Wetlands of Tropical Islands under Changing Climate: A Case from Nicobar Group of Islands, India

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Abstract

Wetlands have significant value to the tropical islands owing to their significance in terms of biodiversity, coastal protection, and economic values. This chapter highlights the impact of climate change on the wetlands of tropical islands, with Nicobar group of islands in India as a representative case. Nicobar has a prominent tribal group practicing community living by gathering resources available from the terrestrial and coastal waters. The islands are vulnerable to sea level rise and extreme events such as *tsunami*, earthquake, and cyclones that affect their routine life. The receding arable and forest areas also affect their livelihood. The projected changes in mean temperature and precipitation for Nicobar region indicate that the rainfall pattern is all set to change significantly during different seasons and the pattern of change in Nicobar would be different from that in Andaman. The magnitude of climate vagaries is likely to be more prominent in the years to come. This chapter illustrates the vulnerability of tropical island ecosystems in general and the Nicobar Islands in particular, to changing climate

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and calls for incorporating sea level rise into coastal planning and development of appropriate decision-support systems for taking adaptive action, in order to mitigate the impacts of climate change on these islands and their wetland ecosystems.

Keywords
Climate change • Digital elevation model • Resource depletion • Vulnerability

11.1 Introduction

Wetlands are one of the most productive and biologically diverse ecosystems, which provide essential habitats for many species and play crucial role in hydrological cycle. Wetlands play important roles in nutrient cycle, climate change (climate mitigation and adaptation), food security (provision for crops and nurseries for fisheries), job security (maintenance of fisheries, soil quality for agriculture), and a range of cultural benefits, including knowledge (scientific and traditional), recreation and tourism, and formation of cultural values, including identity and spiritual values (ten Brink et al. 2013). Even though wetlands cover only 7 % of the earth's surface, they deliver 45 % of the world's natural productivity and ecosystem services (Panigrahy et al. 2010).

In an island ecosystem, wetlands are very important, and they range from marine to freshwater systems. Wetlands of small islands assume even greater significance, because they are the largest component of such island ecosystems in terms of area and species composition. Further, they regulate water quantity, facilitate groundwater recharge and floods, and at times resist the impacts of storms. Most importantly, wetlands help in erosion control and sediment transport, thereby contributing to land formation and increasing resilience to storms (ten Brink et al. 2013). All these ecosystem services improve water security including those from natural hazards and help in climate change adaptation of small islands. However, in recent times, wetlands in most of the islands have come under increased pressure from anthropogenic activities, climate change events, sea level rise (SLR), and extreme events, affecting the very existence of these important ecosystems. The SLR and sea surges will have significant and profound effects on settlements, living conditions, and island economies more than any other casual factors because of concentration of human populations, agricultural lands, and infrastructures in the coastal zone. This in turn makes the coastal communities rely more on the wetland resources for their livelihood resulting in further degradation of wetlands habitat and shrinking of their geographical extent. These changes are manifested by way of decrease in their ecosystem services that are a major cause of concern for island communities across the world.

Even though total submergence of the islands is not an immediate event due to climate change (IPCC 2007), the decreasing ecosystem services of the island wetlands may trigger socioeconomic consequences including large-scale migration of people in the near future. Such migrating population, termed as climate refugees, from small islands to large or developed countries would undermine the socioeconomic fabric of many islands in the tropical region. Therefore, proper understanding of the climate change and variability over these tropical islands with an emphasis on the wetland resources of Nicobar group of islands will assist in devising appropriate strategy for wetland management and improve their ability to provide continued ecosystem services.

11.2 Importance of Wetlands in the Tropical Islands

As majority of Small Island Developing States (SIDS) are situated in the tropics, they are bestowed with vast expanses of coastally sensitive ecosystems, which include coral reefs, mangrove forests, and sea grass beds with rich marine biodiversity. A typical wetland ecosystem of an island has several components from the seafront to the center of the island (Fig. 11.1). The mangroves and corals in the seafront protect shorelines and serve as nursery grounds to fish seed and juveniles, which is vital for sustainability of the fishery sector. There are few fishes such as groupers and snappers which require a primary spawning area near corals. They are much valued in the food market also. Therefore, a reduction in island wetland areas may affect such fishes which have habitat preferences to coral reefs, mangroves, and other low-lying wetlands. Apart from raising the shores of the islands and protecting them against SLR, mangroves and coral reefs also act as a barrier and natural breakwater to small islands. This provides a natural protection to islands against storm surges and *tsunamis* as evidenced from the variations in impact of 2004 *tsunami* in Andaman and Nicobar Islands (ANI), India. Coral reefs are the main habitat for a variety of marine life and together with lagoons are integral component of the island tourism sector. Hence, the contributions of wetlands are significant in sustaining the economy of small islands. Further, the freshwater component of island wetlands is limited in size, yet they are very important to meet the vital freshwater requirement. The freshwater wetlands not only provide drinking water but also play

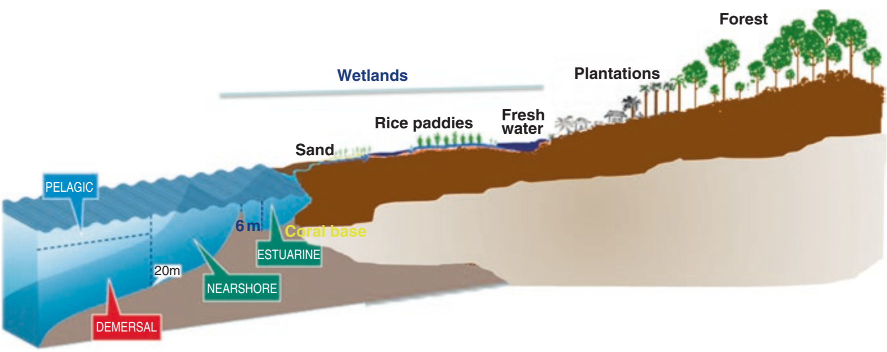

Fig. 11.1 Schematic diagram showing wetlands in a typical tropical island landscape

a key role in maintaining the salt balance in the groundwater resources of the islands by pushing back the seawater. The schematic diagram of the wetlands in an island ecosystem is shown in Fig. 11.1.

