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Climate Change and Its Impact on Hydrology, Rainfall, and Temperature Patterns in the Manas River Basin: A Comprehensive Study of Environmental Consequences and Conservation Strategies

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Abstract: ***Freshwater ecosystems are highly susceptible to the impacts of climate change, resulting in significant alterations in river discharge, droughts, temperature shifts, and water quality. This vulnerability is particularly evident in the Manas River Basin, where changing precipitation patterns and reduced water flow during the summer season have profound ecological consequences. The altered water quality and habitat loss are posing an imminent threat to the unique and endemic plant and animal species inhabiting Manas National Park. The park's ecological fragility, economic marginalization, and the presence of endangered species with limited geographic ranges exacerbate the challenges it faces from climate change and human activities. Wetlands, grasslands, and woodlands are at the forefront of these environmental shifts, experiencing habitat reduction, displacement of native species, and the proliferation of invasive ones. Urgent global recognition and collaborative efforts are required to address these pressing environmental issues. Extensive research is essential to establish practical guidelines for the preservation of the delicate balance of local ecosystems in the face of climate change, ensuring coexistence between nature and human activities. It is imperative that effective conservation practices, adaptive management, and international cooperation are embraced to safeguard regions as ecologically sensitive as the Manas River Basin in the era of rapid global warming.***

Keywords: The Manas River, Hydrology, Rainfall, Wild Life Sanctuary, Climate, Vegetation, Meteorological aspects

1. Introduction

Since the period of Industrial Revolution, human emissions of greenhouse gases from fossil fuel combustion, deforestation, and agricultural practices have led to global warming and climate change. Most commonly observed changes in the climate include higher temperatures, changes in rainfall patterns, changes in the frequency and distribution of weather events such as droughts, storms, floods and heat waves, sea level rise and consequent impacts on human and natural systems. Many scientists and researchers argue that the impacts of climate change will be devastating for both nature and human society, but in respond to that the awareness is very low (Harrington, 2022).

It is easy to notice the short term environmental changes but hard to perceive the long term climate changes. The foundation for the modern scientific view of climate change emerged during the 19th Century when the evidence of past glaciation led to the realisation that the earth’s climate was not stable and had changed substantially over time (Riedy, 2016).

Few climate scientists have put forward two kinds of responses to the threat by climate changes which include: adaptation and mitigation. Adaptation involves the process of adjustment to climate change, whereas mitigation involves reduction in human emissions of greenhouse gases and replacing fossil fuels with renewable or low emission alternatives.

Hydrology:

The field of hydrology examines how water acts in both the atmosphere and the earth's surface and subsurface (Huda and Singh, 2014). Long - term water resource planning relies heavily on knowledge of land surface hydrology. Having precise data on the amount of water resources accessible throughout various river catchments is crucial for effective integrated water resource management. The hydrologic cycle relies heavily on precipitation, which is why it is considered a primary climatic factor. The rate and volume of runoff are both affected by the amount of rain that falls. The water - balance equation for a river is commonly used to analyze the hydrologic cycle (Brooks et al., 1991). In contrast, modern water resource management makes use of innovative methods for gauging water accessibility. Surface and sub - surface characteristics of the landscape are just as crucial as atmospheric factors in the hydrologic cycle when it comes to evaluating surface runoff and developing a water resource plan for various water resource locations.

Impact of Climate Change on Hydrology

Climate and water on the Earth’s surface are closely linked. Water plays a very important role in a large - scale exchange of mass and heat between the atmosphere, the ocean, and the land surface, thus influencing the climate, and also being influenced by the climate. (Kundzewicz, 2008).

The threat of climate change has increased interest in climate research, which focuses on observing, understanding and modelling the five interconnected components that comprise the climate system: atmosphere, oceans, land surface, cryosphere, and biosphere (Davies, 2005).

Although climate change will certainly affect the hydrological cycle, its results will not be evenly distributed over the globe. As the concentrations of anthropogenic emissions, especially carbon dioxide, in the atmosphere rise, radiative forcings enhance the natural greenhouse effect and lead to warmer surface temperatures with an increase of between 1.5°C. The oceans transport heat from low latitude to colder, mid and high latitude, and provide the majority of the water in the climate system. The land surface affects albedo, evapotranspiration and atmospheric dynamics through vegetation cover, soil properties and land surface texture. Spatial and temporal scales also play an important role in the climate system (Saher et al., 2021).

Rainfall:

Hydrological and water quality models depend heavily on precipitation since it affects the rate and magnitude of flow and mass transfer (Chaubey et al., 1999). Management of water resource application and efficient exploitation might benefit from an examination of the rainfall parameters of a watershed/river catchment, or drainage basin. A region's potential crop production, farming system, and agricultural productivity pattern can be determined by studying the type and features of rainfall, which has applications in emergency management, planning, and engineering design (e. g., reservoir construction, flood control work, drainage network design, soil conservation, etc.) (Lee, 2005). For sustainable progress, understanding the features of rain in relation to its temporal variation is crucial. Watershed runoff and hydrologic conditions are both impacted by global and regional climate change, which is a direct result of the world's growing industrialization (Barman et al., 2012). Understanding the effects of rainfall variability on local economies necessitates a regional - level investigation (Beecham et al., 2010). The vegetation cover in a watershed area has a direct or indirect effect on the amount of precipitation that falls there because it absorbs and stores some of the rain that falls during the storm's early stages before the rest of the precipitation evaporates. Net precipitation is calculated by subtracting the amount of water lost through evaporation and transpiration from the amount of water that falls to the ground (Stevenson et al., 2014).

The water cycle is less stable over very long periods of time due to natural and human - caused interference, which increases the range of fluctuations. The availability and safety of water have become more precarious as a result of global warming. It's no surprise that as the human population rises, so does the pressure to ensure our existence. As a result, their actions have both immediate and long - term consequences for our environment (Opondo, 2022). By clearing forests to make way for crops and buildings, as well as by modifying the distribution of temperature and rainfall patterns, humans are affecting the weather and climate. Climate variables, including temperature, evapotranspiration, precipitation intensity, and total precipitation, affect all soil water, surface water, and groundwater and change the hydrological cycle in a watershed and throughout a region.

The Manas River

The Manas River is a transboundary river since it flows through territory belonging to both Bhutan and India in the Himalayan foothills.

