11

Impacts, Vulnerability and Adaptation of Inland Fisheries to Climate Change in India

MANAS KR. DAS[1]

ABSTRACT

Inland fisheries and aquaculture in India assume a significant role in view of change in temperature and rainfall pattern, breeding and recruitment of fish in river Ganga with special reference to geographic distribution of various species of inland fishes. It has been reported that the annual mean minimum water temperature in the upper stretch of river Ganga has increased by 1.6°C during 1980–2009. The effect of climate change has a great economic impact in fisheries industries as experienced in some of the case studies from the eastern part of India. Efforts have been made to find out the reasons for vulnerability of inland fisheries due to climate change. On the basis of data generated through research various adaptation options have been suggested.

***Key words*:**

1. INTRODUCTION

The year 2010 has been declared as the world's warmest year by WMO and in India the decade ending with 2010 has been declared the warmest decade by Indian meteorologists. Thus the major environmental challenge of 21st century is global warming and the associated climatic change. Climate change is projected to impact broadly across ecosystems, societies and economies, increasing pressure on all livelihoods and food supplies, including those in the fisheries and aquaculture sector.

[1] Fishery Resource & Environmental Management Division, Central Inland Fisheries Research Institute, Barrackpore, Kolkata, West Bengal, India.
Corresponding author E-mail: mkdas412@rediffmail.com

The significance of fisheries and aquaculture in India lies in the fact that fisheries and aquaculture sector in India provides nutritious food, has high potential for rural development, domestic nutritional security, employment generation, as well as export earnings. India occupies third position in fisheries and second in aquaculture production. The Fishery sector has shown a steady growth in India and hence it is called the sunrise sector. Indian share in global fish production is 4.36% with 9.92% in inland and 2.28% in marine. Its contribution to the National GDP is 1.07%, to National Agriculture and allied activities are 5.84%. The Export potential is 18% of agricultural exports. The sector provides direct and indirect engagement to 14 million people. India relies on fisheries for around 13.5% of its national animal protein intake and the average per capita fish protein consumption is 0.51 $kg^{-1}/capita^{-1}/yr^{-1}$. But the contribution of fish to total animal protein consumption for the non-vegetarian population is much higher than the overall Indian average (Dey *et al.,* 2005).

Currently, there is a minimum shortfall in supply of fish compared to the demand. To meet the projected demand emphasis is on the expansion of Inland Fisheries in general with special importance on Fresh Water Aquaculture. Thus any potential direct or indirect effect of climate change will have immense implication on regional food security especially in the eastern Indo-Gangetic states of India. It is, therefore, imperative to think of the vulnerability and adaptation strategies in dealing with the impending change.

Perceptible changes in the climate of the earth are evident both on global and regional scales in the past few decades. Some observed changes in climate parameters in India have been consolidated by India's Initial National Communication, 2004 NATCOM to UNFCCC. Some of the changes relevant to inland fisheries are:

(i) An increase of 0.4ºC in surface air temperatures over the past century at the national level,

(ii) A trend of increasing monsoon seasonal rainfall along the west coast, northern state of Andhra Pradesh, and north-western India (+10% to +12% of the normal over the last 100 years) while a trend of decreasing monsoon seasonal rainfall over eastern part 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 yr^{-1} (Unnikrishnan and Shankar, 2007) consistent with 1–2 mm yr^{-1} global sea level rise estimates of IPCC, and

(v) Indications of recession of some of the Himalayan glaciers, the source of water for the perennial rivers such as the Ganges, Indus and Brahmaputra, but the trend is not consistent across the entire mountain chain.

With this background of evident climate change the impact, vulnerability and adaptation issues were investigated under the ICAR Network Project on Impact Adaptation and Vulnerability of Inland fisheries to climate change at the Central Inland Fisheries Research Institute, Barrackpore, India. The aspects covered were, (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 drought in the year 2009 in the Ganga river basin and its impact on the fishery of river Ganga and on aquaculture in its plains, (ii) the potential impact of extreme events like drought/floods/cyclones in the Gangetic West Bengal, (iii) vulnerability of the inland fisheries sector in the highest inland fish producing state of India, West Bengal, and (iv) the adaptations options in inland fisheries to cope with the climate change. The study area was primarily **(i) t**he entire length of the main channel of river Ganga divided in three main stretches-upper (Tehri to Kannauj), middle (Kanpur to Patna) and lower (Sultanpur to Katwa), (ii) and the state of West Bengal, India where the study on the impact on aquaculture, fish seed production and vulnerability assessment of the fisheries sector was conducted.

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 and fish landings were collected consulting approximately 200 scientific papers, CIFRI Annual Report (1947 to 2009), Reports of Central Pollution Control Board on water quality of Ganga, Handbook in Fisheries Statistics, Govt. of India, data of IIMT, Pune and from other published literature on Ganga river system. The data were analyzed statistically to evaluate the impact of climate variables on inland fisheries and fishers in the river Ganga and in the fish hatchery farms located in the plains of West Bengal.

2. IMPACT ON AQUATIC RESOURCES

Changes in Temperature and Rainfall Pattern in Ganga Basin

Seasonal pattern of rainfall in the middle stretch of river Ganga: Analysis of the monthly data of rainfall at Allahabad site of the middle stretch of river Ganga from 1979–2009 split into three equal periods (January–April), (May–August) and (September–December) indicated that the percentage of total rainfall in the peak breeding period (May–Aug.) declined by 7% whereas it increased by 4% in the post-breeding period of Indian Major Carps (IMC) the most important commercial fishery, when resorption of eggs begins (Fig. 1).

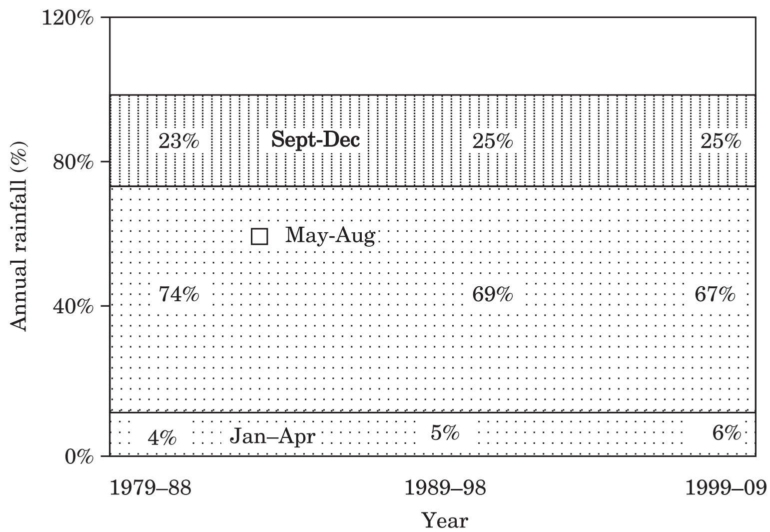

Fig. 1. Rainfall pattern at Allahabad during 1979–09.

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 1.6°C (Fig. 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.

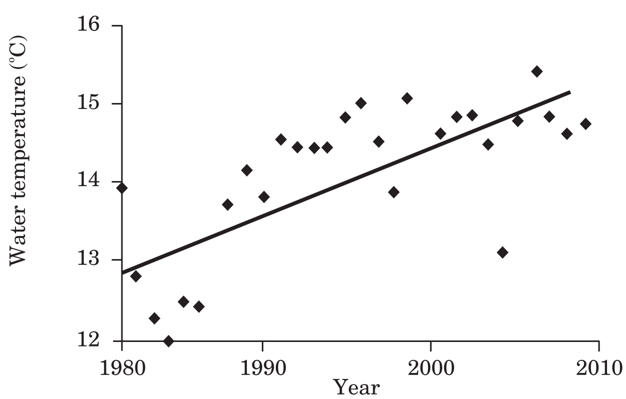

Fig. 2. Increase of water temperature at Haridwar by 1.65°C during 1980–09.

***Pattern of air and water temperature and rainfall changes in Gangetic plains (West Bengal)*:** Temperature alteration: In India an increase in temperature is witnessed with the end of the winter months January–February through spring and finally to summer from the months of April–May. This increase in temperature is not linear with sudden temperature increase within a short period of time.

