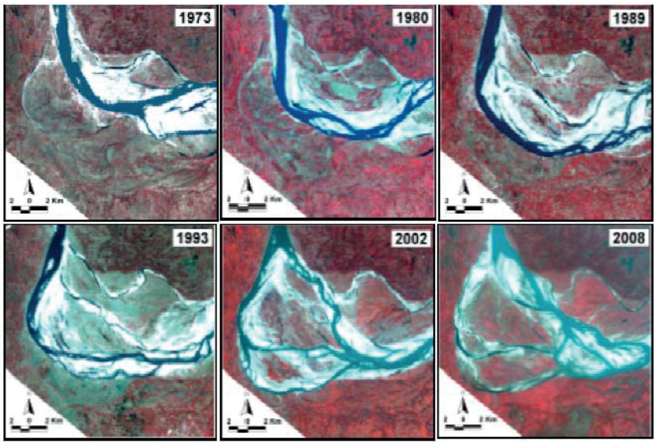

Fig. 4. Satellite image showing the development of bend 4

Рис. 4. Спутниковые изображения, показывающие развитие 4-го изгиба

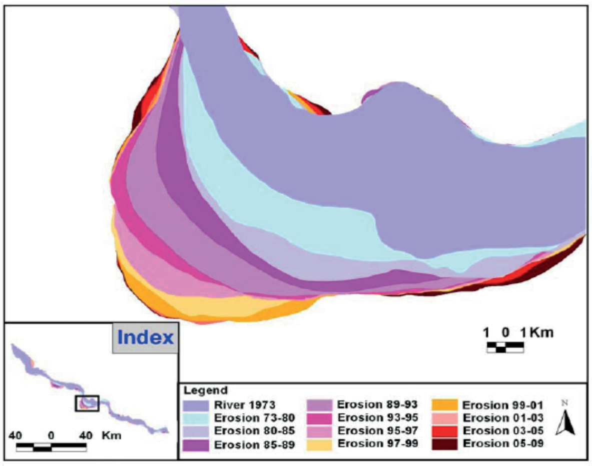

Fig. 5. Progression of bank erosion at bend 4

Рис. 5. Прогрессирование эрозии берега на 4-м изгибе was eroding rapidly through extension during the period 1973-93. The rate of erosion at that time was about 500 ha/y. The maximum land eroded in this bend was 630 ha during 1989-93 as shown in Fig. 5. In 1989 it showed two apexes, but in 1993 the downstream apex was abandoned (Fig. 4). After a few years, the main channel started to decline and split into multithreaded channels thereby reducing the width of the single channel. The maximum lateral extension of erosion at this bend is about 9 km. The frequent shifting or changing pattern of the Ganges River channel might force the Hilsa fish to change their migration route from one to another.

Sinuosity ratio and braiding index of the Ganges River

In case of upper reach (the Farakka-Hardinge bridge) result showed that there was an increasing and decreasing trend of the sinuosity ratio over the period of time. In 1973, it was 1.18, and in 1985, 1995, 2005, and 2010 it was 1.28, 1.37, 1.34, and 1.28 respectively. This result also showed that sinuosity of the upper reach has increased from 1.18 to 1.37 during the last couple of decades (1973-1995). After 1995, the results showed that sinuosity of the same reach has decreased from 1.37 to 1.28. But in case of lower reach (Harding bridge-Gualanda transit) there was not found any significant changes in sinuosity ratio during a couple of decades, and it has little increased from 1.08 to 1.17 (Fig. 6). The increasing and decreasing trends of the sinuosity ratio of the Ganges River clearly indicated that it is a dynamic river and always changes its channel pattern.

This analysis also showed that braiding index was 1.22 and 1.43 in 1973 and 1985 respectively. In 1995, 2005, and 2010 the braiding index was 1.51, 1.61, and 1.72 respectively. These values of braiding index indicated that it exceeds 1.5, which means the Ganges River has become a braided river since 1995 (Fig. 6).

