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Hydrology Study and Climate Change Vulnerability Assessment to inform Management Planning of Gosabara Wetland Complex in Gujarat

August 2017

Forest Department, Govt. of Gujarat

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Indo-German Biodiversity Programme
Conservation and Sustainable Management of Coastal and Marine Protected Areas

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Executive Summary

Wetlands are crucial ecosystems, and human activity induced stressors have induced large amounts of pressures on these ecosystems. The objective of this report is to assess the hydrological regime and effects of climate change on Gosabara Wetland Complex, located near Porbandar district in Gujarat, and explore potential solutions for their informed management planning. The carbon sequestration potential of the wetland was also assessed.

Gosabara Wetland Complex, located in the Porbandar district of Gujarat, is spread over 129km^2. It lies between 21°38'49.17"N and 69°35'25.95"N, and 21°29'51.11"N and 69°47'21.19"N. The wetland is formed by Karli Recharge Reservoir and Karli Tidal Regulator, and is a combination of estuary and fresh water habitat. Based on the historical data available, the rainfall in the wetland has ranged from 527.9 mm to 1778.8 mm between 19999-2000, with 2004 being the lowest rainfall year, and, 2010 being the year with highest rainfall. The hydrological assessment has been carried out assuming the rainfall level of the lowest rainfall year, 2004, with monsoon rainfall (June 2004 to September 2004) of 478.4 mm, and post monsoon rainfall (October 2004 to May 2005) of 15.4 mm.

The storage capacity of the wetland was estimated using four different assumption regarding the bottom surface area and average depth:

Assumptions		Storage capacity (Million cubic metres)
1	Bottom surface area = 15km^2 Average depth = 30cm	5.32
2	Bottom surface area = 15km^2 Average depth = 50cm	8.87
3	Bottom surface area = 18km^2 Average depth = 30cm	5.79
4	Bottom surface area = 18km^2 Average depth = 50cm	9.65

The total water inflow to the wetland, comprising of water from rainfall over the wetland and the surface run-off from the catchment area, was estimated as follows:

Month	Rainfall (mm)	Total magnitude of water generated in the catchment (m^3)	Inflow due to run-off from catchment (30% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)	Total inflow to wetland (Mcum)
	(a)	(b)	(c)	(d)	(e)	
Jun 2004	128.7	153,410,400	46,023,120	14,414,400	60,437,520	60.44
Jul 2004	76.9	91,664,800	27,499,440	8,612,800	36,112,240	36.11
Aug 2004	263.4	313,972,800	94,191,840	29,500,800	123,692,640	123.69
Sep 2004	9.4	11,204,800	3,361,440	1,052,800	4,414,240	4.41
Oct 2004	15.7	18,714,400	5,614,320	1,758,400	7,372,720	7.37
Nov 2004	0	0	0	0	0	0.00
Dec 2004	0	0	0	0	0	0.00
Jan 2005	0	0	0	0	0	0.00
Feb 2005	0	0	0	0	0	0.00
Mar 2005	0	0	0	0	0	0.00
Apr 2005	0	0	0	0	0	0.00
May 2005	0	0	0	0	0	0.00

To account for the availability of water in the wetland in a given month, the total water inflow during the lowest rainfall year is mapped against water losses due to evaporation losses, by estimating the average monthly evaporation rates (as given below).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total evaporation during the month (cm)	11.625	13.048	20.15	23.64	27.06	22.65	16.18	13.70	15.18	15.99	12.66	11.43

With the total evaporation losses from Gosabara wetland during the post monsoon period (October to January) of about 50-52 cm, and the average depth of wetland assumed to be about 50cm, the water is likely to last till the end of January. The following measures have been recommended to improve the water retention capacity of the wetland beyond the month of January:

- Dredging in identified locations ensuring that a height below groundwater table level is not reached
- Regulating the level of siltation entering the wetland from the catchment run-off through sediment or silt traps
- Construction of rainwater storage structures for increasing availability of water during post monsoon months
- Sourcing of water from an external artificial source of water to meet the post monsoon months' water requirement of the wetland, depending on the availability of such as source

The climate risks were identified using a combination of trend analysis based on historical data and 20 year projection using a climate model. The 20-year projections for air temperature in the Gosabara wetland region showed a sharp increase in temperature in the range of 1ºC to 1.4ºC projected in the months of December and March, and an overall steady increase in temperature across all the other months in the range of 0.2°C and 0.8°C. As temperature increases, the evapo-transpiration rate is also expected to increase, thus, expediting the process of evaporation of the available water. This is significant especially for the months of December, which falls in the peak season of migratory birds visiting the wetland, and reduced water availability due to rapid evaporation can be a constraining factor to potentially affect the bird population.

Rainfall in the wetland region is projected to increase in the month of August within the range of 0.8 mm and 1.3 mm per day, and decrease from 0.2mm to 0.6 mm per day in the month of September, over the next 20 years. An increasing trend in rainfall is projected mainly for the months of June, August and October, with a decrease in average rainfall projected for rest of the months. This implies that water availability from rainfall in the next 20 years is likely to be more uneven during the monsoon season (June–September), with potentially a higher concentration of rainfall during August, and lower rainfall in July and September.

The sea level near the coasts adjoining Gosabara wetland is projected to increase in the range of 36.45–55.35 mm by 2020, 48.6–73.8 mm by 2025, 60.75–92.25 mm by 2030, and by 72.9–110.7 mm by 2035, as compared to the base period of 1985–2005. The corresponding inland shifts in the coastline due to sea level rise are estimated to be in the range of 1.21–1.84 m by 2020, 1.62–2.46 m by 2025, 2.02–3.07 m by 2030, and 2.43–3.69 m by 2035, as compared to the base period of 1985–2005.

Significant changes in temperature, rainfall and evaporation patterns are likely to cause phonological changes in aquatic and terrestrial beings in the wetland including fishes, insects, algal growth and vegetation patterns, thus, disturbing the food web of bird population visiting the wetland. This points to the need for specific adaptation measures to be put in place to ensure steady water and food availability, especially during the peak season for migratory birds. Some adaptation measures to manage the impacts of these climate risks have been detailed:

- Outreach and educational programmes for sensitization and awareness of the surrounding communities
- Training programmes for management officials responsible for maintenance of the wetland
- Sustainable water management, including improving water retention of the wetland and exploring external sources of water
- Expanding vegetation cover and controlling existing invasive species
- Strengthening monitoring protocols and improving the knowledge database of the wetland
- Human activity diminution, such as prevention of over grazing by cattle, extraction of water, etc.
- Shoreline control measures to prevent coastal erosion due to potential sea level rise
- Use of financial incentives to motivate the stakeholders towards wetland conservation
- Creating open channels between policymakers and researchers
- Development of migration corridors in the long run

The results of carbon sequestration assessment showed that because of the existing fluctuating ecological characteristics of the wetland, the net carbon sequestration potential of the wetland is low. Only with targeted management interventions that could seek to retain water presence across the wetland can aid in net addition and long-term storage of organic carbon. Increasing the carbon sequestration potential for the Gosabara wetland while ensuring that the ecological character of the wetland is not disturbed would require:

- Replacement of the *Prosopis juliflora* occupied land vegetation sub-habitats with native species such as *Acacia nilotica*, *Azarithiracta indica, etc.,*
- Gap plantation using similar native species on the land vegetation sub-habitat for the wetland

The carbon sequestration potential of the wetland can be increased through plantation of tree species on the land area that does not get submerged during the wet season. Preference needs to be given to non-invasive locally abundant species.

1. Background

Wetlands cover 6 per cent of the world's land surface and contain about 12 per cent of the global carbon pool, which play an important role in the global carbon cycle. Wetlands act as major carbon reservoirs on earth. According to Ramsar Secretariat, about one-third of the world's terrestrial carbon is trapped and stored in wetlands, double to that of forests. As per estimations, carbon sequestration potential of restored wetlands (over 50-year period) comes out to be about 0.4 tonnes carbon per hectare per year (C/ha/year). Coastal wetlands in India, especially the mangrove wetlands in the eastern region and west coast, serve as carbon sink, sequestering approximately 1.5 metric tonne C/ha/year, and the upper layers of mangrove sediments have high carbon content, with conservative estimates indicating the levels of 10 per cent.

The interconnected nature of water, food and energy systems is a fundamental relationship in any ecosystem. Water security, including both the availability and quality of water, is an increasing challenge faced by the entire world. In fact, the global and local water cycles are strongly dependent on wetlands is well established. Hence, the adversities faced by India's wetlands have the potential to adversely impact the local water carbon and nutrient cycles.

The human interaction with wetlands during the last few decades has been of serious concern; the rapid population growth, accompanied by intensified industrial, commercial and residential developments, has led to pollution of wetlands by domestic and industrial sewage, and agricultural run-off as fertilisers, insecticides and feed lot wastes. This, along with a general lack of effort directed towards conservation of wetlands, has created a major threat to wetlands. Hydrologic conditions can directly modify or change the chemical and physical properties of wetlands, such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties and pH level. These modifications of the physiochemical environment, in turn, have a direct impact on the biotic response in the wetland (Gosselink & Turner 1978). With a slight change in hydrologic conditions in wetlands, the biota may respond with significant changes in species composition and ecosystem productivity. Wetlands perform numerous valuable functions, such as recycling of nutrients; purifying of water; attenuate floods; maintain stream flow; recharge ground water; provide drinking water, fish, fodder, fuel and wildlife habitat; control the rate of run-off in urban areas; buffer shorelines against erosion; and, recreation to the society.

Climate change is another pressing issue affecting the hydrology and biodiversity of wetland ecosystems mostly through changes in precipitation and temperature regimes. The impact of climatic variations on the wetland ecosystems greatly depends upon temperature and water availability through run-off in the inland fresh water bodies, and rise of sea level and storm surges in coastal area wetlands. The predicted hydrologic changes associated with climate change can also affect the performance of infrastructure (e.g., surface water management systems), thereby affecting the different uses of water in many areas. Several examples of impacts resulting from projected changes in extreme climate events include:

- change in base flows;
- altered hydrology (depth and hydroperiod);
- increased heat stress in wildlife;
- extended range and activity of some pest and disease vectors;
- increased flooding, landslide, avalanche, and mudslide damage;
- increased soil erosion;
- increased flood run-off resulting a decrease in recharge of some floodplain aquifers;
- decreased water resource quantity and quality;
- increased coastal erosion and damage to coastal buildings and infrastructure;

- increased damage to coastal ecosystems, such as coral reefs and mangroves, and increased tropical cyclone activity

Climate change is also expected to act in conjunction with a range of other pressures, many of which, depending on the region, may pose far greater immediate concern for wetlands and their water resources in the short to medium term. Wetland systems are vulnerable and particularly susceptible to changes in quantity and quality of water supply. It has been observed that climate change may have its most pronounced effects on wetlands through alterations in hydrological regimes, as well as through impacts on the biodiversity of wetlands' ecosystem.

In India, there are about 26 designated National Ramsar wetlands / sites as per their habitat functions and on the basis of importance of biodiversity. The wetland system is sandwiched between fluvial and marine forces, and also has some fragile zones in their flood plains, lakes and river mouths. Currently, wetland areas are designated as per classifications that are primarily biodiversity centric. Given the role played by wetlands in water and food security, there is a strong necessity that such criteria include the consideration of hydrological services of wetlands. However, only a few scientific studies have been undertaken so far. According to Parrette et. al., 1993, wetlands, or the lack thereof, were a significant factor for severe flooding in medium and large river systems in their middle and lower reaches. The anthropogenic impact on the original wetlands had destroyed their ability to modify flooding; support water supply and basin yield; enhance aquifer recharge, etc. Understanding the functions of wetlands will make it easier to evaluate and preserve wetlands and the water bodies. Any sustainable development of wetland needs primarily identification of hydrological pathways in terms of inflow and water quality.

Gujarat contributes about 22.77 per cent of the total wetland area of the country, which is the highest amongst all states in the country (NWA, 2011). The total wetland area estimated in Gujarat is 3,474,950ha, which accounts for about 17.56 per cent of geographical area of the state (NWA, 2010). The Gujarat coast, due to its varied physiographic features, geomorphology, coastal processes and river discharges into the sea, provides a wide variety of coastal features. Coastal wetlands such as coral reefs, mangroves, tidal flats, mudflats, marshes, creeks, estuaries and beaches are exclusively found here. Wetlands can be wet or dry for one or more seasons in a year. Seasonal wetlands in arid and semi-arid regions may be wet, only periodically. Functions of such seasonal wetlands and their role in environment, in parts, are determined by the timing of wet and dry periods and water quantity. The spatial and temporal characteristics of inflow and water quality are very crucial in the wetlands. However, the information available on these aspects is generally limited. Therefore, in the intended project proposal these hydrological aspects have been included to understand the hydrological processes in the selected wetlands.

The CMPA project is one of the flagship projects of the Indo German Bilateral Technical Cooperation, co-managed by the Ministry of Environment, Forests and Climate Change, Government of India and GIZ-India. The project aims at improving the management of selected existing, and potential coastal and marine protected areas through strengthened participatory management, capacity development, and information, communication and training.

The project is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), and implemented by the Ministry of Environment, Forests and Climate Change (MoEFCC), and GIZ, on behalf of BMUB. Under this project, the following research study is being conducted with the objective of supporting integrated management planning for two coastal wetlands of Gujarat — Khijadiya Sanctuary and Gosabara Wetland Complex. This report provides the finidings and results of the study for Gosabara Wetland Complex.

1.1 Objective and scope

The overarching aim of this study is to support integrated management planning of Gosabara Wetland Complex via following specific objectives:

- Conducting a hydrological analysis of the wetland, including the review of current water management practices and recommending measures for the maintenance of hydrological regimes in support of biodiversity and ecosystem services
- Assessing vulnerability of the two wetland to climate change and identifying adaptation options
- Assessing carbon sequestration potential and flux of the wetland

1.2 Overview of Gosabara Wetland Complex

Gosabara Wetland Complex, located in the Porbandar district of Gujarat, is spread over 129km^2. It lies between 21°38'49.17"N and 69°35'25.95"N, and 21°29'51.11"N and 69°47'21.19"N. Mokarsagar is a name given to group of several wetlands situated around the villages of Kuchhadi, Zavar, Chhaya, Odedar, Ratanpar, Vanana, Ranghavav, Bhorasa, Dharampur, Gosa, Narvai, Bhad, Lushala, Navagam, Tukda, Mokar and Pipliya. Gosabara Wetland Complex is the name given to the group of wetlands in the Porbandar district of Gujarat that includes Medha creek, Kuchhadi, Subhashnagar, Zavar, Kurly I, Kurly II, Vanana, Dharampur, Gosabara, Bhadarbara, Mokarsagar, Bardasagar and Amipur.The wetland is formed by Karli Recharge Reservoir and Karli Tidal Regulator. There is a combination of estuary and fresh water habitat. The wetland is dominated by sedges and other hydrophytic vegetation. It is a lifeline for the community as well as the wetland dependent biodiversity, including both the flora (mangrove, macroalgae, macrophytes) and fauna (birds, reptiles, insects and mammals).

Figure 1 Gosabara Wetland Complex on map of India

2. Hydrological assessment

2.1 Hydrological characterization of the wetland

Gosabara Wetland Complex is located in Porbandar district, which lies between 21°29'51.11"N to 21°38'49.17"N and 69°35'25.95"E to 69°47'21.19"E. The wetland is formed by Karli Recharge Reservoir and Karli Tidal Regulator. There is a combination of estuary and fresh water habitat. The wetland is dominated by sedges and other hydrophytic vegetation. It is a lifeline for the community as well as the wetland dependent biodiversity, including both the flora (mangrove, macroalgae, macrophytes) and fauna (birds, reptiles, insects and mammals). The location of the wetland is shown in Figure 2.

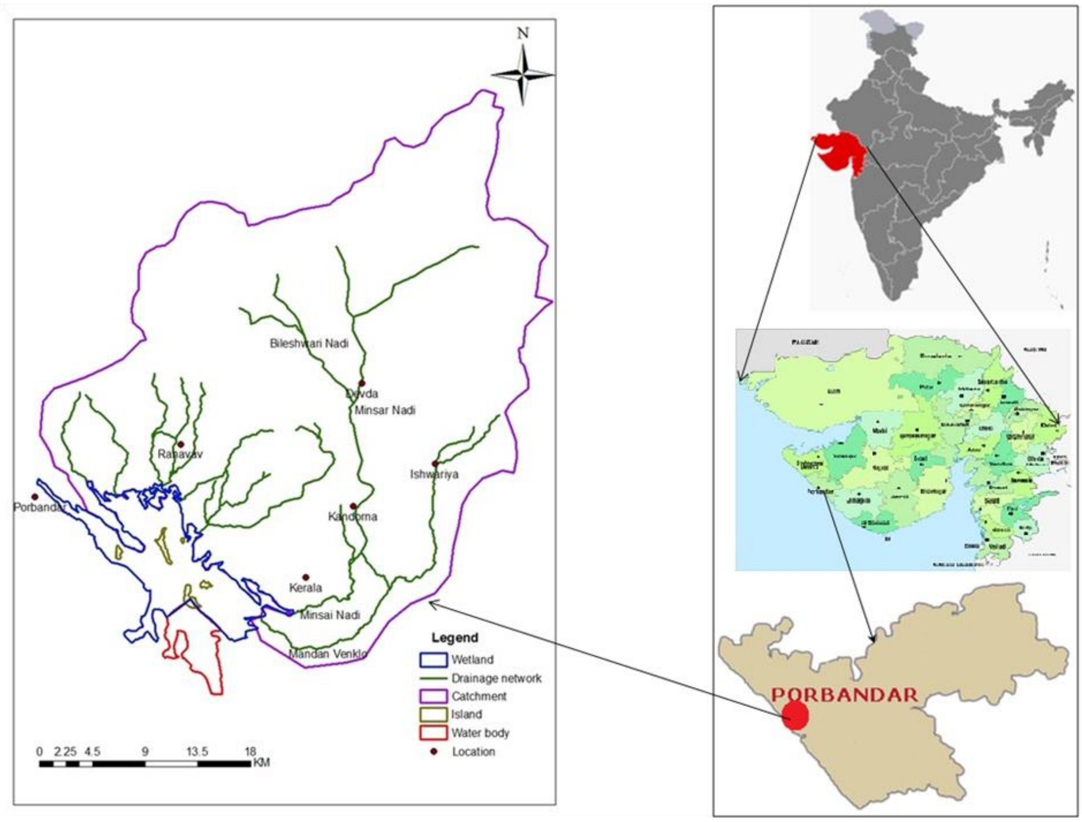

Figure 2 Location map of the Gosabara wetland area and its catchment area

With help of SOI topographical sheets, DEM and satellite images, the catchment area has been delineated for Gosabara wetland and the total catchment area was found to be about 1305km^2, which includes catchment area without wetland (1,192km^2), wetland area (89km^2), islands within wetland (3km^2) and water body (21km^2). The locations of these areas are given in Figure 3. The synoptic view of satellite image of the wetland area is also shown in Figure 4.