It meets three more significant streams before it branches out into India in western Assam. Flowing for a total of 400 kilometers, the river begins in Tibet and flows through China for 24 kilometers before entering Bhutan for 272 kilometers and finally entering Assam for 104 kilometers until finally merging with the massive Brahmaputra River near Jogighopa. At Bangpari in Assam, the Aie River, a significant tributary of the Manas, meets it.

The Manas or Gongri River is the main artery of the river system, and it originates in the Indian state of Arunachal Pradesh's West Kameng District. It runs south and west until entering Bhutan near the city of Tashigang. The Kulong Chu, which has its source in the Himalayan mountains of northern Bhutan, joins it in Tashigong. Tashigong's river bed is around 550 meters wide, and it rises 606 meters above sea level. The Kula Kangri Mountain (1, 666 m) in northern Bhutan is the source of the Tongsa (Mangde) Chu, while the Bumthang River (sometimes spelled Murchangphy Chu) flows south from the Bumthang Valley and combines with the Manas River to produce the Kulong Chu.

The water level in the river here is 121 meters. After flowing roughly southwest for about 29 kilometers in Bhutan, the Aie River enters India through the village of Agrong in the Goalpara district of Assam. It then meanders for another seventy - five kilometers before draining into the Brahmaputra not far from Jogigopa. The Black Mountains are the source of the Aie River, which is roughly 110 kilometers long and begins at an elevation of around 4, 915 meters near the settlement of Bangpari. The Manas river is 104 kilometers long in India.

There are little meadows in the foothills nestled among the heavily wooded hillsides that surround the river valley and provide a variety of brooks, streams, and other natural drainage routes that eventually empty into the river. The lower parts of the river feature numerous areas of soft, sandy ground interspersed with scattered trees (Negi, 1991).

Manas Wildlife Sanctuary:

There are little meadows in the foothills nestled among the heavily wooded hillsides that surround the river valley and provide a variety of brooks, streams, and other natural drainage routes that eventually empty into the river. Located in the Himalayan foothills, where wooded slopes give way to grassland and tropical vegetation, it has a gradual alluvial slope. There's a wide range of animals there, including some critically endangered species like tigers, pygmy hogs, Indian rhinoceroses, and elephants. Perils to the Location: Dangerous since it was seized and occupied by Bodo tribe militants seeking political retribution between 1992 and 2011. From 1988 to 1993, the park's infrastructure was severely damaged, and from 1990 to 1996, a large number of trees and animals, including virtually all of the Park's rhinoceroses and half of its tigers, perished as a result of the political unrest. As the insurgents finally capitulated in 2003 and started working with the government through the Bodoland Territorial Council, things stabilized and improved with local residents, although destruction was still a real possibility. The park's northern boundary is with Bhutan, while its southern border is with the town of Barpeta Road, which is 41 kilometers north of the regional headquarters of Guwahati. Bhutan's Royal Manas Wildlife Sanctuary lies to the north of the Manas River, the heavily populated region of North Kamrup lies to the south, and there are forested areas to the east and west. Since then, the Park's infrastructure has started to recover and be rebuilt.

Dates and History of Establishment

Royal hunting grounds were set aside in 1907 when the North Kamrup Forest Reserve was established and more acreage was added in 1927. Manas was designated a rhinoceros sanctuary (36, 000 acres) in 1928. The reserve grew to 39, 100 hectares in 1955 and in 1971, in response to local encroachment, the government established a seed farm on 890 ha within the Sanctuary.

To protect the Indian tiger population, Project Tiger was launched in 1973, and the Manas Reserve became its centrepiece. The reserve now spans an area of 283, 712 hectares. In 1988, Bhutan established the neighboring Royal Manas National Park. The area was designated as a core zone of the Manas Biosphere Reserve (283, 700 acres) in 1989. In 1990, the Sanctuary expanded to cover 52, 000 hectares after the neighboring Panbari, Koklabari, and Kahitama Forest Reserves were incorporated into the park (Oliver, 1993).

It was designated as endangered in 1992 when Bodo insurgent groups destroyed habitat and killed off large numbers of animals in a protest against population growth and competition for forest resources. The Park established the Buxa - Manas Elephant Reserve's central zone (283, 700 acres) in 2001. The Bodo people were granted limited independence in 2003 when the Bodoland Territorial Council (BTC) was officially recognized. Chirang Ripu Elephant Reserve incorporates the Park.

Finally the removal off the list of endangered places took place in 2011.

2. Physical Features

A 64 - kilometer journey to the south brings you to the confluence of the Manas and the Bholkaduba, from which the Beki runs off to join the Brahmaputra. Heavy rainfall, high grades, and friable bedrock upstream cause these and five other rivers passing through the Reserve to bring vast volumes of silt and rock down from the foothills. In the southern Terai grasslands, where the water table is quite close to the surface, there are deep layers of fine alluvium with underlying plains that could be used for farming. As a result of the park's terrain, the Manas basin in the west frequently floods during the monsoon, but the water usually recedes quickly. Wildlife drowning is minimal since animals can safely seek refuge on islands (Shahin, 2006).

Climate: The relative humidity might reach up to 76 percent, making the weather hot and sticky. From about the middle of March through the end of October, with the heaviest precipitation occurring during the monsoon months of about the middle of May through the end of September, the western half of the Reserve is flooded. It rains an average of 3, 330 millimeters per year here. The months of November through February, when minor rivers dry up and large rivers decrease in volume, are dry and quite warm (Shahin, 2006).

Vegetation: Natural diversity abounds in Manas because of its location on the boundary between the Indo - Gangetic and Indo - Malayan biogeographical regions. Grasslands, which are the most prevalent form of flora, sub - Himalayan alluvial semievergreen forest, and east Himalayan mixed moist and dry deciduous forest are the three main types of vegetation. Wet deciduous forest takes over areas away from rivers and streams, and eventually, in the northern portion of the Park, semi - evergreen climax forest takes over (Kundzewicz, 2008). Among the common trees found, there are Aphanamixis polystachya, Anthocephalus chinensis, Syzygium cumini, etc. The majority of the best trees have been cut down. The burning of vegetation and, on a smaller scale, elephants are responsible for their creation and upkeep. Wild buffalo herds, gaurs, barasinghas, elephants, and waterbirds all find riparian grasslands to be the ideal homes. Forty - three species of grasses have been identified, including Imperata cylindrica, Saccharum naranga, etc. (UNESCO). Some examples of the trees and shrubs found here include the swamp - dominant Dillenia pentagyna, the savanna - dominant silk cotton Bombax ceiba, the Phyllanthus emblica, and the Clerodendrum, Leea, Grewia, etc. Along the riverbanks and in the many pools, you can find a rich diversity of aquatic plants (Menon, 1995). Among the 374 described dicotyledon species, 89 are trees, 139 are monocots, 43 are grasses, and 15 are orchids (Jain, 1983).

