Climate Change Effects on the Sundarban Mangrove Ecosystem and Tiger Population Dynamics in the Indian Region

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Abstract

In this study, we investigate the impact of climate change, encompassing both natural and anthropogenic scenarios, on the Sundarban mangrove ecosystem—the world's largest natural low-lying mangrove habitat—and its implications for the Royal Bengal Tiger habitat. Situated along the Ganges River between India and Bangladesh, the Sundarban spans approximately 9,600 square km. Employing a multi-source approach, we analyze climate parameters from satellite and real observations, alongside data on mangrove and tiger populations from various sources. Our findings reveal a concerning decrease in mangrove coverage in the present decade, attributed to climate change factors such as rising temperatures, coastal storms, sea-level rise, high humidity, and inadequate rainfall, particularly during the monsoon period. Simultaneously, the Royal Bengal Tiger population in the region has dwindled from 250 in 1960 to a current estimation of 70–80, with the decline attributed to poaching, climate change, and habitat loss. The analysis underscores the interconnectedness of climate, mangrove health, and tiger population, indicating a pressing need for conservation efforts. The study provides critical insights for researchers and policymakers, enhancing our understanding of the complex dynamics between climate change and coastal biodiversity, with significant implications for mangrove ecosystems and tiger habitats. Furthermore, it emphasizes the potential migration of tiger populations from Sundarban to alternative regions due to habitat loss, emphasizing the urgency of addressing climate-induced threats to preserve these vital ecosystems.

INTRODUCTION

In India, mangrove distribution is accounted about 3% of global mangroves and 8% of mangroves of Asia. About 60% of the mangroves is found on the east coast of Bay of Bengal whereas 27% is found on the west coast border by the Arabian sea, and 13% on Andaman & Nicobar Islands. In India Mangroves area is larger in the east coast around 80% and 20% in the west coast [1, 2].

The east coast has more in mangrove ecosystem due to heavily nutrient rich alluvial soil on the banks of Ganges, Brahmaputra, Mahanadi, Godavari, Krishna, and Cauvery rivers in comparison to the west coast. Mangrove is halophytic plant species which is known as salt tolerant forest ecosystem. It provides a wide range of ecological and economical products and services and supports coastal and marine ecosystems [3–5]. The east coast has the world’s largest mangrove forest, i.e. the gigantic Sundarban in West Bengal. It covers about 9,600 sq. km of mangroves forest and water, which is sedimented by three rivers i.e. Ganges, Brahmaputra, and Meghna. It is a most dominant flora due to mangroves distribution which has identified 36 true mangroves in the Indian Sundarban [6]. The Sundarban covers 6000 sq km of forest over Bangladesh and 4000 sq km in West Bengal, India [7]. The wildlife of Indian mangrove is quite diverse and interesting which is included the Royal Bengal Tiger, estuarine crocodile and different types of monkeys, deer, fishing cats, snakes and wild pigs. The Royal Bengal tiger (*Panthera tigris tigris*) is the iconic species of this forest [8, 9]. Tangible benefits of mangroves comprise timber and non-timber products, fishery, and other livelihood support systems whereas non- tangible benefits like ecological and social functions, such as coastal protection against wave and current abrasion, shelter and habitat for

wildlife, and tourism. Last few decades have experienced gradual increase and unusual accumulation of CO_2 in the atmosphere mainly due to industrial activity, global warming, ice melt increase in water in oceans, tidal waves [11, 12].

Due to climate change and sea level rise, there is gradually reduction on Mangrove ecosystem which directly relates the reduction of tourist and attractive elements as well as the loss of “flora and fauna” of the nation. This will also highly impact on the forest dependent livelihoods in present and future [13, 14]. Stress on wetlands has increased due to the rapid population growth, technological development, urbanisation and economic growth. Recent surveys quotes that deforestation is root cause in a destruction of about 44% and 26% of mangroves along the west and east coast, respectively [15, 16]. If climate change and the sea level rise greatly change, the forest coverage, diversity and the attractive elements in the Sundarban will be reduced and tourism activities will be also reduced significantly in the long period [17–19].

Tiger Eco-system

As the Sundarban is famous for Royal Bengal tiger (*Panthera tigris tigris)* and it’s also vastly distributed by mangrove population so it’s a suitable area for tiger habitat. Tigers can live in a wide range of habitats, like mangrove swamps, evergreen forests, tropical rain forests, savannas, grassland and also Rocky Mountains. In current situation the tiger population is gradually decreasing in such manner which leads to be endangered. It is due to the different factors like illegal hunting, a declining prey base, and degradation of habitats [20] and also change of diverse array of habitats. The food of tiger is biogeographically diverse. Tiger reserves within India, which holds wild tiger population more than half of the current estimation. As tiger is the national animal for India, hence India is need to protect the Royal Bengal tigers Which are going to be extinct in India.