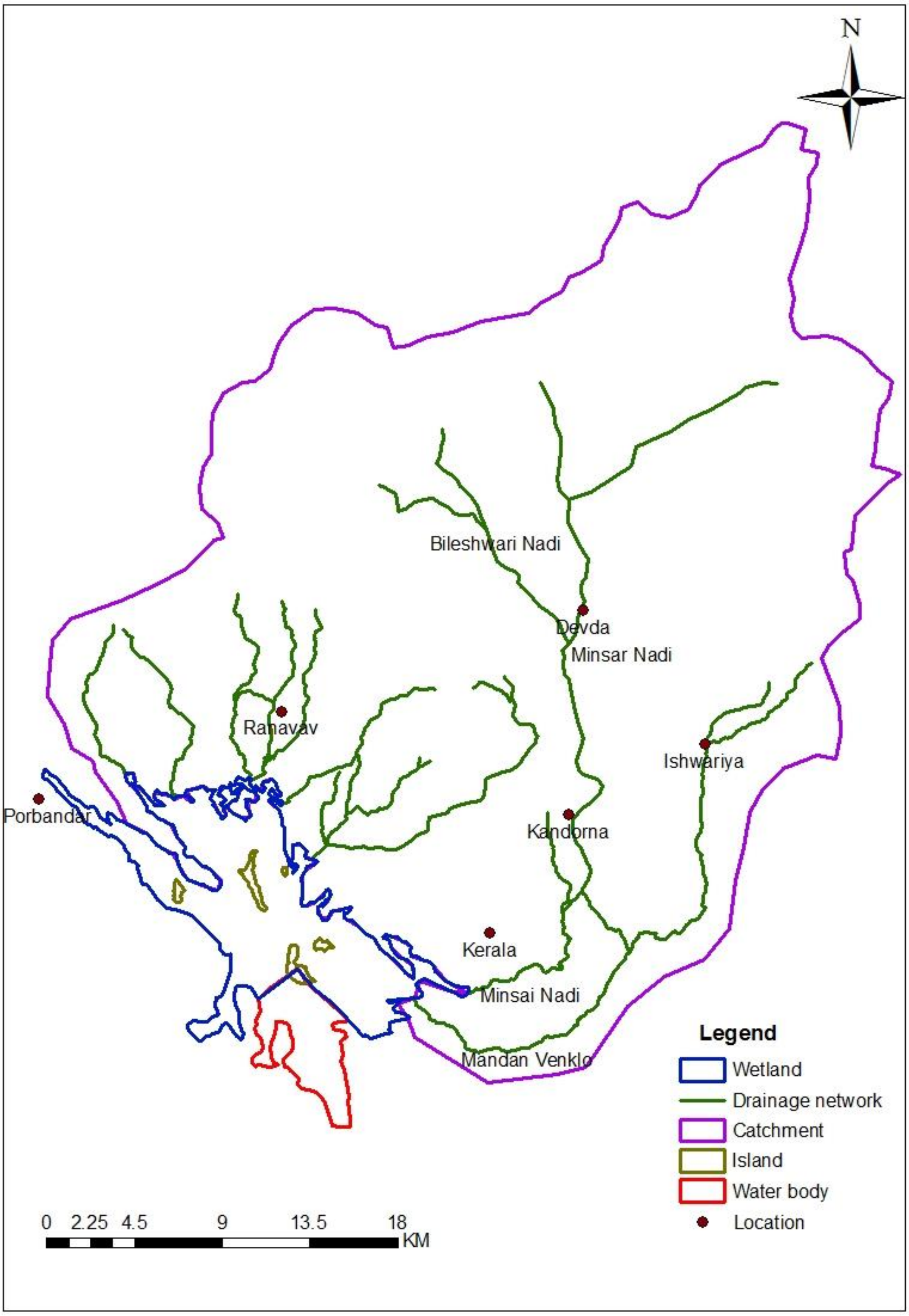

Figure 3 Location of catchment, wetland, island and, water body in and around the Gosabara wetland area

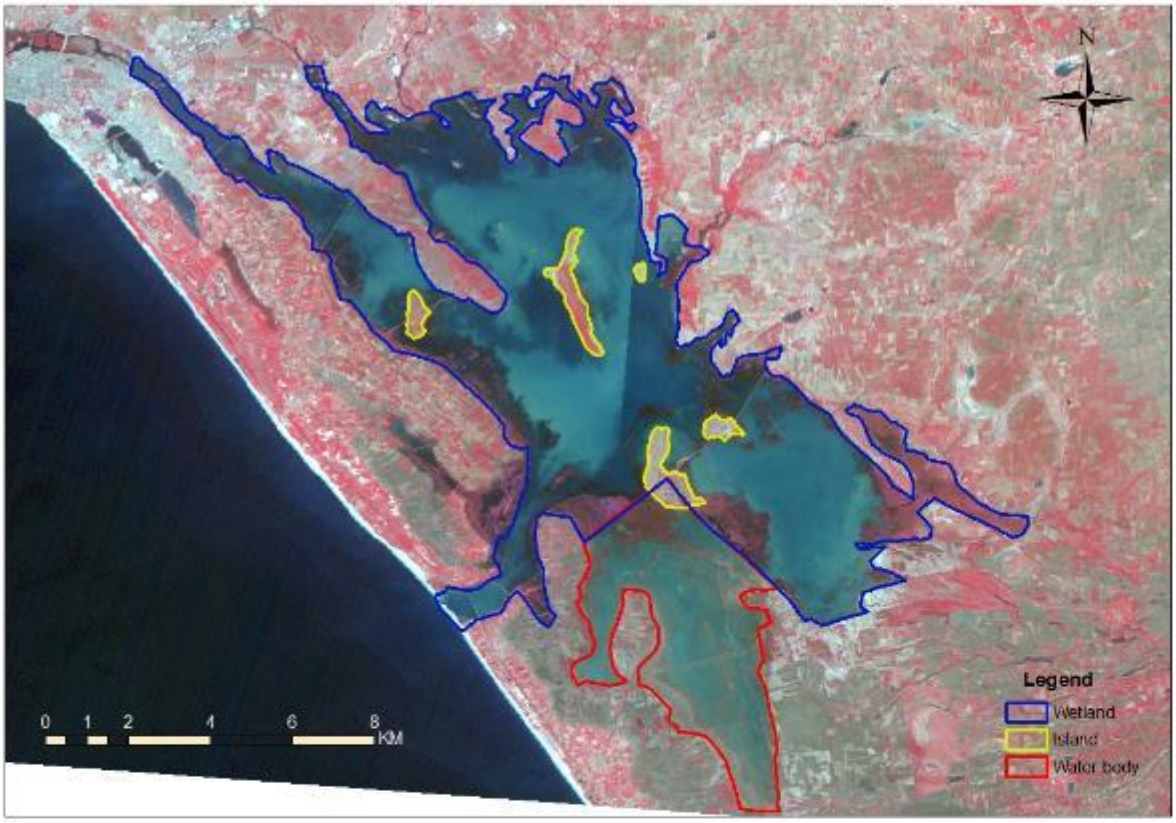

Figure 4 Synoptic view of Gosabara wetland from Satellite image (22-10-2008)

Soil and land use

The soils of Porbandar district are classified into three main categories. They are shallow to medium black soils, deep black soils (Ghed area) and coastal alluvial soils. Shallow to medium black soils are widely spread, and occur in 75.22 per cent of the district area and found in almost all taluks. They are more productive and rich in lime, magnesia and alumina and poor in phosphorous, nitrogen and organic matters. Coastal alluvial soils are found in the coastal parts of Porbandar *taluka* where the soils are less productive as they are saline. Agriculture is the main occupation in the Porbandar district and it occupies 52.41 per cent of the area. The Porbandar block has the maximum area of land, which is under non-agriculture use (122.28km^2) and less forest area (46.65km^2).

Climate

Based on the long-term data for the period of 1951–80 (IMD) the average monthly rainfall (mm) data of Porbandar is given in Table 1 and 2. The average maximum long-term humidity is found in the month of August (83.5 per cent) and minimum in the month of December (47.5 per cent). The long-term minimum, maximum and average Potential Evapo Transpiration (PET) rate in mm/day are 4.0 (August), 6.6 (April) and 5.3, respectively. The recent data of monthly rainfall at Gosabara in Porbandar district (2004 to 2010) is given in Table 2. The lowest annual rainfall observed was to be in the year 2004 i.e., 527.9mm.

Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total (mm)
1.3	1.6	3.4	0	0.4	128.5	245	149.5	71.3	27.6	9.9	1.4	639.9

Table 1 Long-term monthly average rainfall (IMD) in mm in Porbandar district

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2004	0	0	0	0	33.8	128.7	76.9	263.4	9.4	15.7	0	0	527.9
2005	0	0	0	0	0	199	193.3	41.6	261	0	0	0	694.9
2006	0	0	0	0	0	47.5	473.3	262.6	132.7	0	0	0	916.1
2007	0	2.3	0	0	0	137.4	207	830.7	165.3	0	5.7	0	1348.4
2008	0	0.5	0	0	0	92.6	263.7	55.6	230.9	0	1.9	0.1	645.3
2009	0	0	0	0	0	273.2	1,036.2	137.3	9.1	0	0	0	1,455.8
2010	0	0	0	0	0	37.6	733.4	563.3	344.1	17.9	82.5	0	1,778.8

Table 2 Monthly rainfall in mm at Gosabara wetland, Porbandar district

The evaporation data for Gosabara wetland has been considered to be the same as Khijadiya wetland, due to geographical proximity of the two wetlands. The average daily evaporation is provided below.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (mm/d)	3.75	4.66	6.5	7.88	8.73	7.55	5.22	4.42	5.06	5.16	4.22	3.69

Table 3 Average daily evaporation from wetland (2011–16)

2.2 Assessment of water quality profiles

Intensive field survey was conducted in the month of March 2017 and it was found that there was not much water avalable in the wetland to establish water quality profile. It was also learnt that there is no historical water quality data available within the wetland to develop water quality profile. However, during the field survey, a few water samples were collected within the wetland and analysed physical parameters in the field using micropocessor-based electrodes (pH and electrical conductivity). The chemical and trace metal analysis has been carried out at Deltaic Regional Centre, National Institute of Hydrology, Kakinada. The chemical analysis data is given in Table 4 and the location of the sample collected from wetland is shown in Figure 5. The chemical analysis data indicates that all the samples are under saline except MK5B. This is mainly due to the drinking water pipeline leakage, which was lying stagnated in the stream course of the wetland. Other chemical parameters are not suitable for drinking water limits (BIS, 2012) and trace metals were within the drinking water limits.

Sample Id	Temp in ^{0}C	pH	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	Cd	Li	Zn	Fe
MK1	28.0	6.7	>20,000	1,784	819	>2,500	160	17,600	240	436	35	0.0378	BDL	0.0952	BDL
MK2	28.8	6.8	9100	60	248	>2,500	90	2,820	550	259	46	0.0556	BDL	0.1896	1.5493
MK3	28.8	8.6	10,900	80	272	>2,500	65	3,500	220	355	23	0.0533	BDL	0.2559	1.2193
MK4	22.7	7.6	>20,000	160	467	>2,500	125	10,250	1,500	855	67	0.0485	BDL	1.0733	BDL
MK5A	20.7	6.5	8,500	64	245	2,325	80	2,760	440	216	17	0.0524	0.0016	0.0687	0.2139
MK5B	27.0	7.0	970	16	49	260	55	220	320	58	8	0.0522	BDL	0.0569	BDL
MK6	28.0	7.9	7,400	60	97	2,250	65	2,640	170	135	38	0.0503	BDL	0.1002	1.4265
MK7	27.0	6.7	5,500	40	102	1,500	80	1,520	510	285	6	0.050	0.1242	0.0166	BDL

*Table 4: Assessment of water quality profiles of the wetland**

**Electrical conductivity (μmhos/cm) and all units are in mg/L. BDL: Below Detectable Limit*

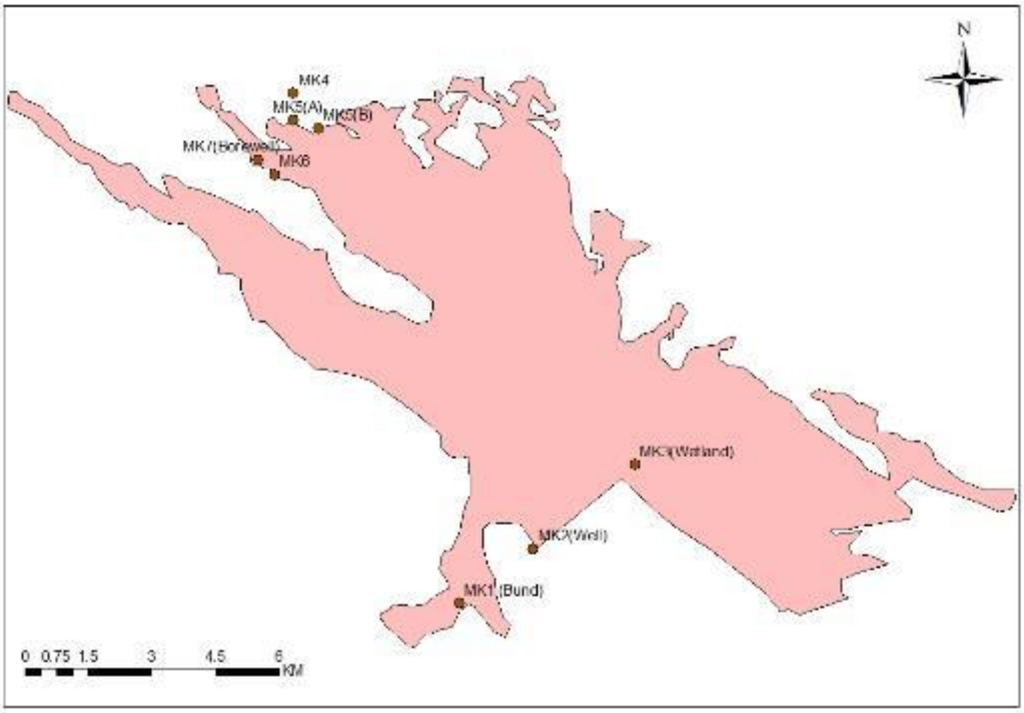

Figure 5 Location of water samples collected within the wetland in March 2017

2.3 Water balance model of the wetland

Hydrologically, wetlands are divided into various zones in terms of inundation, viz., permanently inundated, semi-permanent, regularly, seasonally, irregularly and intermittently inundated. The identification of flow pathways into wetlands and demarcation of its catchment area is of immense importance in estimating inflows into wetlands. The water quality assessment in terms of physical, chemical and trace metals are essential for sustainable development of wetlands. The hydrological pathways in wetlands are mainly from precipitation (total rainfall, intensity of rainfall and interception), surface flow (overland flow, stream flow and run-off), groundwater (recharge into wetlands and discharge from wetlands), evapotranspiration and tides (frequency and magnitude). The water balance equation for typical wetland is as follows:

$$\frac{\Delta V}{\Delta t} = P_n + S_i + G_i - ET - S_o - G_o \pm T \tag{4}$$

P_n= net precipitation, S_i= surface inflows (sheet, stream flow), G_i= ground water inflow, ET = evapotranspiration, S_o= surface outflows, G_o= ground water outflows, T= tidal inflow (+) and outflow (-), $\frac{\Delta V}{\Delta t}$ = change in volume of water storage per unit time.

Generally, the ground water inflow is equal to ground water outflow and, hence, net groundwater flow is considered as zero in most water balance studies. Since the wetland is heavily silted causing the bottom to be almost impervious, there is hardly any loss of water as losses from the bottom of the wetland. Therefore, the water balance of the Gosabara wetland can be written in simplified terms as:

Change in storage = Total inflow –total outflow

While 'total inflow' includes inflow due to surface run-off from catchment + inflow due to direct rainfall over the wetland, 'total outflow' includes evaporation losses + overflow. If the amount of inflow is more than the capacity of the wetland, it shall go as overflow.

Computation of water balance components

Rainfall

The above Table 2 indicates that the lowest rainfall was received during the year 2004, which was 527.9mm while the highest rainfall was received during 2010 — as high as 1778.8mm. As far as water year from June to May is concerned, the rainfall received during June 2004–May 2005 was 494.1mm only. To prepare a management plan for Gosabara wetland, the worst conditions of rainfall (or drought) of the period 2004–05 has been considered for the analysis. The rainfall received during the monsoon months of this year (June 2004 to September 2004) was 478.4mm while the rainfall received during the post monsoon period of October 2004 to May 2005 was only 15.4mm — all of which was received during October 2004.

Estimating storage capacity of the wetland

A wetland is a very shallow water body with depths of generally a few centimeters or less. Since the depth is very less, there is not much difference in the top surface area (which is maximum surface area at full water level or FWL) and in the bottom surface area. The general shape of the seasonal coastal wetland and its major water balance components are shown in Figure 6 (Kashaigili et al 2006). In the absence of water level–water spread area–capacity relations of any wetland, a trapezoidal shape may be appropriate to assume for the computation of water balance components.