Fauna: The Park is home to more endangered and endemic species than any other protected region in India. Fifty - five different kinds of mammals, fifty different kinds of reptiles, and three different kinds of amphibians have all been spotted in the area (Das, et al.2010). Several species found here are only found in Southeast Asia and are found nowhere else in the west, while others are found nowhere else in the east. Once upon a time, before the tribal invasions, this area was home to the greatest number of elephants, the second - greatest number of tigers, and the third - greatest number of rhinoceroses in the country (Shahin, 2006).

Flora: East Himalayan mixed moist and dry deciduous forests resemble those found in the Sub - Himalayas, which are characterized by their semi - evergreen flora (ii), and grassland (iii) make up the three primary types of vegetation. More than 42.84 percent of the park is made up of alluvial grasslands. The burning of vegetation and, on a smaller scale, elephants are responsible for their creation and upkeep. Wild buffalo herds, gaurs, barasinghas, elephants, and waterbirds all find riparian grasslands to be the ideal home. There are numerous species of trees and shrubs in addition to the 43 types of grasses. One can find a wide variety of plant life in the Manas River's water. The 139 known species of monocotyledons, the 15 known species of orchid, and the 374 known species of dicotyledons all include trees. At least 543 different plant species have been documented as thriving inside the perimeter. Among these, around 374 are monocots, 139 are dicots, and the remaining 30 are pteridophytes or gymnosperms (Riedy, 2016).

Local Human Population:

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Most of the 28.800 residents in the park's bordering villages are members of the Bodo tribal group (Vagholikar et al., 2010). The District Revenue Authority is in charge of collecting these taxes. In the surrounding areas, woodlands that were once used by native peoples for grazing and tree products have been cut down by the timber and paper industries for pennies on the dollar, and then illegally purchased by immigrant farmers. The native population was so insulted by the government's refusal to provide them access that they would rather see the rainforest destroyed than give it up to invaders. As their population grew, the villages were no longer able to avoid accessing the national park's protected woodlands. From 1988 to 2003, the park was under attack by rebel groups motivated by resentment over perceived neglect. In the same year that the Bodo renounced violence, the Bodoland Territorial Council was established and granted some authority (Bora, 2018).

Conservation Value:

A biogeographical crossroads between the Indo - Gangetic and Indo - Malayan Manas is home to stunning landscapes and a wide variety of wildlife. It is the most species - rich of India's wildlife sanctuaries, thanks to the variety of ecosystems that support 22 species on the endangered or threatened list. It serves as the backbone of a large tiger reserve that safeguards a vital elephant migration route between the states of West Bengal, Arunachal Pradesh, and Bhutan. Its wetland ecosystems are significant on a global scale (Li et al., 2020).

Meteorological Aspects:

The Manas basin receives moisture from the boreal winter and summer monsoon circulations due to the area's proximity to both monsoonal and mid - latitude weather systems. For a long time, scientists believed that the land - sea temperature difference and the resulting thermal circulations were responsible for the monsoon's annual cycle. Precipitation during the winter and early spring comes primarily from synoptic weather systems that originate in the Mediterranean and track eastward toward South Asia.

Between June and September, when the South Asian summer monsoon sweeps across the Indian subcontinent, the region's atmosphere takes on a distinctly seasonal appearance due to the presence of certain climatic factors. The low - pressure area from the Bay of Bengal to western India is known as the "monsoon trough. " A high - pressure area may be seen hovering over the Mascarene islands in the subtropical southern Indian Ocean, specifically at 30"S.50°E. A sign of the beginning of the South Asian monsoon is the presence of a strong cross - equatorial south - westerly flow across the Arabian Sea, with a maximum wind speed of about 100 knots near 1.5 km level and known as the low - level cross - equatorial jet. The Tibetan anticyclone and the tropical easterly jet are two of the most significant features of the upper troposphere's circulation, each with an amplitude of up to 200 hPa. The Western Ghats and the adjacent portions of north - eastern India and the neighboring territories get the most precipitation during the southwest monsoon. Seventy - five to eighty percent of India's yearly precipitation falls between June and September (Yang et al., 2019).

Observers have noticed shifts in the forest ecosystem, particularly the marsh, and grassland, all across the park and along the Manas River's banks. This has the potential to have a devastating effect on environmental conditions, which are largely determined by things like temperature, soil moisture, and humidity. There is no question that these changes have had an impact on the Manas River's hydrology and the nearby flora and wildlife. The silt load on the river flow is affected by changes in water output and upstream habitats, which in turn influences surroundings further downstream. When the ice caps that supply the Manas River melt, so too does the amount of sediment in the river. The flash floods triggered by the river killed a large number of wild animals and severely damaged the park's vegetation and infrastructure (Wang et al., 2019).

Study Area

Eastern Bhutan and northeast India are drained by the 41, 350 square kilometer watershed that is the Manas River, a major tributary of the Brahmaputra River. Out of its total length of 376 kilometers, 272 kilometers flow through Bhutan and the remaining 104 kilometers run through Assam to the point where the river meets the mighty Brahmaputra at Jogighopa. A total of 18, 300 km2 of Bhutanese territory is drained, between the coordinates of 26º10′ to 26º 50′ N Latitudes and 90º00′ to 91º00′ E Longitudes, while a total of 23, 000 km2 of Assam, India is drained. Some of the river's main stem originates in southern Tibet and flows into India over the Bumla pass in Arunachal Pradesh's northwestern region.

The Manas River travels from the southwest via Bhutan and into the south - central foothills of the Himalayas in India's Assam. This route follows the river's original course as it was carved out by glaciers.

The Aie River begins its journey into India at the village of Agrong in the Goalpara district of Assam after flowing roughly 29 kilometers south - westward through Bhutan. The next 75 kilometers or so of its winding path take it to the Brahmaputra, not far from Jogigopa. The Black Mountains provide the source of the 110 - kilometer - long Aie River, which begins at an elevation of around 4, 915 meters near the village of Bangpari; the Manas is 376 kilometers long along the course of its longest tributary, the Kur, of which roughly 104 kilometers are located in the Indian state of Assam.