In the tropical Indian Ocean region, ANI are considered a biological paradise, with 8425 species of fauna, of which 846 species are endemic. The coral reefs of these islands rank next only to the Australian Great Barrier Reef, in terms of their global biodiversity. The sea grass beds in ANI occur in shallow coastal waters and sheltered bays, where the clear water allows penetration of sunlight down to the bottom. It is widely recognized that ecologically and economically, wetlands are the most important component of an island ecosystem and are vital for sustaining livelihood of island communities.

11.3 Impact of Climate Change on the Wetlands of Tropical Islands

11.3.1 Climate Change: An Overview

Climate change is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. It may be a change in average weather climatic conditions or the distribution of events around that average (e.g., more or fewer extreme weather events). In general, climate change means a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere often referred as global warming and which is in addition to the natural climate variability observed over comparable time periods (UNFCC 1994). The interlink between different processes involved in climate change and response is depicted in Fig. 11.2. It shows that the human causes of climate change can be reduced by mitigation efforts, while the impact of climate change can be reduced by adaptation activities. This is more important for protecting the wetlands of islands and sustaining their ecosystem services.

Global warming continues steadily every decade. Each of the last three decades has been warmer than the preceding decades since 1850. Analysis of observational data showed a global mean temperature increase of around 0.6 °C during the twentieth century (IPCC 2007). It is clear that several trends associated with global warming of anthropogenic origin are intensifying and that specific rates of their intensification can be quantitatively estimated. Although global warming is not spatially uniform across the globe, probably there is no region in the world that is not experiencing some rise in average temperature.

The increase in mean temperature and SLR is of greater concern for the small islands (independent or part of continental states) than the continents. New observations and reanalyses of temperatures averaged over land and ocean surfaces show consistent warming trends in all small island regions during 1901–2004 (Trenberth et al. 2007). Besides, mean sea level rose by about 2 mm/year that is also affected by the local tectonics and El Niño-Southern Oscillation (ENSO) events that

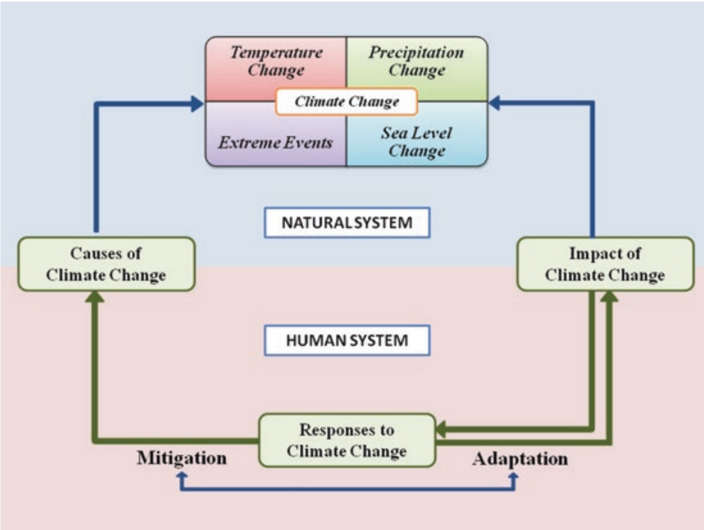

Fig. 11.2 Components of climate change process

originate in the sea. Intergovernmental Panel on Climate Change (IPCC 2007) also found much of the rainfall variability to be closely related to ENSO events, combined with seasonal and decadal changes in the convergence zones.

11.3.2 Climate Change and Its Impact on the Tropical Islands

11.3.2.1 Climate Change Events

The climate regimes of small islands are quite variable, generally characterized by large seasonal variability in precipitation and by small seasonal temperature differences in low-latitude islands and large seasonal temperature differences in high-latitude islands (IPCC 2007). In the Indian Ocean, the climate regimes of small islands in tropical regions are predominantly influenced by the Asian monsoon, the seasonal alternation of atmospheric flow patterns that results in two distinct monsoon patterns influenced by the ENSO events (IPCC 2007). Thus, wetlands are highly influenced by the occurrences of extreme climate and weather events in the region. In addition, the inherent characteristics of isolation, relatively small population and limited domestic land-based resources of small islands, bring about their own environmental and social challenges.

Reconstructed sea levels based on tide gauge data and TOPEX/Poseidon altimeter records in the Indian Ocean during 1950–2001 (Church et al. 2006) indicated relative SLR of 1.5, 1.3, and 1.5 mm/year (with error estimates of about 0.5 mm/year) at Port Louis, Rodrigues, and Cocos Islands, respectively. The situation appeared to be very grim for the Maldives as the available data suggested SLR of 4 mm/year measured at Male and Gan sea level sites (Khan et al. 2002). However, Church et al. (2006) noted that the SLR records from the Maldives has shown high variability in the SLR values between sites, and a 52-year reconstruction of SLR range suggested a common rate of rise of only 1.0–1.2 mm/year. In spite of this variability in measurements, SLR and the potential for stronger increase in storms surges pose an increasing threat to these islands by affecting the coastline, shoreline, infrastructures, sandy beaches, coastal wetlands, and their ecosystems.

