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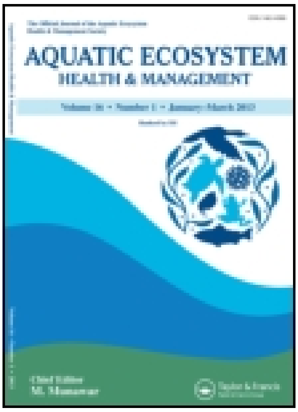

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Impacts and vulnerability of inland fisheries to climate change in the Ganga River system in India

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Climate change is evident in India as manifested by increased air temperatures, regional variation in the monsoon, frequent occurrence of droughts, and a regional increase in severe storm incidence in coastal states of India. The impacts are evident for freshwater fisheries and fishers of the River Ganga and the water bodies in its plains and deltaic areas. Analysis of time series data for 32 years from published literature and from current investigations showed a 0.99°C increase in the minimum water temperature recorded in the upper stretch of River Ganga and 0.5 to 1.4°C increases in aquaculture water on the Gangetic Plains of West Bengal. The minimum air temperature showed a 15% shift upwards during the colder months of January–February. Rainfall showed a 1% increase in the post monsoon months of September–December. The impacts were manifest in a geographic shift of warm water fish species such as Glossogobius giuris, Xenentodon cancila *into the colder stretch of the River Ganga. The breeding of the Indian Major Carps (IMC) has been affected and a consequent decline in fish spawn availability in River Ganga recorded. However a positive impact on breeding in fish farm hatcheries in the Gangetic Plains was evident in the advancement and extension of the breeding period for IMC by 45–60 days. Drought in West Bengal during 2009 was evident in rainfall deficits of 29% and 27% in the districts of North 24 Parganas and Bankura, respectively, in the fish breeding months of March–September and 92% of fish spawn hatcheries were affected. These districts recorded losses on average 61% to 73% of fish spawn during 2009 compared to the previous four years. A study of the potential impact of cyclones and storms on saline water inundation using a digital elevation model generated for coastal district of South 24 Parganas indicated the potential for 3% to 11% submergence of aquaculture areas in response to 1 to 2 meter rises due to sea water incursions. The inland fisheries sector in coming years will face stiff competition for water from the industrial, municipal and agricultural sectors and climate change will compound these problems. Under such a scenario implementation of integrated water resource management involving different stake holders of fresh water would be the most effective management approach.*

Keywords: River Ganga, temperature, rainfall, geographic distribution, fish breeding, drought, cyclone, vulnerability index, adaptation

Introduction

Changes in the climate of the earth have become evident both on global and regional scales in the past few decades. Changes in India's climate have been summarized (Anonymous, 2004) and some of the changes relevant to inland fisheries are: (i) an increase of 0.4°C in surface air temperatures over

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the past century at the national level; (ii) a trend of increasing monsoon seasonal rainfall along the west coast, in the northern state of Andhra Pradesh, and in north-western India (+10% to +12% of the normal over the last 100 years) matched with a trend of decreasing monsoon seasonal rainfall over eastern parts of the state of Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala states (−6% to −8% of the normal over the last 100 years); (iii) a trend of multi-decadal periods of more frequent droughts, followed by less severe droughts and an overall increasing trend in severe storm incidence especially along the coast of the states of Gujarat and West Bengal at the rate of 0.011 events per year and a rising trend in the frequency of heavy rain events; (iv) a rise in sea level between 1.06–1.75 mm per year (Unnikrishnan and Shankar, 2007) consistent with 1–2 mm per year global sea level rise esti-mates of IPCC; and (v) indications of recession in some of the Himalayan glaciers, the main source of water for perennial rivers such as Ganga, Indus and Brahmaputra, though the trend is not consistent across the entire mountain chain.

India has 12 major rivers, with a total catchment area of 252.8 10^{-6} ha. Another 48 rivers are classified as medium rivers, whose total catchment area is 24.9 10^{-6} ha. The total annual discharge in the rivers that flow in various parts of the country amounts to 1869 km^3. Many of these rivers are perennial, though a few are seasonal. This is because precipitation over a large part of India is strongly concentrated in the summer monsoon season from June to September/October and the tropical storm season from May to October (Kale, 2003). In the Indian context the average water yield per unit area of the Himalayan rivers, for e.g. Ganga and Brahmaputra, is almost double that of the south peninsular river systems for e.g. Godavari and Cauvery, indicating the importance of snow and glacier melt contributions from high mountains. The average intensity of mountain glaciation varies from 3.4% for Indus to 3.2% for Ganges and 1.3% for Brahmaputra as a whole. However the maximum intensity of glaciation is seen in the tributaries of these river systems (Mall et al., 2006).