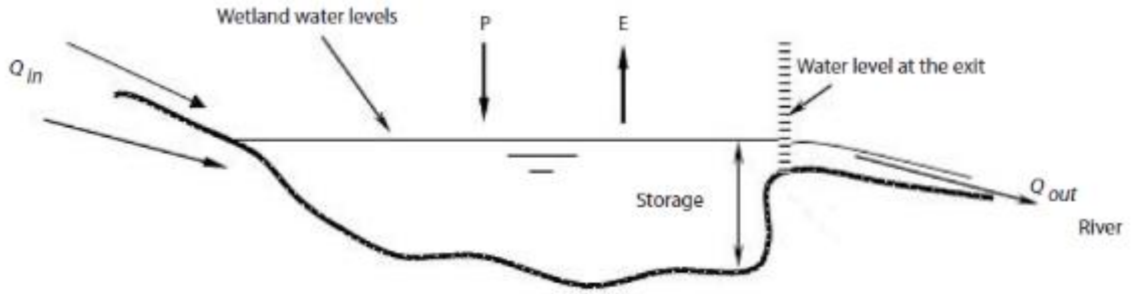

Figure 6 Seasonal wetland and water balance components

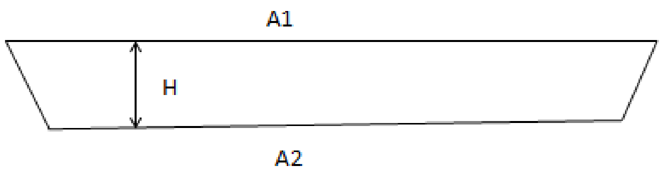

Figure 7 Cross-section of a hypothetical wetland

Water bodies with larger depths are referred generally as lakes. Because of the very shallow depths, there is not a very significant difference in top surface area and bottom surface areas of a wetland. However, due to sedimentation, the sides of the wetland are not exactly vertical but have a slanting shape because of which the bottom surface area of the wetland is less than the top surface area.

The total catchment area of Gosabara wetland: 1192km^2 (excluding wetland area), wetland area without island and without waterbody: 89.1km^2, island: 3.22km^2 and waterbody: 20.62km^2.

Considering the water body area to be the maximum water spread area, and assuming that the bottom area to be smaller than the maximum water spread area, the bottom surface area can be considered to be about 15–18km^2.

Thus,

A1 = 20.62km^2

A2 = 15–18km^2

Since the wetland is a shallow waterbody, the average depth for the wetland can be assumed to be 30cm or 50cm, although the depth may be more or less than the average in different parts.

Now, considering the wetland as a conical frustum, the volume can be estimated as:

$$V = \frac{1}{3} * H * (A1 + A2 + \sqrt{(A1 * A2)})$$

Where A1, A2 and H are surface area of the top surface, surface area of the bottom surface and average depth of wetland, respectively. For different assumption of bottom surface (15–18km^2) and depth (30cm or 50cm), the storage capacity of the wetland is given in Table 5.

Assumptions		Storage capacity (Million cubic metres)
1	Bottom surface area = 15km^2 Average depth = 30cm	5.32
2	Bottom surface area = 15km^2 Average depth = 50cm	8.87
3	Bottom surface area = 18km^2 Average depth = 30cm	5.79
4	Bottom surface area = 18km^2 Average depth = 50cm	9.65

Table 5 Various combinations of wetland storage capacity

2.4 Estimation of total inflow

Total inflow to the wetland is the sum of inflow due to surface run-off from catchment + inflow due to direct rainfall over the wetland. Total inflow due to surface run-off can be calculated as 30 per cent of the total volume of water generated by the rainfall falling over the catchment. A higher value of run-off percentage (30per cent) is considered based on catchment characteristics as compared to 21 per centfor Jamnagar. The catchment area of the wetland is 1,192km^2 (excluding the wetland area). The total wetland area including the water body and island is 112.94km^2 (89.1km^2 + 3.22km^2 + 20.62km^2). The estimated run-off from the catchment is 30 per cent of rainfall at different months of 2004–05 and total inflow to wetland is given in Table 6. From Table 6, it is clear that the total water received by the wetland during 2004 monsoon (June–September, 2004) was 224.65Mcum while the estimated storage capacity of the wetland is less than 10Mcum. After filling the storage capacity, the rest of the water overflows. Although there would be evaporation losses during monsoon, since the total inflow is much more than the capacity and the rainfall shall be received all through the monsoon, it is safe to assume that by the end of monsoon the capacity of the wetland shall be more or less filled; whether the wetland shall be able to survive the evaporation losses during the post monsoon period remains a question.

Month	Rainfall (mm)	Total magnitude of water generated in the catchment (m^3)	Inflow due to run-off from catchment (30% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)	Total inflow to wetland (Mcum)
	(a)	(b)	(c)	(d)	(e)	
Jun 2004	128.7	153,410,400	46,023,120	14,414,400	60,437,520	60.44
Jul 2004	76.9	91,664,800	27,499,440	8,612,800	36,112,240	36.11
Aug 2004	263.4	313,972,800	94,191,840	29,500,800	123,692,640	123.69
Sep 2004	9.4	11,204,800	3,361,440	1,052,800	4,414,240	4.41
Oct 2004	15.7	18,714,400	5,614,320	1,758,400	7,372,720	7.37
Nov 2004	0	0	0	0	0	0.00
Dec 2004	0	0	0	0	0	0.00
Jan 2005	0	0	0	0	0	0.00
Feb 2005	0	0	0	0	0	0.00
Mar 2005	0	0	0	0	0	0.00
Apr 2005	0	0	0	0	0	0.00
May 2005	0	0	0	0	0	0.00

Table 6 Computed wetland inflows for the year 2004–05

2.5 Estimation of evaporation losses

No detailed meteorological data of Porbandar is available with the authors. However, since there is no much significant variation in the climatic setting of Jamnagar and Porbandar, the evaporation losses at Porbandar can be assumed to be similar to that of in Jamnagar for the purpose of present analysis. Therefore, evaporation estimated for Jamnagar has been used for Porbandar. Based on the daily evaporation rates of Jamnagar area for the period of 2011–16, the average evaporation rates obtained for different months are given in Table 7 and monthly evaporation losses considered for Gosabara wetland is given in Table 8.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation (mm/d)	3.75	4.66	6.5	7.88	8.73	7.55	5.22	4.42	5.06	5.16	4.22	3.69

Table 7 Average daily evaporation from wetland (2011–16)

Month	Average daily evaporation (mm/d)	Total evaporation during the month (mm)	Total evaporation during the month (cm)
Jan	3.75	116.25	11.625
Febr	4.66	130.48	13.048
Mar	6.5	201.5	20.15
Apr	7.88	236.4	23.64
May	8.73	270.63	27.063
Jun	7.55	226.5	22.65

Month	Average daily evaporation (mm/d)	Total evaporation during the month (mm)	Total evaporation during the month (cm)
Jul	5.22	161.82	16.182
Aug	4.42	137.02	13.702
Sep	5.06	151.8	15.18
Oct	5.16	159.96	15.996
Nov	4.22	126.6	12.66
Dec	3.69	114.39	11.439

Table 8 Total monthly evaporation losses considered for Gosabara wetland

No method exists for direct measurement of actual evaporation from open water surface like lakes and wetlands. It has to be determined indirectly. A number models have been developed to indirectly estimate evaporation such as energy balance models, water balance models, mass transfer models, combination models, pan evaporation models, equilibrium temperature models and empirical models. The energy balance is considered to be the most accurate of all the available methods. However, extensive data and instrumentation requirements, associated costs and the requirement of precision in data, often limit their use. In such cases, the combination methods, typified by the Penman model, are used as the standard method for estimation of evaporation. The Penman combination method is a universally accepted method. It is based on the sound combination of the principles of mass and energy transfer. Penman-Monteith method has been suggested by FAO as the standard method for reference evaporation and evapo-transpiration (Allen *et al.,* 1998).

Using the daily meteorological data of the study area (2011–16), daily evaporation rates have been obtained using the Penman–Monteith method. The Penman–Monteith equation as per Allen et al.(1998), is:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} U_2 \left(e_s - e_a\right)}{\Delta + \gamma(1 + 0.34U_2)} \qquad (6)$$

where,

ET_o = lake evaporation [mmd^{-1}]
R_n = net radiation [$MJm^{-2}d^{-1}$];
G = heat flux density [$MJm^{-2}d^{-1}$];
U_2 = wind speed measured at 2 m above the ground [ms^{-1}];
e_s = saturated vapour pressure at air temperature [kPa];
e_a = actual vapour pressure at air temperature [kPa];
Δ = slope of saturation vapourpressure–temperature curve [kPa^0C^{-1}];
ϒ = psychrometric constant [kPa^0C^{-1}]; and
λ = latent heat of vapourization [$MJkg^{-1}$]

While calculating evaporation using the above equation, the term G has been neglected because it is negligibly small for a shorter time scale of a day or less. Other required parameters have been estimated using standard methods. Mean saturated vapour pressure is calculated as average of saturated vapour pressure from maximum and minimum temperatures, as per Allen et al. (1998). The saturation vapour pressure, e_s, which is a function of temperature, is estimated as per Shuttleworth (1993). Slope of the saturation vapour pressure–temperature curve (Δ) has been calculated from mean air temperature as per Allen et al. (1998). The psychometric constant (Υ) has been calculated as per Nokes (1995). The latent heat of vapourisation (λ) has been calculated from the air temperature as per Nokes (1995). Net radiation, R_n, is calculated as per Allen et al. (1998).

Based on this method, if the average depth of the wetland is 50cm at the end of the monsoon (June to September), the total evaporation losses for the post monsoon period (October to January) is 52cm. Thus, the wetland shall more or less be dry by the end of January. The same was observed during field visit undertaken in the month of March 2017. However, it was observed that the wetland was completely dry in most parts and there was some water in the d/s end. This was due to the depth in this part being more (over 1mt) compared with other parts. For estimation of evaporation in volume terms, data on surface area corresponding to various depths in the wetland is required. Evaporation loss in a period in volume terms is estimated by multiplying the average surface area by average evaporation rate during that period. The interpolated depth–area–capacity tables are presented in Figure 8, which can be used for estimating evaporation losses in volume terms.

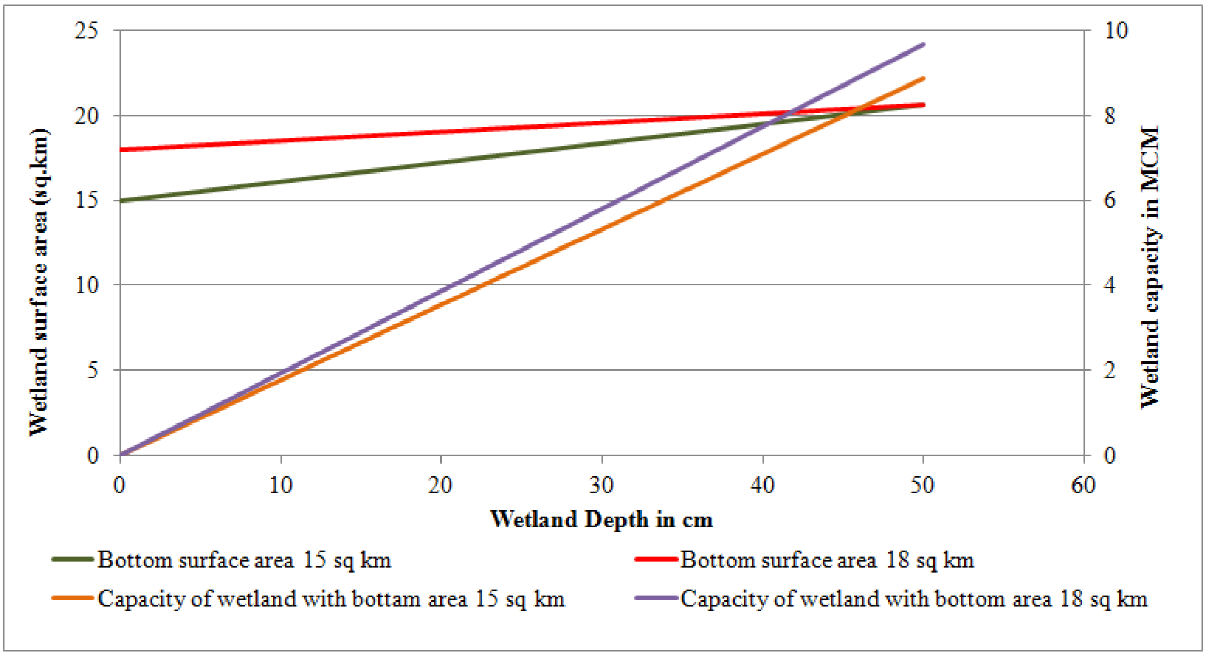

Figure 8 Wetland water spread area and capacity at different depths of the wetland

2.6 Results of the assessment

The total evaporation losses from Gosabara wetland during the post monsoon period (October to January) is about 52cm. Since the average depth of wetland is only about 50cm, the water can last till the end of January. If the water has to be retained in Gosabara until May-end, the following activities are proposed:

i) Evaporation is one of the major factors causing drying of the wetland in summer and it depends mainly on water spread area. Therefore, water spread area can be reduced without decreasing the capacity. This can be achieved by increasing the storage capacity of the wetland through dredging to trap the overflowing water. However, since a wetland cannot have a large depth, this dredging could be done only in pockets (and not all over the wetland) and the water in these dredged pockets may be pumped to other parts during the dry period. Furthermore, the dredging may be done in those areas where ground water salinity is not too high, to avoid mixing of highly saline water with fresh or brackish surface water

ii) If we want to maintain a specific depth of 30cm (of the average depth of 50cm) throughout the summer, then we have to work out the total evaporation losses of water during the summer at 30cm depth. The corresponding water spread area at 30cm depth is 18.37km^2 if bottom area is 15km^2 and it is 19.57km^2 if the bottom area is 18km2 from the interpolation tables. Currently, the average evaporation for the post monsoon period of October–May is 5.57mm/d. Therefore, the total evaporation losses would come out to be 0.102Mcum per day for 15km^2 assumed bottom area condition and 0.109Mcum for the 18km^2 assumed bottom area condition. Since there are 243 days between 1 October and 31 May, the total evaporation loss for these 243 days comes out to be 24.86Mcum and 26.49Mcum for these water spread areas, respectively. This means that about 25–27Mcum of water shall be required for the post monsoon period (October to May) to maintain the 30cm depth in the wetland throughout the summer (if no increase in the present capacity is done). Some of this water is likely to be received during the post monsoon months. The total water available during October–May was about 7.37Mcum (say 7Mcum). This means that about 18–20Mcum of total additional water may be required for the wetland for the post monsoon period of October–May, to overcome the evaporation losses and maintain a depth of 30cm in the wetland throughout the post monsoon period i.e., October–May, for rainfall conditions similar to that of year 2004–05. An external source of water from nearby reservoirs through pipelines may be explored to maintain water levels in the wetland during the summer months.

2.7 Recommendations for improving water retention in the wetland

When considering the water retention capacity of some forms of wetlands, such as mires, swamps, marshes, and wet grasslands, it is crucial to particularly focus on:

- Water retention capacity of the wetland soil, the ability to retain water in soil pores of the aeration zone
- Water retention capacity of the wetland (marsh and swamp), the ability to retain water on the surface of wetland areas
- Water retention capacity of the plateau in the adjacent area, can occur as a result of the delay of groundwater outflow by the creation of peat in a fen or bog on the slope of the valley.

Rainwater can be retained in soil pores in the unsaturated zone, which is a zone between the ground level, and the groundwater table level. The higher the level of groundwater, the smaller the soil retention capacity, with the soil retention capacity being defined as the space that can be filled with inflowing water as a result of flood or excessive precipitation.

In a natural wetland, if the groundwater table level is located on the surface of the ground, water retention capacity equals almost to zero. Therefore, every single drop that falls on the surface on such wetland can, theoretically, run-off to the river. The drainage of wetlands does not minimisethe flood wave.

Natural wetlands that are covered with some kind of swamp plants, for example shrubs, are characterised by significant hydraulic resistance. Moreover, small elevation differences of the terrain are typical to these areas. This is the reason why water in the form of snow melt or flood water run-off from the area of wetlands slowly. Therefore, swampy river valleys can be treated as retention reservoirs. Water that flows into the area of the wetland can slowly run-off back into rivers, which decreases the flood wave on a river section situated below the wetland. This phenomenon is clearly visible; for example, the wide (over 10km width) Biebrza valley in Poland. Water can be retained on the surface of the valley for more than a few months. Therefore, as discussed above, a single drop of water can freely, but slowly, get back to the river it came from. Some of the potential management options include:

Dredging

The depth of the wetland is an important parameter when looking at the water storage capacity of the wetland. Rainwater is retained in soil pores in the unsaturated zone, which is a zone between the ground or surface level, and the groundwater table level. The higher the level of groundwater, the smaller the soil retention capacity, with the soil retention capacity being defined as the space that can be filled with inflowing water as a result of flood or excessive precipitation.

Dredging can be used as a measure to increase the level of water stored in the wetland during monsoon months, thus, increasing the water availability during non-monsoon months.

However, it may be noted that increasing depth of the wetland through dredging may not be able to fulfill the requirement, as explained earlier. If we increase the depth by about 50 cm, the additional storage capacity would be only about 5 Mcum, which is not adequate. If we increase the depth too much, it would become a lake and will not be preferred by some of the water birds that prefer only shallow water. Moreover, too much depening may also be risky as it may give rise to possible interaction with the brakish/saline ground water. Since the groundwater surrounding Gosabara wetland is likely to be highly saline due to seawater interaction, dredging beyond the groundwater table depth can lead to a significant increase the salinity levels of fresh or brackish surface water, and the soil quality of wetland. Nevertheless, careful dredging can be done in some selected pockets of the wetland, where ground water salinity is not too high; the water in these dredged pockets can be pumped across other parts of the wetland during the dry period (post monsoon period of October–May).

Siltation prevention measures:

Through the hydrological assessment exercise, it was found that siltation from the run-off of streams surrounding the wetland is one of the reasons for reduced water retention capacity of the wetlands. However, siltation is also an essential ecological feature of wetlands, and removing siltation process can lead to adverse biodiversity impacts. However, certain temporary siltation prevention measures to regulate the level of silt entering the wetland can be explored, such as siltation traps.

Any depression, swale, or low-lying place that receives muddy flows from exposed soil areas can serve as a sediment trap site. Installing several small traps at strategic locations is often better than building one large basin. The simplest approach is to dig a small hole or build a dike (berm) of earth or stone where concentrated flows are present. This is likely to help detain run-off so sediment can settle out. The outlet can be a rock-lined depression in the containment berm. A temporary sediment or silt trap can also be formed by excavating or by constructing a small embankment of stone, stone-filled bags, or other material to retain sediment.