11.3.2.2 Vulnerability of Wetlands in Tropical Islands to Changing Climate

The coastal wetlands of tropical islands are threatened by SLR, increase in sea surface temperature, sea surges, and possible increases in extreme weather events arising from a combination of human activity and climate change. The major impacts, as a consequence, are accelerated coastal erosion, saline intrusion into freshwater lenses, increased flooding from the sea, and loss of wetlands.

Sea level rise is arguably the most certain and potentially devastating climate change impact on these islands. Coastal inundation caused by SLR will decrease the land area of these islands with further consequence to inland wetlands and coastlines. It has long been recognized that islands on coral atolls are especially vulnerable to SLR, and the long-term viability of some atoll states are thus threatened. However, coasts particularly of islands respond dynamically in different ways to SLR which depends on factors such as the geological setting, coastal type, whether soft or hard shores, the rate of sediment supply relative to rate of submergence, sediment type (sand or gravel), presence or absence of natural shore protection structures such as beach rock or conglomerate outcrops, presence or absence of biotic protection such as mangroves and other strand vegetation, and the health of coral reefs (Mimura et al. 2007).

Apart from SLR and consequent coastline changes, the threat is likely to be amplified by increasing sea surface temperature and changes in tropical cyclones. Interestingly, several studies concluded that chemical, rather than geomorphological changes, could reduce the habitability and adaptive capacity of the low-lying islands. Oceanic absorption of atmospheric carbon dioxide as a result of increase in atmospheric CO_2 leads to ocean acidification (Caldeira and Wickett 2003; Royal Society 2005), which is likely to have detrimental effects on coral islands by reducing the productivity of corals and increasing the dissolution of calcium. Nevertheless, the impacts on coral reefs emanating from the events associated with climate change will not be uniform throughout the small island realm with lots of uncertainty expected in the combined effect.

Under the Special Report on Emissions Scenarios (SRES), small islands are seen to be particularly vulnerable to coastal flooding and decreased extent of coastal vegetated wetlands (Nicholls 2004). The expected changes in climate will also result in ecological problems of the coastal wetlands such as that from invasive alien species (Wilkie 2002). Due to the adverse living conditions brought out by changing climate in islands located at lower altitude, many species would migrate to islands located at higher latitudes. It is anticipated that mid-latitude and high-latitude islands are likely to be colonized by invasive species posing threat to the native species.

11.3.2.3 Water Resources

In an island ecosystem, freshwater from surface water bodies and groundwater are very important natural resources that may be seriously compromised due to climate change, particularly by decrease in precipitation and SLR. The freshwater aquaculture ponds, along the coast of these islands, provide livelihood security to small and marginal farmers. Coastal groundwater is a dynamic and replaceable resource, which plays a significant role in the overall circulation of water through the hydrologic cycle. In those areas away from the coast, groundwater will be impacted less directly and more slowly by climate change as compared to surface water, but in coastal areas groundwater will be directly affected by SLR (Ranjana et al. 2013). Sea level rise would directly affect the coastal river basin areas and increase saline water intrusion to the coastal areas of islands. Owing to factors of limited size, availability, and geology and topography, water resources in small islands are extremely vulnerable to changes and variations in climate, especially rainfall (IPCC 2001). Atolls and islands with limestone/coral as base have no surface water or streams and are fully reliant on rainfall and groundwater harvesting. Many small islands are experiencing water stress due to reduced rainfall and increased extraction of groundwater, which is often more than its recharge. Moreover, pollution of groundwater is emerging as a major problem especially on low-lying islands due to the rising human population and consequent developmental activities.

Rainfall is the only source of freshwater in small islands, and any variation in the amount of rainfall and its distribution would affect the availability of freshwater. Lower than the average rainfall leads to reduction in the amount of water flow in the streams and the rate of recharge of the groundwater while it increases the instances of drought. Further, it will heavily impact fisheries, coral reefs, and other wetland ecosystem resources and associated livelihoods. The dependency on rainfall significantly increases the vulnerability of small islands to future changes in amount and distribution of rainfall.

11.3.2.4 Agricultural Production Systems

Most of the tropical islands are dependent on subsistence farming for survival and cash crops for economic development apart from tourism. While subsistence agriculture provides local food security, cash crops such as sugar cane, bananas, and minor forest products (MFPs) are exported in order to earn foreign exchange. The situation has been changing as many island states are experiencing decrease in gross domestic product (GDP) contributions from agriculture, partly due to the drop in competitiveness of cash crops, cheaper imports from larger countries, increased costs of maintaining soil fertility, and competing uses for water resources, especially from tourism (FAO 2011). The projected impacts of climate change include extended periods of drought and / or loss of soil fertility and degradation as a result of increased precipitation, both of which will negatively impact on agriculture and food security. In addition, these islands have to invest heavily to rebuild their infrastructure affected by events associated with SLR. Together they increase the cost of production and decrease the seasonal availability of perishable agricultural commodities. But not all effects of climate change on agriculture are expected to be negative. For example, increased temperatures in high-latitude islands are likely to make conditions more suitable for agriculture and provide opportunities to enhance resilience of local food systems.

11.3.2.5 Fisheries

Wild capture fisheries practiced in coastal wetlands contribute sizeable portion of the GDP in the islands. However, in contrast to agriculture, the mobility of fish makes it difficult to estimate future changes in marine fish resources. Since the life cycles of many species of commercially exploited fishes extend from freshwater to ocean water, land-based and coastal activities will also affect the populations of such species. As the coral reefs and other coastal wetland ecosystems are sensitive to increase in sea surface temperature and other climate change events, consequent impacts would be felt on fishery production, which in turn will adversely affect the GDP as well as livelihood of people living in these islands (Graham et al. 2006). Further, these islands may experience loss of biodiversity in coastal wetlands due to inhospitable environmental conditions and its associated migration of some of the sensate fish species.