The Gangetic River system, India's largest, harbours about 265 species of freshwater fish and supports a complex mix of artisanal, subsistence, traditional and semi-intensive culture fisheries based on the main river and adjoining water bodies of the Gangetic Plains situated mainly in the three Indian states of Uttar Pradesh, Bihar and West Bengal (Vass et al., 2009). Given likely climate warming scenarios, water problems in the Ganga River basin will increase and may be critical in terms of the ecosystem goods and services derived from the inland water bodies via fisheries. Balancing the needs of the aquatic environment and other users may become difficult in many of India's aquatic ecosystems as population and associated demands increase (Das, 2009).

Given the evidence of climate change, two assessments of the impact of the climatic changes on inland fisheries were undertaken: (i) Analyses of the time-series data on climate variables, air and water temperature for the last three decades and of the extreme events like the 2009 drought in the Ganga River basin and their impact on the fishery of River Ganga and on aquaculture in its plains; and (ii) Analysis of the potential impact of sea level rise and inundation during cyclones on aquaculture facilities of the Gangetic Delta of West Bengal.

Materials and Methods

Study area

The areas assessed included: (i) the entire length of River Ganga (2,525 km) consisting of the upper stretch from (Tehri to Kannauj), the middle stretch (Kanpur to Patna) and the lower stretch (Sultanpur to Katwa); (ii) fish hatcheries in 4 districts viz., North 24 Parganas, Bankura, Burdwan and Hooghly of Gangetic Plains of West Bengal; and (iii) aquaculture water bodies of a coastal district South 24 Parganas (Sunderbans) of Gangetic Delta of West Bengal.

Time series data on various aspects of climate and inland fisheries related to the Ganga River system and of the aquaculture water bodies in its plains viz. air temperature, water temperature, rainfall, plankton availability, availability of spawn, fish landings etc. were collected by consulting approximately 200 scientific papers, CIFRI Annual Report (1965 to 2009), Reports of Central Pollution Control Board on water quality of Ganga, Handbook of Fisheries Statistics, Government of India, data of IIMT, Pune, and from other published literature on the River Ganga system. Statistical analyses were done to evaluate the impact of climate variables on inland fisheries and fishers in the River Ganga, and in the fish culture farms located in the plains and deltaic areas of West Bengal.

Drought impact study

A survey based on a structured questionnaire was developed to cover fish spawn hatcheries in West Bengal the highest fish spawn producing state of India. A random sample of 50 operative hatcheries in the districts of Bankura and North 24 Parganas in South Bengal were surveyed, with 34 hatcheries responding to the survey. Several responses that did not fit our objectives with respect to size and species of fish cultured, etc. were rejected and 27 responses were analyzed, representing 54% of the sample of the West Bengal State fish spawn industry and constituting all major fish spawn production centers in the state. The survey questionnaire covered aspects of fish brooder species, brooder management, techniques of breeding, breeding season, duration, spawn price during breeding season and marketing. Comparisons were made for the various parameters in the hatcheries during the survey year 2009 with previous years 1999–2008.

Cyclone impact study

The water resources of the coastal district South 24 Parganas of Gangetic Delta of West Bengal were assessed. LISS III images of IRS 1D were used to delineate the water bodies of the districts. Initially, images were geo-referenced with the help of SOI topographical sheets on the scale of 1:50K. TNT MIPS 7.2 (developed by Microimage Inc., USA) software was used for the image processing and GIS analyses. Feature mapping (supervised classification) techniques were used for extracting water feature from the imagery. Extracted water feature rasters were converted into vectors and water areas were estimated using the software's built-in routines. Each pixel of LISS III image represents $\approx$576 m^2 depending on the position of pixel relative to the nadir. Water areas which were represented by less than 9 pixels were considered as a noise in the data-processing and those features deleted from the database.

To assess the impact of cyclonic events on coastal areas of the district a Digital Elevation Model (DEM) were generated with the help of SRTM (shuttle radar topography mission) data which were downloaded from USGS site. SRTM provide global elevation data at up to 30 m (1 arc-second) resolution. Images were resampled by cubic convolution and converted into contours at 1 m intervals using the TNT MIPS software. Areas were estimated for each contour interval.