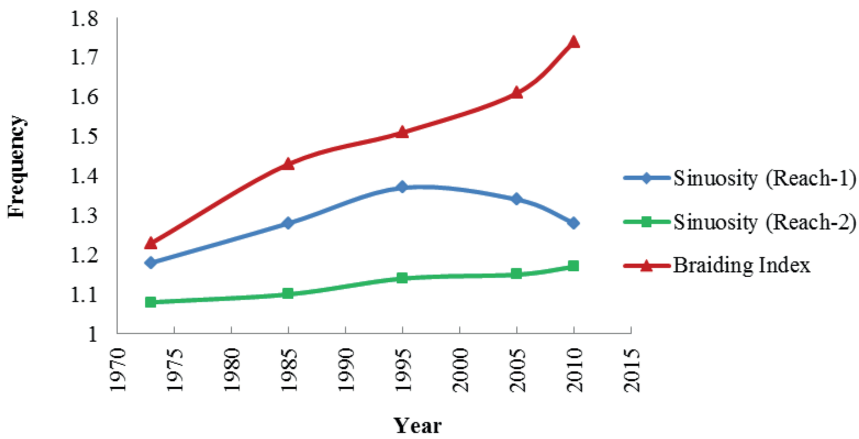

Fig. 6. Sinuosity ratio and Braiding index of the Ganges River during 1973-2010

Рис. 6. Степень извилитости и индекс ветвления р. Ганг за период 1973-2010 гг.

Water level and long profile analysis

Water level gauging stations at different locations along the Ganges River namely Gualanda transit, Urakandi, Mahendrapur, Sengram, Satbaria, Kalyanpur, Talbaria, Dadpur, Hardinge bridge, Samadia, Ruppur, Sardah, and Rampur Boalia have been used for the analysis. The combined long profile of the Ganges River from Gualanda transit ot Rampur Boalia showed that average water level in the month of October and November changed significantly in between 2003 and 2010 (Fig. 7).

In 2003 (during October and November) in some locations — including Satbaria of Sujanagar upazila in the Pabna district, Kalyanpur of Kumarkhali upazila and Dadupr of Mirpur upazila in the Kushtia district, and Samadia of Bagha upazila and Ruppur of Charghat upazila in the Rajshahi district — had the water level about 6.0 m. On the other hand, in case of 2010 (during October-November) the situation was much worse. On average the water level in the aforementioned locations was about 6.5 m, and the lowest average water level was found at the Ruppur of Charghat upazila in the Rajshahi district — it was about 4.5 m. Fig. 8 also shows that in 2003 in January and February (a minor peak season of Hilsa spawning) the water level in some locations (like Satbaria of Sujanagar upazila in the Pabna distict, Kalyanpur of Kumarkhali upazila and Dadpur of Mirpur upazila in the Kushtia district, and Samadia of Bagha upazila and Ruppur of Charghat upazila in the Rajshahi district) were much more lower than the threshold (10 m), and on average it was below 2 m. Compared to the average water level of the respective months (January-February) of 2010 with 2003 at same locations, it was