The months January to April are the transition months from winter to summer. Analysis of the air temperature data (1984–2009 of IIMT Pune) during the breeding months of the Indian carp fishes *i.e.*, (April–August) from four districts in the Gangetic Plains of West Bengal, India 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. Analysis of the data was done taking the frequency of occurrence of (4°C and above) difference of temperature between the three consecutive months as a basis for evaluating the shift of elevated temperature towards cooler months January–February. Analyses showed that the frequency of occurrence of this temperature differences was maximum in February–March (average 55%) and March–April (average 28%) during previous three decades (1964–1994). But, such trend was not evident in the recent one and a half decade (1995–2009) where the frequency of occurrence of

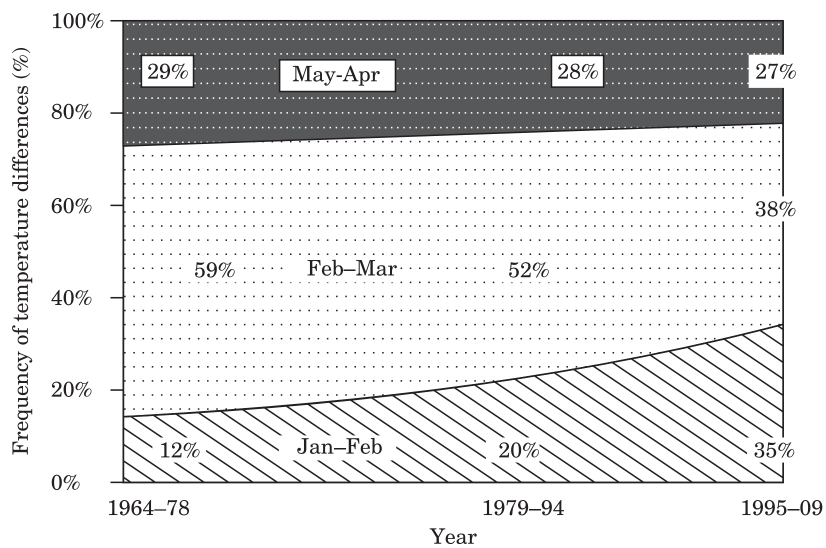

Fig. 3. Shift of temperature difference at 24 Parganas (N) during 1964 to 2009.

(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%) (Fig. 3). This corroborates earlier findings regarding enhanced temperature during the colder months of January–February (Vass *et al*., 2009).

Seasonal pattern of rainfall: Since rainfall is another important criterion that triggers the early maturation of brood fish, the rainfall data (1980–2009) of the 24 Parganas (North) collected by IIMT, Pune were analyzed. It showed that the proportion of annual total rainfall occurring in the monsoon months (May–August) 68% during 1980–1989 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 (North) (Fig. 4). Similar rainfall distributions were observed at Alipur (Fig. 5) district of West Bengal during 1980–2009.

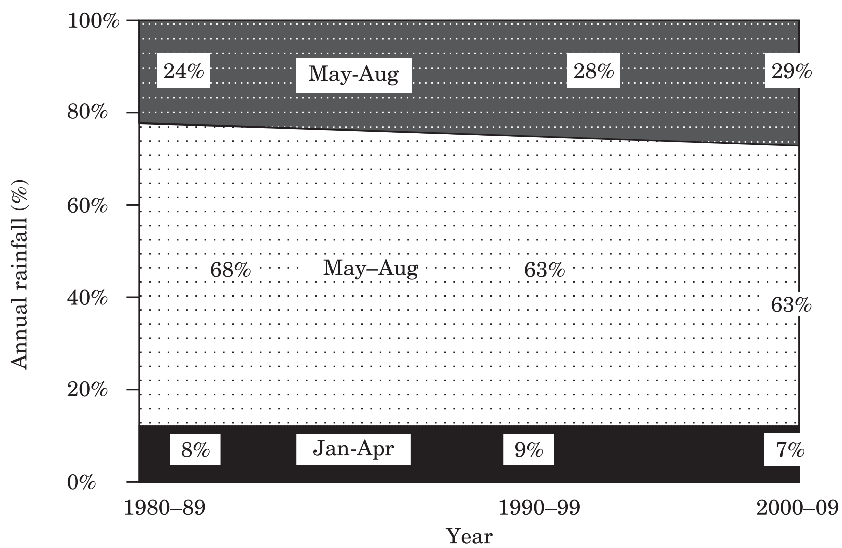

Fig. 4. Rainfall pattern at Dum Dum during 1980–2009.

3. IMPACT ON FISH

Breeding and Recruitment of Fish in River Ganga

The fish spawn availability index declined from an average of 1529 ml during (1965–69) to an average of 568 ml in recent years (2005 to 2009) (Fig. 6) (Natarajan, 1989). It also showed a continuing decrease of Indian Major Carps (IMC) seed (*Labeo rohita, Catla catla, Cirrhinus mrigala*) which forms the major commercial fishery in the river Ganges and its plain land. The percentage of major carp spawn decreased from 46% in 1965–1969 to 10% in 2005–2009, whereas other fish seed increased from 54% in 1965–1969 to 90% in 2005–2009 in the total seed collection.

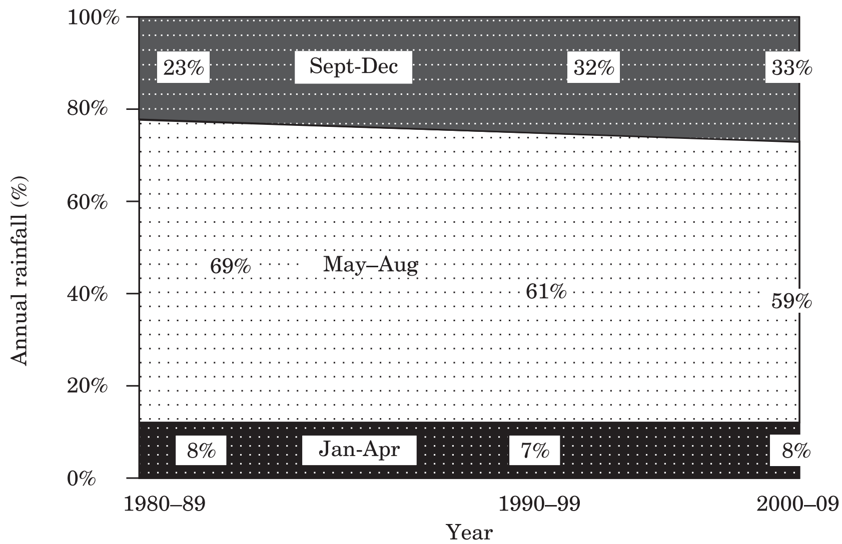

Fig. 5. Rainfall pattern at Alipore during 1980–2009.

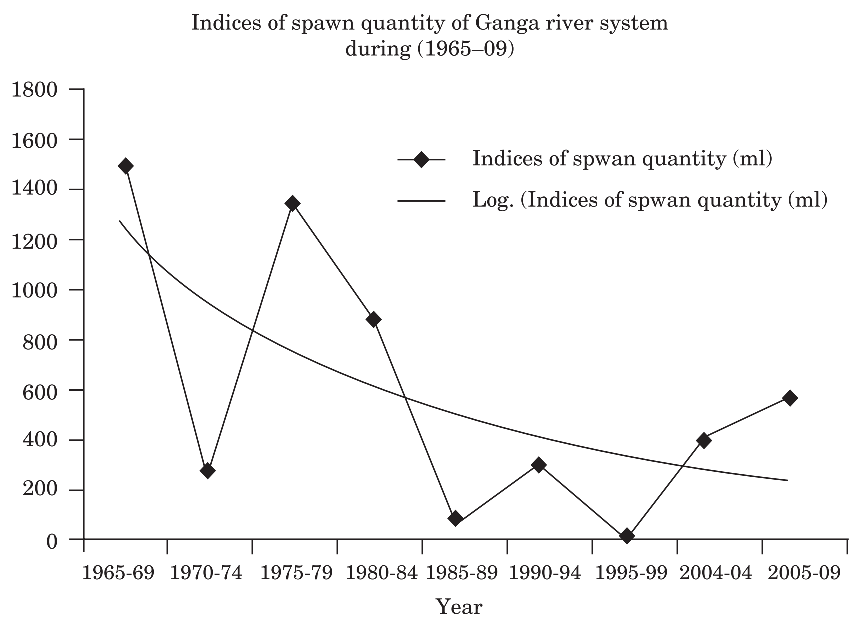

Fig. 6. Indices of spawn quantity of River Ganga.