Figure 9 Examples of temporary silt traps

Source: http://transportation.ky.gov/EnvironmentalAnalysis/Environmental%20Resources/5Sediment%20Traps%20and%20Basins.pdf

Construction of rainwater storage structures for increasing water retention:

One of the key findings from the hydrological assessment was that the inflow from rainfall and run-off during monsoon months from July to October was more than the required amount of water for the wetland. Moreover, the climate change projections have shown an increasing trend in rainfall over the next 30 years, especially in these monsoon months. Thus, one method of increasing water retention in the wetlands, which can be explored, is the construction of or installation of artificial small water reservoir structures at strategic locations for storing rainwater, especially during the peak monsoon season. These structures can be supplemented with water outlets or drip-based outlets, which can release a regulated amount of water from the structures to the wetland on need basis.

Sourcing of water from an artificial source during the summer seasons:

According to hydrological modelling results, about 18– 20Mcumof water shall be required for the wetland, for the post monsoon period to overcome the evaporation losses, and to maintain the 30cm depth in the wetland (assumed) throughout the summer (1 October to 31 May period). This can be an alternative measure reliant on availability of an external water source, if no measures can be taken to increase the existing storage capacity of the wetland.

3. Climate risks and vulnerability

This section provides a detailed assessment of the vulnerability of the Gosabara wetland complex to the impacts of climate change, with particular emphasis on understanding the likely changes in hydrological regimes in these regions.

3.1 Key climate change issues and influencing factors

Climate change refers to any change in climatic conditions over and above the natural variability of the climate system, resulting either from natural causes, or by human action, or both. Recently, climate change has been directly linked to the intensification of emissions of greenhouse gases on the terrestrial atmosphere (IPCC, 2007a). Greenhouse gases that are naturally found in the atmosphere are carbon dioxide (CO_2), ozone (O_3), methane (CH_4), nitrous oxide (N_2O) and water vapour (H_2O). Moreover, there are a number of entirely man-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine and bromine containing substances, sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).[1] The presence of these gases modulates the temperature of the earth's surface. However, since the industrial revolution, there is evidence that human activities, especially the burning of fossil fuels (coal, oil and natural gas), have caused an increase in the concentration of some greenhouse gases, especially CO_2, which is considered to have the strongest effect on global warming.[2]

The main characteristics of climate change are: increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and, increases in ocean temperatures and ocean acidity — due to seawater absorbing heat and carbon dioxide from the atmosphere. As a result of global warming, the type, frequency and intensity of extreme events, such as tropical cyclones (including hurricanes and typhoons), floods, droughts and heavy precipitation events, are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed; for example, increases in the frequency and intensity of heat waves and heavy precipitation events. Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding. Melting of glaciers can cause flooding and soil erosion. Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increases would potentially severely increase the rate of extinction for many habitats and species (up to 30 per cent with a 2°C rise in temperature), and coral reefs, forests, and mountain habitats are likely to be significantly affected, in particular. Increasing level of seas means greater risk of storm surge, inundation and wave damage to coastlines.[3]

The range of impacts that climate change may have on wetlands is wide and varied. Climate change is predicted to alter patterns of rainfall, river flow, groundwater level and sea level and also result in changes to other variables such as temperature and evaporation. These are all important drivers of

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[1] Source: IPCC, https://www.ipcc.ch/ipccreports/tar/wg1/518.htm

[2] Source: 'Possible impacts of climate change on wetlands and its biota in the Brazilian Amazon', Braz. J. Biol. vol.74 no.4 São Carlos Nov. 2014, http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1519-69842014000400810

[3] Source: https://unfccc.int/resource/docs/publications/impacts.pdf

wetland structure and function. However, the overarching driver is via changes in wetland hydrology, particularly the frequency and duration of inundation events. Changes in frequency and duration of the wet phase are predicted to result in a shift in vegetation community composition towards species tolerant of drier conditions, and may also result in the loss of biodiversity, particularly, if permanent wetlands dry out more frequently. The various impacts of climate change on wetlands are summarised in Figure 10 below.

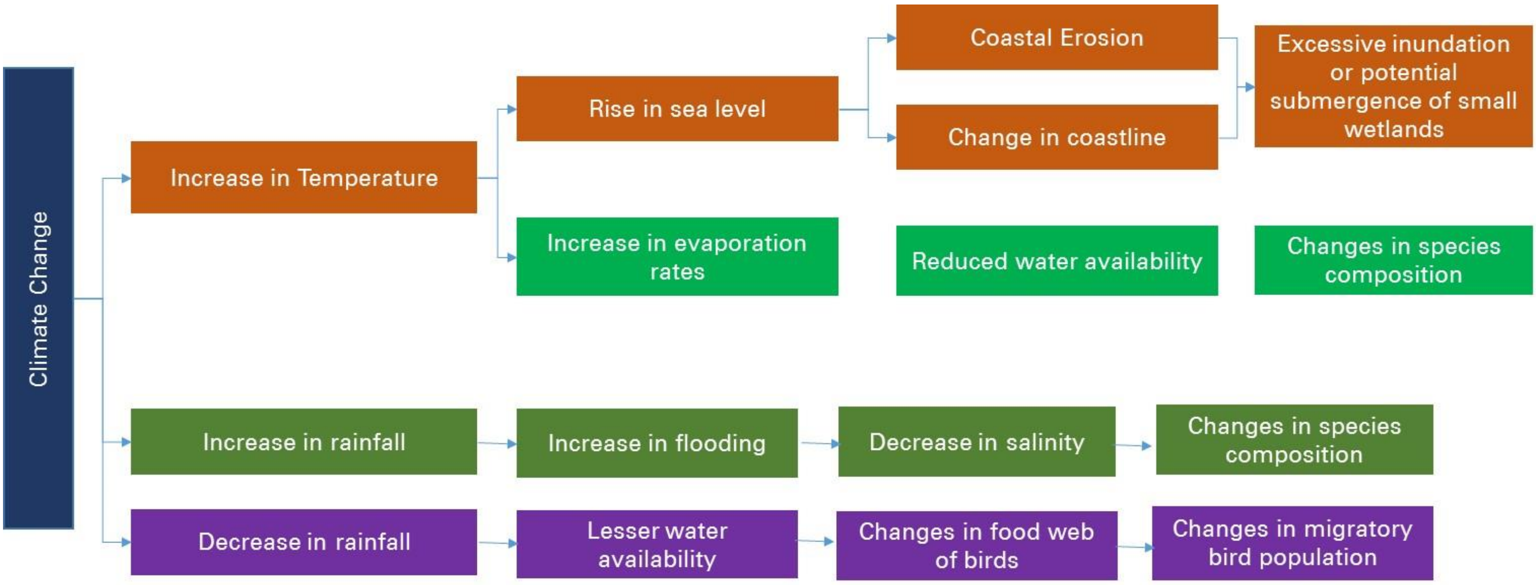

Figure 10 Potential impacts of climate change on coastal wetlands

3.2 Approach to assessing climate vulnerability

Climate change affects wetlands, mostly, due to changes in temperature and rainfall patterns. Thus, for this project, rainfall and temperature are the two climatic parameters, which have been assessed to study the vulnerability of these wetlands to the impacts of climate change. As part of the assessment, the available historical monthly dataset for temperature levels and rainfall patterns have been assessed to identify the trends in these climatic parameters, post which, projections for these parameters have been developed for a 20-year period from 2016 to 2036.

Broadly, the *Framework for Assessing the Vulnerability of Wetlands to Climate Change* developed by the Ramsar Convention Secretariat along with modelling tools was used for assessing climate change, and external risks to the wetlands.

Our approach to the Vulnerability Assessment (VA) as showcased in the schematic table below is broadly based on:

- determining the probability of a risk event occurring and the effect of this on the wetland system, given its sensitivity and adaptive capacity;
- developing possible options that could reduce the adverse impacts from that event; and
- formulating the desired outcomes for the system within an adaptive management framework to ensure that the response options being implemented are achieving the desired outcomes

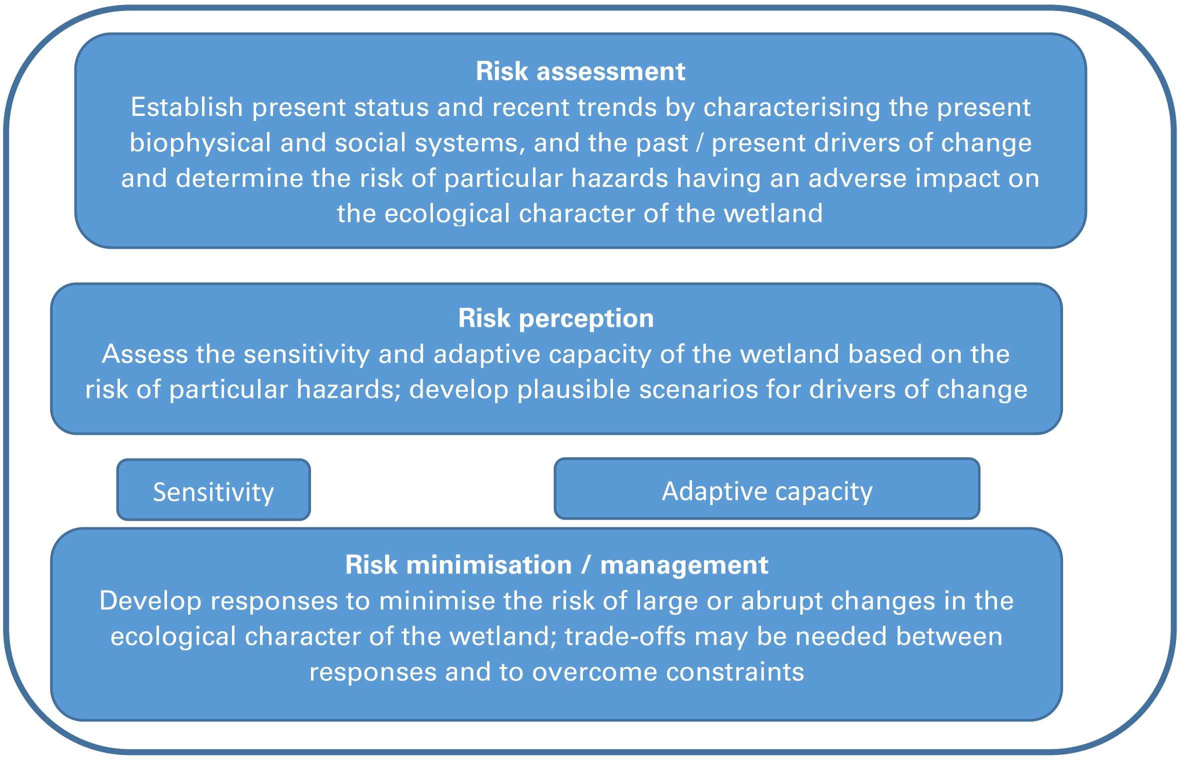

Figure 11 Approach to climate risk and vulnerablity assessment

Based on this framework, the climate vulnerability of Gosabara wetland complex has been investigated in the following sections, by analysing multiple aspects of the near surface air temperature and rainfall over the region, both for the current climate and under global warming. For temperature analysis under current climate, we make use of the European Centre for Medium Range Weather Forecast (ECMWF) Reanalysis (ERA) Interim (ERA-I) data product. [4]The data product assimilates both in-situ as well as satellite-based observations using advanced data assimilation techniques, and it has been widely used for both, for analysing the current climate and for also validating the climate models used in the Intergovernmental Panel for Climate Change (IPCC) reports. Comparison of ERA-I data with those obtained from the India Meteorological Department shows a good level of agreement on a wide range of space and time scales, thus, adding credibility to its use over the Indian region. For rainfall, we use the Tropical Rainfall Measuring Mission (TRMM) satellite retrievals for the period 1998–2014.

In order to study the climatic parameters and structure the projections under the climate change scenario, the Representative Concentration Pathways (RCPs) published by IPCC in their Fifth Assessment Report (AR5, 2013–14), have been utilised. These pathways are greenhouse gas concentration trajectories / pathways, which are designed taking into consideration the combined effect of emissions and likely mitigation strategies by various countries. Each of these RCPs, illustrated below in Figure 12, are considered to be as likely.

The number appended to each RCP represents the radiative forcing (expressed in Watts per square metre) due to the combined effect of greenhouse gases in the year 2100 as compared to the pre-industrial levels. RCP2.6 assumes that the emissions peak around 2020, with substantial decline after that. RCP4.5 peaks around 2040, then declines. RCP6.0 peaks around 2080, then declines. RCP8.5 assumes that emissions keep rising throughout the 21st century, thus implying the lack of any mitigation strategies to curb greenhouse gas emissions. One may note that the emission peak mentioned above and the corresponding concentration peak (seen from Figure 12) do not occur at the same time due to

[4] Source: https://www.ecmwf.int/en/research/climate-reanalysis/era-interim)

the storage and subsequent release of gases like CO_2 by the land and ocean reservoirs as a part of the carbon cycle.

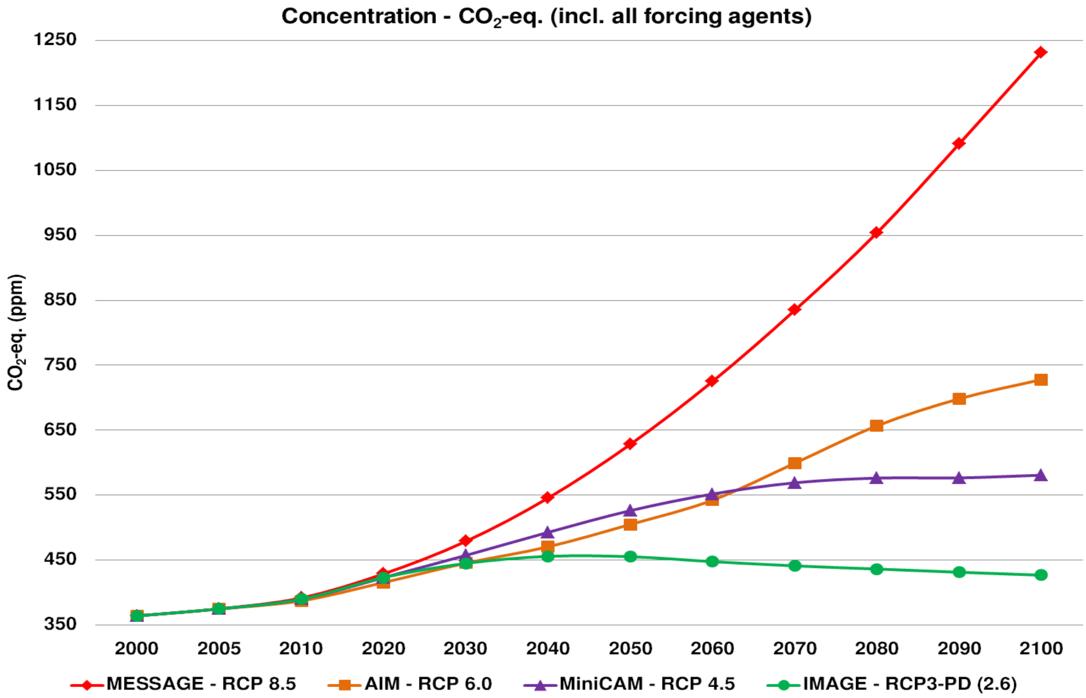

Figure 12 Atmospheric CO2-equivalent concentrations (ppmv) of all forcing agents in RCP Scenarios (IPCC AR5)

For the purpose of this report, the changes in climatic parameters – near surface air temperature and rainfall, have been considered under the RCP 8.5 scenario, where emissions keep rising throughout the 21st century. The following sections illustrate the results of an analysis of the historical trends and modelling exercise carried out for studying the impacts of climate change on the regions surrounding Gosabara wetland.

3.3 Climate change assessment, projections and vulnerability of Gosabara wetland complex

As a manifestation of climate change, different parts of the world have been warming at different rates depending on both local and remote influences. The historical temperature characteristics over Gosabara wetland region are analysed by using daily mean T2m from the ERA-I reanalysis. Firstly, the temperature dataset obtained from ERA-I is bi-linearly interpolated to a finer grid resolution of 10km x 10km. The temperature data is, then, averaged for the individual months to assess the climatological mean pattern and, subsequently, the trends have been computed and presented in the form of a monthly grid diagram for each wetland. For the presentation of trends, the boxes that have a trend significant at the 95 per cent level, are stippled. In addition to the assessment of month-wise climatology of T2m and the corresponding trends in the last few decades, projections for the next two decades (2016–36) under the RCP8.5 scenario has been made by applying a quantile-based bias correction technique to climate simulations of one of the leading IPCC climate models.

Similarly, for rainfall, the Tropical Rainfall Measuring Mission (TRMM) satellite data at a native resolution of 25km x 25km is first bi-linearly interpolated to a finer grid resolution of 10km x 10km. Similar to temperature, the rainfall is averaged for the individual months to assess the climatological mean pattern, and subsequently the trends have been computed and presented in the form of a monthly grid diagram for each wetland, with stippling representing grid boxes that have a trend significant at the 95 per cent level. Similar to temperature, rainfall projections for the next two decades (2016–36) under the RCP8.5 scenario have been made by applying a quantile-based bias correction technique to climate model simulations.

3.3.1 Temperature characteristics over the Gosabara Wetland Complex in the current climate

An analysis of the historical temperature dataset for the region, illustrated in Figure 13, shows that May and June happen to be the hottest months of the year, with highest average temperatures ranging between 31°C and 32°C. The months of December and January happen to be the coldest, with daily mean temperatures ranging between 20°C and 21°C. It is to be noted that the actual temperature over a given location may be different from that over a 10km x 10km grid box in Figure 13.