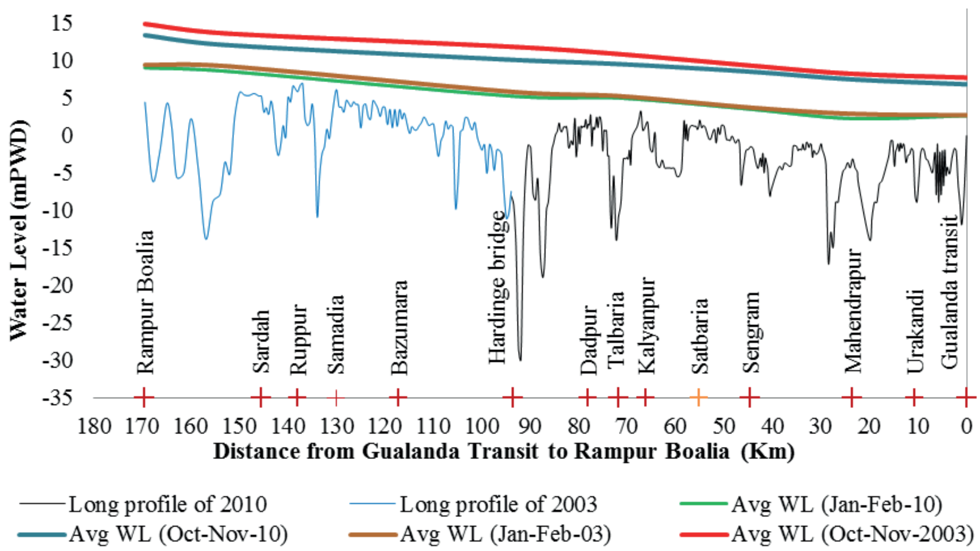

Fig. 7. Showing the long profile of the Ganges River with average water level (January-February and October-November) at different station in 2003 and 2010

Рис. 7. Длинный профиль р. Ганг со средним уровнем воды (январь-февраль и октябрь-ноябрь) на различных станциях в 2003 и 2010 г.

seen that the average water level in all stations along the Ganges River was lower (< 2 m) than the water level of January-February in 2003.

There was no significant change of the average water level between 1960s (pre-Farakka) and 1980s (post-Farakka), but a significant change in the average water level of October-November (wet season) occurred in 2000s (Fig. 8), that was, probably, due to the lower precipitation and some sorts of human interventions in the gangatic delta regions of Bangladehs associated with operation of the Farakka barrage.

Fig. 9 illustrates that during the dry season (January-February) there was a significant change in the average water level in the Ganges River over time. Dry season water level fell rapidly during the post-Farakka period (1980s and 2000s), compared to the pre-Farakka period (1960s). It was also found that in between the operation of the Farakka and Ganges Water Treaty (signed in 1996 between India and Bangladesh) the dry season water level was found to increase a little more in the upstream region, compared to the downstream region, but it was still much lower than the pre-Farakka period (1960s). This analysis also shows that the average water level of two respective months (January-February) in the post-Farakka period at different stations along the Ganges River was found to be at least 2 m lower than the pre-Farakka period (1960s).

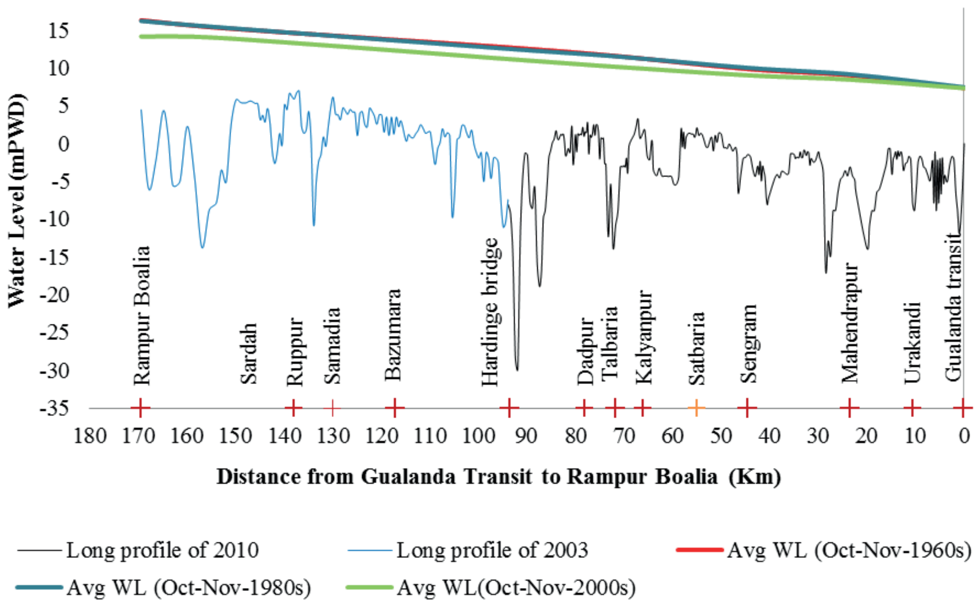

Fig. 8. Combined long profile (2003 and 2010) with average water level (october-november) at different station between pre-farakka (1960s) and post-farakka (1980s and 2000s)

Рис. 8. Комбинированный длинный профиль (2003 и 2010 г.) со средним уровнем воды (октябрь-ноябрь) на различных станциях в период до возведения дамбы Фаракка (1960) и после (1980-е и 2000-е гг.)