Results

Impact on aquatic resources

Changes in temperature and rainfall pattern in the Ganga basin

Analysis of monthly rainfall data of the middle stretch of the River Ganga at Allahabad from 1979–2009 was split into three equal periods (January–April), (May–August) and (September–December) and revealed the percentage of total rainfall in the peak breeding period (May–August) declined by 7% while it increased by 4% (Figure 1) in the post-breeding period of Indian Major Carps (IMC) the most important commercial fishery in the river.

Water temperature changes in the upper stretch of River Ganga

The annual mean minimum water temperature in the upper colder stretch of River Ganga at Haridwar during the period 1980–2009 increased by 0.99°C (Figure 2). As a result, the stretch of River Ganga around Haridwar has become a more congenial habitat for warm water fishes of the middle stretch of the river.

Pattern of air and water temperature and rainfall changes in Gangetic Plains (West Bengal)

In India temperature typically increases at the end of the winter months, January-February, through spring and finally to summer from the months of April–May. This increase in temperature occurs suddenly within a short period of time.

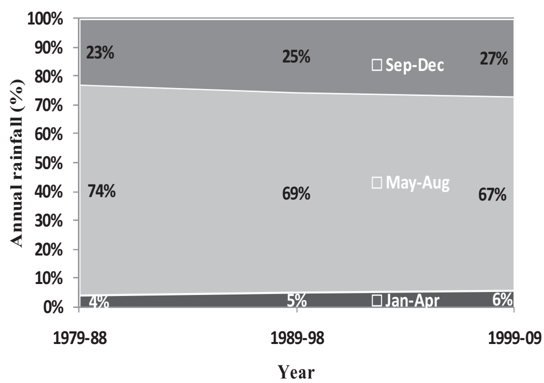

Figure 1. Shifting seasonal pattern of rainfall at Allahabad during 1979–2009.

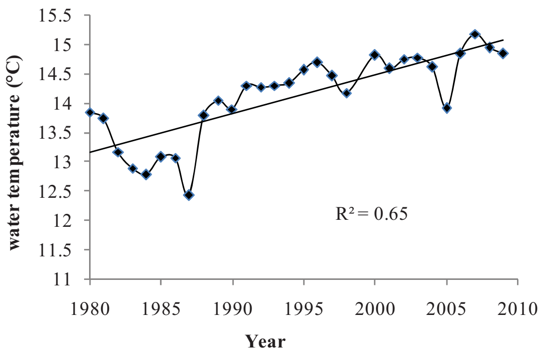

Figure 2. Annual trend in mean minimum water temperature at Haridwar (1980–2009). (Color figure available online.)

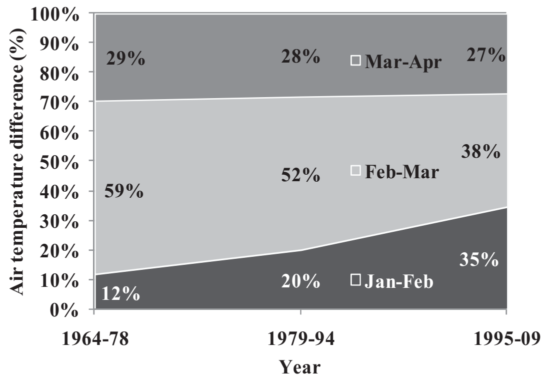

Figure 3. Shift of temperature at 24 Parganas (N) from 1964 to 2009.

The months January to April are the transition months from winter to summer. Analysis of the air temperature data (IMD, 1980–2009) during the breeding months of the Indian carp fishes i.e. (April-August) from four districts in the Gangetic Plains of West Bengal where aquaculture hatchery farms are located indicate that the mean minimum air temperature increased by 0.67°C in the 24 Parganas (N) districts and by 0.1°C in district Bankura.

The differences of temperature between the months January–February, February–March and March–April during the period 1964–2009 indicated a shift towards higher temperature during January–February months. The frequency of occurrence of (4°C and above) difference of temperature between the three consecutive months was taken as a basis for evaluating the shift of elevated temperature towards cooler months January–February. Analyses revealed that the frequency of occurrence of these temperature differences was at a maximum in February–March (avg. 55%) and March–April (avg. 28%) during previous three decades (1964–1994). But, such a trend was not evident in the recent one and a half decade (1995–2009) where the frequency of occurrence of (4°C and above) difference in minimum temperature shift towards colder months i.e. January–February (from 20% to 35%); February–March (from 52% to 38%) and March–April (from 28% to 27%) (Figure 3). This corroborates Vass et al. (2009) regarding increased temperature during the colder months of January – February

Since rainfall is another important factor triggering the early maturation of brood fish the rainfall data (1980–2009) of the district, 24 Parganas (N) collected by IMD Pune were analysed. It showed that the proportion of annual total rainfall occurring in the monsoon months (May–August) was 68% during 1980–89 and gradually decreased to 63% during 1990–1999 and also during 2000–2009 and increased in post monsoon months (September–December) from 24% during 1980–1989 to 28% during 1990–1999 and 29% during 2000–2009 at Dumdum, 24 Parganas (N) (Figure 4). Similar pattern of rainfall distributions were observed at Alipur (Figure 4) district of West Bengal during 1980–2009.