The conflicts between man and animal are major factors that affect the big cats and also human move deeper into the territory of tigers, which is a major problem for animals to survive. Due to lack of protection from illegal hunting by the villagers and lack of wildlife health management it’s difficult to maintain the tiger population in current scenario. The interference with the population numbers of the prey, there is a danger for tiger survival. The water is also a critical factor to sustain the tiger due to lack of rainfall and climate change and temperature increase it’s difficult for the tiger to sustain themselves. The most prolific part of India where the tiger species are live i.e. the lower parts of the Himalayan Mountain range, the mangrove swamps of Sundarban in West Bengal and the dense vegetation of the various forests of the far East. The wide variety of different habitats that tigers occupy is testimony to their adaptability to various conditions. Today, the big threat to the survival of tigers is the loss of their natural habitats. Tigers are solitary animals and require space in which to hunt. Still, parks and nature reserve actually protect and conserve their numbers and need to be supported.

MATERIALS AND METHODS

Here the meteorological data like temperature, rainfall and humidity are adopted from IMD (India meteorological Department) observations and satellite like TRMM (Tropical rainfall measuring mission and NCEP (National center for environmental prediction) reanalysis products. The sea level and tiger data is adopted from the CSIRO (The commonwealth Scientific and Industrial Organization) and Indiastat.

The study considers the Sundarban mangroves forest of West Bengal, India from 1987 to 2013. We have adopted data for the mangrove coverage over West Bengal region from http://www.indiastat.com/forestandwildlife/13/forests/108/forestcover19802015/450042/stats.aspx from 1987 to 2013. The statistical analysis shows there is reduction in mangrove population in the present decade compared to past because of climate change i.e. increase in temperatures, coastal storms, rise in sea level, high humidity and poor rainfall (particularly in the monsoon period) etc. For this, there is also a direct impact on forest dependent livelihoods such as Royal Bengal tigers. we have also adopted the tiger data from http://ifs.nic.in/Dynamic/misc/fwstats04/table6_6.pdf from 1972 to 2013 [21]. The analysis provides a better result for the cause of reduction of mangrove ecosystem and tiger habitat due to climate change in current scenario.

RESULT AND DISCUSSION

As India is plenty of mangrove forest both the east and west coast(table S1) and Sundarban is the world largest mangrove forest (Fig. 1). For that we have considered the Sundarban mangroves forest of West Bengal, for our research work (Fig. 2).There are some factors which are the root cause of reduction of mangrove forest over Sundarban region are given below,

Increasing Temperature

Due to increase in CO_2 level in the atmosphere which resulted increase in global mean temperature [22]. Between 1906 and 2005, the global average surface temperature has increased by 0.74 degree centigrade and it is further expected to increase 1.1–6.4 degree centigrade at the end of this century [23].On the basis of previous study it is already reported that there is a negative impact on mangrove species due to rise in temperature. So here we have consider the inter annual variability of temperature and its Pearson correlation coefficient value between the mangrove coverage and annual average temperature in Degree Celsius over West Bengal (Sundarban) of India (Fig. 3A). Here the negative correlation indicates the decrease in mangrove coverage and increase in annual average temperature and the trend value is also increasing for the time period of 1987 to 2013. The rise in temperature, increase salinity not only affects the biodiversity but also creating disturbance in the entire systems. Due to the global warming there is a cause of ice melt which is causing sea level rise both at regional and global scale [24].This will make a huge effect on mangrove forest. It also affects the physiological function of mangrove plant by damaging the membrane fluidity and also organ function [25]. The marine organisms are sensitive to the increasing temperature, because many coastal organisms already live close to their thermal tolerance [26, 27]. So if there is further increase in temperature then it will be a harsh situation for the coastal organisms for their survival.

The Indian mangroves support a huge group of fungi, plankton and other benthic community which might face a potential risk due to further increase in temperature and it also affect the ontogenetic transition. It is already emphasized that the mangrove might face the species composition change and changes in the fruiting and flowering periods [28, 29].The mangrove plants require an ideal temperature for their photosynthesis. If the temperature will increase then there is a reduction of photosynthesis, it will also affect the net productivity. By the current analysis of temperature of the last years there is increase in temperature in all the part of India. The mangrove plants can support 0.6 ^{0}C rise in temperature in the coastal region [30].If the temperature does not exceed an upper threshold then there is increasing in mangrove productivity.