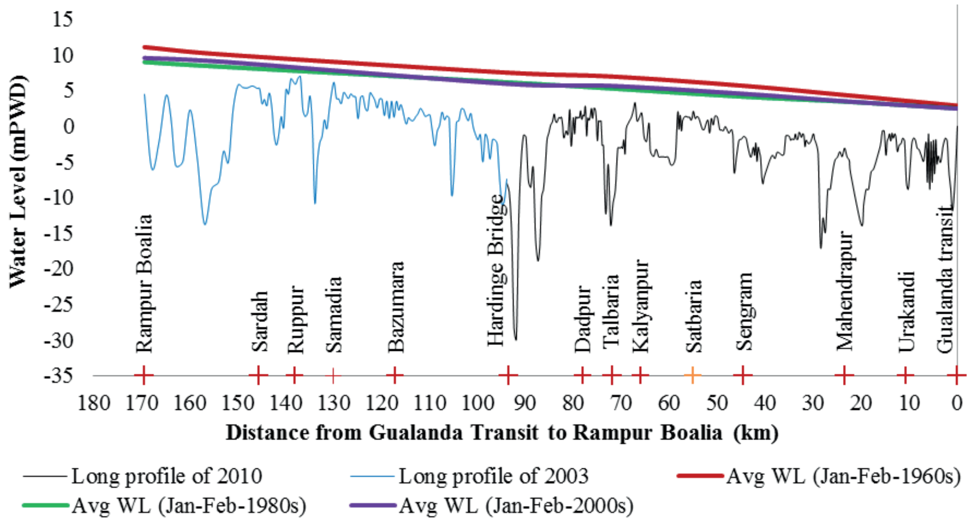

Fig. 9. Showing the combined long profile (2003 and 2010) with average water level (January-February) at different station between pre-farakka (1960s) and post-farakka (1980s and 2000s)

Рис. 9. Комбинированный длинный профиль (2003 и 2010 г.) со средним уровнем воды (январь-февраль) на различных станциях в период до возведения дамбы Фаракка (1960) и после (1980-е и 2000-е гг.)

Catch Per Unit Effort (CPUE)

The historical analysis reveals that *Tenualosa ilisha* is one of the dominant fish species of Ganges, and that once was it mainly abundant to the upstream regions. In the present study the Hilsa migration (as well as the decreasing trends of Hilsa catch in some areas, where Hilsa was once abundantly found) has been investigated by interviewing the fishermen. Around 6 sites (the villages Kathatlbaria, Horisonkorpur, Chock Muktarpur, and Yousufpur in the Rajshahi district; Dhuplia and Roghunatpur in the Manikganj district) have been visited, and 150 fishermen have been interviewed, most of whom were engaged in fishing all the year round in Ganges. Over 95% of professional fishermen in the all study sites stated that fish catch and its abundance decreased year by year, or even day by day, in the Ganges River due to commissioning of the Farakka barrage in 1975 in the upstream of the river (West Bengal in India) and due to shifting of the river's channel.

It has also been reported by the fishermen that the growth of the Char island within the main channel and the formation of many multi-channels decreased the overall width of the single channel — another reason for the decline in Hilsa migration and catch in the study areas.

Catch Per Unit Effort (CPUE) of Hilsa (in the upper Ganges in Bangladesh) in the pre-Farakka period (1960s) was more than 50 kg boat-1 day-1, which dropped from 13.57 kg boat-1 day-1 in 2000 to 18.75 kg boat-1 day-1 in 1985 (Fig. 10).