Temperature and rainfall pattern during drought in West Bengal (2009)

The air and water temperature data (IIMT Pune) of 24 Parganas (N) West Bengal for the period 1999–2009 analysed indicated that the mean maximum air temperature increased by 1.98°C in the months January to April and 1.42°C in May to September during 2009 as compared to the average temperature of these months between 1999–2008 (Figure 5). The mean minimum air temperature increased by 0.37°C and 0.58°C in January to April

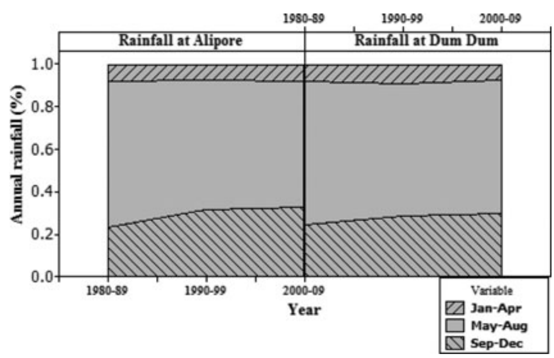

Figure 4. Shifting seasonal pattern of rainfall at Alipur and Dum Dum during 1980–2009.

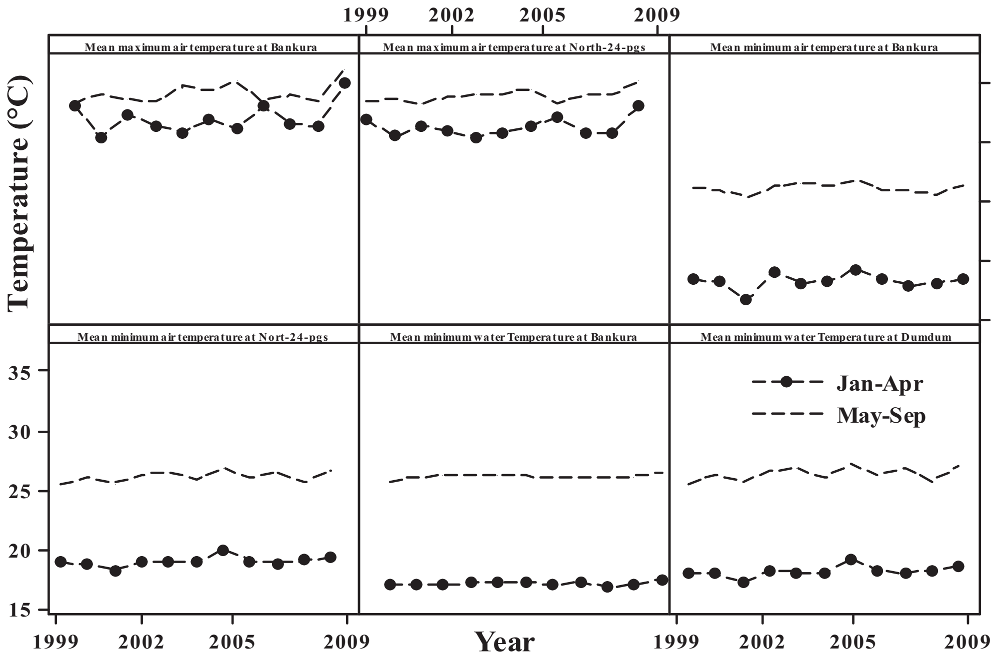

Figure 5. Temporal variation of annual mean air and water temperature for the districts of West Bengal during 1999–2009.

and May to September respectively during 2009 as compared to the previous years (Figure 5).

The mean minimum water temperature in 24 Parganas (N) (Dum Dum) during 1999–2009 increased by 0.55°C during January–April and by 1.4°C during May–September (Figure 5).

In Bankura district the mean minimum air temperature increased by 0.40°C and 0.34°C in January to April and May to September respectively during 1999–2009 (Figure 5). Mean maximum air temperature increased by 1.36°C between January to April and 1.22°C in May to September (Figure 5).