11.4 A Case Study of Nicobar Islands Under Changing Climate

11.4.1 The Background

The islands of the Andaman and Nicobar are similar to other tropical islands in several features such as remoteness, limited physical size, wetlands diversity, vulnerability to climate change, and developmental needs. The ANI are situated in the Bay of Bengal off the eastern coast of India in north to south orientation (Fig. 11.3) and connect with Indo-Malaysian realm, thereby forming a part of south as well as Southeast Asia. The Nicobar group of islands is separated from the Andaman group by 10° channel. The Nicobar group has 22 islands of which 13 are inhabited and are divided into three subdivisions, *viz.*, Car Nicobar, Nancowry group, and Great Nicobar. Many of these islands are coralline in origin. These islands are mainly inhabited by the tribals (Nicobarese and Shompens) and a large number of non-tribal settlers from mainland. Among the tribals, Nicobarese are the largest tribal group inhabiting 12 islands with major population in Car Nicobar. They were the last indigenous people to arrive in these islands and have racial mixture with the natives of Southeast Asia. A vast majority of the Nicobarese still pursue their traditional occupation of coconut plantation and pig rearing. The livestock of the tribals comprises of pigs (82 %) and goats (18 %), reared in extensive open semi-feral system (Swarnam et al. 2015). The tribals also utilize the vast coastal fishery resources of these islands. Many of the mangrove patches around the uninhabited islands are still in pristine stage, and in other islands it is largely intact.

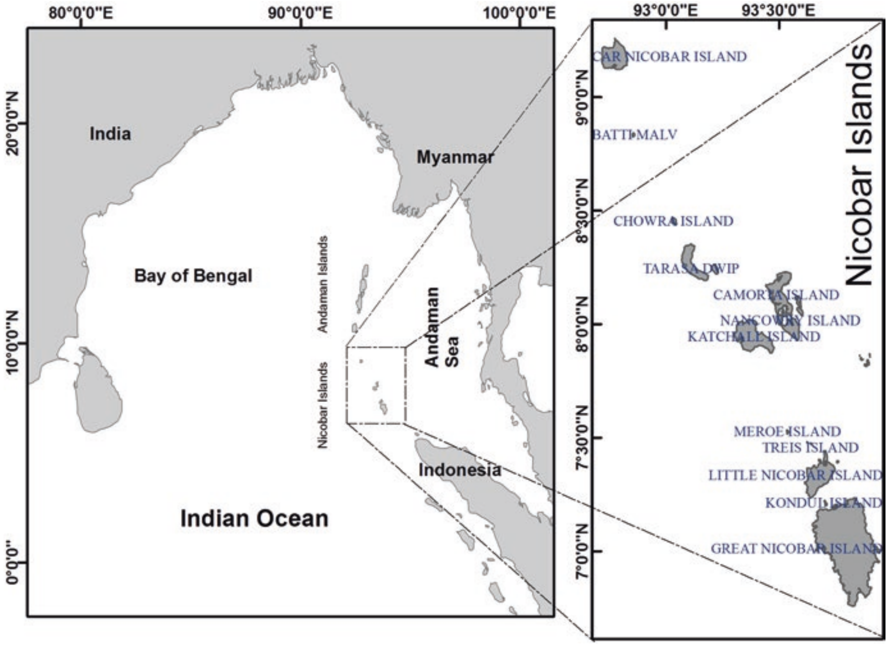

Fig. 11.3 Andaman and Nicobar Islands and Bay of Bengal region

11.4.2 Physiography and Land Use in Nicobar Islands

The physiography of an island is one of the most important factors influencing the land cover and land use. Wetlands in different physiographic locations have different characteristics and biodiversity composition. In addition, coastal erosion, stream flow, vulnerability to increase in sea level, and sea surges are influenced by the physiography of this island group. The Nicobar Islands are generally surrounded by shallow seas and coral reefs. Baring a few, the terrain in the islands is mostly undulating with the main ridges running north–south. In between the main ridges, deep inlets and creeks are formed by submerged valleys. Great Nicobar has five perennial rivers.

Among the Nicobar group of islands, Car Nicobar is flat except for some cliffs in the north and small hilly areas in the center. It is bordered by a flat ground consisting of coralline diluvium. Nancowry and Kamorta have a hilly terrain covered with grass, forming undulating meadows. In the central group, Katchal is slightly hilly in the center but has a remarkable flat area, like Car Nicobar. Trinket is a flat island, while Chowra is almost flat, except for a hill that is located at its southern tip. The other islands, *viz.*, Teresa, Tillangchong, and Bompoka have hilly terrain. The Great Nicobar Island, hilly and undulating, is the southernmost landmass of the Nicobar group of islands. The physiography of each island has profound influence on the distribution of crops and type of farming within and between the islands.

Table 11.1 Area estimates of wetlands in Nicobar

Wetland category	Number of wetlands	Total wetland area	% of wetland area
Inland wetland – natural			
Lakes/ponds	2	32	0.13
River/stream	4	367	1.48
Total – inland	6	399	1.61
Coastal wetlands – natural			
Lagoons	1	2	0.01
Creeks	11	75	0.3
Sand/beach	156	6858	27.74
Intertidal mud flats	94	6541	26.46
Salt march	38	2454	9.93
Mangroves	12	209	0.85
Coral	59	8158	33
Total – coastal	371	24,297	98.28
Subtotal	377	24,696	99.9
Wetlands (2.25 ha), mainly Tanks	25	25	0.1
Total	402	24,721	100

Source: SAC (2009)

In Nicobar group of islands, more than 90 % of reported area is under forest cover, and only the remaining is available for other uses including agriculture. However, the proportion of agricultural land to total area significantly varies from island to island. In Car Nicobar and Katchal, over 40 % of the total geographical area is under crops, and the rest of the islands has cultivable area ranging between 1 % and 19 %. The climate is very congenial for the growth of plantation crops; consequently, coconut occupies 84 % of area under agriculture (Swarnam et al. 2015). The dense canopy cover of coconut trees reduces the striking velocity of raindrop, the thick surface roots enable maximum infiltration of runoff water, and hence the rate of erosion is minimized. The existing land use favors accumulation of water in the shallow aquifers, which is the major source of freshwater.