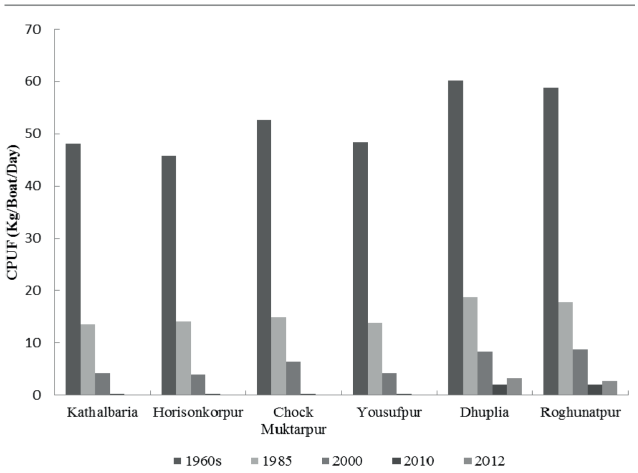

Fig. 10. Catch per unit effort (kg/boat/day) of Hilsa in study areas

Рис. 10. Улов на единиуц усилия (кг/лодка/день) индийской тенуалозы в исследуемых районах

The average catch decreased gradually in a significant manner. At present the mean CPUE of Hilsa declined more drastically in all the study areas, but the decreasing trend is more noticeable in the upstream region. In 2010 the mean CPUE of Hilsa in the upstream and downstream was 0.22 and 1.99 kg boat-1 day-1, respectively, compared to the 0.12 and 2.91 kg boat-1 day-1 in 2012 at the same areas. However, in 2012 the mean CPUE in the downstream slightly increased from 1.99 to 2.91 kg boat-1 day-1 (Fig. 10).

Discussion

Dams, barrages, or any other infrastructure on a river can block the natural route or delay the upstream fish migration [8: 16-21], thus contributing to the decline (or even extinction) of the species that depend on the longitudinal movements along the river during certain phases of their life cycle, by altering the aquatic habitat, which supports all their biological functions [2: 1119-1132; 29: 185-192; 31]. Dams or barrages on a river indirectly affect the fish population structure and assemblages both upstream and downstream by varying the water discharge regime and water quality [31].

Our study demonstrates that the average water level of the Ganges River has significantly changed since the pre-Farakka (1960s) till post-Farakka (1980s and onward) period, which was much lower than the threshold (10 m) value, probably, due to the dry season water withdrawal at the Farakka barrage, associated with the lower precipitation during monsoon due to the climate change and global warming. Adel and Pine Bluff [1: 83-93] found that after 1975 (post-Farakka period) India has reduced the Ganges discharge through Bangladesh to 40% from its original annual average discharge of 223 m^3s^{-1} by diverting the water for irrigation in its upper state. The water supply in the dry season has been reduced substantially in the Ganges River [32]. The present study also clearly indicates that the dry season (January-

February) water level of Ganges solely depends on the discharge of the Farakka barrage, and it directly affects the migration of the Hilsa fish in the Ganges River of Bangladesh. Therefore, this findings lead us to conclude that the Farakka barrage acts as a physical barrier for the long movement of the Hilsa fish from the Bay of Bengal to the Ganges River system (Bangladesh to India and vice versa), which has seriously affected their abundance. Similar findings have also been obtained from the Indian part, as two recent studies report that the upstream migration of Hilsa into Hoogly-Bhagirati and other rivers is greatly hampered by commissioning of the Farakka barrage [12; 36: 46-51].

The sinuosity ratio and the braiding index of a river give a clear overview of the shifting pattern of the river course and the formation or multiplication of the river channel over a period of time. In case of the braiding index, a value higher than 1.5 indicates the changes of the main channel of a river as well as the development of the char or island within the river channel. Comparing the sinuosity ratio and the braiding index, the present study indicates that the changing rate of the braiding index is more than the sinuosity ratio, and it was prominent in the upper reach of the Ganges River. Temporary sediment blockage by the Farakka barrage may have caused an increase in sinuosity ratio at the upper reaches of the Padma River or the meandering bend [44: 669-675]. On the basis of the changing trends of the sinuosity ration and braiding index of the Padma River it can be concluded that this river is dynamic, and it changes its course over time. The situation is similar in India as an Indian study also indicates, that the Farakka barrage, besides blocking the migratory route, also decreases the water flow requirement for Hilsa spawning and migration [12].