In Bankura district the mean minimum water temperature during 1999–2009 increased by 0.46°C during January–April and by 0.39°C during May–September (Figure 5).

Pattern of rainfall during drought in West Bengal (2009)

Analysis of the rainfall data (IMD Pune) of West Bengal for the period 1999–2009 indicated that during the year 2009 the amounts of rainfall in several months deviated from the 1999–2008 mean: March was 20.6 mm (−25%), April −2.0 mm (−96%), May −229.2 mm (+146%), June −69.6 (−71%), July −278.7 (−11%), August −329.6 (+6%) and September −293.9 (+9%) respectively. In the district of North 24 Parganas (Figure 6) and Bankura (Figure 6) rainfall during the fish breeding months (March–September) was decreased by 29%, and 27%, respectively during 2009 in comparison to the time period 1999–2008. The majority of the fish hatcheries studied are located in these districts.

Impact on fish

Breeding and recruitment of fish in River Ganga

The fish spawn availability index declined from an average of 1529 ml during (1965–1969) to an average of 568 ml in recent years (2005 to 2009) (Figure 7) (Natarajan, 1989; CIFRI Annual Report, 1965–2009). It also showed a continuing decline of IMC spawn with decreasing percentage of major carp spawn (46% in 1965–1969 to 10% in 2005–2009) whereas other fish spawn increased from 54% in 1965–1969 to 90% in 2005–2009 in the total spawn collection.

The majority of fishes of the Ganga River system breed during the monsoon months, i.e. June to August, because of their dependence on seasonal floods, which inundate the Gangetic floodplain areas essential for reproduction and feeding. The monthly data of rainfall from the middle stretch of the river at Allahabad from 1979–2009 revealed that the percentage of total rainfall in the peak breeding period (May–August) declined by 7% whereas it increased

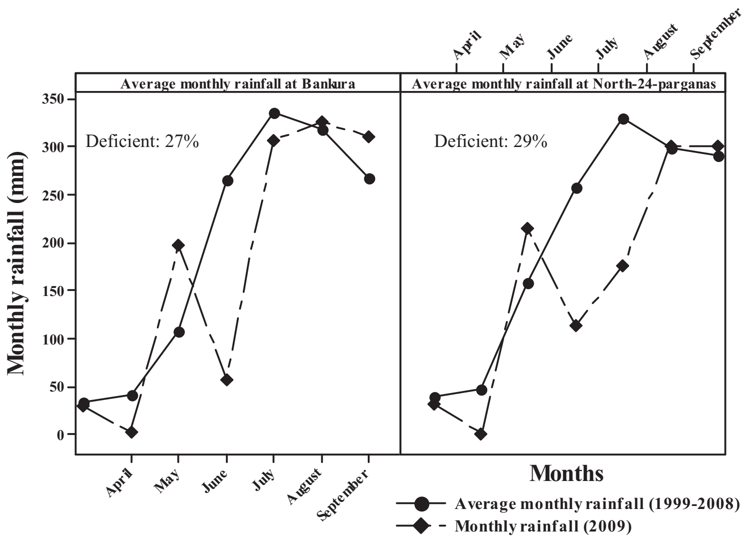

Figure 6. Averages rainfall distribution during 1999–2008 compare with 2009 for deficit in rainfall of Bankura and North 24 Paraganas districts of West Bengal.

by 4% in the post- breeding period when resorption of eggs of IMC sets in (Figure 1). This shift and decrease in the rainfall pattern compounded by the abstraction of water in the river Ganga has resulted in the alteration of the required flow and turbidity during the breeding season and are the major factors responsible for the failure in breeding and consequent recruitment of young ones of IMC in the River Ganga. An adequate flood level during the monsoon months (June–September) is required in the River Ganges to inundate the floodplains where the majority of the Gangetic carps breed. This phenomenon has a close relationship with the spawn availability in river (Natarajan, 1989). Similar declines in availability of Asian carp spawn as a result of breeding failure due to inadequate water discharge and velocity was recorded in Yangtse River in China (Duan et al., 2009).

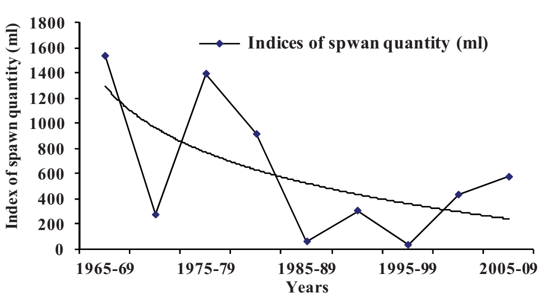

Figure 7. Indices of spawn quantity in middle stretch of River Ganga from 1965 to 2009. (Color figure available online.)