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 essentially needed for reproduction and feeding. The monthly data of rainfall from the middle stretch of the river at Allahabad from 1974–2009 (Fig. 1) indicated that the percentage of total rainfall in the peak breeding period (May–August) declined by 7%, whereas it increased by 4% in the post-breeding period when resorption of eggs of Indian major carps sets in.

This shift and decrease in the rainfall pattern resulting in the alteration of the required flow and turbidity during breeding season is a major factor responsible for failure in breeding and consequent recruitment of young ones of Indian major carps in the river Ganga (David, 1959; Kamal *et al.*, 1980; Natarajan, 1989).

Breeding of Fish in Aquaculture Farms in West Bengal, India

Extended breeding period: The aquaculture hatcheries in the state of West Bengal extensively breed the Indian major carps, (*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 decade the phenomenon of IMC maturing and spawning as early as March is observed. The average minimum and maximum temperature throughout the state has increased and rainfall pattern has changed. Analysis of the air temperature data (1999–2009) recorded by IIMT Pune, during the maturing and breeding months of Indian Major Carps *i.e.*, (January–April & May–September) from two districts (North 24 Parganas and Bankura) in 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 cooler months (Fig. 3). Data collected from the hatcheries indicate that during 1980, breeding of Indian major carps started during the last week of May, whereas during recent years (2005–2008) breeding programs in the hatcheries were initiated during mid April. As a result an extended breeding period of Indian major carps by 40–60 days with breeding season extending from 110–120 days (pre 1980–85) to 160–165 days (2000–2008) is evident in fifty fish seed hatcheries. 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 help in the maturation of the gonads of Indian major carp. Thus there has been a positive impact of climate change.

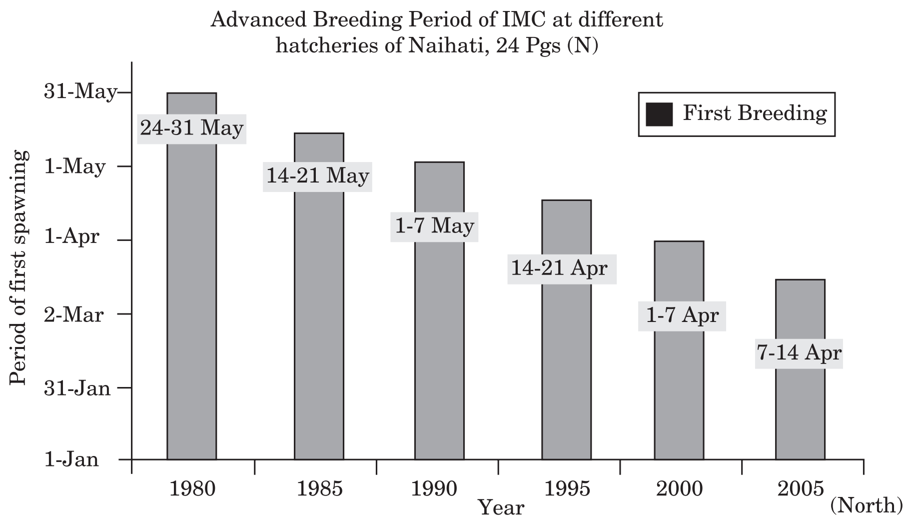

Fig. 7. Advanced breeding period of IMC at different hatcheries of Naihati 24 Pgs (North) (*Source*: Dey *et al*., 2007).

Geographic Distribution of Fish in River Ganga

Temperature has long been a focus of biogeographic studies because of its overwhelming influence on the physiology of exothermic organisms (Hutchins, 1947). Because fish are exothermic organisms, their survival, growth, egg development and even competitive ability all are temperature dependent. Biogeographic distributions often provide insight into thermal limits for ectotherms such as fish whose physiology and reproductive success are strongly influenced by temperature. These thermal limits can be used to project distributional changes following climate change by assuming fish will migrate along isotherms to remain within a suitable thermal envelope (Rahel, 2002). With this background the distributional pattern of fishes and plankton of river Ganga were analysed from the published records available.

There is a perceptible shift in geographic distribution of the fishes of river Ganga. The study conducted from 2005 to 2009 recorded presence of several species of fish in the upper stretch of river Ganga from Deoprayag to Haridwar that never recorded earlier from this stretch but found in the middle warmer stretch of the river as indicated by the published records (Menon 1954). These are the warm water fish species (*Glossogobius giuris, Puntius ticto, Xenentodon cancila* and *Mystus vittatus*) earlier available only in the middle stretch of river Ganga, are now available in the cooler stretch of the river around Haridwar. Thus a perceptible shift in geographic distribution of the fishes of the Ganga has occurred in the upper cooler stretch of this river. At Haridwar during 1980–2009 the minimum water temperature increased by 1.6ºC (Fig. 2) as a result the stretch of the Ganga around Haridwar has become a more congenial habitat for the warm water fishes.

Geographic Distribution of Plankton

At present in the cooler stretch of river Ganges at Haridwar and above some of the stenothermal genera of phytoplanktons like *Amphicampus, Tetracycles, Diatoma* and *Ceratoneus,* which predominantly inhabit the cold mountainous waters, have become insignificant. With the increase in the annual mean minimum water temperature by 1.6ºC depletion of these stenothermal phytoplankton has occurred.

Reproductive integrity**:** All the stages of reproduction in fish *viz*., gametogenesis and gamete maturation, ovulation/spermiation, spawning and early development stages are affected by temperature. Imbalance or rapid change in temperature are stressful to fish and may also be linked with other stressors. If stress is maintained then the effects start manifesting by the inhibition of reproductive function, cessation of ovulation, depression of reproductive hormones in blood and ovarian failure. Temperature change modulates the hormone action at all levels of reproductive endocrine cascade. Investigation was conducted on *C. carpio* subjected to enhanced temperature. The optimum range of the fish is 15–32ºC and its upper critical range is 30–41ºC. It spawns optimally in the range of 12–30ºC. Mature female *C. carpio* fishes were subjected to an enhanced temperature of 34ºC to study the effect on the reproductive integrity of the fish. A decrease in the Gonado somatic index occurred. There was accumulation of liver and ovarian cholesterol. As a result depletion of the hormone estradiol was evident. Histology of the ovary of *C. carpio* exhibited impaired vitellogenesis in oocytes. Failure of incorporation of vitellogenin due to increased temperature (which is mainly responsible for increase in gonadal weight) has resulted in lower GSI and estradiol level in serum (Das *et al.,* 2008).

Growth of Fish**:** Water temperature strongly affects metabolism, consumption, growth fish behavior, habitat selection, spawning, foraging, and predator–prey interaction. Previous work has shown that the growth rate potential provides a good measure of habitat quality (Tyler and Brandt, 2001) and effectively incorporates biotic and abiotic characteristics of the environment in a metric that directly relates to the fitness of fish (Brandt and Kirsch 1993; Mason *et al*., 1995).

Investigations were conducted to assess the impact on the growth of Indian major carp (*Labeo rohita*) fingerlings reared simulating unit rise in temperature in tropical countries in thermostatic aquarium for five weeks at water temperature of 29ºC, 30ºC, 31ºC, 32ºC, 33ºC, 34ºC and 35ºC. Fish reared at 34ºC water temperature exhibited a significantly ($P < 0.05$) faster growth (SGR–2.36% body weight per day) than those at other temperatures. The change in growth rates were insignificant between 29ºC, 30ºC, 31ºC and 32ºC treatment groups but growth rates significantly increased in the temperatures ranging from 32ºC to 34ºC and there after it decreased. Carp reared under unit rise of temperature from 29ºC to 35ºC grew significantly faster at 34ºC (18.38 cg in a day) than those at 29ºC–33ºC and 35ºC. It wuld take average 54–55 days for a carp to double in weight at 30ºC to 33ºC and 35ºC, but at 34ºC it would take only 35–36 days (Das 2010).

***Fish health*:** Fluctuating temperature very often disturbs the homeostasis of fish and subjects them to physiological stress and shift in habitat or mortality. In the climate warming scenario, fishes will be subjected to the hazard of rapid temperature changes. It is more so in the tropical waters where daily variations in water temperature and thermocline in deep water bodies will assume significance. These effects would often become additive or synergistic with those of other adverse (*e.g*. low pH, algae, oxygen shortage). It is essential to understand that these temperatures change though sublethal, can place a stress of considerable magnitude on the homeostatic mechanism of fishes at the primary, secondary and tertiary level.