Poor Rainfall

Rainfall is currently decreasing in the regional basis but there is a prediction that 25% of rainfall will increase by 2050 in response to climate change and the regional basis of rainfall will be uneven [31]. However, Intergovernmental Panel on Climate Change projects (IPCC) highlights that there is significantly increase of precipitation in the parts of central Asia and poor in the parts of Southern Asia for the forthcoming years [32].The inter annual variability of maximum rainfall over West Bengal from 1987 to 2013 (Fig. 3B).The poor rainfall is shown by the decrease trend line and also positive correlation value between rainfall and mangrove coverage show both are gradually declining on this time period particularly in the monsoon period (Fig. S1). The poor rainfall and increased temperature lead to the rise in salinity which is unfavourable for the growth of mangrove species [33].As the increase in soil salinity, there is also increase in tissue salt level in mangrove plants and which cause reduction of water availability, which reduces productivity. It will also impact on net primary productivity of mangroves and seedling survival as well as there is reduction of mangrove area due to the conversion of upper tidal zones to hyper saline flats [30]. Reduction of precipitation can result in mangrove encroachment into salt marsh and freshwater wetlands [34, 35].

Increase rainfall will result in increased growth rates and biodiversity, increased diversity of mangrove zones and increase in mangrove area [28, 36].By the previous study, mangroves tend to be taller and more diverse on high rainfall shorelines relative to low rainfall shorelines, including Australia [36].Areas which have higher supply of fluvial sediment and nutrient are likely to have higher rainfall with higher mangrove diversity as well as reduced exposure to sulphate and reduce salinity[37].

High Humidity

Due to the climate change, high humidity also a important factor for the reduction of growth of mangrove plants by reduce the leaf area ratio and net assimilation rate. With increase Salinity and humidity, there is the reduction in growth in mangroves such as *Aegiceras corniculatum* and *Avecennia marina* [38].The inter annual variability of maximum humidity for the period of 1987 to 2013 over West Bengal (Fig. 3C).The increase trend shows humidity is increasing whereas the negative correlation between high humidity and mangrove coverage indicate reduction in mangrove coverage and increase in humidity. The humidity was at a higher range (84%-96%) during the monsoon than in the pre-monsoon (76% – 77%) and

post-monsoon (69% – 79%). The humidity of the troposphere is controlled by the intensity and availability (seasonal) of solar radiation. The pattern of humidity showed higher variation during the months of post-monsoon in consistence with temperature in comparison to that of rest of the seasons.

Sea level rise

Due to the global warming there is increase in global sea level rise i.e. (12-22cm occurred during 20th century) [23]. There is also reduction of habitat due to sea level rise i.e. 20–70% reductions over the next 100 years in the ecological important zones [31]. By the climate modelling it's clearly shows that there is a larger change in sea level led to mangrove ecosystem collapse [41, 42].Due to the data availability we have consider the sea level for the period of 1993 to 2013 over West Bengal(Fig. 4).Here the increase trend line and equation show sharp increase in mean sea level i.e.14mm per year, which is a danger condition for the mangrove forest over West Bengal,India for the future scenario. By the sea level rise there is also the cause of sedimentation and erosion of coastal land. For the outward growth of coast, there is a migration of wildlife such as tiger, crocodile and some other organisms from the coast land. Due to migration there is also risk of attack to the local peoples by the Royal Bengal tigers in the Sundarban area, for this the local people has fenced for the protection. So the sea level rise will be the greatest threat to the Indian mangroves. There are three different mangrove responses to sea level trends [42].Stable: Mangroves generally don't change position when sea level remains stable. Site specific relative sea level falling: Mangroves will gravitate towards the sea and sometimes laterally if sea level falls. Site specific sea level rising: Mangroves will retreat landward as sea level rise. Mangroves nearest the sea margin die back due to stress caused by the rising tide while new growth occurs at the landward fringe. The biggest concern connecting sea level rise to mangrove ecosystems is the rate of change in elevation of mangrove sedimentation. The rate of change in elevation of the mangrove sediment surface is exceeded by the rate of change in relative sea level [43].

CONCLUSION

It's the time to look forward for climate change and its impact on mangrove ecosystem. If the impact of climate change will be continued like this then one day, it will come there is no ecosystem like mangrove and the Royal Bengal tiger. So, we should focus on the potential threats like overgrowing population, technological development, urbanization and economic growth.