Breeding of fish in aquaculture farms in West Bengal

The aquaculture hatcheries in the state of West Bengal extensively breed the IMC, *C. catla, L. rohita* and *C. mrigala* which forms the mainstay of inland aquaculture in the country. These fishes are bred in captivity by the technique of hypophysation during the monsoon season (June–September). In recent decades the phenomenon of IMC maturing and spawning as early as March has been observed. The average minimum and maximum temperatures throughout the state have increased and rainfall patterns have changed. Analysis of the air temperature data (1999–2009) recorded by IIMT Pune, during the maturing and breeding months of Indian carps i.e. January–April and May–September from two districts North 24 Parganas and Bankura, West Bengal in the Gangetic Plains of India where aquaculture hatchery farms are located indicate that the mean maximum and the mean minimum air temperature and the mean minimum water temperature has increased and higher temperature is witnessed during colder months (Figure 3). Data collected from the hatcheries indicate that during 1980 the breeding of IMC started during the last week of May, whereas the 2005–2008 breeding programmes in the hatcheries were initiated during mid April. As a result an extended breeding period of IMC by 40–60 days with breeding season extending from 110–120 days (pre-1980–1985) to 160–165 days (2000–2008) is evident in fifty fish spawn hatcheries in four districts of West Bengal, India viz. North 24 Parganas, Bankura. This is in agreement to our previous findings (Dey et al., 2007). Temperature is one of the important factors influencing the reproductive cycle in fishes. This climatic factor along with rainfall and photoperiod stimulate the endocrine glands which aid the maturation of the gonads of IMC.

Geographic distribution of fish in River Ganga

The study conducted from 2005 to 2009 found several species of fish in the upper cooler stretch of the River Ganga from Deoprayag to Haridwar that had not been recorded previously from this stretch but previously found in the middle warmer stretch of the river (Menon, 1954). These are the warm water fish species: *Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus*. Thus a shift in geographic distribution of the fishes of River Ganga has occurred into the upper colder stretch of the Ganga River. At Haridwar during the period 1980–2009 the minimum water temperature increased by 0.99°C (Figure 2) and created more congenial habitat for warm water fishes.

Impact of drought on breeding and rearing of fish

The impact of deficient rainfall and high temperature during the drought period of 2009 on the fish spawn hatcheries in two districts, Bankura and 24 Parganas (N) of West Bengal, was investigated. These two districts have the highest number of IMC hatcheries. Bankura has 279 hatcheries with a capacity of 13,400 million spawn and North 24 Parganas has 142 hatcheries with a capacity of 5604 million spawn (Handbook on Fishery Statistics, 2009). Of the total number of hatcheries surveyed, 92% of the fish spawn hatcheries were affected by the drought conditions in the state. The results indicated that, 12%, 20%, and 68% of fish spawn hatcheries were affected by low rainfall, high temperature and both low rainfall and high temperature respectively in these two districts.

Fish spawn production in North 24 Parganas district declined from 4532 million in 2008 to 4368 million spawn in 2009 (Handbook on Fishery Statistics, 2009). Hatchery production in Bankura was stable with some hatcheries forced to cease fish breeding for 20–25 days as there were no buyers (Figure 8).

Demand for fish spawn declined drastically along with the selling price of the fish spawn. As a result of scarcity of rainfall the nurseries and rearing ponds had either very little water or were dried up completely rendering them unsuitable for stocking of hatched eggs. During the period 1999–2008 the price of fish spawn during months March–April was Rs. 600/bati but declined to Rs. 450–500/bati in 2009. During the other season the price per (bati) had ranged between Rs. 220–250 previously but declined to Rs. 100–120 per bati during 2009 as there were few buyers (Table 1).

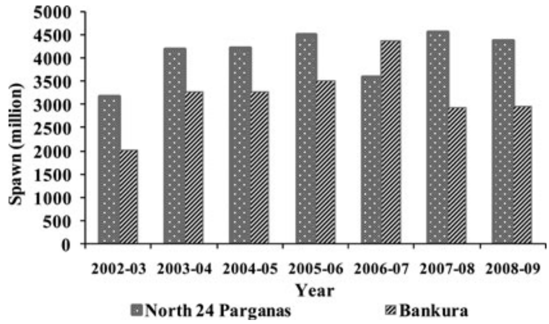

Figure 8. Fish spawn production in districts of Bankura and North 24 Parganas from 2002 to 2009.