***Impact of high temperature*:** Investigations were conducted by Das *et al*., 2002 on the alteration occurring in the levels of various stress sensitive blood and tissue parameters of the fish *L.rohita* and *Rita rita*, acclimatized at 29ºC and subjected to a rapid sublethal rise to 35ºC and then maintained at this temperature. The results indicated that the homeostatic mechanism of the fish is stressed. The changes evident are hypercholesterolemia indicating impaired sterol mechanism, hyperglycemia and decreased blood sugar regulatory mechanism. Pituitary activation as evidenced by interrenal ascorbic acid depletion and cortisol elevation is pronounced. Oxygen consumption in both the fishes increased as judged by increased haemoglobin. Simultaneously it is observed that compensatory responses were initiated in the fishes within 72 hours. Obviously adaptation to the stress of elevated temperature occurs. But if the sresss of enhanced temperature is of chronic nature as in a climate warming scenario then the tolerance limits would be exceeded in fishes.

4. IMPACT OF EXTREME EVENTS (DROUGHT) ON HATCHERY FISH SEED PRODUCTION IN WEST BENGAL

The increased seasonal and annual variability in precipitation resulting in flood and drought are likely to be the significant drivers of change in inland aquaculture and fisheries in recent years. In 2009 the monsoon in India got delayed by two weeks, this resulted in the deficit rainfall of 54% of the long term average for the period. The impact of drought has been felt across the country. The state of West Bengal in 2009–10 also recorded deficient rainfall in twelve districts. The implications are important because the state is the highest fish producer in the country and is also a major supplier of fish seed to other states of India (Ministry of Agriculture, 2008). With this background a study was conducted in 2009 in two drought affected fish seed producing districts of West Bengal *viz*., 24 Parganas (North) and Bankura to assess, (i) the alteration in air and water temperature and rainfall during the fish breeding months of March–September, 2009 and (ii) their impact on fish spawn production and economics (Das *et al.,* 2011).

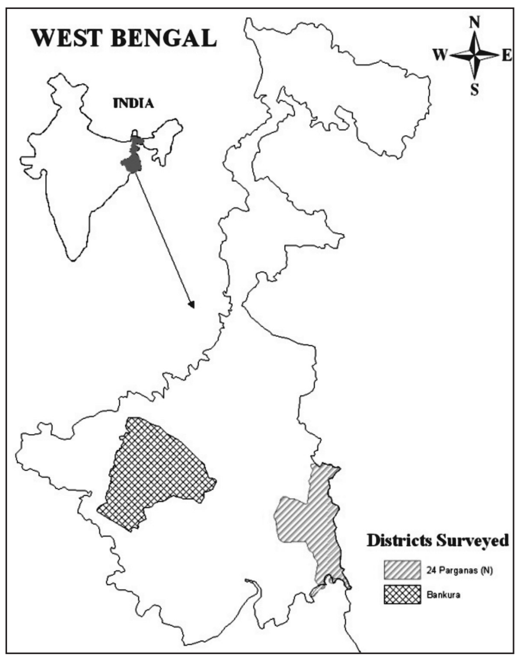

Fig. 11.8.

Temperature and Rainfall Assessment

Annual maximum and minimum air temperature, total monthly and annual rainfall data of the districts surveyed were collected from the Regional Meteorological centre, Kolkata and were statistically analyzed. The water temperature of the districts surveyed was derived from the recorded air temperature of the periods January–April and May–September during 1999–2009 based on the worked out relationship between air and water temperature (monthly mean values), [$y = 1.150x - 3.7305$ ($R^2 = 0.9634$)] (Dey *et al.,* 2007; Vass *et al.,* 2009).

Impact Study on Fish Seed Production

The survey covered fish seed hatcheries affected by drought in the districts of Bankura and 24 Parganas (N) of West Bengal, India (Fig. 8). A total of 50 operative hatcheries, running and sustaining for the last 10 years were surveyed randomly. Two questionnaires (for hatcheries and fishers) were prepared based on preliminary survey of the hatcheries and also based on earlier survey (Dey *et al.,* 2007). The parameters taken into consideration were fish species, brooder management, breeding procedure and techniques, breeding season duration, cost of spawn production and marketing. Data prior to 2009 was collected from available recorded data and through personal interview.

5. SEASONAL ALTERATION IN TEMPERATURE AND RAINFALL

Air Temperature

In North 24 Parganas the mean maximum air temperature increased by 1.97°C during the period January to April and by 1.37°C during May to September in 2009 compared to the 1999–2008 during those months (Fig. 9). The mean minimum air temperature increased by 0.34°C and 0.54°C in January to April and May to September, respectively during 2009 as compared to 1999–2008.

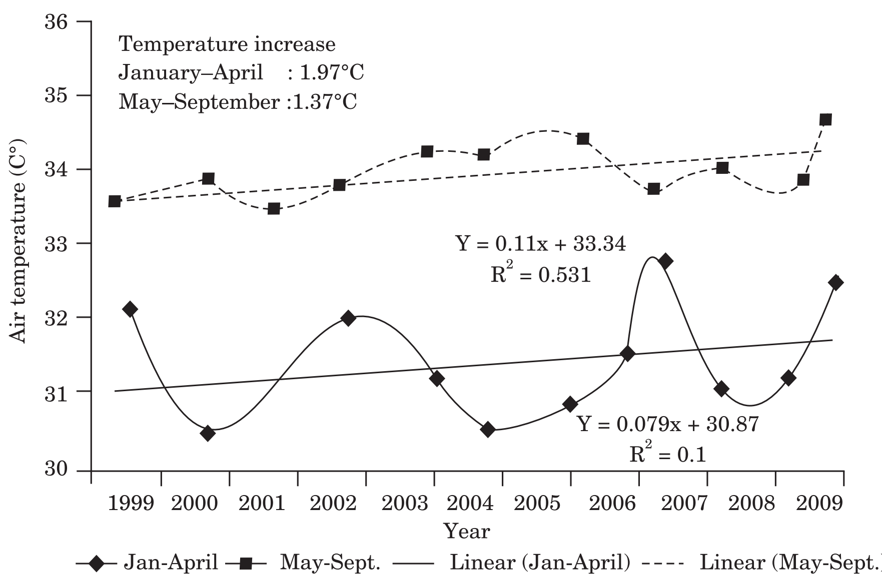

Fig. 9. Mean maximum temperature at North 24 Parganas.

In Bankura district the mean maximum air temperature increased by 3.26°C between January and April and by 2.26°C during May to September

(Fig. 10) whereas the mean minimum air temperature increased by 0.26°C and 0.28°C during January to April and May to September, respectively in 2009 as compared to 1999–2008 during these months.

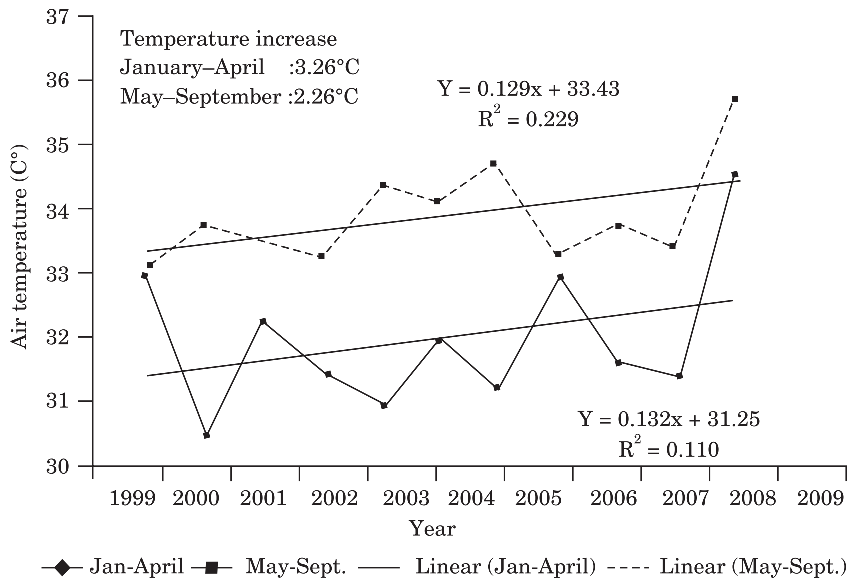

Fig. 10. Mean maximum air temperature at Bankura during 1999–2009.