Additional threats like natural calamities drought, hurricanes, erosion etc and also anthropological activities like exploitation, encroachment and reclamation of vast wetland areas for commercial, agricultural and residential development. For this, there is a reduction in mangrove coverage over West Bengal (Sundarban area) by that there is also drastically decline of tiger population on Sundarban area in current scenario (Fig. 5). Proper monitoring along with restoration work, awareness and educational material regarding mangrove importance and benefits towards human beings and also using the media like magazine, films, posters, documentary videos on mangrove ecosystem can save the flora and fauna of nation. If we will not save our wetland ecosystem then they would not be to protect and help us. In

India it is not started to analyse or estimate the impacts of climate change on mangroves. For the combustion of fossil fuel the amount of CO_2 is emitted more in India and it is the highest amount in comparison to the other countries. Apart from that, Indian metro cities are highly populated such as Mumbai, Chennai and Calcutta situated on coastal line which are the major source of reduction of mangroves for the urbanization and human exploitation.

Declarations

Availability of data and materials

The manuscript contains all the available data.

Competing interests

The authors declare no conflicts of interest.

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Authors' contributions

Parthasarathi Barik performed the experiment, carried out literature survey, contributed to analysis, interpretation and writing manuscript. Krushna Chandra Gouda formulated the algorithm, carried out literature review, interpreted the results and prepared the manuscript.

References

1. FAO. The world's mangroves 1980-2005. Forestry Paper No. 153,Rome, 2007; 77 .
2. SFR. Forest Survey of India 2007. India State of Forest Report, Dehradun. 2009; pp. 27-31.
3. Kathiresan K, Bingham BL. Biology of mangroves and mangrove ecosystems. Advances Mar Biol.2001; 40: 81–251.
4. Field C, Osborn J, Hoffman L, Polsenberg J, Ackerly D, Berry J, et al. Mangrove biodiversity and ecosystem function. Global Ecology & Biogeography Letters. 1998; 7(1):3–14. doi: 10.2307/2997693
5. Lugo AE, Snedaker SC. The ecology of mangroves. Annu Rev Ecol Syst.1974; 5: 39–63.

6. Untavale AO. Mangroles of India. In: Mangroves of Asia and the pacific-status and management. UNDP/UNESCO Project Research and Training Pilot Program on Mangrove ecosystems. 1986; (RAS/79/002. UNOP/UNESCO. Manila).
7. Uddin MS, Shah MAR,Khanom S,Nesha MK. Climate change impacts on the Sundarbans mangrove ecosystem services and dependent livelihoods in Bangladesh. Asian Journal of Conservation Biology.2013;2:152-156.
8. Mandal and Nandi. Fauna of Sundarban mangrove ecosystem. Records of Zoological Survey of India. 1989;1-27.
9. Naskar K and Mandal R. Ecology and Biodiversity of Indian Mangroves. Daya Publishing House, Delhi, India. 1999;386-388.
10. Hazra S, Ghosh T, Gupta RD and Sen G. Sea Level and associated changes in the Sundarbans. Science and Culture.2002;68:309-321.
11. Ewel KC, Twilley RR, Ong JE. Different kinds of mangrove forests provide different goods and services. Global Ecol Biogeog Let .1998;7: 83–94.
12. Friess DA, Webb EL. Variability in mangrove change estimates and implications for the assessment of ecosystem service provision. Global ecology and biogeography. 2014; 23(7):715–725. doi: 10.1111/geb.12140.
13. Woodruff JD, Irish JL, Camargo SJ. Coastal flooding by tropical cyclones and sea-level rise. Nature. 2013; 504: 44–52. doi: 10.1038/nature12855 PMID: 24305147
14. Hoozemans F, Marchand M, Pennekamp H. Sea level rise: a global vulnerability assessment for population, coastal wetlands and rice production on a global scale. Deltares,1993.
15. Kathiresan K, Rajendran N. Ecosystem in the Indian Ocean region. Ind. Jour Mar. Sci.2005; (34)1:104-113.
16. Selvam V. Environmental classification of mangrove wetlands of India. Current Science. 2003; 84: 757-765.
17. Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K, et al. A world without mangroves. Science.2007; 317: 41.
18. Giri C, Pengra B, Zhu Z, Singh A, Tieszen LL. Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuarine, coastal and shelf science.2007; 73: 91-100.
19. Alam M. Subsidence of Ganges-Brahmaputra Delta and associated drainage, sedimentation and salinity problems. In Milliman, J.D., Haq, B.U. (Ed.) Sea Level Rise and Coastal Subsidence, consequences and strategies.1996; 169-192.
20. Miquelle DG, Pikunov DG, Dunishenko YM, Aramilev VV, Abramov VK, Smirnov EN et al. Theoretical Basis of Accounting the Amur Tiger and Its Prey Resources in the Far East of Russia. Dalnauka, Vladivostok.2006; 183.