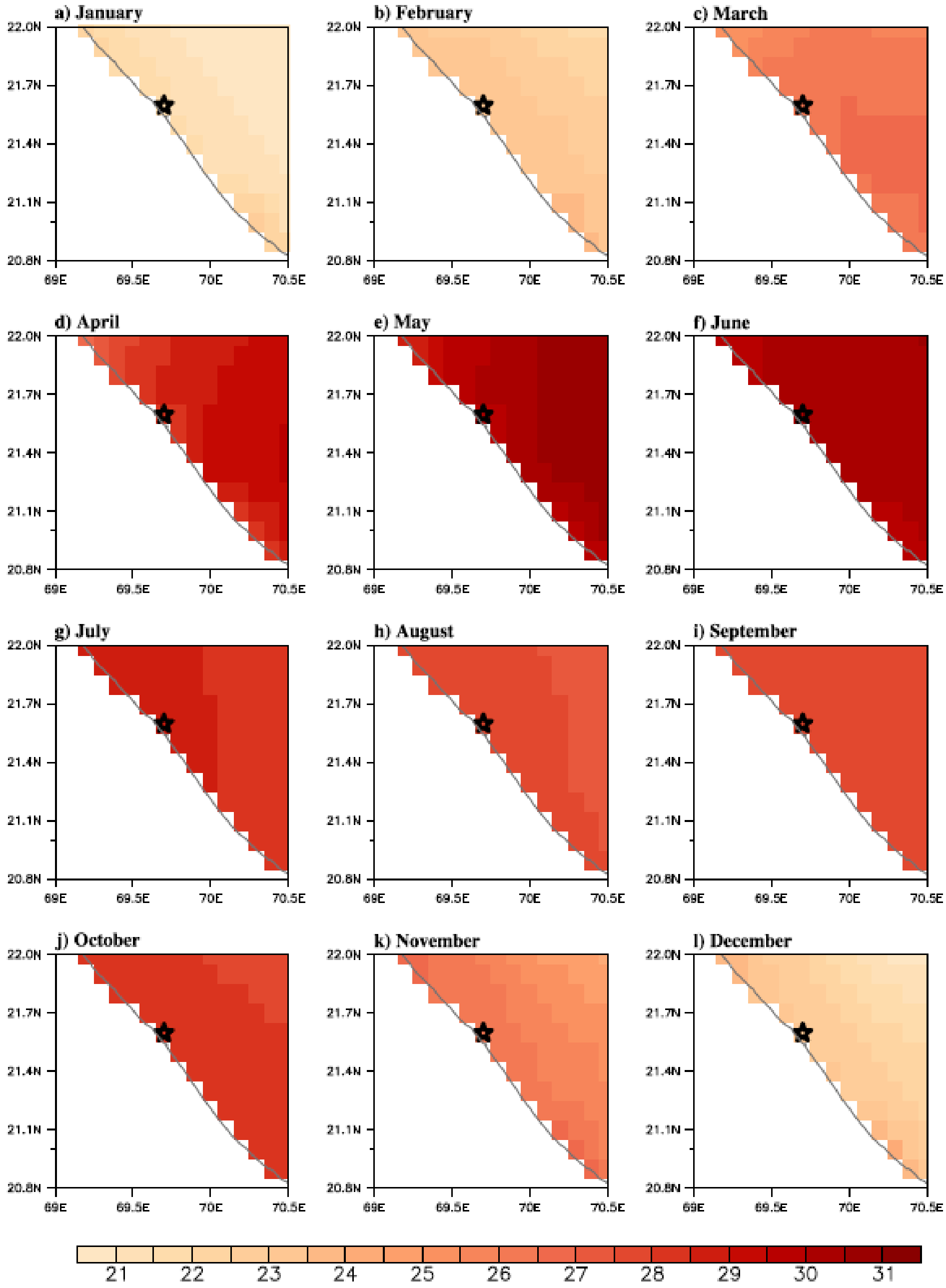

Figure 13 Climatological mean 2m air temperature (degree C) over the Gosabara wetland complex region (marked by a star) from ERA-Interim reanalysis dataset for the period 1979–2016 for individual months

The trend analysis of temperature dataset between 1979 and 2016 is illustrated in Figure 14 below. It can be seen that the highest trend in daily mean temperature occurs in the months of November and March.

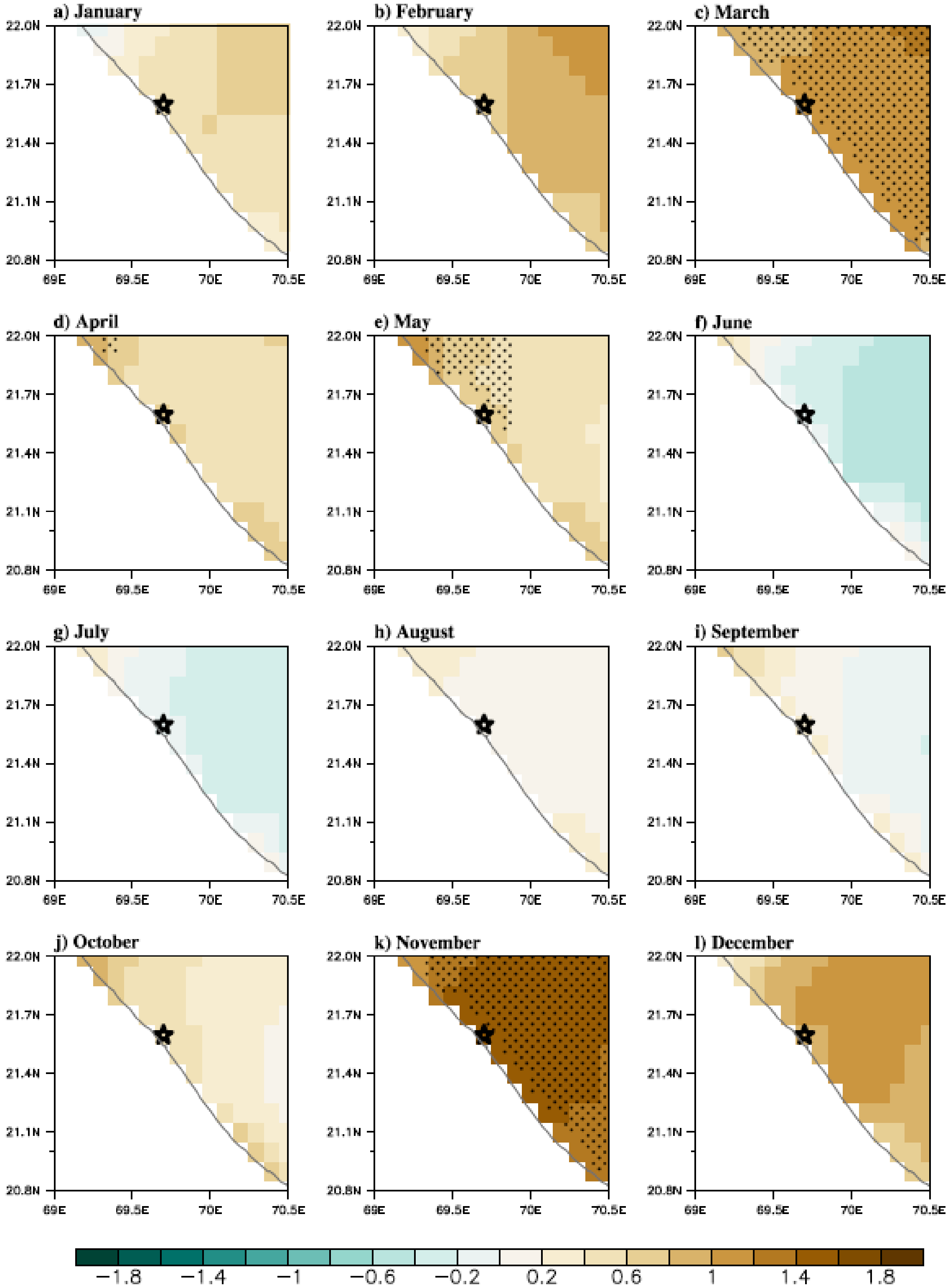

Figure 14 Observed trend in the mean 2m air temperature (degree C per 38 years) over the Gosabara wetland complex region (marked by a star) from ERA-Interim reanalysis dataset for the period 1979–2016 for individual months

3.3.2 Temperature characteristics over the Gosabara Wetland Complex under global warming

The 20-year projections for air temperature in the Gosabara wetland region are illustrated in Figure 15 below. It can be seen that a sharp increase in temperature in the range of 1ºC and 1.4ºC is projected in the months of December and March, over the next two decades.

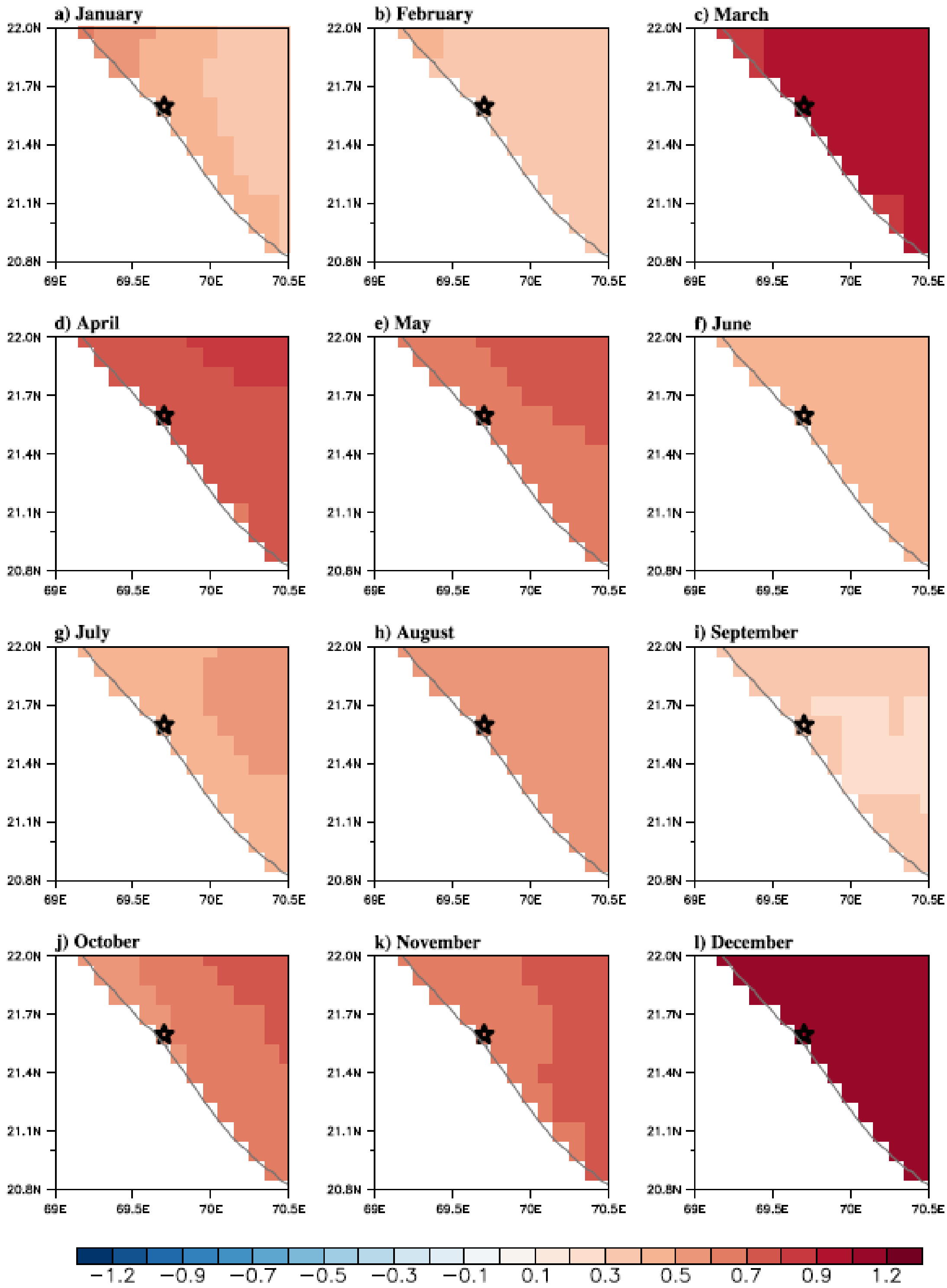

Figure 15 Projected change in 2m-air temperature over the Gosabara wetland complex region (marked by a star) under the RCP8.5 global warming scenario in the near-term (2016–36) as compared to the baseline period of 1985–2005

Apart from these two months, there is an overall steady increase in temperature across all the other months in the range of 0.2°C and 0.8°C. As temperature increases, the evapo-transpiration rate is also expected to increase, thus, expediting the process of evaporation of the available water. This is significant especially since December falls in the peak season of migratory birds visiting the wetland, and reduced water availability due to rapid evaporation can be a constraining factor to potentially affect the bird population.

3.3.3 Rainfall characteristics over the Gosabara Wetland Complex under current climate

Figure 17 illustrates an analysis of the historical rainfall data for the region between 1998 and 2014. It can be seen that July and August are the wettest months with the maximum average rainfall per day, followed by June and September.

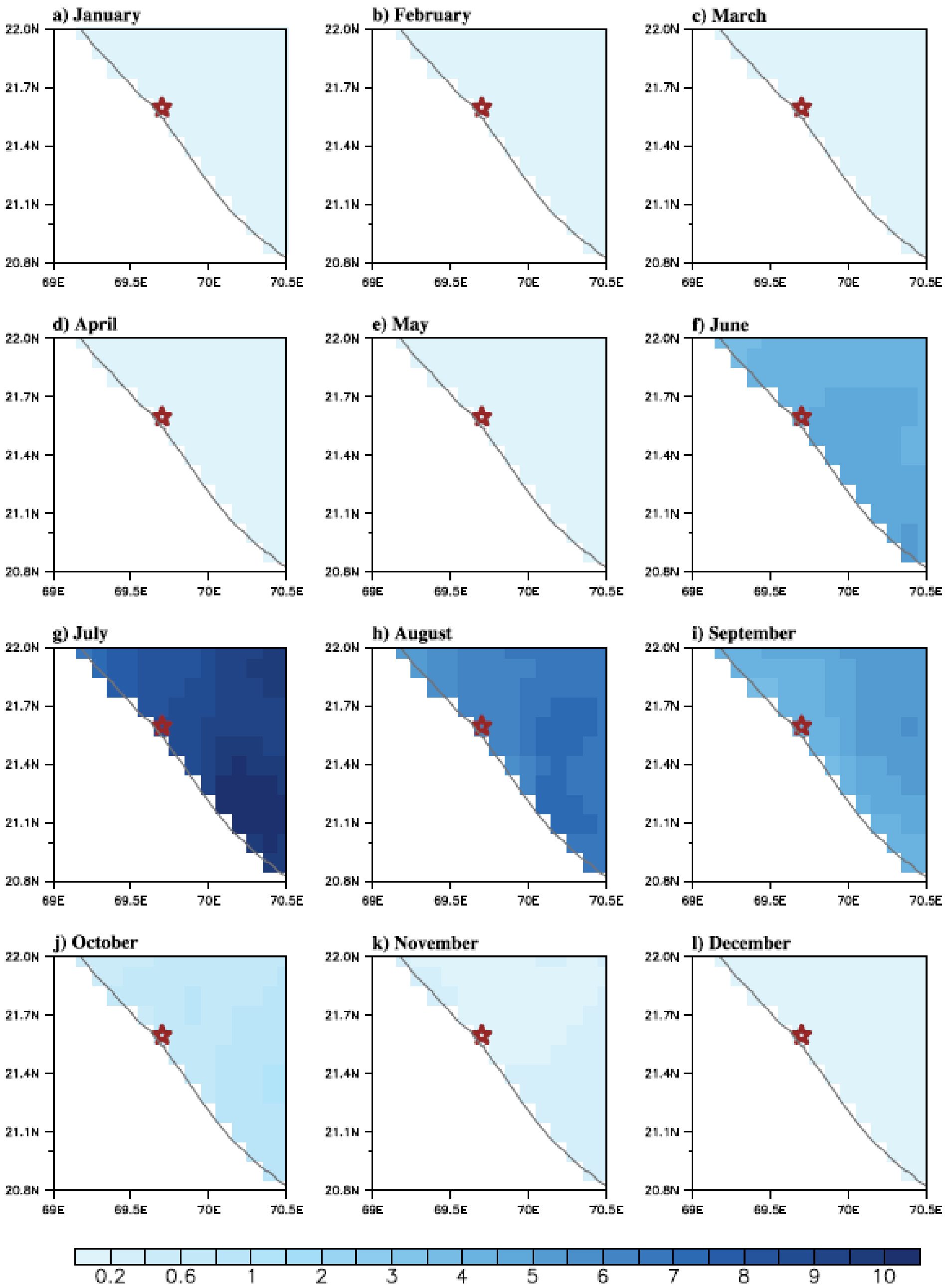

Figure 16 Climatological mean rainfall (mm/day) over the Gosabara-wetland complex region (marked by a star) from TRMM satellite retrievals for the period 1998–2014 for individual months