Water Temperature

Based on the derived relationship between air and water temperature the mean minimum water temperature in North 24 Parganas increased by 0.39°C during January–April and by 0.62°C during May–September (Fig. 11) and in Bankura it increased by 0.30°C during January–April and by 0.32°C during May–September (Fig. 12).

Rainfall

Deficient rainfall of 15% was recorded during the monsoon months June to September in 12 districts of West Bengal during 2009. Fish breeding practices in hatcheries of West Bengal usually starts just after winter 1st week of February with spawn becoming available by mid March. Thus rainfall from March to September is important as it is the breeding season of fishes. In North 24 Parganas district during 2009 rainfall deficit was 20.15% and in Bankura it was 10.43% compared to the years 1999–2008 in the fish breeding months of March to September. During the optimum fish breeding months June–September the rainfall deficit was 24% in North 24 Parganas and in Bankura it was 15% (Figs. 13 and 14).

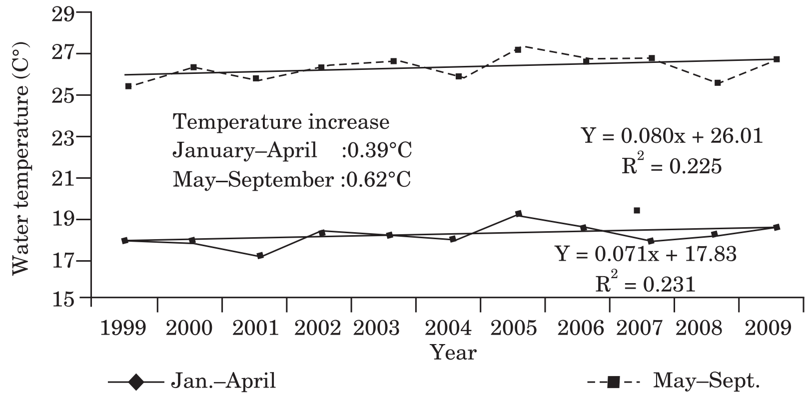

Fig. 11. Mean minimum water temperature at 24 Parganas (N) during 1999–2009.

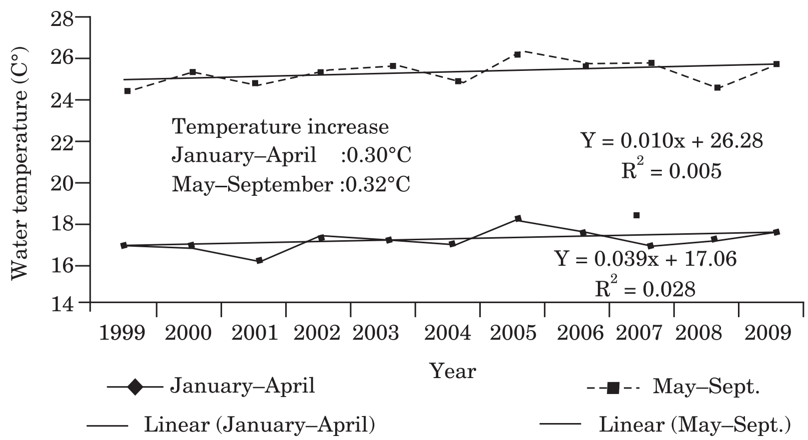

Fig. 12. Mean minimum water temperature at Bankura during 1999–2009.

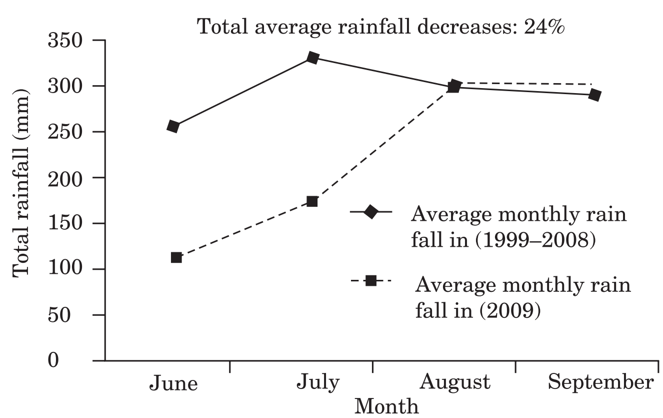

Fig. 13. Total average rainfall distribution at North 24 Parganas between the months June–September during the year 1999–2008 & 2009.

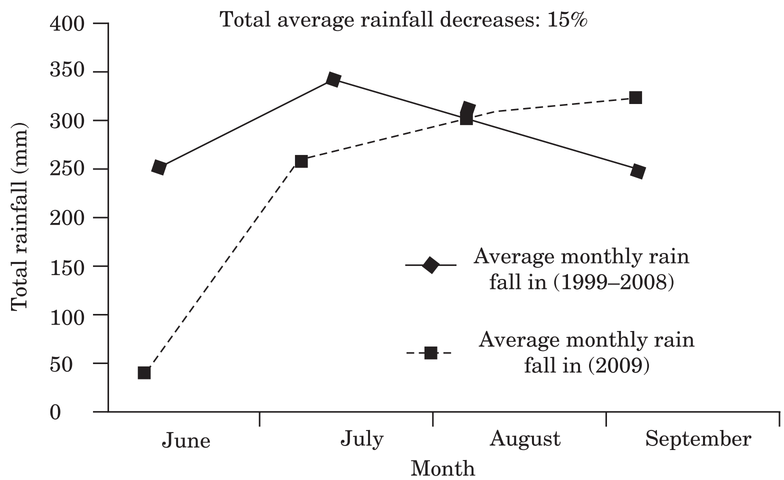

Fig. 14. Total average rainfall distribution at Bankura between the months June–September during the year 1999–2008 & 2009.

6. IMPACT ON FISH SEED PRODUCTION

The survey of hatcheries in the two districts indicated that seed production in 20% of the hatcheries were affected by high temperature, 12% were affected by water scarcity and 68% were affected by cumulative effect of high temperature and water scarcity (Table 1).

Table 1: Impacts of climate factors on fish seed production in hatcheries.

Weather factors	***Affected hatcheries (%)***	***Resultant impact***
Deficient rainfall	12	Low demand due to water scarcity in nurseries & ponds.
High temperature	20	High temperature caused fish spawn mortality in incubation tank, unknown disease & inadequate milting.
Both low rainfall & high temperature	68	Low demand as well as low survival rate
Total	100	

Qualitative contribution of the attributes impacting fish seed production indicated that in North 24 Parganas low milting of the male brooders resulting in breeding failure during the pre monsoon season of March–May contributed maximum 45%. Spawn death after fertilization because of enhanced temperature contributed 35%. Low demand of fish seed because of scarcity of adequate water in nurseries and rearing ponds during June–September contributed 20% [Fig. 15 (a)].

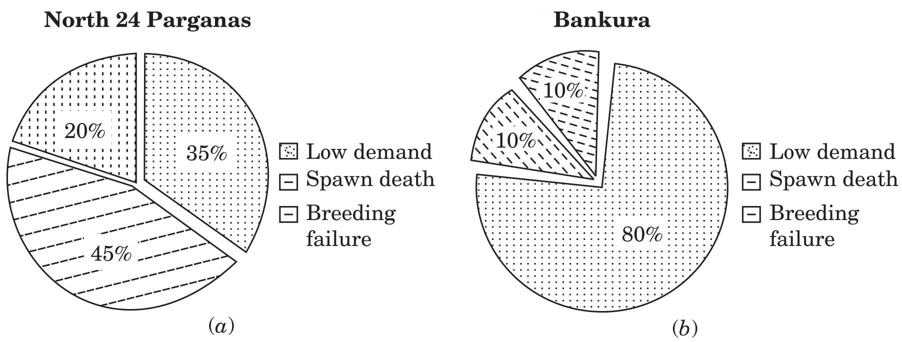

Fig. 15a, b. Percentage contribution of attributes impacting fish seed production.

In Bankura low demand (80%) both during advanced breeding months from March toMay and seasonal months of June and July was the main factor. This is because of scarcity of adequate water in nursery and rearing ponds due to deficient rainfall. Although the sale of fish seed increased during August–September but low sale price could not offset the low demand during March to May when price of spawn was high. Spawn death due to enhanced temperature contributed 10% and breeding failure due to low milt of male brooders contributed 10% [Fig. 15 (b)].