21. http://www.livemint.com/Politics/JhHG6uB8ZvujYVi5oMaEMM/Tiger-population-in-India-rises-to-2226-in-2014-up-30-sin.html.
22. Christopher D, Harley G, Hughes AR, et al. The impacts of climate change in coastal marine systems. Ecology Letters. 2006; 9: 228-241.
23. Solomon S, Qin D, Manning M, Alley RB, et al. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.
24. IPCC, 2001. Climate Change 2001, Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change.Cambridge University Press, Cambridge, UK.
25. Hochachka PW, Somero GN. Biochemical Adaptation:Mechanism and Process in Physiological Evolution. Oxford University Press,New York,2002.
26. Somero GN. Thermal physiology and vertical zonation of intertidal animals: optima, limits and costs of living. Integ. and Comp. Biol.2002.; 42: 780-789.
27. Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, et al. Climate change, human impacts and the resilience of coral reefs. Science.2003;301: 929-933.
28. Field C. Impacts of expected climate change on mangroves. Hydrobiologia. 1995; 295: 75- 81.
29. Ellison J. How South Pacific mangroves may respond to predicted climate change and sea level rise. In: Gillespie, A.Burns,W. (Eds.),Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand and Small Islands States.Kluwer Academic Publishers, Dordrecht,Netherlands, (Chapter 15), 2000; pp: 289-301.
30. Dash SK, Jenamani RK, Kalsi SR and Panda SK. Some evidence of climate change in twentieth-century India. Climatic Change.2007; 85: 299-321.
31. Houghton J, Ding Y, Griggs D, Noguer M, van der Linden P, Dai X, Maskell K, Johnson C (Eds.). Climate Change 2001: The Scientific Basis (Published for the Intergovernmental Panel on Climate Change) .Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA,2001.
32. IPCC (ed). Climate change 2007: the physical science basis. Cambridge University Press,New York, 2007.
33. Sandilyan S, Thiyagesan K and Nagarajan R. Salinity rise in Indian mangroves- a looming danger for coastal biodiversity. Current Science. 2010; 98: 754-756.
34. Saintilan N, Wilton K. Changes in the distribution of mangroves and saltmarshes in Jervis Bay, Australia. Wetl. Ecol. Manage. 2001; 9:409–420.
35. Rogers K, Saintilan N, Heijnis H. Mangrove encroachment of salt marsh inWestern Port Bay, Victoria: the role of sedimentation, subsidence, and sea level rise. Estuaries. 2005A; 28: 551–559.
36. Duke NC, Ball MC, Ellison JC. Factors influencing biodiversity and distributional gradients in Mangroves. Global Ecol. Biogeogr. 1998; 7:27–47.

37. McKee K. Soil physiochemical patterns and mangrove species distribution reciprocal effects? J. Ecol. 1993; 81: 477–487.
38. Ball MC. Ecophysiology of mangroves. Trees Struct Funct. 1988; 2:129–142.
39. Galbraith H, Jones R, Park R, Clough J, Herod Julius S, Harrington B et al. Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. Waterbirds.2002; 25: 173-183.
40. Ellison JC, Stoddart DR. Mangrove ecosystem collapse during predicted sea- level rise:holocene analogues and implications. J. Coast Res.1991; 7:151-165.
41. Ellison JC. Mangrove retreat with rising sea level,Bermuda. Est Coast Shelf Sci.1993; 37:75-87.
42. Cahoon DR, Hensel P. High-resolution global assessment of mangrove responses to sea-level rise: a review. In: Gilman, E. (Ed.), Proceedings of the Symposium onMangrove Responses to Relative Sea Level Rise and Other Climate Change Effects, 13 July 2006, Catchments to Coast, Society of Wetland Scientists 27th International Conference, 9–14 July 2006, Cairns Convention Centre, Cairns, Australia. Western Pacific Regional Fishery Management Council, Honolulu, HI, USA, ISBN: 1934061-03-4 ,2006 ;pp. 9–17.
43. Cahoon DR, Hensel PF, Spencer T, Reed DJ, McKee KL, Saintilan N. Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. In: Verhoeven JTA, Beltman B, Bobbink R, Whigham D. (Eds.), Wetlands and Natural Resource Management. Ecological Studies, vol. 190. Springer-Verlag, Berlin/Heidelberg. 2006; pp. 271–292.

Figures

Figure 1

Mangrove distribution over east and west coast of India. Here West Bengal (Sundarban) is the largest mangrove forest followed by Gujarat.