As an anadromous fish, Hilsa (*Tenualosa ilisha*) completes its life cycle through migration in various water bodies (sea water — estuary — fresh water). Some factors directly affect the Hilsa migration behaviour in inland water in respect to the river morphology. These are the river depth, water flow, river channel shifting, as well as other river dynamisms. The Ganges River (locally known as the Padma River) is one of the major rivers that harbors many fish species.

CPUE of Hilsa has significantly decreased over time. This findings are also similar to the average catch in the Indian part of the Gangeas River, Bhaumik and Sharma [12] also point out that once Hilsa catch at Allahabad, India, had a significant contribution to the total Indian catch, but now the catch is very insignificant at that point due to the Farakka barrage. There is almost no Hilsa in the upper Ganges parts, Delhi and Kanpur. These results reveal that the Farakka barrage has an enormous negative impact on the upstream migration of Hilsa from Bay of Bengal, and, therefore, the Hilsa catch in the Ganges River dropped significantly both in Bangladesh and India. The fishermen of the respective villages downstream of the river stated that the effective management of the Hilsa fishery in the previous year (2011) during the ban period was the main reason of slightly increased CPUE of Hilsa in theses areas.

The analysis of the secondary data regarding the Ganges River shows that the water level of the Ganges River has been decreasing year by year due to the dry season (January-February) water withdrawal at the Farakka barrage. The long profile of Ganges with the average water level in both October-November (wet season) and January-February (dry season) divulged that the average wet season water level did not significantly change due to the Farakka barrage, but a huge change was observed during the dry season, when the fishermen of the upstream region (mainly the fishermen of Rajshahi along the Ganges River) caught little to no Hilsa in their areas. The siltation of the river bed decreased the overall water depth of the Ganges River and increased the depth of the bed profile, and it was even more prominent in Ruppur, Samadia, Dadpur, Kalynpur, and Satbaria. As a result, it hampered the fish migration from downstream to upstream and vice versa due to the low water level and increasing river bed.

It has also been established that the migration route of the fish species changed because of the dam constructions, which can create spawning difficulties [18: 522-528]. For instance, in China, the research of Xie et al. [43: 343-344] demonstrated that the production of Chinese major carps has decreased due to the construction of the three Gorges Dams, which are considered as the largest hydropower project in the world. The Fraser River basin of Canada is the largest Pacific Salmon producing system of the world. However, the salmon stock (especially Sockeye salmon) declined significantly in the Fraser River basin in Canada due to the construction of several temporary dams in the late 19th and early 20th century. To rebuild the stock, the International Pacific Salmon Fisheries Commission (IPSFC) was formed in 1937, which allowed constructing the fish passage facilities to ensure the migration activities of salmon. After that initiative, the salmon stock regenerated, and the catch also increased [20: 141-159]. We can also look at the Columbia River basin in the USA, which is a classic example of reducing the production of migratory fish species (especially salmon) due to commissioning of several dams. The catch of salmon sharply declined. Having realized the negative impact of dams on salmon production, the USA government spent more than US $7 billion to save historically large runs of salmon in the past 30 years. The effort included several technological measures (e. g. setting up fish ladder, effective fish passage facilities for downstream migrating juvenile salmon, voluntarily spilling water to decrease the number of downstream migrants that pass through turbines, etc.) However, according to Williams (2008), these initiatives may keep salmon stocks from going extinct, but the technological measures will not likely provide complete mitigation for altered freshwater ecosystems by high-head dams [40: 241-251].

The tagging experiments conducted by CIFRI revealed that Hilsa from Bhagirathi-Hooghly riverine system could not move across the barrage due to the obstruction of the three tier sluice gates, and the fish lock provided in Farakka barrage is also nonfunctional [12]. Therefore, it is necessary to design and install effective fish passing devices (especially for salmon) like Frasier or Columbia River systems to ensure the upstream and downstream migration of Hilsa. Opening of the barrage during the migratory season is also one of the options to enhance the Hilsa stock. However, it should not be ignored that the socio-economic condition in the Ganges basin is not similar to such of the USA, Canada, or Europe. Therefore, adequate biological and socio-economical researches are essential to find out, what measures could best suit the South-East Asia context. Like IPSFC, a similar initiative could be taken by Bangladesh — India — Myanmar by establishing International Indian Shad Fisheries Commission for joint management action, research, data sharing, and surveillance.