3.3.4 Rainfall characteristics over the Gosabara Wetland Complex under global warming

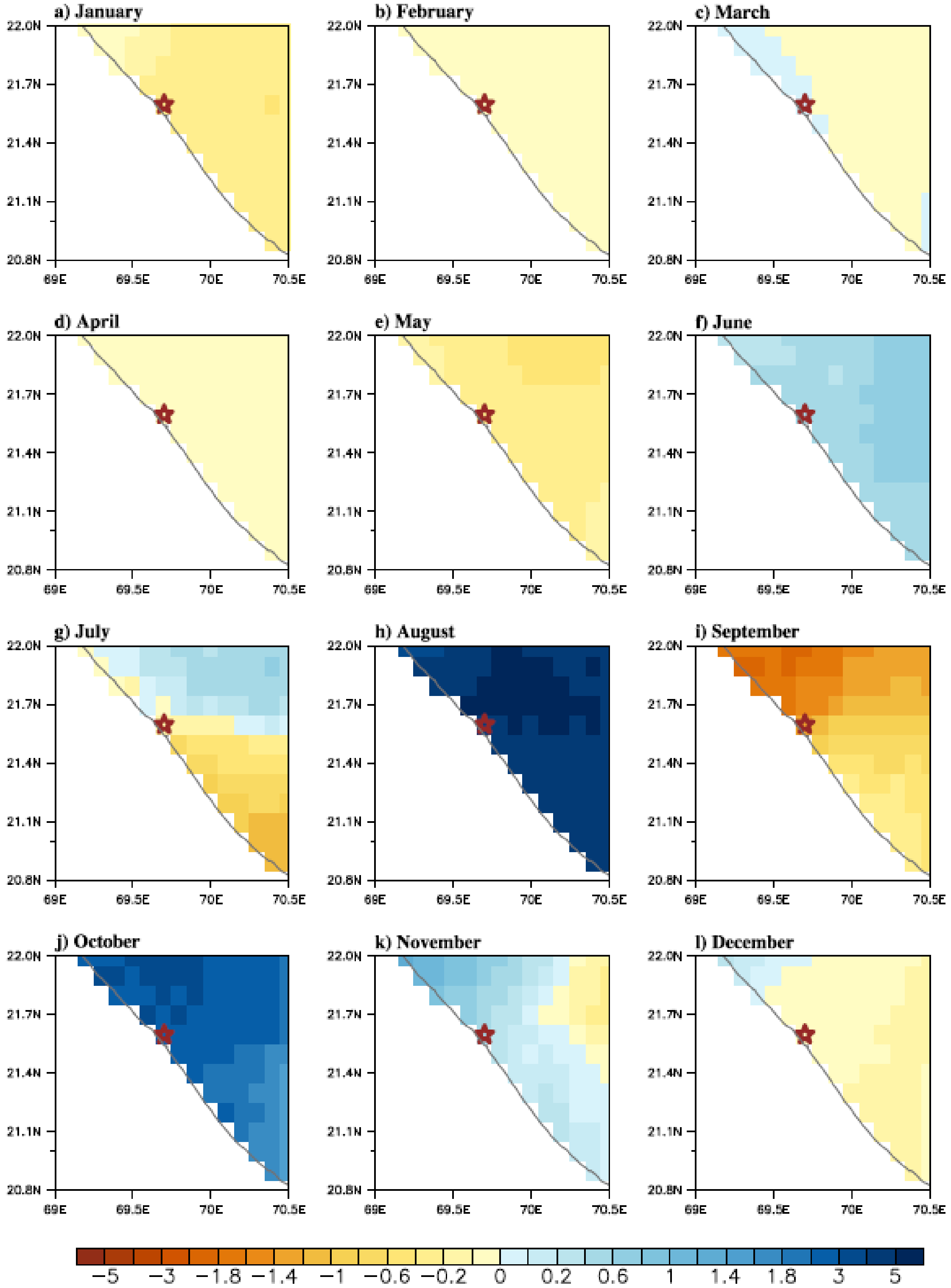

Figure 17 Projected change in rainfall over the Gosabara wetland complex region (marked by a star) under the RCP8.5 global warming scenario in the near-term (2016–36) as compared to the baseline period of 1985–2005

It is projected that rainfall is likely to increase in the month of August within the range of 0.8mm and 1.3mm per day, over the next 20 years. However, in the month of September, rainfall is likely to decrease from 0.2mm to 0.6mm per day. An increasing trend in rainfall is projected mainly for the months of June, August and October, with a decrease in average rainfall projected for rest of the months. This implies that water availability from rainfall in the next 20 years is likely to be more uneven during the monsoon season (June–September), with potentially a higher concentration of rainfall during August, and lower rainfall in July and September. This points to the need for specific adaptation measures to be put in place to ensure steady water availability, especially during the peak season for migratory birds, either through exploration of alternative sources of water, or through installation of strong water harvesting measures.

A summary of the projected monthly average changes in temperature and rainfall levels in Gosabara wetland and its catchment is provided below in Tables 9 and 10 respectively.

Month	Change in temperature (ºC)	Change in rainfall (mm/month)
January	0.45	-7.98
February	0.37	-0.01
March	0.91	0.00
April	0.74	-0.12
May	0.67	-9.62
June	0.46	14.91
July	0.48	-10.62
August	0.56	148.61
September	0.31	-29.48
October	0.61	80.62
November	0.68	7.68
December	1.09	-1.75

Table 9 Projected temperature and rainfall changes in Gosabara wetland, 2016–36

Month	Change in temperature (ºC)	Change in rainfall (mm/month)
January	0.45	-7.09
February	0.37	-0.01
March	0.92	-0.40
April	0.76	-0.25
May	0.69	-10.50
June	0.46	138.93
July	0.48	1.80
August	0.55	151.59
September	0.32	-41.40
October	0.63	87.99
November	0.68	13.52
December	1.10	-1.18

Table 10 Projected temperature and rainfall changes in Gosabara catchment, 2016–36

3.3.5 Sea level rise projections for the coastlines neigbouring Gosabara wetland complex

Given that the geographical location of the Gosabara wetland complex is vulnerable to sea level changes, we assessed the observed and projected changes in sea level over the region, and discussed the associated vulnerabilities. The observed and projected sea level rise (SLR) is in the context of observed and projected global warming and associated climate change. The primary factors governing

SLR over a region include: (1) thermal expansion associated with increase in temperature of the ocean (known as thermosteric effect), (2) salinity change (halosteric effect), (3) melting of sea ice, (4) changes in the amount of water mass exchange between the oceans and terrestrial water storage (rivers, lakes, ice sheets, glaciers, etc.), and (5) sediment deposition along the coasts.

Coastal inundation is one of the major impacts due to SLR. This process leads to a shift in the coastline inland due to the increase in sea level, and thus may lead to loss in wetland area, if the shift is sufficiently large. An increase in sea level also potentially affects the freshwater availability by contaminating the reservoirs. Not to mention, a cyclone of high intensity would lead to greater storm surges when combined with SLR.

The third assessment report of the IPCC reported an SLR trend ranging between 1.0mm and 2.0mm per year, depending on the region. The fourth assessment report estimated the global mean SLR trend to be about 1.8mm per year for the period 1961–2003, whereas the fifth report (AR5) estimated the global mean SLR trend to be about 1.7mm per year for the period 1901–2010. The primary mechanisms of estimating the observed sea level changes are: (1) tide gauges, and (2) satellite altimeters. In the vicinity of Gosbara wetland, the Mumbai coastal station is known to have a long enough timeseries of tide gauge observations. Given the unavailability of sea level data over the coastline adjoining Gosabara wetland, the sea level timeseries available for the Mumbai coast is used as a proxy for estimating the corresponding SLR over the wetland's coastline. Unnikrishnan et al. (2015) obtained the net SLR trends estimated from tide gauge records as shown in the table below.

Station	Period of analysis	Number of years of data availability	Trends in relative sea level rise (mm per year)	GIA correction (mm per year)	Net sea level rise trend (mm per year)
Mumbai	1878–1993	113	0.77 + 0.08	-0.31	1.08
Kochi	1939–2007	56	1.45 + 0.22	-0.36	1.81
Visakhapatnam	1937–2000	53	0.69 + 0.28	-0.24	0.93
Diamond Harbour (Kolkata)	1948–2010	61	4.61 + 0.37	-0.35	4.96

Table 11 Historical SLR trends over Mumbai, Kochi, Visakhapatnam and Diamond Harbour

As can be seen from the table above, two trends have been reported — one is the uncorrected trend (trends in relative SLR), and the other is the corrected trend (net SLR). The data correction includes the impact of glacial isostatic adjustment (GIA) on the relative SLR to estimate the net SLR. It can be seen from the table that the net SLR has been reported as 1.08mm yr^{-1}, 1.81 mm yr^{-1}, 0.93 mm yr^{-1}, and 4.96 mm yr^{-1}, over Mumbai, Kochi, Visakhapatnam and Kolkata, respectively. The large trend at Diamond Harbour (Kolkata) can be attributed to subsidence in the deltaic region.

In a study by Unnikrishnan et al. (2015), satellite altimeter data was used for the period 1993–2012 and found that the SLR trends in the northern part of the Indian Ocean during the above period have been higher than that observed during the most part of the 20th century. Since the difference in trends could also be due to the fact that the previous trends computed for the 20th century were from tide gauge data whereas the trends for 1993–2012 were computed from satellite data, the authors computed the SLR over Kochi for the period 1992–2007 using tide gauge data and found that the trend was around 3.7mm yr^{-1} as opposed to 1.45mm yr^{-1} for the entire available period. This confirmed that the accelerated trend was not an artefact of different sources of data. As emphasised by the authors, a similar acceleration in SLR is also reported at global scale in the AR5 Summary for Policymakers (SPM). The SPM reports a global mean SLR of 1.7mm yr^{-1} for the period 1901–2010, whereas the trend for the period 1993–2010 is 3.2mm yr^{-1}.

Since the estimated trends in SLR for Mumbai would be most suitable for estimating trends over the coast near Gosabara wetland area, the range of trend of Mumabi of 2.43–3.69mm yr^{-1} {as reported in Unnikrishnan et al. (2015)} has been used to project the SLR and corresponding shifts in the coastline over the wetlands, as shown in Table 12 below. In another recent study by Nayak et al. (2013), the estimated trends in SLR available have been used to estimate the corresponding shifts in the coastline over Mumbai, Kochi, Chennai and Visakhapatnam. A SLR trend of 1.2mm yr^{-1} over Mumbai for the 20th century has been considered, and the shift in the coastline along the representative station has been estimated to be about 4m during the 20th century. Using these estimates and some simplifying assumptions, it can be concluded that an approximate increase of 120mm of sea level would lead to a shift in the coastline by about 4m. Using these numbers as representative of the coast near Gosabara wetland, and some simplifying assumptions, a coastline shift in the range of 1.21–3.69m can be projected by 2035, with a base period of 1985–2005, as shown in the table below.

Year	Projected sea level rise (mm)	Projected coastline shift inland (m)
2020	36.45–55.35	1.21–1.84
2025	48.6–73.8	1.62–2.4
2030	60.75–92.25	2.02–3.07
2035	72.9–110.7	2.43–3.69 m

Table 12 Sea level rise projections near Gosabara wetlands, 2020–35

Table 12 shows that the sea level near the coasts adjoining Gosabara wetland is projected to increase in the range of 36.45–55.35mm by 2020, 48.6–73.8mm by 2025, 60.75–92.25mm by 2030, and by 72.9–110.7mm by 2035, as compared to the based period of 1985–2005. The corresponding inland shifts in the coastline due to sea level rise are estimated to be in the range of 1.21–1.84m by 2020, 1.62–2.46m by 2025, 2.02–3.07m by 2030, and 2.43–3.69m by 2035, as compared to the based period of 1985–2005.

Additionally, the Gujarat State Action Plan on Climate Change (2014) also provides an estimate of the loss in wetland area in Gujarat, which is expected to have been caused by a potential sea level rise of 0.1–0.5m, resulting in the wetland losing between 2,508.3km^2 and 12,541.5km^2 of area.

Sea level rise (m)	0.1	0.2	0.3	0.4	0.5
Estimated loss in wetland cover (km^2)	2,508.3	5,016.6	7,524.9	10,033.2	12,541.5

Table 13 Sea level rise and estimated losses in wetland cover in Gujarat

This clearly demonstrates that sea level rise due to climate change can inundate a large part of a wetland or even lead to submergence of some wetlands, depending on the pace of climate change and consequent sea level rise.

3.4 Impacts of climate change on hydrology of Gosabara wetland complex

The climate change scenarios for Indian conditions have been discussed in above sections and provided projections of daily precipitation and daily mean temperatures for Gosabara wetland for a period of 20 years (2016–36). An analysis of historical ERA–Interim reanalysis dataset for temperature from 1979–2016 for the wetland shows that May and June are the hottest months in the year with an average monthly temperature ranging between 31°C and 32°C, followed by April and July with an average monthly temperature ranging between 29°C and 30°C. However, there is no significant change observed in the rainfall pattern during 1979–2016. The water balance components of the wetland indicate that the rainfall which is falling on wetland area is enough to fill the wetland capacity of about 80 per cent in the dry year (2014–15) and rest of the capacity gets filled from run-off from the catchment. Therefore, further analyses have been carried out on temperature alone in both wetlands. The temperature increase is expected to have a significant impact on several components of the hydrologic cycle. As per WMO/ICSU/UNEP (1989) report, evapotranspiration is expected to elevate globally by 10–20 per cent. However, a number of studies have also indicated decrease in evaporation for many regions in India and the world due to rise in temperature (Peterson et al., 1995; Liu et al., 2004; Roderick and Farquhar, 2004; Verma et al., 2008; Jaswal et al., 2008). This decrease in evaporation has been attributed to the change in vapour pressure regime.

The 20-year (2016–36) projected change (compared to the baseline period of 1985–2005) in air temperature is seen that a sharp increase in temperature within the range of 1°C and 1.5°C is projected in the months of March and December. It can also be seen that the temperature levels across the region are projected to increase across most months within the range of 0.2°C and 0.8°C throughout the year. This implies that an overall increase in temperature is projected for Gosabara wetland complex region for the next two decades. As temperature increases, the evapotranspiration / evaporation rate is also expected to increase. This is significant especially since December is the peak season of migratory birds visiting the wetland, and reduced water availability due to rapid evaporation can be a limiting factor, affecting their breeding and, subsequently, the bird population.

Rainfall analysis of Gosabara wetland

Figure 18 shows the projected rainfall data for the 20-year period (2016–36) for Gosabara wetland, showing clearly the increasing trend in the annual rainfall at Gosabara wetland catchment.

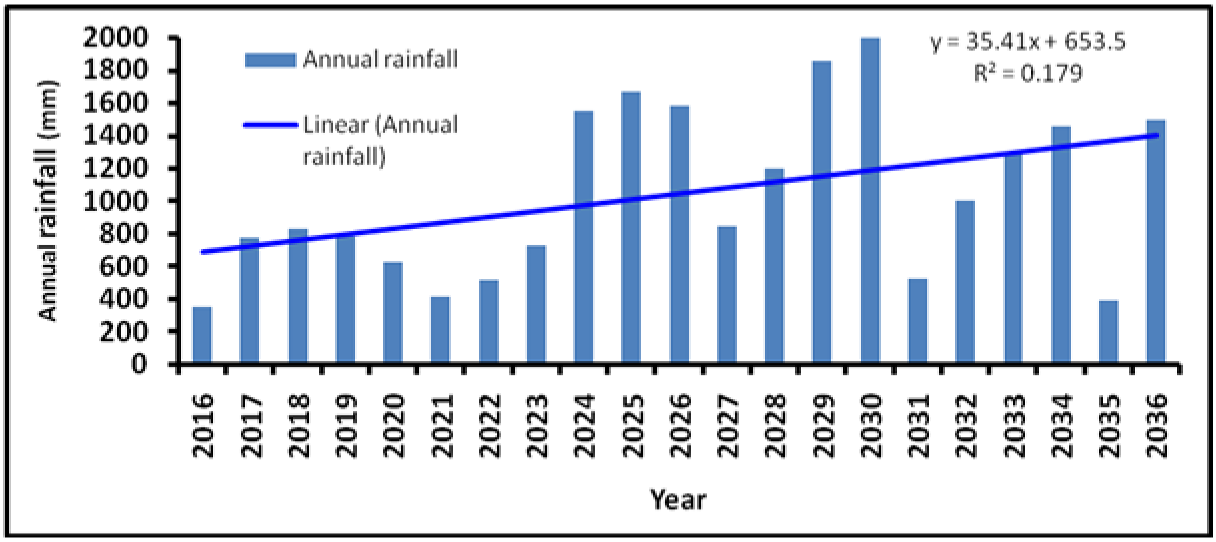

Figure 18 Projected annual rainfall of Gosabara wetland for 2016–36

Gosabara wetland received 494mm rainfall during the dry water year (from June 2004 to May 2005), which was earlier considered for hydrological analysis. In comparison, the data of projected rainfall for the 20-year period indicates that the rainfall could be less than this in a couple of years, with lowest rainfall being projected for the water year 2035–36 with a rainfall of 364.8mm. Therefore, detailed water balance would be computed after considering the climate parameters.

Temperature analysis of Gosabara wetland

It was learnt that the mean temperature in the region surrounding Gosabara wetland area is likely to be higher in the next two decades as compared with that of the present temperatures. Therefore, it is important to know its significance for the wetland hydrology. The observed daily mean maximum, minimum and average temperatures during the period of six years from 2011 to 2016 are 35.1°C, 13.2°C and 26.5°C, respectively. The projected mean daily temperature data for Gosabara wetland for the 20-year period is available and is shown in Figure 19. The projected daily mean maximum, minimum and average temperatures during 2016–36 are 36°C, 14.5°C and 27.2°C, respectively. Therefore, we can say that the average temperatures over the next two decades shall be more than the historical data sets as analysed above (1985–2005 and 2011–16).