11.4.3 Status of Wetlands in Nicobar

Area estimates of various wetland categories for Nicobar Islands were carried out by Space Applications Centre (SAC), Ahmedabad, India, using remote sensing and geographical information system (GIS). It revealed enormous diversity in wetlands according to their genesis, geographical location, water regime and chemistry, dominant plants, and soil or sediment characteristics (Table 11.1). The major wetland types in Nicobar are corals (8158 ha), followed by sand/beaches (6858 ha) and intertidal mud flats (6541 ha). Compared to the 4.6 % intertidal mud flats of Andaman group of islands, Nicobar mud flats occupy 26.5 % of wetland area (SAC

2009). The inland wetlands account for only 2 % when compared to coastal wetlands (24,297 ha) that account for 98.5 % of total wetland area. Similarly mangroves, which dominated the wetland area in Andaman Islands (51.47 %), account for less than 1 % of wetland area in Nicobar Islands. Similar is the case with creeks and paddy fields. The salt marsh and mangrove ecosystems in Nicobar Islands are subject to increase in water levels following the monsoon. Wetlands of Nicobar Islands support a large number of plant and animal species adapted to fluctuating water levels, making the wetlands of critical ecological significance. With the relevance of carbon footprint gaining momentum in a climate change perspective, wetlands are going to contribute largely to the green carbon indices of various commodities relevant to the islands. Further, the fishery, a major livelihood and nutrition related activity, in the islands, is dependent on the wetlands. Reduction in wetlands will reduce the area for nursery growth phase of fishes and may result in less marine fish production.

11.4.4 Climate Change Projections for Nicobar Islands

The Nicobar group of islands experience hot and humid climate because of their location in equatorial zone surrounded by Andaman Sea and Bay of Bengal. The islands receive good rainfall, ranging from 2750 to 3000 mm each year, from both southwest and northeast monsoons. Maximum amount of rainfall is received during the monsoon (June–November) and minimum in dry season (January–April). The rainwater quantity during the showers decides the water lens formed on the seawater around the islands which in turn decides the groundwater recharging. Therefore, rainfall projections are done to understand the vulnerability of islands with respect to rainfall. The historical climatic data shows the mean relative humidity as 79 %, maximum temperature as 30.2 °C, and minimum temperature as 23.0 °C.

The analysis of historical rainfall data pertaining to these islands since 1951 showed no significant change in the average decadal rainfall, but the pattern of rainfall has changed with increase in the number of extreme rainfall events. The change in pattern of extreme rainfall events over Nicobar Islands during winter and post-monsoon seasons when there is a decreasing trend has consequences for the inland wetlands particularly of freshwater aquifers (Velmurugan et al. 2015). Lal (2004) also indicated increase in daily rainfall intensity for many of smaller islands.

In an effort to understand future climate patterns, Intergovernmental Panel on Climate Change (IPCC) approved model; MAGIC/SCENGEN software (ICAR 2015) was used to generate two possible scenarios for the years 2025 and 2050 for rainfall and temperature in four seasons for Andaman and Nicobar group of islands. We looked into the seasonal variations also because of the typical rainfall-associated livelihood pattern, which is embedded in the cultural practices of the tribals residing in the islands. The projected rainfall for 2025 showed significant differences among the four seasons and between the two island groups of Andaman and Nicobar. The rainfall modeled for 2050 also significantly differed among the seasons, but not between the island groups. A decrease in precipitation (lower than mean seasonal

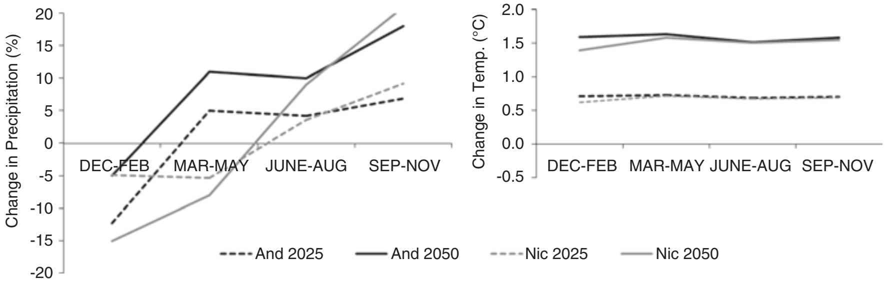

Fig. 11.4 Change in precipitation (%) and temperature (°C) in Andaman and Nicobar Islands during 2025 and 2050 as projected by MAGICC/SCENGEN software (Source: Velmurugan et al. 2015)

rainfall) was projected for December–February for Andaman Islands and for December–May for Nicobar Islands, with the rest of the seasons to have increase in precipitation (Fig. 11.4). The decrease in winter monsoon and summer monsoon showers can affect ecosystems such as coral reefs and mangroves. The surplus rains during the rest of the seasons can compensate for drinking water-related issues. The temperature projected for 2025 showed significant change among seasons and between the island groups. In contrast, the temperature for 2050 period significantly differed among the seasons but was similar between the two island groups. The plot of mean temperatures for the two projected years, 2025 and 2050, illustrates a similar projected increase in mean temperatures for all the seasons and between the two island groups. Increasing temperatures have indicated ecological/weather problems in the islands with increasing incidents of extreme events such as cyclones, coral bleaching, droughts, floods, and erratic monsoons. The possibility of further increasing temperature trends in our simulations exposes the need for proper adaptation strategies for the islands to mitigate such weather events.