Spawn death, breeding failure and low demand for fish spawn, were all considered in assessment of the impact of scanty rainfall and high temperature in these two districts of West Bengal. Among the attributes loss due to spawn death was maximum (45%) in district North 24 Parganas while in district Bankura the maximum loss was due to low demand of fish spawn which was 80% among the other three attributes. In a study conducted in West Bengal by Milwain et al. (2002) high water temperatures was reported as a major constraint for increasing mortality levels in 65% of the hatcheries of North 24 Parganas.

Economic loss

An economic loss analysis in two representative hatcheries viz., Naihati and Ramsagar hatchery (Table 1) from the Bankura and North 24 Parganas districts respectively conducted based on our studies in 2006 and 2009, respectively, indicated loss in income of 61% in Naihati and 73% in Ramsagar during 2009 as compared to 2006.

Potential impact of cyclones on inland fishery resources

Tropical cyclones are major hazards in tropical coastal regions, both in terms of loss of life and economic damage. Many violent severe local storms occur over the Gangetic plain of West Bengal due to "Nor'westers." Such cyclones originate in the Bay of Bengal during the spring (April–May)

Table 1. Comparative pre and post drought monetary return from hatcheries of 24 Pargana (N) and Bankura districts.

Area/Year/Season	Expected Number of Spawn/Set (1)	Average Rate/ Bati (Rs.) (2)	Total Number Sets (3)	Total (In Rs.) (1) × (2) × (3)
Naihati, 24 Pargana (N)				
2006				
Mar–Apr	15 Bati × 75,000	600	16	144,000
May–Sep	60 Bati × 75,000	250	40	600,000
Total Earning				744,000
2009				
Mar–Apr	9 Bati × 75,000	500	16	72,000
May–Sep	45 Bati × 75,000	120	40	216,000
Total Earning				288,000
Ramsagar, Bankura				
2006				
Feb–Mar	9 Bati × 70,000	550	16	79,200
Apr–Sep	90 Bati × 70,000	250	48	1,080,000
Total Earning				1,159,200
2009				
Feb–Mar	6 Bati × 70,000	600	16	57,600
Apr–Sep	60 Bati × 70,000	90	48	259,200
Total Earning				316,800

*Bati: a volumetric measure in cup (bati) 100–135 ml which holds between 30,000 and 75,000 hatchlings depending on the species involved.

and fall (October–November) inter-monsoon periods. These cyclones hit the coastline with tremendous speed and inundate the shores with strong tidal wave, severely destroying and disturbing coastal resources. The intrusion of seawater into the upstream riverine zone through estuaries, creeks and inlets is highly likely to alter the chemical composition of inland waters.

We assessed the potential impact of such extreme events like cyclones and storms in the coastal Gangetic districts of West Bengal. The South 24 Parganas district was selected as it has the highest water area under aquaculture and is the highest fish and prawn producing district in the state.

Investigations were conducted in the water areas of South 24 Parganas during the occurrence of cyclone Aila in May 2009. Due to that cyclone saline waters intruded from the Bay of Bengal into the Hooghly-Matla estuarine system and simultaneously the agricultural fields and inland water areas close to the 81 km coast line of the district 24 Parganas. Investigations revealed the average water salinity in the rivers Hooghly and Matla increased approximately on average of 6 ppt from 12 to 17 ppt and in confined inland waters by an average of 11 ppt from 8 to 23 ppt. As a result agriculture and aquaculture activities were disrupted by saline waters (Das and Sharma, 2010; CIFRI/NPCC Annual Reports, 2005–2011; Mitra et al., 2011; Mukherjee et al., 2012).

Mapping of water resources related to inland fishery in South 24 Parganas district showed 1060 water bodies with an area >0.5 ha. (Table 2). Most of the water bodies were less than 10 ha. Due to limitation of the image resolution imageries the water bodies having area below 0.5 ha could not be delineated.

The potential impact of cyclonic events like AILA on coastal areas of South 24 Parganas district, based on the DEM generated, showed that during cyclones causing sea level rises of 1 to 2 m, 3 to 11% of the land area of the district respectively would be submerged. Thus up to 11% of the land area constituting agricultural fields and aquaculture pond is highly vulnerable to the extreme events of cyclones and storms (Figure 9).

Discussion

It is apparent from the above discussion that climate change can impact the aquatic ecosystems and fisheries already subjected to various anthropogenic stresses. In fact the ecological malady afflicting the inland open water resources and consequent decline in fisheries can be traced to the anthropogenic

Table 2. Delineated surface water area of South 24 Parganas.