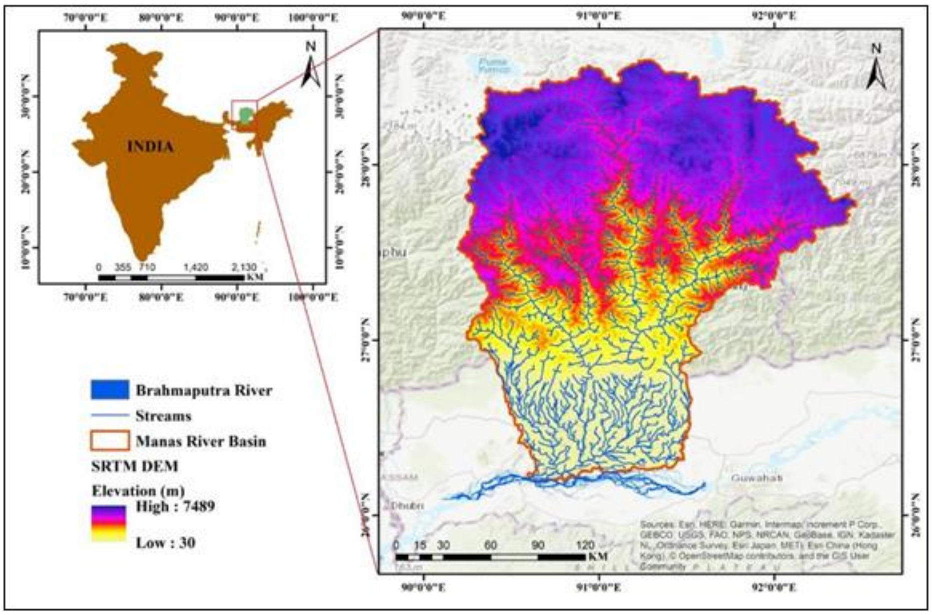


Figure 1: Location of Manas River Basin

When it exits the western side of Manas National Park, it divides into the Beki and the Bholkaduba. The Manas National Park is located on a vast low - lying alluvial terrace below the foothills of the outer Himalaya, and is traversed by the Manas River as well as five other smaller rivers. Besides serving as a natural boundary between India and Bhutan, the river is also a recognized international boundary. There is not a single flat area within the watershed's 140 - kilometer radius; the catchment rises from an elevation of 100 meters near the Indian border to the Great Himalayan peaks at over 7, 500 meters along the major Himalayan range bordering Bhutan and Tibet. It is one of the world's most biodiverse regions because of the convergence of several different types of ecosystems, including the Sub - Himalayan Bhabar Terai formation and the riverine succession that continues up to the Sub - Himalayan Mountain Forest. It gets as low as around 150 C and as high as about 370 C. May through September sees the heaviest rains, with an average of 333 cm (13 feet) every year.

The main vegetation types found along the Manas River are:

- In the northern regions, Sub - Himalayan Light Alluvial Semi - Evergreen woods
- Mixed moist and dry deciduous woods in the East Himalayas (the most common type)
- Woodland on a low - lying savanna, and
- Nearly 50 percent of Manas National Park is made up of Assam Valley Semi - Evergreen Alluvial Grasslands.

Data Sources:

For the research project, the following database have been used. For the PET calculation by Thornwaite and Mather procedure, temperature - based heat index, i. e., i= [T0c/5]1.514 with a location specific correction factor of unadjusted PET is used for the assessment of soil moisture and runoff variability over time. In order to compare daily runoff with other parameters of water balance equation [P= RO+PET+ΔST, where RO= Runoff, P= Precipitation, PET= Potential Evapotranspiration and ΔST= Changes in soil moisture], the T - M procedure is used. Daily water level and discharge data was collected for the period of 20 years (1999 - 2019) from the Assam Water Resource and Management Institute, Basistha, Guwahati. Daily rainfall and temperature data was also collected from the Barpeta Division Water Resource Department, Govt of Assam, for the same period of 20 years. Additionally, daily temperature information have been gathered from the Barpeta Division Water Resource Department, Government of Assam, for a 20 - year period (1999 - 2019). By collecting a soil sample from the research region and performing a laboratory test, soil testing have been carried out. The toposheets of the research area, has been used in the mapping, which is done at a scale of R. F.1/50, 000, from Survey of India.

3. Result and Discussion

Rainfall Pattern and Temperature Trends

As precipitation has such a profound effect on the rates and volumes of flow and mass transfer, it is an indispensable part of hydrological and water quality models. Management of water resource application and efficient exploitation might benefit from an examination of the rainfall parameters of a watershed/river catchment, or drainage basin. Yet, shifts in the weather are being triggered by human activity. The river Manas experiences a yearly shift in its rainfall pattern. And this is what the records of rainfall are demonstrating. Rainfall data from 2005 to 2019 has been compiled, and the variations in rainfall illustrate how they have an effect both directly and indirectly on the vegetation in the Manas river basin. Rainfall frequency throughout both the yearly and monsoonal seasons has declined gradually between 2005 and 2019, as evidenced by the data.