The fishing community in the South-East Asia is basically a poor and the most disadvantaged group of the society, as they have less human and financial capital to switch to other jobs. It is anticipated that the climate change will have an enormous impact on fish abundance in open water fisheries. Moreover, the human interventions like establishing dams and barrage are also the prime reasons for the capture fisheries decline. Therefore, millions of fishers in this part are vulnerable, and their livelihoods are at risk. The Hilsa fishers of Bangladesh and India are facing tremendous pressure due to the sharp decline of catch caused by barrages and dams. The Farakka barrage is not the only barrage in Ganges: India has established other dams (like Tehri Dam and Bansagar Dam) in the upper tributaries of Ganges, and the construction of other 14 large dams has already been proposed [42]. Therefore, millions of fishers in India (e. g. Uttarakhand, Uttar Pradesh, Bihar, Madhya Pradesh, and West Bengal) are struggling with their livelihoods as there is a sharp decline in other fishes as well (e. g. major and minor carps rui, mrigal, and punti) due to migratory obstacles, hydrological and other changes associated with large scale water diversions through Upper Ganga, Middle Ganga, and Lower Ganga by several barrages and canals [17]. For instance, CIFRI (Central Inland Fisheries Research Institute, India) estimated that during the post-Farakka period, the yield of Hilsa from river dropped about 90% [12]. In Bangladesh the yield from the Padma River (Bangladesh part of Ganges) now is almost zero (dropped from 50 kg boat-1 day-1 in 1960s to about 1.0 kg boat-1 day-1 in 2012).

There is a record of dams over the globe [30: 4]. According to Workman [41: 8-9], globally there are now about 50,000 dams exceeding 15 m in height. Many new dams are planned or under construction [42]. Dam building is booming in India, China, Thailand, Myanmar, Vietnam, and many other South-East Asia countries. China has constructed several dams in Brahmaputra River, and India is also moving forward to do so. Another largest riverine system of the world, the Mekong River, has seen those as well especially since late 1970s. Currently, there are 20 operational dams and more than 40 dams under construction or being planned in the tributary systems of the four lower Mekong countries [6: 227-234], and 150 more potential dam sites have been identified [7] for the purpose of hydroelectricity production and irrigation. However, the negative impact of dams on river ecology and fisheries should not be ignored. Globally most dams have been constructed in the USA (especially in the last century), however, the USA is in the top list of the countries that have removed or considered removing more dams than any other nation. More than 500 dams were removed in the last two decades in the United States [39: 15-22] as dams have an enormous negative impact on river hydrology, ecology, and fisheries. The tragic decline of Indian shad due to the construction of the Farakka barrage could guide the policy makers of the developing nations to think cautiously about managing river by damming, as dams have potential negative ecological and socio-economic impacts. Developing nations could also take a lesson from the developed countries like the USA.

Conclusion

This research attempted to inquiry the hydromorphological dynamics of the Ganges River and its impact on the Hilsa migration and catch in the Ganges River. A minimum water level of 10 m is required for upward migration of Hilsa, though it was found that there was a change of the average water level during the rainy season (October-November) in between the pre-Farakka and post-Farakka period. The average water depth of some places was about 6.5 m. It was also found that during the dry season (January-February) the average water level was below 2.0 m, and even in some locations it was about 0.5 to 1 m, which was not adequate for the upward migration of the Hilsa fish.

Additionally, it was found that Ganges is a meandering river that always changes it channel pattern due to the formation of the meandering bends. That might force the Hilsa fish to change their migratory routes. It was investigated by the several researchers that overfishing of Hilsa fish in the lower Meghna by using several destructive gears (e. g. gill nets, mosquito nets) is another major reason to restrict Hilsa migration to the Ganges River. If the government takes the necessary steps to control the overfishing in the lower Meghna and at the same time dredging in some particular points (like Satbaria, Samadia, Dadpur, Kalyanpur, and Ruppur), the Hilsa will get favorable conditions to migrate to the Ganges River. However, to draw a concreate conclusion about the dredging, a more vigorous research on several aspects of Hilsa fisheries (e. g. physiological, behavioural, economical, ecological) is required.