Similarly, the long-term average of mean temperature also shows increasing trend in the post-monsoon season (Fig. 11.5). The recent observation of change in average temperature (2013–2014) for these islands shows 15 % higher than the decadal average. During that period, drying up of many of the freshwater ponds and falling groundwater level in the islands was reported (ICAR-CIARI 2015). The climate change projections (Lal et al. 2002; Ruosteenoja et al. 2003) report a gradual warming of sea surface temperature (SST) and a general warming trend in surface air temperature in all small island regions and seasons.

An important aspect of climate change more relevant to the islands is change in SST. The average monthly SST extracted from different locations around the Nicobar Islands for 2010 was higher than the corresponding monthly average SST of each of the three different decadal averages (1981–2010, 1991–2010, and 2001–2010), between January and July (Fig. 11.6). During April to July, the increase was higher (0.75–1.25 °C) than the rest of the months. This anomalous increase in SST resulted in mass bleaching of corals (Krishnan et al. 2010). Previously, anomalous SST events and subsequent coral bleaching were recorded in 1998, 2002, and 2005 (Arthur 2000; Krishnan et al. 2010).

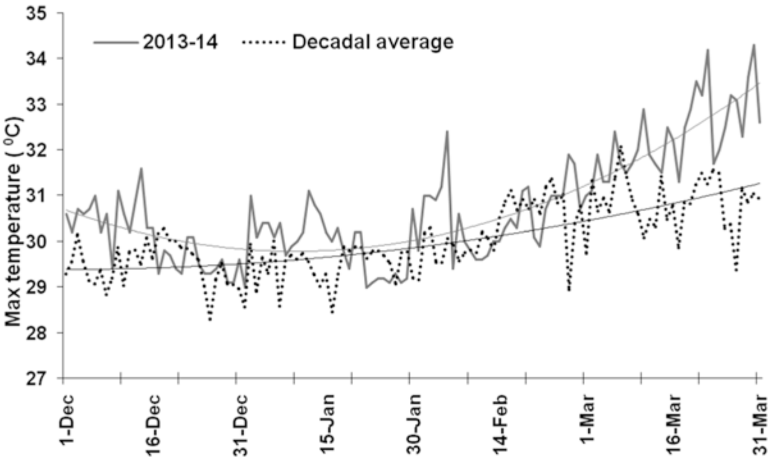

Fig. 11.5 Temperature of 2013–2014 compared with the decadal average (2000–2010) (*Only the period with significant difference, Dec–Mar, is plotted.*)

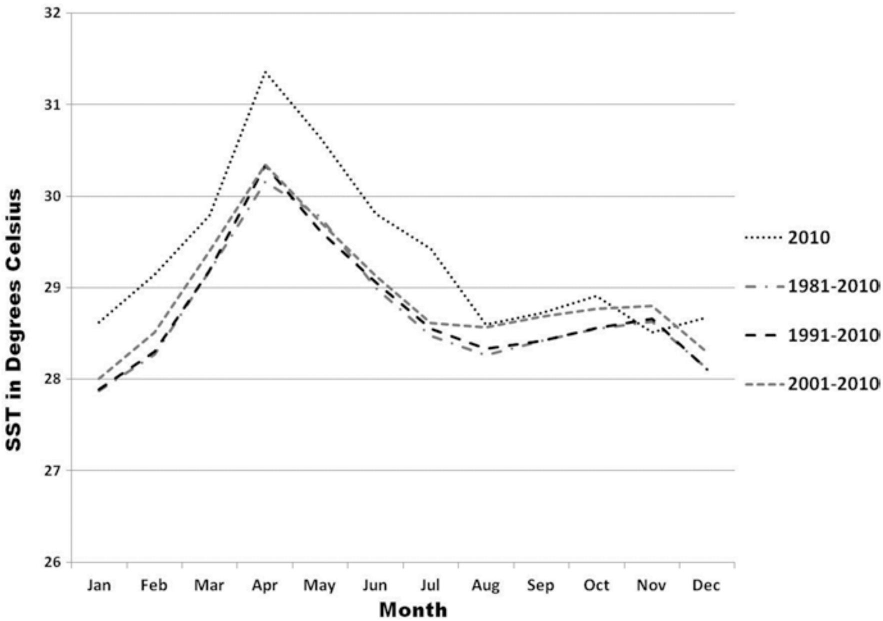

Fig. 11.6 Comparison of sea surface temperature (SST) in 2010 with decadal averages

11.4.5 Impact of Changing Climate on the Wetlands of Nicobar Islands

In spite of uncertainty in magnitude of occurrence, in recent times, the impacts of climate change and weather extremes are certainly felt in Nicobar Islands in the form of increasing monsoon period depressions, dry spell during post-monsoon period, intrusion of seawater into the freshwater aquifer and coastal lowlands, loss of agricultural land, and coastal erosion. A large number of non-climate change factors and disturbances, mainly driven by human activities, can also affect coral reefs (Nyström et al. 2000; Hughes et al. 2003). The "coral reef crisis" is almost certainly the result of complex and synergistic interactions among global-scale climatic and local-scale human-imposed stresses (Buddemeier et al. 2004). This may pose serious threat to the livelihood of tribals inhabiting these islands and trigger other ecological consequences in which the wetlands particularly the mangroves, corals, and inland water bodies are at the receiving end. Hatchery production and farming of groupers and snappers have not yielded good results so far. Decreasing reef areas are going to bring down their population in the sea, as reefs are critical in their life cycle as spawning, nursery, and fishing grounds. Further, the stress on existing resources such as water, mangroves, and reefs will lead to depletion or overexploitation of other island resources. Islands have a unique lifestyle of generating and utilizing resources within the islands. Unstable supply gaps in the resources available within the islands will result in catastrophes. There are historical examples of complete devastation of island civilization in ancient human history such as the collapse of Easter Islands. Unless proper adaptation strategies are devised for Nicobar, there is a life-threatening situation as predicted by the simulations in weather forecasting models.