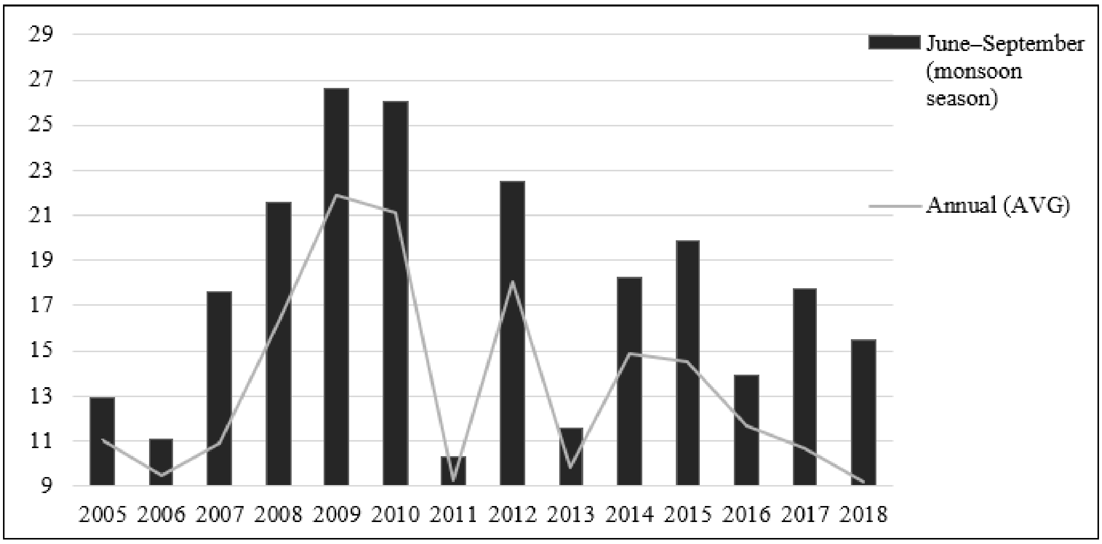


Figure 2: Trend of Rainfall

In the field of hydrology, river hydrology is one of the most important subfields to study. Rainfall frequency and intensity, among other things, affect river hydrologic features like discharge, velocity, and water quality. The Manas River's water level has changed as a result of global warming - caused shifts in precipitation patterns.

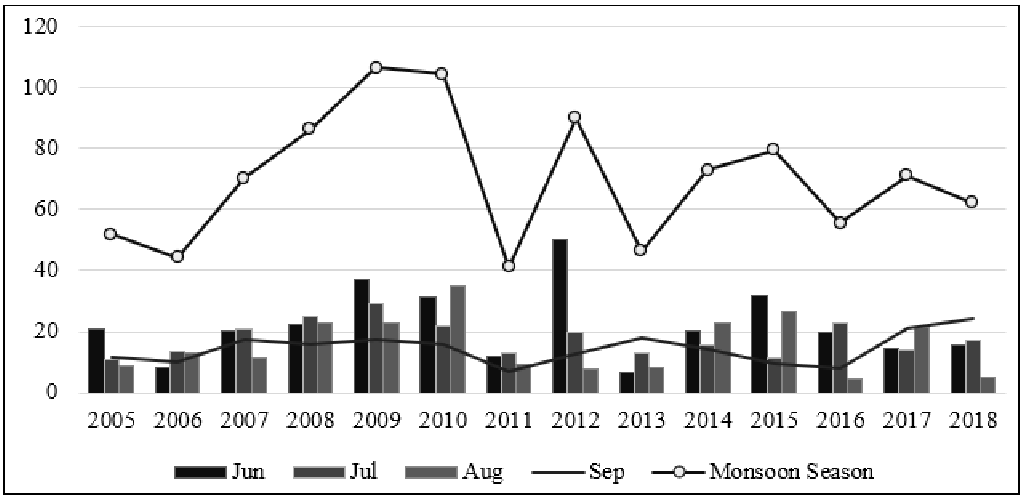


Figure 3: The Manas River catchment's mean monthly rainfall trend

Temperature Pattern:

Moreover, the intra - annual distribution of precipitation and temperature has shifted due to global warming. Similar warming tendencies can be seen in annual and monthly average temperatures. Human activity, however, is contributing to climate change. Manas River's annual temperature pattern shifts. This is what we demonstrate using our temperature records. So far, temperature data (2005 - 2018) has demonstrated that temperature variations have affected the biodiversity of the Manas river basin in both direct and indirect ways.

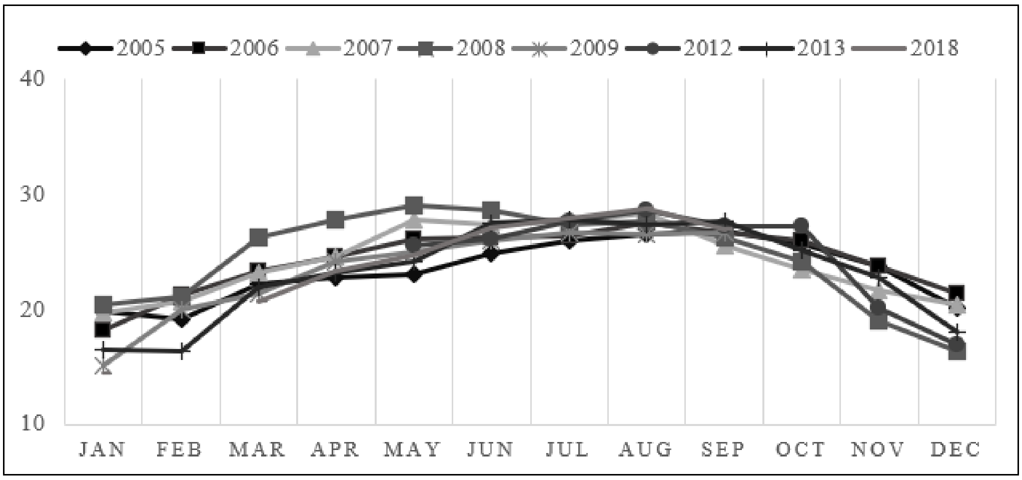
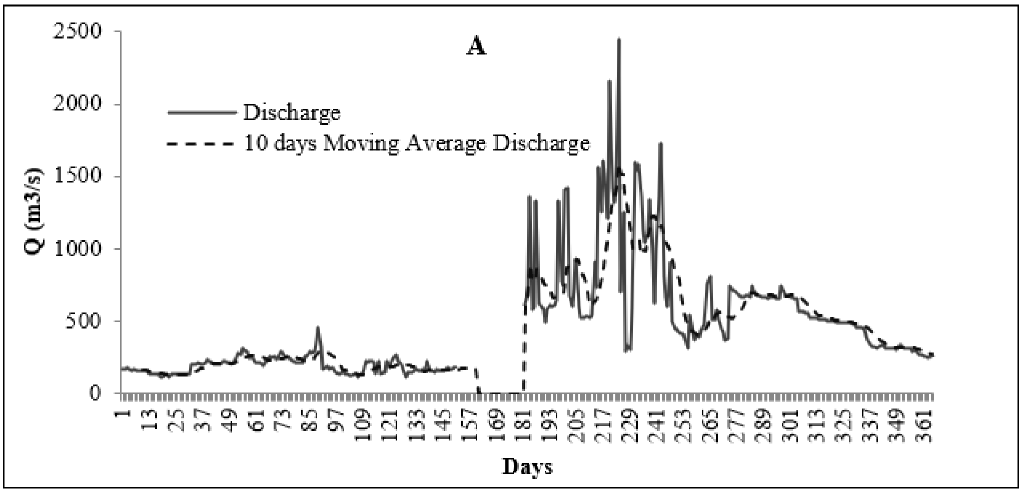
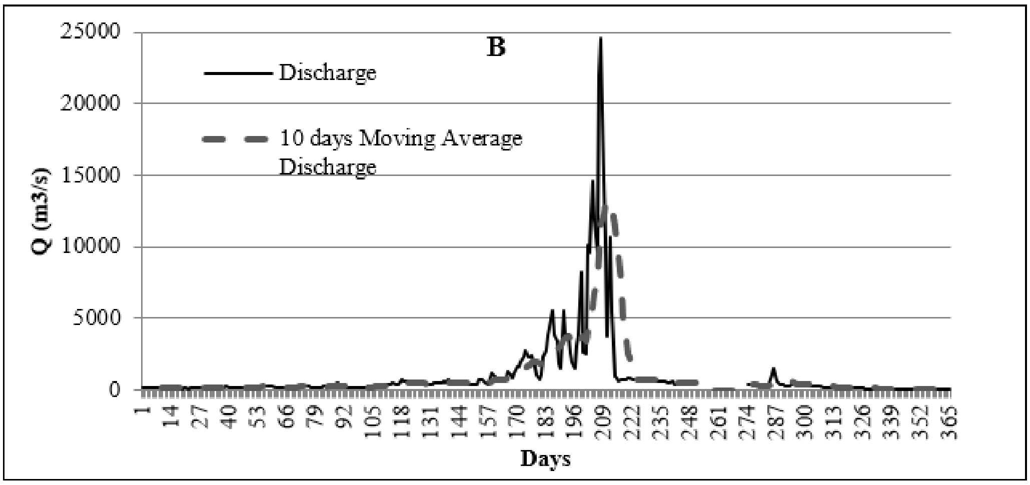