7. ECONOMIC IMPACT

In the years 1999–2008 during the fish breeding months of March and April, the price of fish seed was Rs.600 for *bati* (*bati* is a cup measure 100–120 ml, holding between 30,000–70000 hatchlings depending on species involved) whereas during 2009, the price dropped down to Rs. 450–500 for *bati*. During the months April–September the price per measure ranged between Rs. 220–250 during 1999–2008 but it dropped down to Rs. 100–120 for *bati* during 2009. The deficient rainfall created a situation of water scarcity resulting in either dry up of water or inadequate water level in nursery and rearing ponds. As a result the demand came down.

The comparative economic loss analysis of fish seed production in two selected hatcheries Naihati (North 24 Parganas) and Ramsagar (Bankura) indicated 61% and 73% loss, respectively in income during 2009 compared to 2006. It is evident that elevated temperature and deficient rainfall and resultant inadequate availability of water areas in nursery and rearing ponds for spawn and fry production during the fish breeding months affected spawn production of Indian major carps. This is reflected in a significant drop in the IMC spawn production in the major producing districts of West

Bengal during the drought period of 2009. The implications are quite serious for the country. The production in the district also suffered with fish seed production coming down from 4532 million during 2008 to 4368 million spawn during 2009 (Department of Fisheries and Aquaculture, Government of West Bengal 2008–09).

West Bengal being the prime spawn producing state in India, any decrease in its production will affect effective implementation of fish enhancement technologies in the country through inadequate supply of seed. Further the water stresses created due to drought have the potential of creating conflicts with other agricultural, industrial and domestic users. The impact is likely to be felt most strongly by the poorest aquaculturists, in the eastern region of the country possessing smaller ponds. These ponds retain less water, dry up faster, and consequently will have shortened growing seasons, reduced harvests and a narrower choice of species for culture. However the drought provided the farmers with adaptation options to culture alternate species capable of withstanding water stress. 90% of the hatcheries diverted to culture of species other than IMC like *Pangasius* sp., *Puntius javanicus*, *Clarias gariepinus* and Red Bellied piranha *Pygocentrus nattereri*, which are comparatively more adaptable to the changed weather conditions with satisfactory market demand from IMC. The practice of rearing such species in fish seed hatcheries have increased from 60% to 80% during 2009 as compared to previous survey 2006. Cross breeding of the Indian major carps has been another option practiced by farmers. 55% of the hatcheries were involved with such practice. These farmers reported better survival rate and growth of cross bred species under water stress conditions and better transportable to distant places with less mortality.

8. VULNERABILITY AND ADAPTATION OF INLAND FISHERIES TO CLIMATE CHANGE

Vulnerability Assessment of Inland Fishery to Climate Change in West Bengal

Similar to the agricultural sector, the inland fisheries sector in India is dependent on monsoons, and any variation in the rainfall patterns is likely to impact inland fisheries. Thus some areas are more vulnerable compared to others and are likely to be more affected depending on their socio-economic status. It is therefore imperative to identify the vulnerable areas for the sector and prioritize the plans for optimally utilizing the limited resources of the area. The concept of vulnerability assessment is nowadays being widely used especially in the context of climate change (Smit and Wandel, 2006) and is serving as a means to develop adaptation measures.

In India mapping of regions and communities vulnerable to climate change and extreme weather events is very limited. Some attempt has been made in the agricultural sector in India (Sanghi 1998) but no attempt has been made for vulnerability assessment of the fisheries sector to environmental changes. Keeping this in view the vulnerability index of the inland fisheries sector in West Bengal the highest fish producing state of India, was developed as detailed below

9. METHODOLOGY

The Vulnerability Index (VI) for the inland fisheries of various districts of West Bengal has been developed The VI has been constructed based on the IPCC working method for assessing vulnerability where V = f (E, S, AC). *i.e.*, vulnerability as a function of exposure (E) to climate change, sensitivity (S) to climate change, and adaptive capacity (AC) (Table 2). The parameters were developed based on five major components *viz*., Demographic, Fisheries, Occupational, Geographic and Climate Variability. Each is comprised of several sub-components. These were developed based on secondary data available from the published literature, on each major component, for example annual report of state fisheries department, Hand book of fishery statistics of West Bengal and IMD data.

Table 2: Since vulnerability is dynamic over time, it is important that all the indicators relate to the particular year chosen.

Component	*Sl. No.*	*Indicator*	*Functional relationship with climate change*
Sensitivity (S)	1	Total inland production (S1)	↓
	2	Total fish seed production (S2)	↓
	3	Prawn/shreem production (S3)	↓
	4	Total fish cultured area (S4)	↓
Exposure (E)	1	Variance in annual rainfall (E1)	↑
	2	Mean min–temp–variance (E2)	↑
	3	Mean max temp variance (E3)	↑
	4	Flood prone area (E4)	↑
	5	Cyclone risks (E5)	↑
	6	Density of population (E6)	↑
Adaptive capacity (AC)	1	Total main workers (A1)	↓
	2	Total agrl.labors (A2)	↓
	3	Total fishers (A3)	↑
	4	Marginal workers (A4)	↑
	5	Non-workers (A5)	↑
	6	Total industrial workers (A6)	↓
	7	Literacy rate (A7)	↓
	8	Infant mortality rate (A8)	↑

10. CONSTRUCTION OF VULNERABILITY INDEX

Construction of vulnerability index consists of several steps. First is the selection of study area which consists of several regions/districts. A list of possible indicators is provided in the the Method of Iyengar and Sudarsan (1982) was applied for construction of VI Iyengar and Sudarshan (1982) developed a method to work-out a composite index from multivariate data was worked out and based on the Index.

- When the observed values are related positively to the vulnerability (for *e.g*. higher the variation in rainfall, higher the vulnerability),

$$\chi_{\mathrm{ij}} = (\text{Actual } X_{ij} - \text{Min } X_{ij})/(\text{Max } X_{ij} - \text{Mm } X_{ij})\ [\uparrow]$$

- When the values are negatively related to the vulnerability (for *e.g*. higher the production of a fish lower the vulnerability)

$$\chi_{ij} = (\text{Max } X_{ij} - \text{Actual } X_{ij})/(\text{Max } X_{ij} - \text{Min } X_{ij})\ [\downarrow]$$

The level or stage of vulnerability of region/district is assumed to be a linear sum

$$Y_i = \sum_{i=1}^{k} w_i\, \chi_{ij};$$

$$W_j = C\sqrt{\text{var}}\ \chi_{ij})$$

where C is normalizing constant such that

$$C = [\Sigma 1/\sqrt{\text{var}}\ (\chi_{ij})]^{-1}$$

For classificatory purposes, a simple ranking of the district/zone indices would be enough.

A probability distribution which is suitable for this purpose is the Beta distribution (first kind), which is skewed and takes values in the interval (0,1).

$$f(z) = \frac{z^{a-1}(1-z)\,b-1}{\beta\ (a,b)},\ 0 < z < 1 \text{ and } a,\ b > 0$$

where is the beta function.

Therefore, a simple scale of vulnerability score may be presented as under:

Rank	9	8	7	6	5	4	3	2	1
Low vulnerable ←								→ High vulnerable	

The overall vulnerability (VI: IPCC) scores presented in Table 3 are the combined level of vulnerability of the districts. Combined in the sense they are linear sum of VI on three major components sensitivity, exposure and adaptive capacity of the district are also presented in the same table below, where the VI on major components are the weighted sum of standardized value of sub-components.

Table 3: Vulnerability index and rank of the district of West Bengal.

District	*VI Scores on major components*			*Combined scores on VI:IPCC*	*Overall rank*
	Sensitivity	*Exposure*	*Adaptive capacity*		
Nadia	0.197 (3)	0.185 (2)	0.243 (5)	0.625	1
Murshidabad	0.185 (4)	0.137 (4)	0.251 (4)	0.573	2
East Mednipur	0.221 (6)	0.098 (6)	0.185 (3)	0.552	3
Hooghly	0.198 (2)	0.192 (1)	0.153 (9)	0.543	4
Burdwan	0.168 (5)	0.143 (3)	0.209 (6)	0.520	5
West Mednipur	0.221 (1)	0.098 (7)	0.185 (8)	0.504	6
South–24–pgs	0.094 (8)	0.079 (9)	0.303 (1)	0.475	7
North–24–pgs	0.049 (9)	0.134 (5)	0.276 (2)	0.459	8
Bakura	0.155 (7)	0.090 (8)	0.201 (7)	0.447	9

Parentheses show components wise rank.