11.4.5.1 Mangroves

Mangroves are considered to be the natural protective cover for islands toward the seafront which are also known to provide habitat for several important species. Andaman and Nicobar group of islands together have the second largest area under mangroves in India after West Bengal, as far as density and growth are concerned, and furthermore mangroves of ANI are the best in the country (Planning Commission 2008). It is found along the creeks; the width ranges from 0.5 to 1 km, and in some locations, it can be found several meters inside the islands from the coast (Dam Roy and Krishnan 2005). Ecological conditions in a mangrove ecosystem exert pressure on non-mangrove plant species. However, following the disturbance to the mangrove ecosystem, during storm or cyclones, other plant species may encroach and dominate the area. One known opportunistic plant species in the Andaman and Nicobar is the giant fern, *Acrostichum aureum*, that inhabits as small patches in dry mangrove areas under normal conditions. Under the SRES scenarios, small islands are shown to be particularly vulnerable to coastal flooding and decreased extent of coastal vegetated wetlands (Nicholls 2004). Similarly, in the event of natural disasters such as cyclones (hurricanes), the coastal biodiversity of these islands could be severely affected, and as the adaptation responses of some of these islands are expected to be slow, the impacts of storms would be more pronounced.

During the Indian Ocean tsunami of December 2004, Nicobar group of islands experienced subduction of landmasses, while North Andaman was uplifted. Though earthquake and subsequent subduction are not attributed to climate change, the effects on these islands were similar to that of SLR associated with climate change. Nearly 4200 ha coastal wetlands, mostly rice paddies, were permanently inundated. Withdrawal of tidal water from the mangrove habitats triggered a renewed ecological succession, changes in shorelines, and drying of mangrove stands.

11.4.5.2 Coral Reefs and Associated Biodiversity

Oceanic islands often have a unique biodiversity through high endemism caused by ecological isolation. The ANI are bestowed with the richest coral diversity among all Indian reefs (Krishnan et al. 2011). In total 228 species of hard corals, falling under 58 genera and 15 families, have been reported from these islands (Venkataraman et al. 2003). Recent surveys indicate that the numbers could be close to 80 % of the global maximum (Krishnan et al. 2011). Estimates by Zoological Survey of India (ZSI), India, suggest that over 400 species of corals are found around these islands. The nearshore waters are rich in finfish, shellfish, and other economically important species such as seashells, sea cucumbers, crabs, lobsters, etc.

Changes in the physical and biological structure of benthic reef habitats are likely to have detrimental effects on reef-associated organisms particularly on organisms that depend on corals for food, shelter, or recruitment. Mass coral bleaching, ocean acidification, and intense cyclones due to climate change will cause fundamental changes to the reef habitat, including reduced coral cover, changes to the composition of coral assemblages, and reduced structural complexity (Hoegh-Guldberg et al. 2007). The anomalous increase in SST in Andaman waters during 2010 resulted in mass bleaching of corals. Short-term exposure to such SST anomalies induces bleaching and subsequent recovery; however, prolonged exposure to elevated SST causes chronic stress which can lead to irreversible bleaching. Anomalous elevations in SST by at least 1.0 °C above the expected climatology during the warmest months of the year have been associated with coral bleaching hotspots (Reaser et al. 2000). Available evidence suggests that widespread bleaching would lead to significant reduction in the abundance of many reef fishes around these islands. Many of the butterfly fishes are obligate or facultative coral feeders and are dependent on live coral cover, and damsel fishes depend to a great extent on the structural complexities of the reef for protection. Such coral-dependent species will be most seriously affected, but many other species could suffer long-term population declines due to loss of settlement habitat and essential habitat structure for post-settlement survival (Graham et al. 2006).

11.4.5.3 Water Resources

The freshwater wetlands are vital not only to provide drinking water but also for maintaining the salt balance in the groundwater by pushing back the saline seawater. Water resources of these islands are directly affected by seasonal changes and variations in climate, especially in rainfall, whereas other factors like smaller size, geology, and topography increase the risk of freshwater resources due to SLR. The SLR is projected to inundate several low-lying areas of Nicobar Islands with flat topography. Consequently, several coastal freshwater ponds and other water bodies may turn saline affecting the freshwater biodiversity of these islands.

As these islands are not suitable for large-scale development of surface storage facilities, decentralized rainwater harvesting and recharging the shallow water table are the only options, which directly depend on the rainfall and its distribution. Groundwater is the main source of drinking water supply in these islands. About 90 % of the dry borewells were in compressed sedimentary deposits, which act as aquiclude or even as aquitard, whereas rocky subsoil formation was found to be more successful (Srivastava and Ambast 2011). However, the coralline limestone formations form potential aquifer in shallow horizon in many islands that can be utilized through dug wells of 4–5 m diameter with 6 m depth. As in the case of other small islands, the scarcity of freshwater is often a limiting factor for social and economic development of Nicobar.