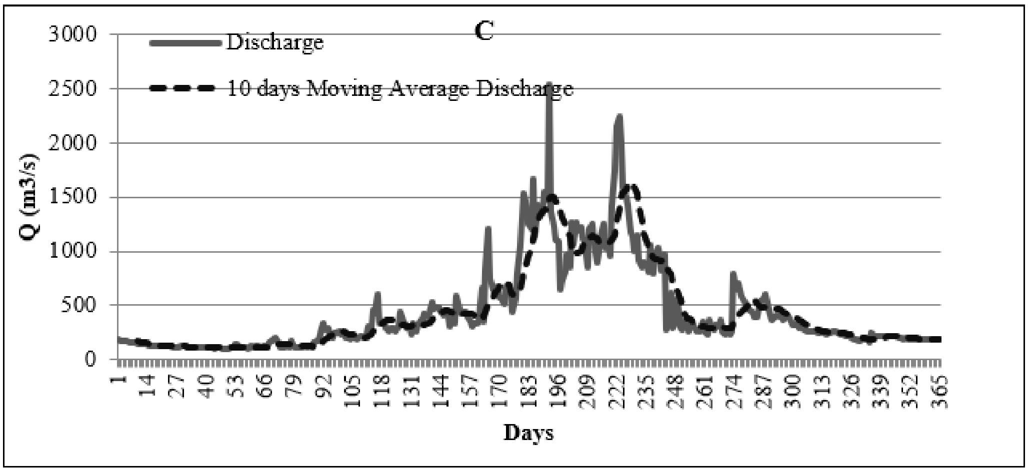
Figure 4: The Manas River catchment's temperature trend

Flow Discharge Variation

The study area being under the wet monsoonal climatic conditions of the foot - hills of Bhutan Himalayas, the rainfall is concentrated in the summer season of five months (May to September) that receives about three - fourth share of total rainfall (about 3300mm) in the year. It is seen that increasing amount of rainfall increases the discharge rate in the Manas river catchment. Analysis of daily hydrograph provides the following interesting result for the year 2015, 2016, 2017 and 2018 respectively.







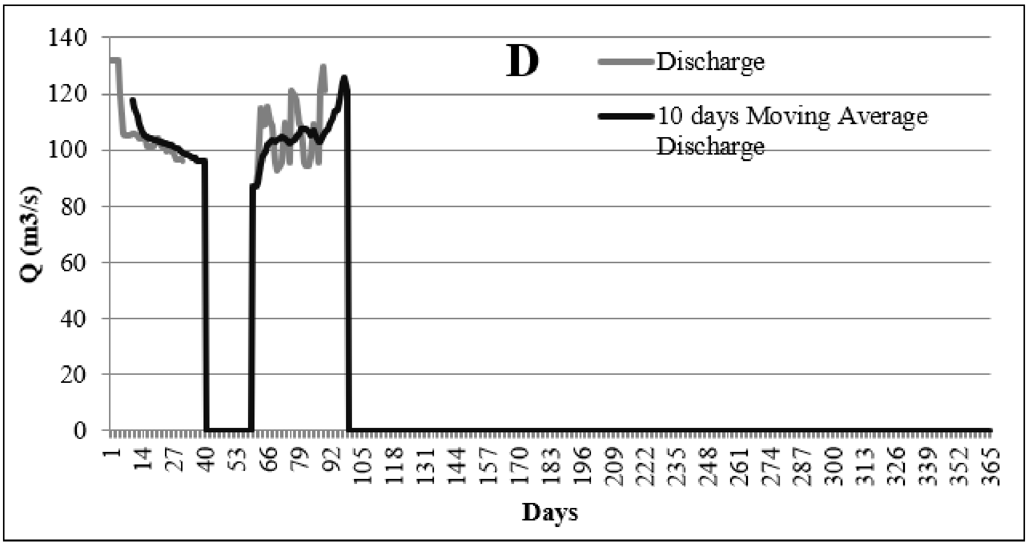
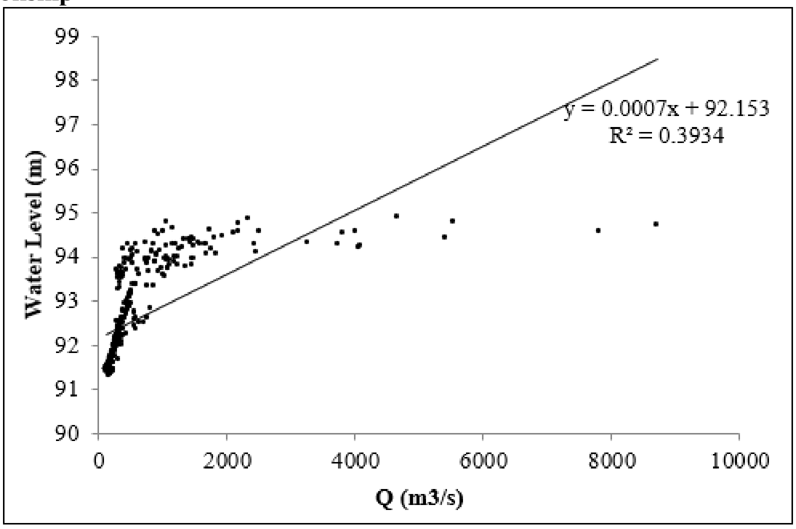


Figure: A represents the hydrograph for the year 2015, **B** represents the year 2016, **C** represents 2017 and **D** represents 2018.