The overall vulnerability score for Nadia was more (VI = 0.625) than all other districts of West Bengal and ranked first (Table 4), where the Sensitivity (0.197) and Exposure (0.185) were more vulnerable and Adaptive Capacity (0.243) was also at moderate vulnerable level. On the other hand the score is minimum (VI = 0.447) for the district of Bankura, where Sensitivity (0.155), Exposure (0.090) and Adaptive Capacity (0.201) were at very low vulnerable level.

Table 4: Classification of the vulnerability based on distribution percentiles.

	Less vulnerable	*Moderately vulnerable*	*Vulnerable*	*Highly vulnerable*	*Very highly vulnerable*
Beta distribution percentiles	<20	20–40	40–60	60–80	>80
Districts	North-24-pgs Bankura	South-24-pgs	Burdwan West Mednipur	East Mednipur Hooghly	Murshidabad Nadia
Frequency in each class (districts)	2	1	2	2	2
Proportion of frequency in each class	0.222	0.111	0.222	0.222	0.222
% of frequency in each class	22.20	11.11	22.22	22.22	22.22

N.B. The 20% cut-off points are estimated by Beta distribution (0.47, 0.50, 0.53, 0.56).

The classification of overall VI shows that Nadia and Murshidabad districts are in the very high vulnerable group among the all districts of the state, where as East Mednipur, Hooghly are in Highly vulnerable group and Burdwan, West Mednipur are in the vulnerable group. It also shows that fisheries in about 66% (six districts out of nine) districts are vulnerable to climate change. Fisheries planner should internalize the fact of district wise vulnerability, during resource allocation and effect of climate change on fisheries mitigation strategies. These six districts are fisheries important districts in the state and should given priority in fisheries planning.

In conclusion it can be inferred that the adaptive capacity components contributes 64% and 60% vulnerability to the total VI in the districts 24 Parganas (S) and 24 Parganas (N), respectively. In the event of occurrence of extreme events like flood, cyclones these two coastal districts with a coastline length ranging between 84.54 km^2 and 7559.23 km^2 will be highly vulnerable because of poor adaptive capacity measured in terms of resource availability (*e.g*. human, technological, and financial capital.)

11. VULNERABILITY AND ADAPTATIONS OF INLAND FISHERIES TO CLIMATE CHANGE

Enhanced Temperature

The changes that will occur in the culture system would be (i) reduction in dissolved oxygen, water quality deterioration, (ii) increased growth and food conversion, (iii) increased disease incidence, (iv) enhanced breeding period in hatcheries, (v) exotic species introduction, (vi) changes in level of production from ponds and hatcheries, (vii) enhanced operating cost, and (viii) increase in capital costs due to creating deeper ponds with aeration facilities.

Changes that will occur in the rivers would be (i) geographic shift of fishes, (ii) habitat loss or gain, (iii) fish breeding alteration/changes, (iv) decrease in fish and related biota species richness, alteration in species composition for capture fisheries, and (v) exotic species invasion.

Adaptation options

These options can primarily be affected in the culture system as detailed:

- making changes in feed formulations and feeding regimes of fishes;
- exploring substitution by alternate species of fish;
- providing monetary input to the changes in operational costs in ponds and hatcheries.

Flood

Increased flooding may expand the number and quality of water areas available for cultivating fish. The experience in the unprecedented floods in Bihar during 2008 affecting huge loss to life property agriculture and fisheries but at the same time the post flood management measures provided opportunities to fisheries and aquaculture in offsetting some of the losses incurred by the people.

Adaptation options

Post-flood

- the floods affected 6051 ha of fish culture areas in various districts of Bihar;
- the post flood fish seed requirement for stocking this area at the rate of 50 kgha^{-1} of 5–10 g size of fish was 300750 kg (300 t) of fish seed;
- thus continuous supply of fish seed from hatcheries or raising of fish seed in hatcheries is required;
- cage culture in large water logged bodies for raising seed from fry to fingerlings.

Pre-flood

- harvesting fish at smaller size;
- giving importance to fish species that require short culture period and minimum expense in terms of input;
- increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL, respectively.

Intense Storm Surges and Sea Level Rise

Increased flooding may expand the number and quality of water areas available for cultivating fish. This will have wider applicability as coastal–floodplain zones expand with rising sea level and storm surges. During the Cyclone Aila devastation a total of more than 70% people were either made homeless or had their livelihoods disrupted. Damages included loss of income, destruction to fish ponds, *bheries* and gear, as well as other assets. Fishermen were totally dependent on fishing and wild fish seeds collection from natural resources as it is the only source of income.

Adaptation options

Post ingress: The ingressed saline water inundated paddy fields which became unfit for agriculture. These areas provided temporary opportunities for converted these areas into ponds for fish culture with saline tolerant fish species *viz Mugil parsia, M. tade and Lates calcarifer.*

Pre-ingress

- Early detections systems of extreme weather events.
- Communication of early warning system.
- Accept certain degree of loss.
- Development and implementation of alternative strategies to overcome these periods.
- Maximizing production and profits during successful harvest.
- Suitable site selection and risk assessment work through GIS modeling.
- Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL, respectively.

Drought

During the drought prevailing in West Bengal in 2009, the deficit in rainfall was within the range of 25% and 37% during the fish breeding months (April to September) in districts of Bankura and North 24 Paraganas, respectively compared to previous years. This has created a situation of water scarcity in fish rearing and culture ponds of West Bengal. Breeding commenced in the month of March but the total number of successful days were restricted to 98 during 2009 in comparison to 150–155 days in previous years. The total fish spawn production came down to 40 lakhs for100 kg fish brooders from 130–140 lakhs for 100kg in fish seed hatcheries in Bankura.

Adaptation options

Pre-drought

About 80% of the hatcheries due to the drought condition diverted from rearing Indian Major Carps to other species like Pangasius (*Pangasius sutchi*), *Puntius javanicus* and *C. garipenus*, which favorably adapt to water stress and high temperature condition.

Post-drought

Smaller ponds that retain water for two–four months can be used for fish production with appropriate species (catfish, tilapia etc.) and management practices.

Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL, respectively.*Water stress (as a gradual reduction in water availability (trend) due to increasing evapouration rates and decreasing rainfall)*

Prediction for water availability as a result of climate change in India indicates water stress in coming years. This would result in decreasing water availability in the major river basins of India. The Gangetic Plains and delta are regions of significant aquaculture activity contributing to income and providing livelihood to thousands of fishers. Thus judicious use of this primary resource is of topical importance for sustaining fisheries and aquaculture in reservoirs, wetlands and other ponds and tanks. The comparative water needs for unit production are given below:

Specific water demand ($m^3 t^{-1}$) for different animal food products* and comparison with needs for aquaculture

Product	*Water demand*
Beef, mutton, goat meat	13 500
Pig meat	4 600
Poultry	4 100
Milk	790
Butter + fat	18 000
Common carp (intensive/ponds)[a]	21 000
Tilapia (extensive/ponds)[a]	11 500
Pellet fed ponds[b]	30 100

a—Muir,1995: b—Verdegem, Bosma and Verreth, 2006. *Source*: data from Zimmer and Renault 2003.

Pond aquaculture when practiced for culturing shrimp and carnivorous fin fish species is water consuming but some other enhancement technologies such as cage culture is totally non-water consuming, except for the need for feeds. Further culture based fishery in pond fed with natural feed, or selected feed ingredients requiring little water to produce ,needs encouragement.

Adaptation options

- Multiple use, reuse and integration of aquaculture with other farming systems

- Intensification of aquaculture practices in resources of wastewater and degraded water such as ground saline water
- Smaller ponds (100–200 m 20 of seasonal nature (1–4) months can be used for rearing/culture of appropriate species of fish/prawn
- Increasing infrastructure sophistication of hatcheries for assured seed production of 34,000 million carp fry, 8000 and10000 million scampi and shrimp PL, respectively

Carbon Sequestration

Aquaculture in India and in other Asian countries is predominantly dependent on fish species feeding low in the food chain and act as carbon sink and aid in carbon sequestration though cultured shrimp and carnivorous finfish feed mainly on fishmeal and fish oil for feeds contribute to carbon emissions.