11.4.6 Vulnerability of Wetlands to Changing Climate

Climate vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. Climate vulnerability depends on exposure, sensitivity, and adaptive capacity. Climate exposure is the extent and magnitude of a climate and weather event, which is almost certain on all the wetlands existing in the island located in the Indian Ocean region. While sensitivity is the degree to which the area of concern is susceptible to a climate impact, in this context, islands with maximum areas with lower elevation are highly sensitive as in the case of Nicobar Islands. Adaptive capacity is defined as the ability of the area of concern to adjust or respond to the changing conditions. But, it depends on the resources and technology available with the community (IPCC 2012).

The digital elevation model (DEM) of the islands shows that among the Nicobar Islands, Trinket and Chowra have over 15 % of the total land area with an elevation less than 10 m above mean sea level (AMSL) and are thus significantly vulnerable to climate change events. About 70 and 93 % of the total land area in Car Nicobar and Great Nicobar have an elevation >20 m above MSL, respectively. Tidal wave in the aftermath of the 2004 tsunami affected such low-lying areas. Similarly, storm surges associated with cyclones would have similar effects, as that of the tsunami, in these areas. The height of storm surge increases when the coastal crossing of storm is associated with high tide. The maximum storm surge disaster for the islands under the worst hypothetical scenario involving a super cyclone with maximum wind speeds of 80 m/s has been determined to be 3.7 m under neap tide conditions (Kumar et al. 2008). Both Andaman and Nicobar group of islands have smaller shelf widths and steeper slopes than the mainland coasts, so the impact of tsunami and storm surges for these islands would be low compared to that of east coast of India under similar conditions (Sadhuram et al. 2006; Kumar et al. 2008). However, Nicobar group of islands are more vulnerable to SLR due to their flat topography, limited space for retreat, and dense coastal settlements. This is the case with most of the coral islands in the Indian Ocean region.

Ramanamurthy et al. (2005) studied the inundation of seawater in Car Nicobar and Great Nicobar during the 2004 tsunami and concluded that the run-up (usually expressed in meters above normal tide or mean sea level) which can be used for determining the extent of vulnerability of human settlement varied from 3 to 7 m with a distance of penetration ranging from 50 to 1000 m. Coastal land in Car Nicobar is characterized by a gentle slope interrupted by streets and houses. As per the tsunami run-up subsector database for Indian Ocean between 1750 and 2007, seven tsunamis have been reported in the Indian Ocean region, and the extent of run-up recorded was 0.76 m in Car Nicobar during 1881. Nicobar Islands lie in the seismic zone V as the expected intensity of seismic activity would be IX or greater on the Medvedev-Sponheuer-Karnik intensity scale (Rai and Murty 2005). Further, massive earthquakes also result in the alteration of island topography leading to subduction of the islands. Analysis of the estimated area that will be affected with 0–5 and 5–10 m increase in sea level reveals that the loss of land would be greatest in Chowra where about 13.34 % of island will be inundated with 0–10 m rise in sea level.

11.5 Adaptation of Wetlands to Changing Climate

Small islands are subjected to a range of climatic and oceanic impacts and that these impacts will be exacerbated by the projected climate change and SLR. In general, both global and local drivers may show increases in the future and will interact to impact small islands and the coastal wetlands in the future. These will probably impact on island environments and their biogeophysical conditions, as well as the socioeconomic well-being of island communities (Clark 2004). Unless adaptation measures are put in place to reduce impacts, it is foreseen that the drivers will certainly impact the islands. Therefore, it is essential to improve the adaptive capacity of these islands aimed at increasing the ability of the built, natural, and social systems to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

The adaptation to climate change and restoration of coastal wetlands include (a) protecting those ecosystems that are projected to suffer as a consequence of climate change and sea level rise and (b) rehabilitating ecosystems degraded or destroyed as a result of socioeconomic developments. The coastal natural resources such as coral reefs and mangrove forests possess a natural ability to adapt to changing environmental conditions, a phenomenon called as natural or autonomous adaptation. Further, they are also rehabilitated and restored as part of resource management that is termed as planned adaptation mechanism, aimed to increase natural protection against SLR resulting in sea and storm surges. This is more relevant to the smaller islands as that of Nicobar Islands in the Indian Ocean region.

With respect to the adaptive capacity of smaller islands, Sutherland et al. (2005) suggest that enhancing adaptive capacity will only be successful when it is integrated with other policies such as disaster preparedness, land-use planning, environmental conservation, coastal planning, and national plans for sustainable development. It is essential to build the capacities of individuals, communities, and governments with regional and international cooperation so that they are able to make informed decisions about adaptation to climate change and to enhance their adaptive capacity in the long run. Therefore, encouraging active participation of local communities in capacity building and environmental education should become an objective of many development programs in small islands. The locals should also be encouraged to identify local options for adaptation.

11.6 Conclusion

From the foregoing discussions, it is evident that the small islands and SIDS are more vulnerable to the perceived climate change though there are variations in effect and uncertainty in estimations. In these islands, wetlands constitute the most important component in terms of biodiversity, coastal protection, and economic values. The coastal and inland wetlands of tropical islands, in particular, are facing the threats posed by climate change. Sea level rise can affect coastal communities and habitats in various ways, including submerging low-lying lands, eroding beaches, converting wetlands to open water, intensifying coastal flooding, and increasing the salinity of estuaries and freshwater aquifers, which would mainly manifest in the form of habitat and biodiversity loss. Climate change leads to increasing sea surface temperature, SLR, and tropical cyclones, which in turn result in possible decreases in growth rates and physical damage of coral reefs around islands.

Some impacts of SLR are already being observed in many Indian Ocean islands, underscoring the immediate need for improving scientific understanding and the ability to predict the effects of rising sea level to improve upon the adaptation measures. Incorporating SLR into coastal planning, in combination with the development of decision-support tools for taking further adaptive action, could lessen the economic and environmental impacts of climate change on these islands and their wetland ecosystems.

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