Stage - Discharge Relationship



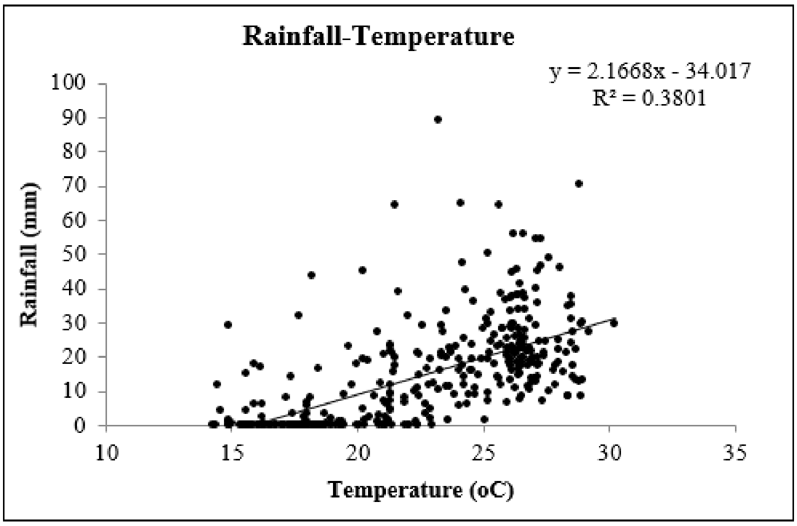
Relationship between Rainfall and Hydro - Meteorological Factors

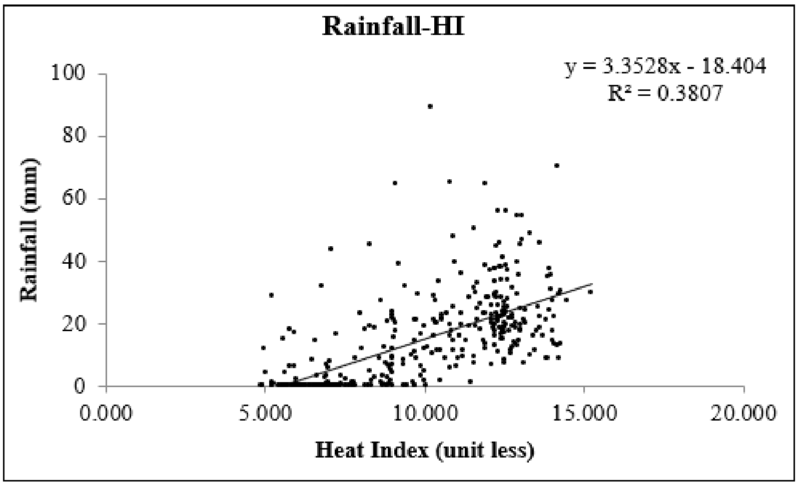
a) As heat index is power function of temperature, the relationship between rainfall and heat index follow almost same trend and, hence, it follow logarithmic relationship (Table 1).
b) Polynomial is best fit function of PET as it has moderate degree of its determinant (R^2 =0.383). It shows that increasing rainfall intensity increases fast the amount of PET especially during pre - monsoon when rising temperature and increasing rainfall increase the amount of evapotranspiration (Table 1)
c) Theoretically, it is said that increase in rainfall is proportional to the increase in the amount and depth of runoff; it means runoff depth and rainfall intensity must have the positive relationship. It is true with some

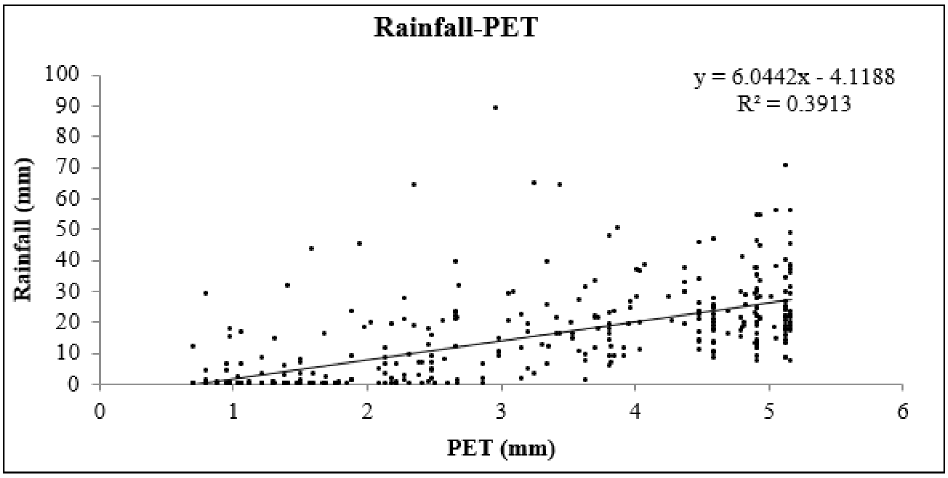
deviations in the present case when an observed value of runoff is regressed with rainfall intensity.