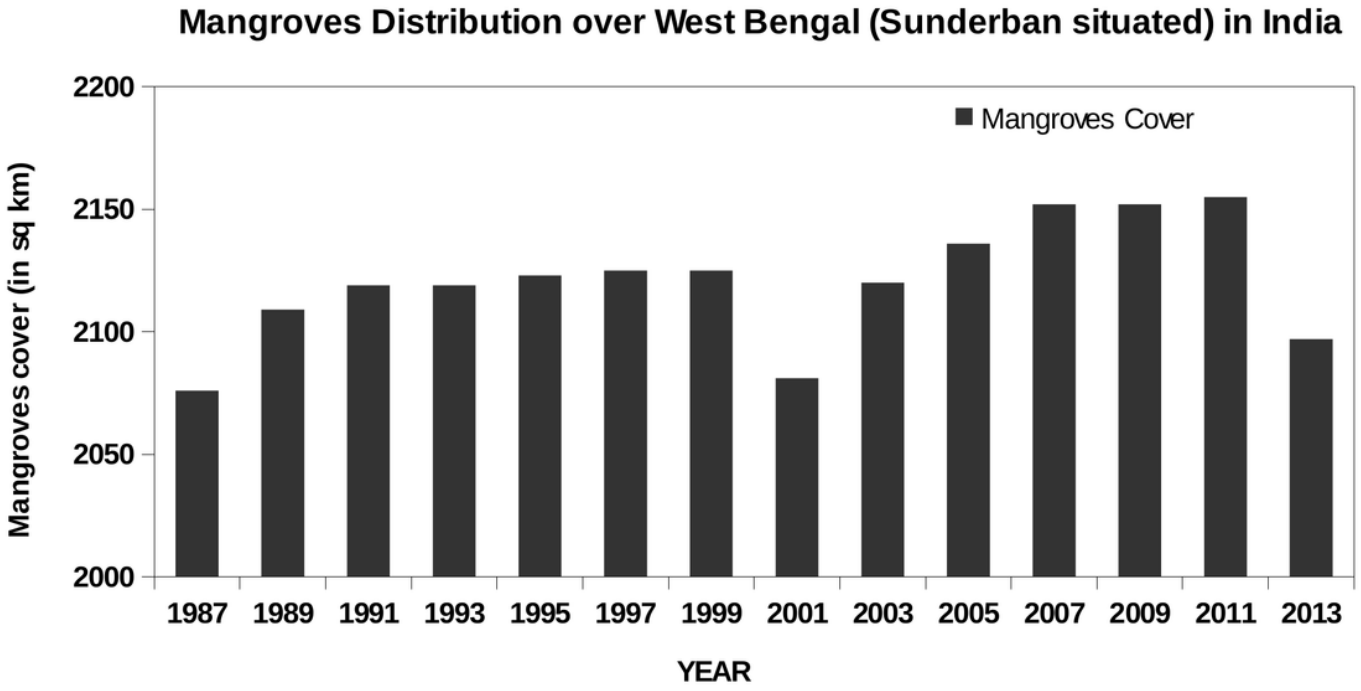

Figure 2

Mangrove coverage over West Bengal (Sundarban) for the period of 1987-2013 of India.