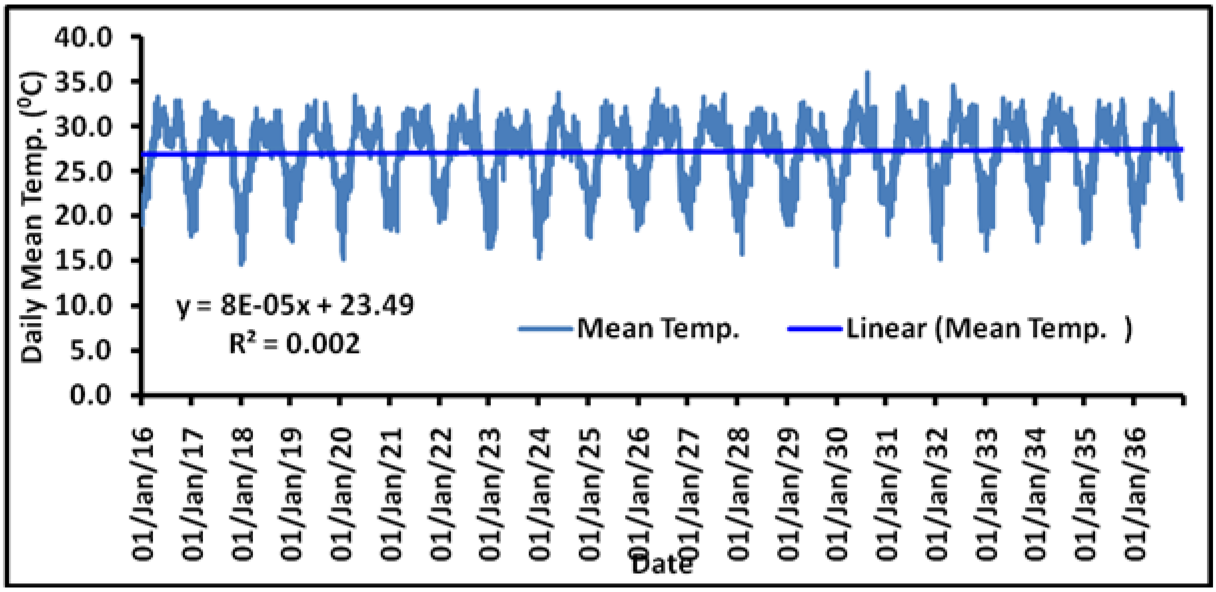

Figure 19 Projected temperature of Gosabara wetland for 2016–36

Effect of temperature change on evaporation of Gosabara wetland

Temperature is often thought to be the only important factor affecting evaporation. However, this is not true. Although temperature is linearly correlated with evaporation and is one of the most important factors determining evaporation, there are many other factors which determine the rate of evaporation from a water body. These include factors such as radiation, humidity and wind. However, temperature is still considered one of the most significant factors. Temperature determines the vapour pressure deficit (VPD) by determining the vapour pressures of air and water. Actual vapour pressure of air, which denotes the partial pressure exerted by water vapour present in air, is a function of temperature and humidity together, the maximum vapour pressure that is thermodynamically stable is called the saturation vapour pressure and is a function of temperature only (Dingman, 1994); it increases with increase in temperature. The slope of the curve of the saturation vapour pressure, which is one of the parameters in many evaporation models, depends solely on temperature. The latent heat of vaporisation also depends on temperature, although it varies little even with larger variations in temperatures. There are other factors which are indirectly dependent on temperature, for example, net long-waver radiation. Apart from temperature factors, humidity and wind are also important for evaporation. Higher the wind velocity, higher will be the rate of evaporation. However, there is an upper bound called critical velocity, beyond which any increase in wind speed does not change the evaporation rate (Reddy, 1997). Other factors influencing evaporation include atmospheric pressure, sunshine hours, water quality and geometry of a water body.

Thus, it is clear from the above description that analysis of the impact of temperature rise or climate change on evaporation needs a detailed data on various parameters, including wind and humidity data. However, since the projected data of these parameters are not available with the investigators (and generally not provided by any climate models), an attempt has been made to analyse the impact of temperature on evaporation using evaporation model which uses only the temperature data. For this purpose the Thornthwaite model has been used as it uses only mean temperature and daylight hours as inputs. However, it may be noted that more realistic estimation of evaporation is obtained by models that use as many parameters affecting the process of evaporation. That is why Penman–Monteith model is considered as the standard model for estimating evaporation. This model was used in the water balance model reported in the earlier section. However, the same model cannot be used for projected data, relying on temperature data alone. So, to make the analysis reasonable, the estimation obtained with Penman–Monteith model has been considered as the actual evaporation and the Thornthwaite (1948) model has been calibrated using this actual evaporation data for the daily data of the period 2011–16. This calibrated Thornthwaite model has then been used subsequently to analyse the possible impact of projected temperature on evaporation from Gosabara wetland. Evaporation estimation has been obtained by the Thornthwaite model for the present (recent period) of 2011–16 and also for the projected period of 2016–36, and the results have been compared.

Present versus projected evaporation in Gosabara wetland

The first necessary to see how close are the projected data with the observed data. Fortunately, for the investigators, projected temperature data was available for the period of 2016–36 and at the same time, observed temperature data was also available for the year 2016. Hence, first the observed data for the year 2016 has been compared with the projected temperature data, as shown in Figure 20 below. It can be seen that the projected temperature data more or less matches with the observed data with a small degree of error. The average error for the projected data is 3.14 per cent.

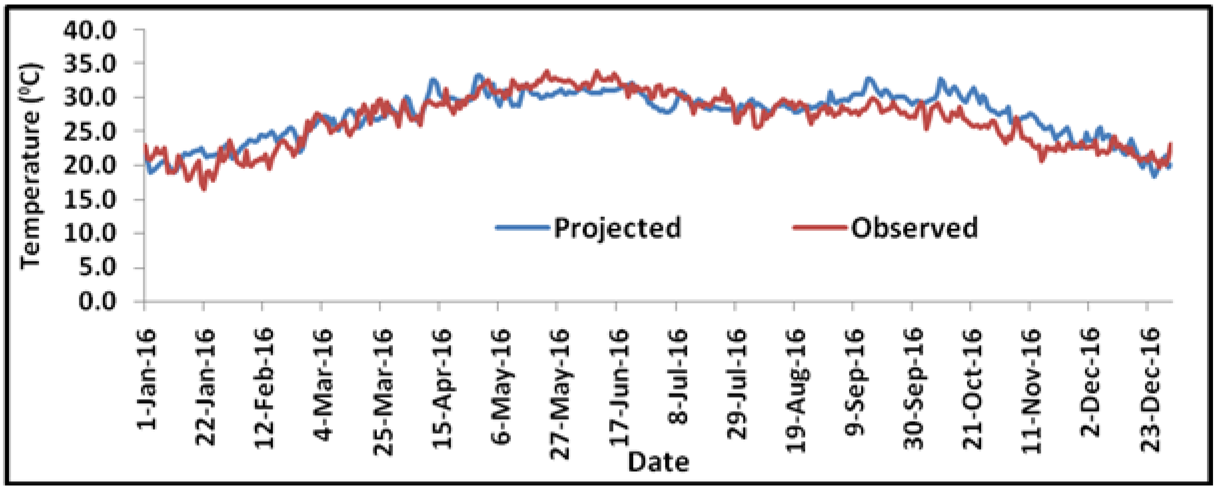

Figure 20 Observed versus projected mean temperature data for year 2016

However, since we are interested in finding out the percentage change in evaporation in future over the present scenario, we use projected data of 2016 (obtained using the projected temperature of 2016) as base data, and compared with the future estimates obtained using the projected temperature data; the comparison would be reasonable, because errors of GCM or RCM model, if any, shall be the same for year 2016 and future years as well. Therefore, for the purpose of evaporation, estimates obtained by using projected temperature data of 2016, has been considered as base data and the evaporation estimates obtained using the projected temperature data for the years 2020, 2025 and 2035 have been compared with the estimates of 2016 to estimate change in evaporation over the period 2016–35. The evaporation estimates obtained by the calibrated Thornthwaite model using base year data of 2016 and projected temperature data for the year 2020, 2025 and 2035, are shown in Figures 21, 22 and 23, respectively. It can be seen from Figure 21 to 23 that there is a likely change in the evaporation regime of the wetland in the future. There are some specific periods where evaporation appears to be marginally increasing. But this variation could be due to the daily variation in the temperature data. In general, no increasing trend of evaporation is observed for Gosabara wetland area in specific months or specific seasons. On the other hand, evaporation appears to be decreasing for the area during many times of the years.

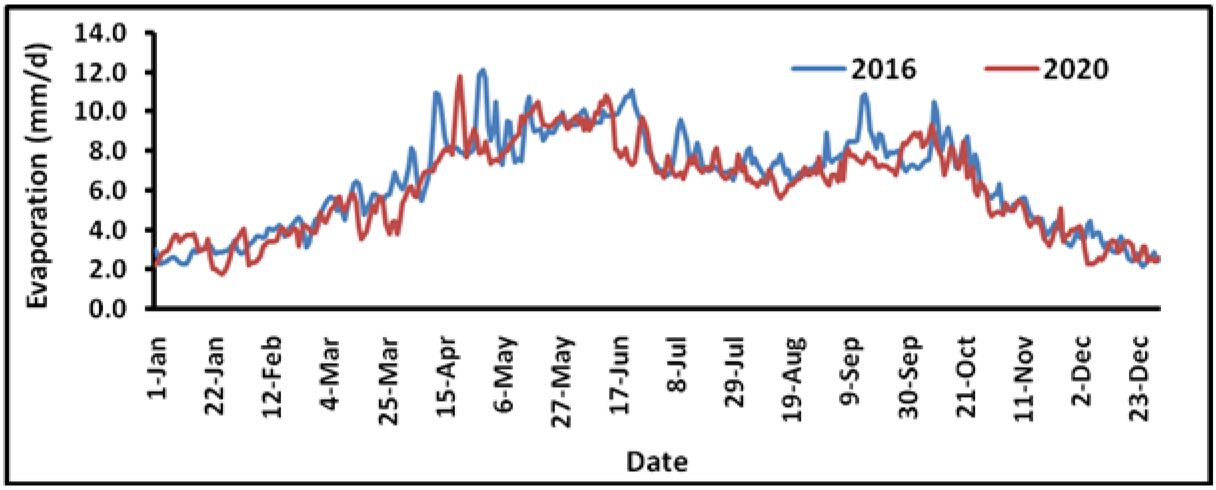

Figure 21 Comparison of projected evaporation rates of 2020 with the evaporation rates of 2016 for Gosabara wetland

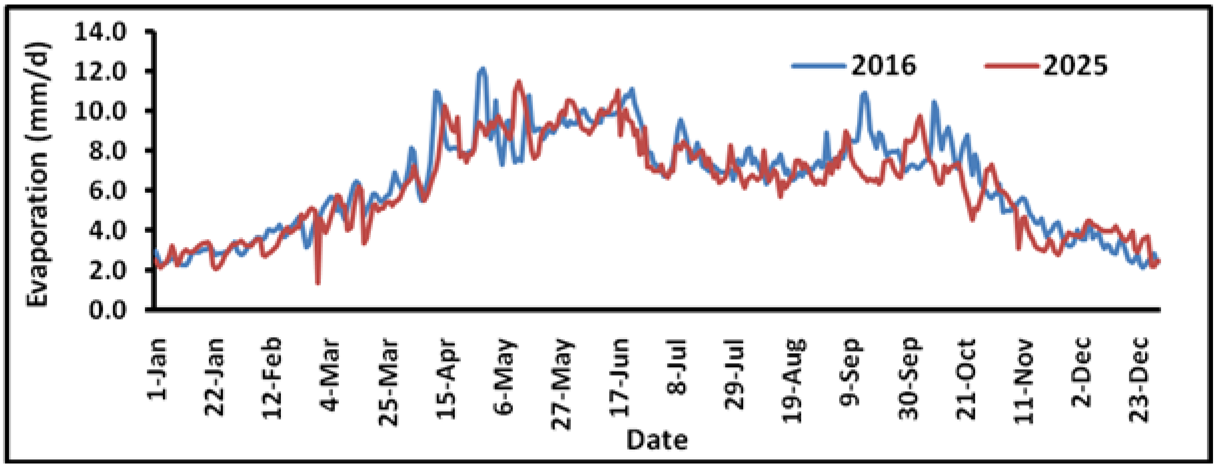

Figure 22 Comparison of projected evaporation rates of 2025 with the evaporation rates of 2016 for Gosabara wetland

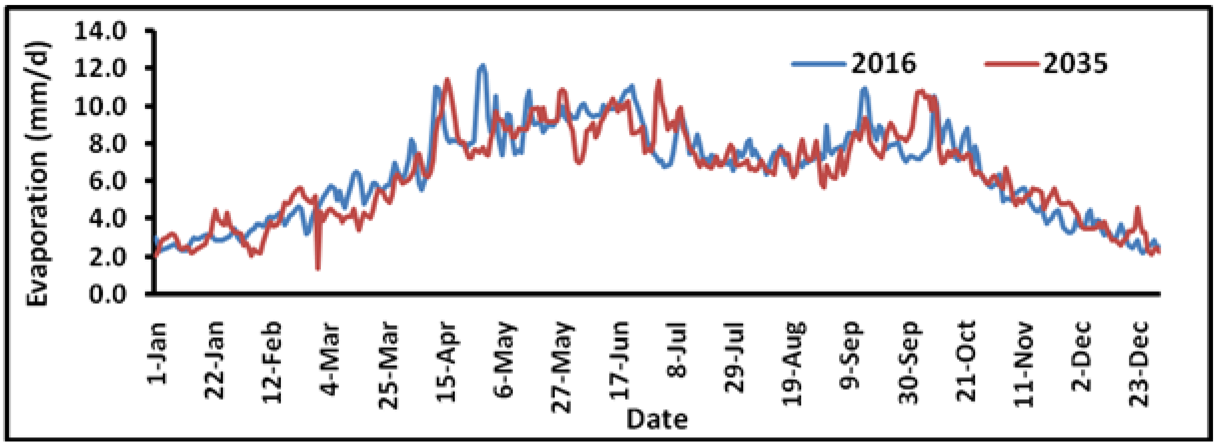

Figure 23 Comparison of projected evaporation rates of 2035 with the evaporation rates of 2016 for Gosabara wetland

Decreasing characteristics of evaporation are further illustrated in Table 14, which shows projected change in evaporation rates for different projected years in relation to the base year 2016. It can be observed that while the mean evaporation rate (taken as mean of daily evaporation rates of 365 or 366 days) is 6.5mm/day for the base year 2016, it is relatively lower for the years 2020, 2025 and 2035. However, there appears to be an increase in the projected evaporation rate from 2020 to 2025, yet it is less than the evaporation rate of 2016. The average change in evaporation appears to be increasing from 2020 to 2035 while the absolute change in evaporation is changing only marginally.

Year	Average evaporation (mm/d)	Average projected change in evaporation (%)	Average absolute change in evaporation (%)
2016 (base year)	6.5		
2020	6.1	-4.0	14.0
2025	6.2	-2.44	13.9
2035	6.4	0.81	15.4

Table 14 Expected evaporation characteristics of different projected years

Table 15 presents the month-wise expected average change in evaporation for different projected years. Negative sign indicates decrease in evaporation and positive sign indicates the increase. It can be seen from the Table 15 that for the winter months of December and January an increase is projected during all three years. During summer, while decrease is projected for the months of March and April, May is showing an increase. The monsoon months from June to September, in general, show decrease in evaporation, except for July 2035. The months of February and October do not show any specific trend.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2016	22.2	-7.51	-17.09	-4.76	0.98	-6.62	-4.23	-9.45	-13.42	-1.18	-2.66	0.98
2020	3.28	2.4	-13.54	-6.04	7.65	-4.45	-0.95	-7.01	-14.48	-6.59	-12.21	37.99
2035	19.17	4.26	-23.1	-3.56	3.22	-10.27	10.49	-3.55	-7.26	7.02	26.73	16.05
Average	14.88	-0.28	-17.91	-4.79	3.95	-7.11	1.77	-6.67	-11.72	-0.25	3.95	18.34

Table 15 Month-wise expected average change in evaporation for different projected years

The above percentage changes have been applied to the evaporation estimates used in the earlier analysis of water balance to understand the possible impact of evaporation on hydrology of the wetland.

Impact analysis for Gosabara wetland

The detailed analysis of rainfall and run-off into Gosabara wetland, as indicated in Table 16, shows that the total water to be received between June 2035 and May 2036 is 171.65Mcum, out of which total water to be received during the monsoon (June–September 2036) is 167.14Mcum and rest during March 2036.

Month	Rainfall (mm)	Total magnitude of water generated in the catchment (m^3)	Inflow due to run-off from catchment (30% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)	Total inflow to wetland (Mcum)
	(a)	(b)	(c)	(d)	(e)	
Jun, 2035	119.8	142,801,600	42,840,480	13,530,212	56,370,692	56.37
Jul, 2035	212.4	253,180,800	75,954,240	23,988,456	99,942,696	99.94

Month	Rainfall (mm)	Total magnitude of water generated in the catchment (m^3)	Inflow due to run-off from catchment (30% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)	Total inflow to wetland (Mcum)
Aug, 2035	21.1	25,151,200	7,545,360	2,383,034	9,928,394	9.93
Sep, 2035	1.9	2,264,800	679,440	214,586	894,026	0.89
Oct, 2035	0	0	0	0	0	0.00
Nov, 2035	0	0	0	0	0	0.00
Dec, 2035	0	0	0	0	0	0.00
Jan, 2036	0	0	0	0	0	0.00
Feb, 2036	0	0	0	0	0	0.00
Mar, 2036	9.6	11,443,200	3,432,960	1,084,224	4,517,184	4.52
Apr, 2036	0	0	0	0	0	0.00
May, 2036	0	0	0	0	0	0.00

Table 16 Inflow parameters for Gosabara wetland under most deficit rainfall conditions during 2016-36

The estimated storage capacity of the wetland is less than 10Mcum. Therefore, after filling the storage capacity, the rest of the water shall go as overflow. By the end of monsoon, the capacity of the wetland shall be more or less filled. Since the expected percentage change in evaporation rate during 2016–36 is likely to be about less than 1 per cent, the average evaporation shall be more or less the same as it is today. This means that no additional water is required for managing the water scarcity challenges of the Gosabara wetlands for the next 20 years, other than the requirement already specified under the water management plan discussed in Section 2.6.

3.5 Impacts of climate change on biodiversity of Gosabara wetland complex

Drops in lake levels, earlier spring run-off, larger floods and hotter summers are likely to have adverse impacts to wetlands and the species that depend on them. Wetlands may disappear from this landscape or be altered and degraded by increased erosion from storm events, alterations in plant and wildlife composition through appearance of invasive species and human actions. These changes in biodiversity and wetland structure could lead to a reduction in services provided by wetlands, mainly that of providing breeding habitats for birds and amphibians (Michener et. al.1997; Davis et. al. 2017).

Wetland species likely to be most at risk are those that are already identified as rare or endangered on international, national or state lists. These wetland species are generally dependent on a special set of habitat requirements that are already rare. Climate change, specifically higher temperatures, and severe floods and droughts are likely to stress and disrupt those special environmental conditions; further, many plants and animals have limited mobility and would not be able to migrate to new areas where appropriate conditions may exist. It is also likely that these changes will threaten populations of plants and animals that are currently common, but also unable to adapt to changing environmental conditions.

Direct impact on birds

Several studies have confirmed that climate change has affected the breeding phenology of birds. This has been observed specifically with regard to climatic warming and range changes. With increasing temperatures, several bird species of North America and Europe were noted to have gradually shifted their breeding season to a date earlier than previous recorded dates (Visser et al, 1998; Dunn & Winkler, 1999; Marra et. al. 2005). Studies have also observed the relationship between spring temperature and egg laying dates of several birds, and the relationship between spring temperatures and leafing dates of several deciduous trees (Wolkovich et. al. 2012), abundance dates of butterflies (Roy et. al. 2001) and spawning dates of amphibians (Walther et. al. 2002). These organisms are consumed by various species of birds around the world. While resident bird species would be able to adapt to their changing habitat, migratory birds would not. Studies have shown that while the phenology of their breeding grounds advance, the migration time of these birds will not advance as these are not triggered by the temperature of said grounds (Both and Visser, 2001; Sanz et. al. 2003). Thus, they will miss the opportunity to optimally exploit the habitat and face increasing competition from the resident birds who by then would be greater in number (Berthold, 1991).