It is clear that the Farakka dam has impeded not only the upstream spawning journey of Hilsa, but also on its way back to the Bay of Bengal. As Hilsa is the intregal part of the Bangali culture (both for Bangladesh and West Bengal, India), the policy makers of both countries should come forward to conserve Hilsa and protect this particular culinary heritage. Bangladesh-India joint initiative is imperative to revive the Hilsa fisheries in the Ganges River not only for Bangladesh site, but also for the part of the Ganges River above Farakka.

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Хасан ФАРУК[1]
Диуан Али АХСАН[2]
Маминул Хаки САРКЕР[3]
Елена Федоровна ГЛАДУН[4]

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ВЛИЯНИЕ МОРФОЛОГИЧЕСКОЙ ДИНАМИКИ РЕКИ ГАНГ И ДАМБЫ ФАРАККА НА ПОДЪЕМНУЮ МИГРАЦИЮ И УЛОВЫ ИНДИЙСКОЙ ТЕНУАЛОЗЫ (*TENUALOSA ILISHA*) В БАНГЛАДЕШЕ

[1] магистр в области рыболовства,
доцент кафедры рыболовства,
Университет Дакка (Бангладеш)
hasanfaruque28@du.ac.bd

[2] доктор философии,
доцент кафедры рыболовства,
Университет Дакка (Бангладеш)
dah@sam.sdu.dk

[3] доктор философии, заместитель
исполнительного директора,
Центр экологической и географической информации
msarker@cegisbd.com

[4] кандидат юридических наук,
доцент кафедры административного и финансового права,
Тюменский государственный университет
efgladun@yandex.ru

Аннотация

Tenualosa ilisha — самая крупная и наиболее ценная промысловая рыба, рассматривающаяся как символ Бангладеша, хорошо известная в Юго-Восточной Азии как

Цитирование: Хасан Фарук. Влияние морфологической динамики реки Ганг и дамбы Фаракка на подъемную миграцию и уловы индийской тенуалозы (*Tenualosa ilisha*) в Бангладеше / Хасан Фарук, Диуан Али Ахсан, Маминул Хаки Саркер, Е. Ф. Гладун // Вестник Тюменского государственного университета. Экология и природопользование. 2016. Том 2. № 3. С. 34-58.
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индийская шэд (гильза), в настоящее время находится под угрозой исчезновения в связи с антропогенным воздействием и климатическими факторами. Целью данного исследования является оценка влияния дамбы Фаракка и морфологической динамики реки Ганг на миграцию индийской шэд и ее уловы в Бангладеше. Результаты исследования показали, что средний уровень реки Ганг во время сезона размножения гильзы за исследуемый период значительно снизился. Ситуация становится еще более проблематичной в некоторых конкретных точках, таких как Сатбария, округ Пабна, Дадпур и Калянпур, округ Куштия, Раппур и Самадия, округ Раджшахи, где уровень воды (6.5-8 м) намного ниже порогового значения (10 м). Результаты исследования также показали, что река Ганг становится более динамичной, т. к. изменения ее ширины и изгибов в исследуемый период были достаточно частыми, кроме того, установлено, что река становится более изменчивой в верхнем течении, чем в нижнем. Снижение уровня воды и частые изменения изгибов реки могут привести к изменениям в миграции индийской гильзы, в частности, ограничить подъемную миграцию вида в верхнем течении реки Ганг. В результате вылов гильзы в Ганге уже значительно снизился (до 1 кг на промысловое усилие в день в 2012 г. по сравнению с 50 кг на промысловое усилие в день в 1960-х гг.), а в некоторых районах в настоящее время вылов фактически отсутствует.

Ключевые слова

Морфология реки Ганг, миграция индийской гильзы, промысловый вылов, коэффициент извилистости, индекс каналов/перекрытий на трансекте по течению реки.

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