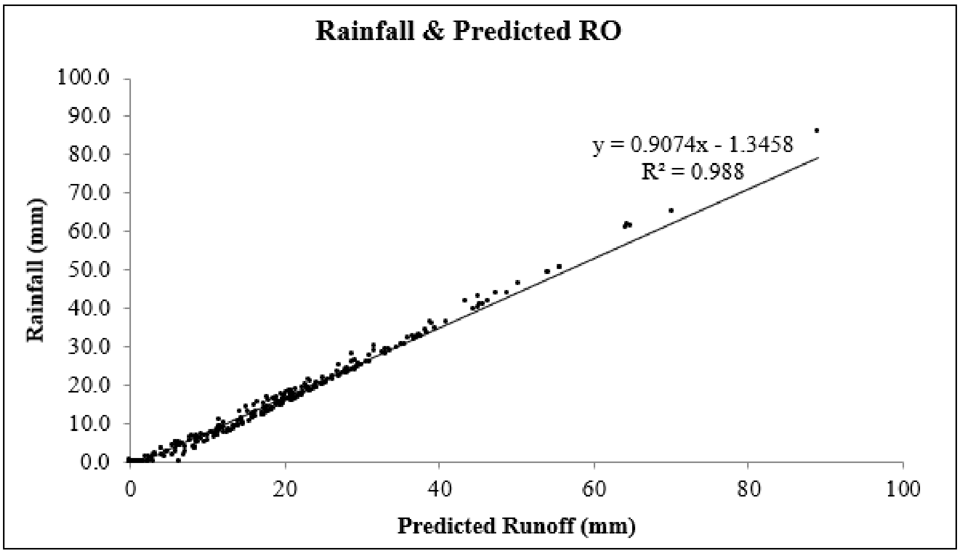
Table 1: Relationship between Rainfall and Hydro - Meteorological Factors

Parameters	Mathematical Function	Y	Degree of Determinant (R^2)
Rainfall - Temperature	Linear	y = 2.166x - 34.01	R^2 = 0.380
	Polynomial	y = 0.019x^2 + 1.309x - 24.95	R^2 = 0.380
	Logarithmic	y = 45.99ln (x) - 127.6	R^2 = 0.373
Rainfall - HI	Linear	y = 3.352x - 18.40	R^2 = 0.380
	Polynomial	y = - 0.050x^2 + 4.323x - 22.72	R^2 = 0.381
	Logarithmic	y = 30.38ln (x) - 53.58	R^2 = 0.373
Rainfall - PET	Linear	y = 6.044x - 4.118	R^2 = 0.391
	Polynomial	y = - 0.487x^2 + 3.441x	R^2 = 0.383
	Logarithmic	y = 15.34ln (x) - 0.343	R^2 = 0.379
Rainfall - Runoff (Predicted)	Linear	y = 0.907x - 1.345	R^2 = 0.988
	Polynomial	y = 0.002x^2 + 0.775x - 0.603	R^2 = 0.993









4. Discussion

In the coming years, the rise in temperature will be much more severe and rapid (Diffenbaugh & Field 2013). According to an estimate, the average global temperature is likely to increase by 1.8–4.0 °C (IPCC 2007). Rising atmospheric temperature is expected to increase the water temperature as well. Since rivers are turbulent and are in close contact with atmospheric air, they respond to atmospheric warming very quickly. It is supposed that there will be an increase in the surface water temperature of streams. Due to the warming of climate, there may also be a change in winter precipitation from snow to rain. This eventually may lead to a change in the flow of the river (Kundzewicz *et al.*2008).

The Manas River Basin, a transboundary river flowing through Bhutan and India in the Himalayan foothills, plays a pivotal role in the region's hydrology, driven by a complex interplay of factors including precipitation, river runoff, and climate change. The hydrology of this region is vital for water resource management and long - term planning. The changing rainfall patterns significantly impact river discharge, water availability, and vegetation in the area, which, in turn, influences wildlife and biodiversity. Climate change - induced shifts in temperature and precipitation patterns have not only altered the river's water level but also the entire ecosystem of the Manas River Basin. The rich and diverse flora and fauna, including endangered species, are under threat from these climatic changes, necessitating conservation efforts to protect this biogeographically significant region. A comprehensive and approved Management Plan is an essential requirement, together with effective patrolling and enforcement capacity to deal with the threats of encroachment, grazing and poaching. The provision of adequate infrastructure, skilled personnel and monitoring arrangements for the region are all essential requirements alongwith scientific research and monitoring for habitat and invasive species management and recovery of wildlife populations. The study region around the Manas River, in particular, emphasizes how, in light of continuous climatic changes, the intricate link between climate, hydrology, and biodiversity demands attention and conservation efforts. The data on rainfall and temperature patterns reveal the pressing need for sustainable practices and conservation initiatives to safeguard the unique and fragile ecosystem of the Manas River Basin.

5. Conclusion

Freshwater ecosystems, like the Manas River Basin, are highly vulnerable to the impacts of climate change, which result in alterations in river discharge, droughts, temperature shifts, and water quality. Changes in precipitation patterns and sediment transport have downstream consequences, affecting the structure and ecology of rivers. The Manas River itself has experienced reduced flow during the summer, coinciding with peak demand, due to changing rainfall patterns. This has led to the deterioration of water quality, as the decreased flow limits the dilution capacity for contaminants. If conservation efforts are not intensified, the unique and endemic plant and animal species in Manas National Park face the looming threat of extinction due to the combined influence of climate change and human activities. The park's ecological fragility, economic marginalization, and the presence of endangered, locally adapted species with limited geographic ranges make it particularly susceptible to biodiversity loss. Wetlands, grasslands, and woodlands are especially at risk, facing habitat reduction, displacement of native species, and the spread of invasive ones due to ongoing climate change trends.

The urgency of these environmental challenges calls for global recognition of the severity of climate change's consequences and immediate collaborative action to mitigate them. Climate change is a natural phenomenon, but its current rate of change and human - induced components pose unprecedented threats to ecosystems. The essential next step is further research to develop practical guidelines for preserving the delicate balance of local ecosystems, ensuring the coexistence of nature and human activities. In this era of rapid global warming, effective conservation practices, adaptive management, and international cooperation are crucial for the preservation of sensitive regions like the Manas River Basin. Involvement of local communities who live and make use of the areas in protection efforts for the region is essential, and a key management objective is to enhance their engagement and awareness in the interest of the preservation of the area.

Given that our understanding of climate change impacts is still evolving, the theory and practice of conservation will likely continue to change at a relatively fast pace. One of the greatest future challenges to the conservation of biodiversity will likely come from how people respond to climate change. There is increasing recognition that, in many places, human responses to climate change may further constrain options for biodiversity conservation, and therefore planning needs to simultaneously consider both human and biodiversity responses. Unless adaptation is accompanied by meaningful mitigation efforts, it will be hard for conservation practitioners to accomplish even their shifting and evolving goals.

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