	Total			Perennial		
Area class	Number	Max Area	Average Area	Number	Max Area	Average Area
0.5 to 10 ha	895	1899.5	1202.4	263	853.6	684.3
10 to 50 ha	107	2324.7	1585.6	76	1734.2	1290.5
50 to 500 ha	51	7553.4	5885.3	41	6523.6	5370.4
500 to 1000 ha	4	2457.4	1760.8	4	2457.4	1760.8
>1000 ha	3	4064.8	3113.5	3	4064.8	3113.5
Total	1060	18,299.8	13,547.6	387	15,633.6	12,219.5

activities associated with population growth in the river basins. In coming years availability of water will be a major constraint for aquaculture considering its varied users in India. Climate change will increase the potential for aquaculture in some regions and reduce it in others. Thus appropriate adaptation strategies are needed for the inland fisheries sector to cope up with the impending threats.

Adaptations options of inland fisheries to climate change

The metabolic growth and food conversion of IMC, which constitute the main species of fish cultured in India, are negatively affected at water temperatures beyond 34°C. Since increased water temperatures decrease the dissolved oxygen content of water, low oxygen tolerant species like catfishes are essential in the culture system. IMC and the exotic carp *Cyprinus carpio* cultured in India are tolerant of low oxygen conditions but may be physiologically stressed (Dutta et al., 2005).

Loss of fish is the prime concern during floods, thus provision for continuous supply of spawn from

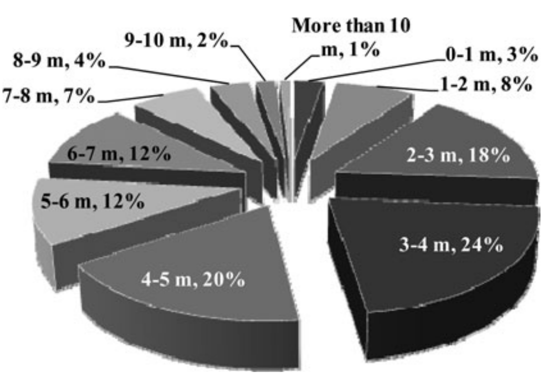

Figure 9. Land submergence (%) under different sea level rise (m) scenario South 24 Parganas.

fish hatcheries is needed. Management practices should promote selection of fish species that require short culture periods and harvesting of fish at smaller sizes.

Smaller ponds that retain water for 2–4 months can be used for fish production with appropriate fish species and appropriate management practices. Over 80% of the hatcheries in West Bengal have shifted from breeding and rearing IMC to other species like, *Puntius javanicus* and *Clariaus gariepinus*, which was comparatively more adaptable to the drought conditions of enhanced temperature and less water in the ponds and have a market demand.

An early warning system for weather events is needed to aid post cyclone management. Fishers in the cyclone prone South 24 Parganas district during post cyclone period are totally dependent on fishing and wild fish spawns collection from the estuary of River Ganga as the only source of income. Due to saline water incursions paddy fields get inundated and become unfit for agriculture. These areas may temporarily be converted into ponds for fish culture with saline tolerant fish species viz. *Mugil parsia, M. tade* and *Lates calcarifer*. It is essential to optimally utilize the normal culture periods and maximize fish production and profit by selecting suitable fish species and appropriate cultural practices.

A seaward green belt should be created by planting of mangrove plants in the inundated areas. This will create in a few years time a widened mangrove fringe protecting the littoral zone of the Indian coastal states, where aquaculture is practiced from cyclonic storms.

In the future, availability of water will be a major constraint for aquaculture considering its varied users. Integrating aquaculture with other practices, including agro-aquaculture and culture-based fisheries, will be useful. Short-cycle aquaculture may also be valuable, using new species or strains and new technologies or management practices to fit into seasonal opportunities.

In India, a sizeable fishermen population depends on freshwater ecosystems for their livelihood and sustenance. Water demands from the industrial, municipal and agricultural sectors will increase substantially with population growth in the coming years. Climate change will compound these problems as far as demand for water is concerned. In such a scenario, implementation of integrated water resource management involving different stake holders of fresh water would be the most effective management approach. It is obvious that the future of fisheries will be shaped by cross-sectoral solutions to the current problems.

Conclusions

From the above discussion it is apparent that climate change can impact aquatic ecosystems and fisheries in India already subjected to various anthropogenic stresses from other sectors. Considering the fact that aquaculture and fisheries have the capacity to buffer society from climate related risks, it is essential to develop appropriate adaptation strategies in harmony with the options adopted by other stakeholders of inland aquatic resources.

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