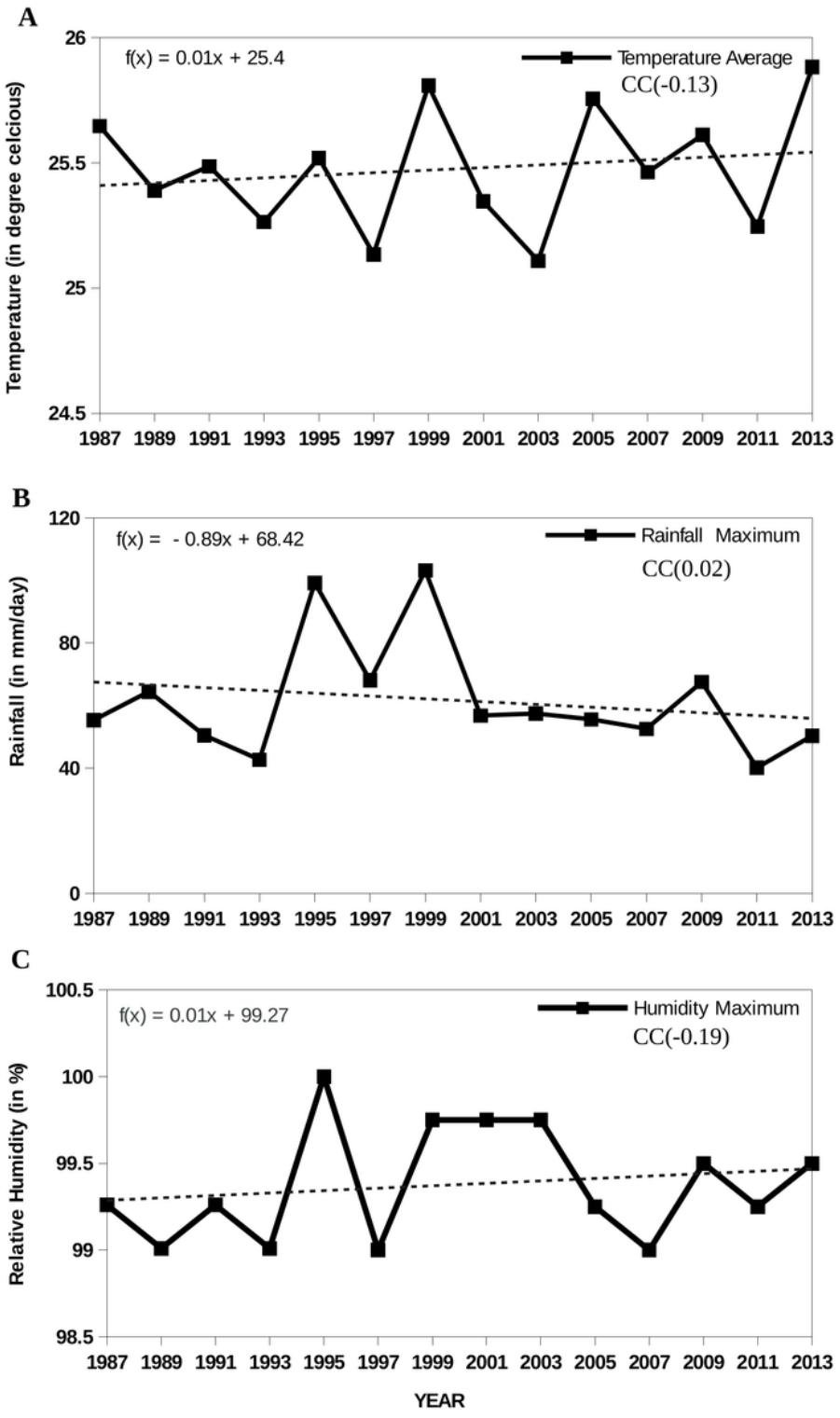

Figure 3

Inter annual variability of the climatic parameters for the period of 1987-2013 over Sundarban region. Here the number in the bracket represents correlation coefficients between mangrove distribution and respective parameters. The equation shows the trend value of climatic parameters.

A) Temperature (Degree Celsius)

B) Rainfall (in mm/day)

C) Relative Humidity (in %)