Aquaculture of Indian and exotic carp uses minimal industrial energy but has a potential significance in the carbon cycle, fixing CO_2 through phytoplankton. Thus, aquaculture has the scope of alternative practices being adopted in response to climate change and in reducing the sectors contribution to GHG emission.

Adaptation options

Adoption of simple techniques of providing a suitable and/or enhanced food source(s) for cultured stock through measures to increase phytoplankton and periphyton growth could be a major energy saving measure.

Periphyton–based practices have developed independently and are used to catch fish in open waters in various parts of the world. In India (West Bengal) the practice is known as *Komor* or *Huri*, in Bangladesh it is called *Katha*, in West Africa *Acadja*, and in Cambodia *Samarahand*. In West Bengal the practice is essentially fixing vertically unused bamboo sticks, tree branches to act as substrates for colonization by the plankton, microbes, invertebrates and other organisms that make up periphyton, in the various household tanks so commonly found in the rural areas. The farmers in this part of India and Bangladesh traditionally believe that *shaola* (periphyton) growing on the substrate form food for the fish and serve as protection against poaching of fish. Indian major carps are grown in these ponds for fish culture to sustain the rural population. In Bangladesh the best result has been achieved if the surface area of the substrate is equal to approximately 50–100% of the pond's surface area. The technology seems to hold promise for the farming of any herbivorous fish which is capable of harvesting periphyton from substrates.

GIS Mapping for Vulnerability Assessment

Assessment of coastal areas: To assess the impact of cyclonic events like AILA on coastal areas of South 24 Parganas Digital Elevation Model was generated from SRTM (Shuttle Radar Topographical Mission) of 90 m spatial resolution data. Contour lines were created with the help of TNT Mips software in meter. The extent of land that may be submerged under scenarios of sea water rise is given. It is observed that 3% land will be submerged in case of 1m sea level increase. But it is also observed due to cyclonic sea ingress up to 2 m agricultural fields and aquaculture pond are affected. A total of 11% area of South 24 Parganas is highly vulnerable to cyclonic events.

Adaptation options

Salinity intrusions that render areas unsuitable for agriculture, particularly for traditional rice farming, could provide additional areas for culturing valued shrimps and other estuarine fish species. If these shifts are to be made, major changes in the supply chains have to be adopted and nations should build these needs into their planning and forecasting.

Sea level rise and saline water intrusion will also impose ecological and habitat changes, including mangroves that act as nursery grounds for many euryhaline species.

Development of a Unified Strategy**:** Improvement of water productivity through higher yields, crop diversifications, and integrating livestock fisheries, is an effective way of improving rural income, alleviating poverty and reducing risk by diversifying income sources. Thereby improving community resilience and reducing environmental degradation that exacerbates climate change. A common framework should be created at the country level that can be used towards implementing the integrated watershed management strategy starting from *Gram Panchayat* (village council) to the river–basin level in a unified manner. Integrated watershed management does not merely imply the amalgamation of different activities to be undertaken within a hydrological unit. It also requires the collection of relevant information, so as to evaluate the cause and effect of all the proposed actions. This framework will need regular maintenance and updating to fully reflect the most accurate ground truth data. Local planning and management strategies have to be evolved and validated through the proposed framework, so as to generate and evaluate various options suitable for local conditions. This would greatly help inland fisheries development in future.

REFERENCES

Brandt, S.B. and Kirsch, J. (1993). Spatially explicit models of striped bass growth potential in Chesapeake Bay. *Transactions of the American Fisheries Society,* **122:** 845–69.

CIFRI Annual Report. (1947–2009). Central Inland fisheries Research Institute (CIFRI), Kolkata, India.

Das, M.K., Shrivastava, P.K., Dey, S., Liakat Mandal, M.d. and Sahu, S.K. (2011). Impact of drought on hatchery fish seed production in West Bengal—A case study (Accepted). J. Inland Fish Society India p. 43.

Das Manas, K.R. (2010). Climate change impacts on inland fisheries–Issues and strategies, pages 146–159 in Lead Papers, National Symposium on Climate Change and Rainfed Agriculture, 18–20 February 2010, CRIDA, Hyderabad, India.

Das, M.K. and Saha, P.K. (2008). Impact and adaptation of inland fisheries to climate change in India. Central Inland fisheries Research Institute, Kolkata, Bulletin no. p. 151.

Das Manas, K.R. Dutta, Tanusree., Acharya, Subhendu. and Bhowmick, S. (2002). Sublethal temperature stress in juvenile *Labeo rohita* (Ham.) and *Rita rita* (Ham.): Some physiological changes. *Indian Journal of Experimental Biology,* **40:** 589–93.

David, A. (1959). Observations on some spawning grounds of the Gangetic major carps. Indian major carps with a note on carp seed resources in India. *Indian J. Fish*, **6:** 327–41.

Department of Fisheries, Aquaculture, Aquatic Resources and Fishing Harbours. Hand book of fishery statistics of West Bengal. (2008–2009). Government of West Bengal.

Dey, M.M., Rab, M.A., Paragua, F.J., Piumsombun, S., Bhatta, R., Alam, M.F. and Ahmed, *M*. (2005). *Fish consumption and food security*: A disaggregated analysis by types of fish and classes of consumers in selected Asian countries. *Aquaculture Economics and Management,* **9:** 89–111.

Dey, S., Srivastava, P.K., Maji, S., Das, M.K., Mukhopadhyaya, M.K. and Saha, P.K. (2007). Impact of climate change on the breeding of Indian major carps in West Bengal. *J. Inland Fish Society*, **39:** 26–34.

Hutchins, L.W. (1947). The basis for temperature zonation in geographic distribution. *Ecological Monograph,* **17:** 325–35.

Iyengar, N.S. and Sudersshan, P. (1982). A method of classifying regions from multivariate data.,Economic and political weekly, *Special article,* pp. 2048–52.

Kamal Yusuf, M., Singh, Balbir and Mathew, P.M. (1980). Assessment of fish seed potentiality of a stretch of river Ganga in Bihar. *Proc. Indian Natn. Science. Academy*. **46:** 120–28.

Mason, D.M., Goyke, A.P. and Brandt, S.B. (1995). A spatially explicit bioenergetics measure of habitat quality for adult salmonines; Comparison between lake Michigan and Ontario. *Canadian Journal of Fisheries and Aquatic Sciences,* **52:** 1572–83.

Menon, A.G.K. (1954). Fish geography of the Himalayas. *Zoological Survey of India*, Calcutta, India **11:** 467–93.

Ministry of Agriculture. (1958, 1976, 1981, 1986, 1988, 1991, 1993, 1996, 2000, 2006, 2008). Handbook of Fisheries Statistics. Department of Agriculture and Cooperation, Fisheries Division. Government of India, New Delhi, India.

Natarajan, A.V. (1989). Environmental impact of Ganga basin development on gene–pool and fisheries ofthe Ganga river system, pp. 545–60, *In*: Proceedings of the International large river symposium [Odge, D.P.D. *Ed*.]. Can. Spec. Publ. *Fish Aquat. Sci.,* p. 106.

Frank Rahel, J. (2002). Using current biogeographic limits to predict fish distributions following climate change, *American Fisheries Society Symposium. American Fisheries Society,* **32:** 99–110.

Sanghi, A., Mendelsohn, R. and Dinar, A. (1998). The climate sensitivity of Indian agriculture. pp. 703–17, *In*: Measuring the impact of climate change on Indian agriculture (Dinar, A., Mendelsohn, R., Evenson, R., Parikh, J., Sanghi, A., Kumar, K., Mckinsey, J. and Lonergan, S., *Eds*.), World Bank Technical Paper No. 402, Washington, D.C.

Smit, B. and Wandle, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, **16:** 282–92.

Tyler, J.A. and Brandt, S.B. (2001). Do spatial models of growth rate potential reflect fish growth in a heterogeneous environment? A comparison of model results. *Ecology of Freshwater Fish,* **10:** 43–56.

Unnikrishnan, A.S. and Shankar, D. (2007). Are sea-level-rise trends along the coasts of the north Indian Ocean consistent with global estimates? *Global Planet Change,* **57:** 301–07.

Vass, K.K., Das, M.K., Srivastava, P.K. and Dey, S. (2009). Assessing the impact of climate change on inland fisheries in river Ganga and its plains in India. *Aquatic Ecosystem Health and Management,* **12:** 138–51.