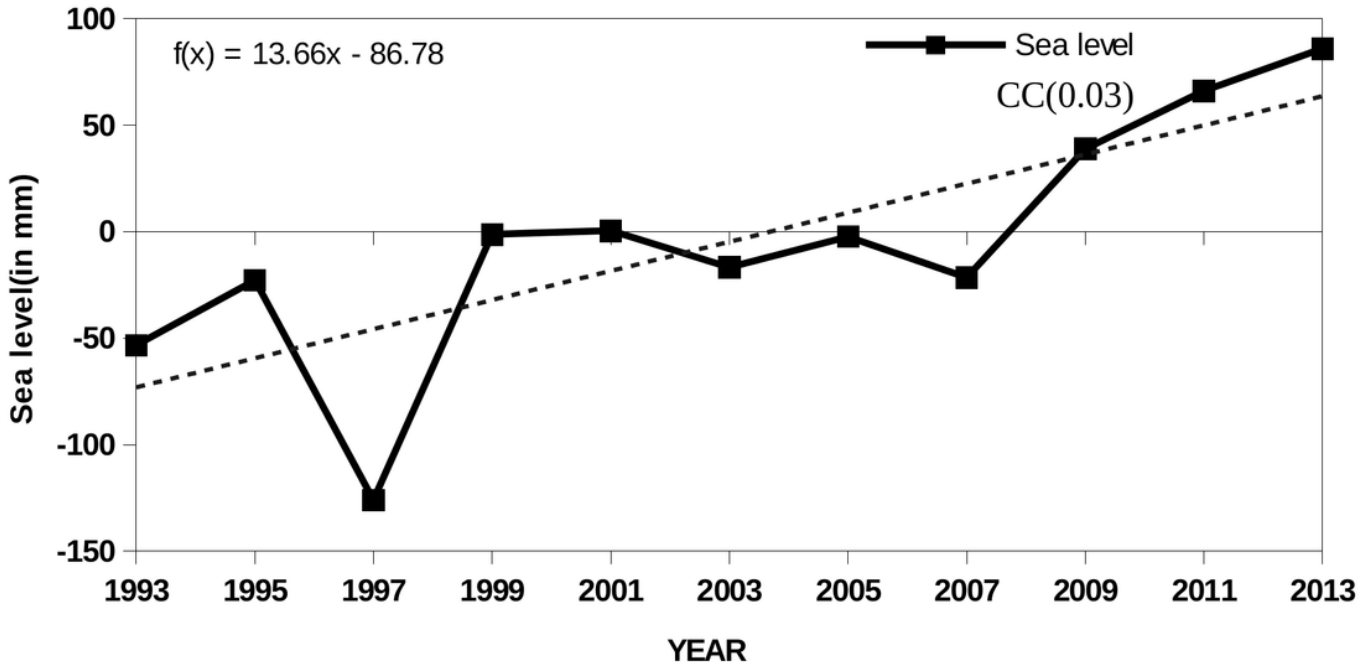

Figure 4

Inter annual variability of the mean sea level rise for the period of 1993-2013 over West Bengal of India. The number in the bracket represents correlation coefficients between mangrove distribution and mean sea level. Here the equation shows the trend value of mean sea level.

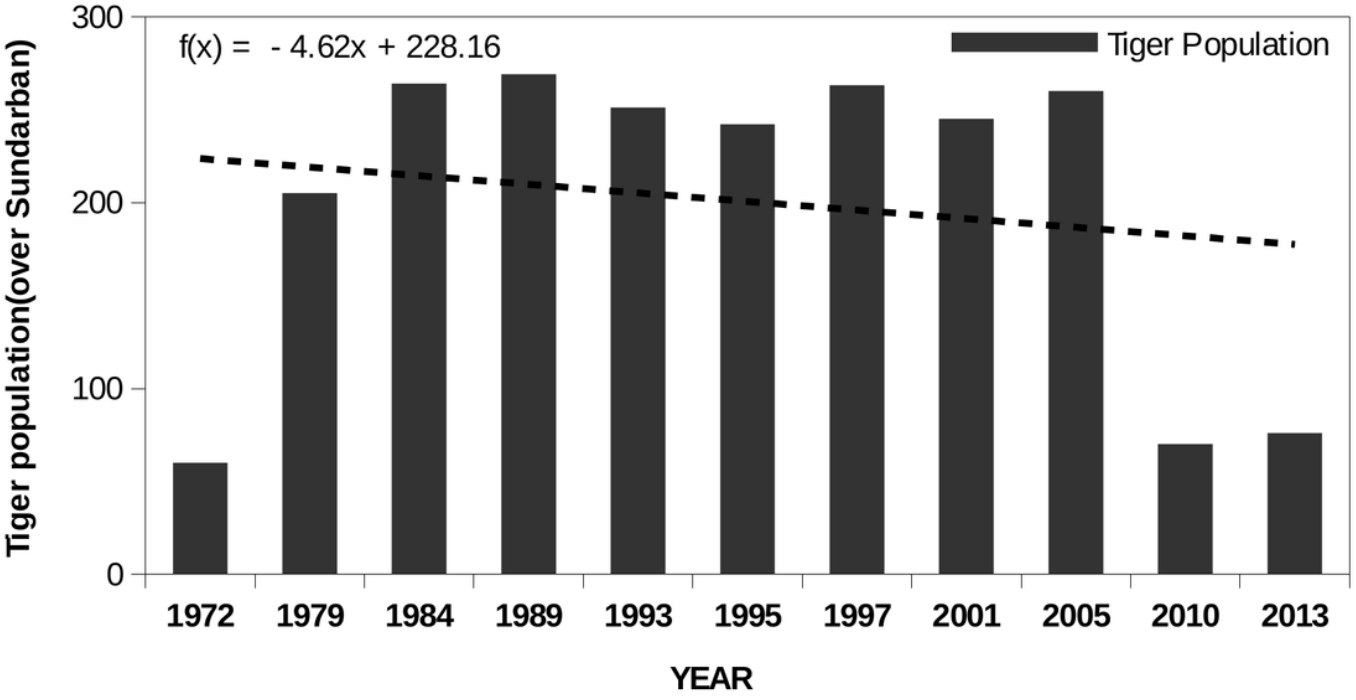

Figure 5

Inter annual variability of tiger population for the period of 1972 to 2013 over West Bengal (Sundarban area).

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