Thus, in case of birds in Gosabara wetland, it may be possible for resident birds, such as the Near Threatened Black headed Ibis and Black Necked Stork, to adapt to the increasing temperatures. Migratory birds, such as the Vulnerable Dalmatian Pelican and Near Threatened Eurasian Curlew, on the other hand, may not get ample time to adapt to these temperature changes, and thus, given the lack of a favourable ecosystem for breeding, a steady fall in the population of such species can take place.

In addition to these direct impacts on birds, there are several indirect impacts as well in terms of their available food support system in the wetlands, which would also get significantly impacted. Since a proper channel of food web is a crucial factor in determining the suitability of an ecosystem for birds, any changes in the food web would affect the bird population, especially the migratory bird population, as they are not isolated due to the location of wetlands. These impacts are described in the following sub-sections.

Food support system for birds in wetlands

Within any biological ecosystem, there are complex interlinkages between the networks of organisms that are dependent on the next as a source of food. This network of trophic interactions is represented as a food web (Polis and Strong, 1996; Dunne et. al. 2002). Thus, the three major aspects of a food web are the nutrients, the organisms and detritus or biological waste.

Due to the fluctuations of hydrology in this ecosystem, wetlands have their own unique food web. They consist of isolated populations of primary producers like algae, aquatic and terrestrial plants (Brock and Jarman 2000). These are then consumed by a variety of insects, crustaceans, fish and birds. As these organisms have interlinking relationships, piscivorous and carnivorous birds and mammals alike make up the top tiers of the wetland food web.

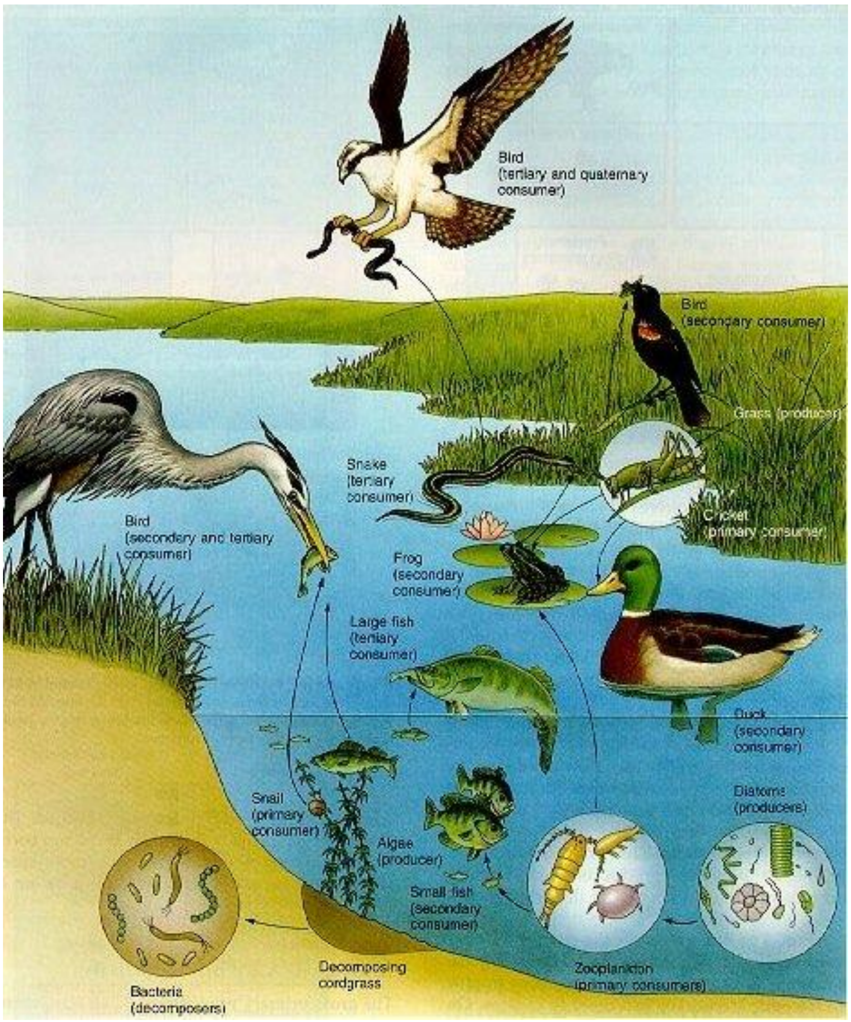

Figure 24 Illustration of a typical wetland food web. It consists of detritus (the decomposing cordgrass), nutrients produced by primary producers (algae, codgrass, diatoms) and a range of consumers (zooplankton, cricket, fish, frog, snake and birds)

Impacts on insects

Insects are a profoundly diverse taxonomic group and possess a wide range of ecologically and biologically pivotal roles that include pollinators, decomposers, prey and parasites (Kremen et. al. 2007; Wilson and Maclean, 2011). They are also extremely sensitive to climate change, as not only do they rely on external environmental temperatures for thermoregulation and have short life cycles, but also have immensely diverse population size that are spatially and temporally distributed (Bale et. al. 2002; Wilson and Maclean, 2011).

As such, studies have shown insects to have clear ecological responses to climate change. A study by Thomas et. al. (2004), renowned for perceiving climate change as the greatest threat to biodiversity, estimated that a total of 1,103 species of butterflies across Mexico, South Africa and Australia would be at risk of extinction due to climate change. With increasing temperatures, butterflies and moth (Order Lepidoptera) distributions were observed to have shifted towards the poles (Parmesan et. al. 1999) and their phenology shifted to earlier periods of spring (Stefanescu et. al. 2003). Increasing temperatures during spring could prompt caterpillars to emerge earlier than in prior seasons (Visser and Holleman, 2001) and shorten development periods (Buse et. al. 1999), a trend seen in other insect orders (Hickling et. al. 2006; Gordo and Sanz 2006).

This is predicted to affect the birds as their breeding season is tuned to both temperature and food availability, i.e., insect availability (Jian-bin, 2006). Therefore, in Gosabara wetland complex, water birds such as the Common and Demoiselle Crane and the majority of terrestrial birds (Figure 25) such as the Rosy Starling and Red vented Bulbul may be directly affected by such ecological responses of their prey.

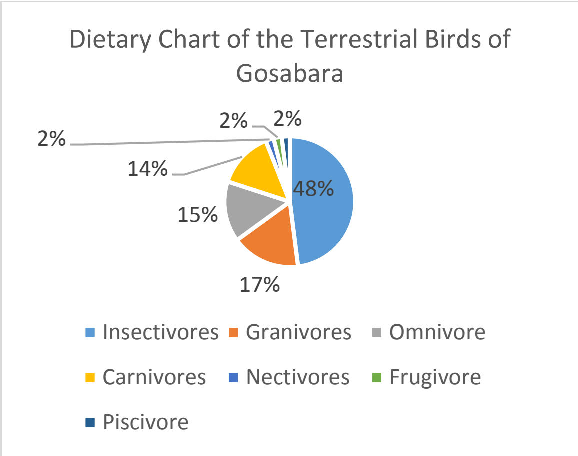

Figure 25 Dietary behaviours of the terrestrial birds in Gosabara wetland. It is to be noted that insectivores make up about half of the terrestrial bird population in the wetland. Source: Interim Report on Faunal Biodiversity Assessment, July 2016

Impacts on fisheries

Climate change has had direct and indirect effects on fish species, both marine and fresh water. Direct effects include effects on growth, development, behaviour, reproduction, mortality and distribution (Franklin et al. 1995; Brander, 2007). Indirect effects the food and habitat of fish ecosystems by reshaping its physiochemical structure, which in turn effect its productivity and composition (Beaugrand et. al. 2002; Brander, 2007).

Fresh water fish are physiologically unable to regulate their own body temperature. Their body temperatures fall in the range of their environmental temperatures (Moyle and Ceche 2004). Behaviourally, they may thermoregulate by departing to microhabitats with a wider range of temperatures (Nielsen et al. 1994; Brio 1998) but they are still restricted to the temperatures of their environment. Fish embryos and larvae are more sensitive to the change in temperature than adult fish (Brett, 1969). Embryonic development and the rate of development increases with increasing temperatures (Das et. al. 2006). However, this phenomenon only occurs within a specific temperature range.

For example, in a study conducted in the state of West Bengal, in India, the embryos of the fish *Labeo rohita* (Rohu) were noted to hatch at higher rates between temperatures of 26–31°C than those in temperatures below or above this range. Embryos that were subjected to 36°C or more hatched at lower rates and several were malformed. The study concluded that these fish could adapt to temperatures up to 33°C and that any increase in climatic temperatures beyond that would result in the decline of their population.

The *Labeo rohita* (Rohu) are a prominent fish in Gosabara wetland and are a source of food for several animals as well as humans. The trend of increasing temperatures in the next few years can be detrimental to these dependent organisms (Das et. al. (2006). Moreover, a similar response to temperature increase can also be expected in other fish species, when exposed to higher temperatures.

Impacts on vegetation

The most predominant and abundant vegetation in an aquatic environment is cyanobacteria. These single-celled plant organisms are one of the primary producers of aquatic ecosystems, acting as a food source for various fish and insect larvae. However, there are species of cyanobacteria that are detrimental to aquatic ecosystems. These cyanobacteria form massive growths (or blooms) with increasing temperatures, increasing CO_2 levels and increasing anthropogenically induced nutrients. The blooms secrete toxins and reduce O_2 levels in water, which damage the ecosystem, effecting the microorganisms, fish and birds that are present therein and, thus, effect the food web (Paerl and Huisman, 2009; Paerl and Paul, 2012).

Another indispensable plant present in the wetland are the mangroves. They are important for maintaining coastal water quality, as nurseries for several fish and crustaceans and breed points of water birds (Mumby et al., 2004; Nagelkerken et al., 2008; Walters et al., 2008). These trees also prevent erosion and flooding during storms, surges and tsunamis (Danielsen et al., 2005; Kathiresan and Rajendran, 2005; Gilman et. al. 2008).

Studies have shown that mangroves would be adversely affected by current climate change trends. It has been noted that the optimum temperature for mangroves to conduct photosynthesis is 28–32°C. If the mangroves were exposed to temperatures of 38°C or above, they would no longer photosynthesise, thus, halting all metabolic activites and eventually die {Clough et. al. (1982) and Andrews et. al. (1984)}. The changing temperatures would also affect the phenology of mangroves as its flowering and fruiting dates would change to an earlier date (Ellison 2000; Gilman et. al. 2008).

Fluctuating rainfall would also be detrimental to the survival of mangroves. During the months of decreasing rainfall and higher evaporation rates, salinity of the soil would increase which would decrease the rate of growth and decrease seedling survival rates (Gilman et. al. 2008). Increase in rainfall would increase the growth rate and colonisation rates of the mangroves (Ellison, 2000).

Thus, the stability of wetland ecosystem would be disrupted due to the effects of climate change. Nutrients and detritus, the very foundations of the food web, would be amongst the first to succumb to this change. This, in turn, would affect all aforementioned organisms, from algae and terrestrial plants to fish and birds. The double threat of increasing global temperatures and fluctuating precipitation patterns could decimate isolated organisms, like plants, microorganisms and fish (Bond et. al. 2008) while more mobile organisms like birds could disperse to different localities to continue their breeding and feeding practices (Brock and Jarman, 2000). This could imply that due to reduced availability in food support, the migratory bird population in Gosabara wetland complex may disperse to a more favourable location in the long run.

To summarize, observed trend in temperature and rainfall could be detrimental to the biodiversity of the the Gosabara Wetland Complex. Higher temperatures and rainfall fluctuation are highly likely to result in phenological and physiological changes across the trophic levels of the food webs of these wetlands, in the following ways:

- Bird breeding phenology may or may not change in response to the changing climatic conditions depending on whether the bird is residential or migratory. A discrepancy between the bird breeding phenology and their prey (insect and fish) phenology is predicted.
- Insects are likely to respond to the changing climate by displaying a change in their ability to thermoregulate, shortening their developmental period and migrating to areas that would be relatively cooler than the wetland where they currently reside.
- Fish physiology, specifically thermoregulation, reproduction and development, would be adversely affected with increasing temperatures.

- Increasing temperatures could create algal blooms which would be detrimental to the overall ecology of the wetland. Mangroves would also be disadvantaged with increasing temperatures and rainfall variation.

3.6 Recommendations for improving adaptive capacity of the wetland

Based on the vulnerability assessment conducted, the following adaptation measures have been identified to respond to the imminent climate change impacts on Gosabara wetland complex. For the purpose of prioritisation based on the immediacy of action required for each measure, these have been categorised into: short term (0–5 years), medium term (5–10 years) and long term (over 10 years).

1. Outreach and educational programmes

External stressor addressed by the measure: Human activity and human ignorance

Proposed implementation time: Short term

Description:

Outreach and educational campaigns aimed at sensitisation towards wetlands should be organised for:

- Communities living near the wetland (eg. Oddar, Ratanpar, Tukda, Bapodar and Mokar villages near Gosabara, amongst others)
- School children
- Tourists
- Professional researchers

These programmes could help generate awareness on the impact of climate change on the wetlands and encourage people to invest in and implement climate change adaptation and mitigation practices.

2. Training programmes for management officials

External stressor addressed by the measure: Lack of technical expertise about wetland conservation

Proposed implementation time: Short term

Description:

The forest department officers and officials can be provided with training specific to climate change impact and mitigation strategies for the management of the wetland. Trainings could cover courses on Wetland species repository, wetland conservation and management, promoting networking between different stakeholders. These programmes could consist of international rangers, officers and scientists from areas that have been successful in implementing said strategies.

Case Study: Effective use of community awareness campaigns and capacity building

A successful example of effective use of community awareness and involvement in wetland restoration is that of Tikamgarh district in Madhya Pradesh. The district has a large number of water bodies used for irrigation, fisheries and drinking purposes, which faced extreme water scarcity for three consecutive years from 2000 to 2003. Due to years of neglect, siltation and encroachment, live storage capacity in most of the tanks had reduced to below 50%.

The district management took an initiative to gauge the interest levels of surrounding communities by organising meetings with Water Users Associations (WUAs) and fishermen societies, thus, motivating them to take action at the field level. Similarly, clear cut directions were given to the Chief Executive Officers of the sub-district level rural local bodies and the Chief Municipal Officers to mobilize their field level staff. Zonal officers heading a team of field staff were given responsibility of a cluster of villages to monitor the programme and provide technical guidance. A Gram Sabha (Village community) participatory workshop was also organized wherein about 200 villagers, students and NGOs reportedly participated.

As a result, there was an overwhelming response from the community in awareness as well as conservation works. Cleaning and desilting activities were undertaken at Hanumansagar, Maharajpura Tank, Nayakhera Tank and Bhimtal through participation of water users groups, especially women self-help groups. 139 tanks were cleaned, and 45 rainwater harvesting structures were constructed. This illustrates how a campaign for conservation of water bodies can be run by motivating the stakeholders. However, such actions also necessitate that the government field level bureaucracy is willing to provide the enabling environment and have institutions with requisite trainings and capacities to plan such initiatives, further train the communities and involve them in a coherent way.

Source: http://www.gwp.org/globalassets/global/toolbox/case-studies/asia-and-caucasus/india.-a-campaign-for-conservation-of-water-bodies-by-water-user-groups-246.pdf

3. Water management

External stressor addressed by the measure: Decrease in level of water in both ground and surface water, increase in evaporation rate, temperature, rainfall

Proposed implementation time: Short term

Description:

In order to determine sufficient water availability in the wetland, water storage and management strategies need to be identified and implemented. These strategies can help reduce flooding and run-off and encourage ground and surface water recharge as well as water retention potential of the wetland. As this would have an impact on several areas of economic value (agriculture, tourism, fisheries amongst others), all stakeholders must be consulted for this activity.

Some of the measures for improving water retention in the wetland are detailed above in Section 2.7. These measures must be supplemented by improved monitoring of water extraction from the wetland by the surrounding communities and measures to secure a suitable alternative water source for their usage, if required.

4. Expanding vegetation cover

External stressor addressed by the measure: Habitat degradation and loss, invasive species

Proposed implementation time: Short/medium term

Description:

Vegetation is key to any ecosystem. The wetlands have their own unique, but isolated native species that provide various resources to all fauna that dwell there. Vegetation cover can be expanded through the introduction of native species (species as recommended in the Floral Baseline Survey by GIZ) in the wetland areas. Moreover, building a canopy cover along the edges of the wetland complex can also help in hydraulic retention. Plants like Phragmites karka (Tall reeds) are a good example of native species that not only has hydraulic retention properties but is also adept at treatment of wastewater (Billore et. al. 1999)

5. Invasive species control

External stressor addressed by the measure: Invasive species, temperature rise, rainfall fluctuation, water level decrease

Proposed implementation time: Short/medium term

Description:

Climate change impacts on the wetlands result in an increase in the invasion of exotic species. Measures need to be identified and implemented to curb such invasion as they are detrimental to all native species of the wetlands. Invasive species like *Prosopis* and *Eichhornia crassipes* have already been found to encroach into the wetland to a significant level, and have been reducing native vegetation and adversely affecting some invertebrates, fish and birds. These invasive species could be gradually replaced by identified native species.

Examples of country level measures against invasive species control

Several countries have taken the initiative to manage invasive species contaminating their ecosystems.

- Singapore took action to remove the highly toxic climber: the Zanzibar yam (Dioscorea sansibarensis) from the Singapore Botanic Gardens by removing a majority of the obstinate aerial bulbils that were germinating at alarming rates in the forest (Choo, 2009).
- China has undertaken several measures, such as cutting, burning and herbicides to eradicate the cordgrass (Spartina sp.) (An et. al. 2007). The more effective means of controlling cordgrass growth was by flooding their salt marshes through the construction of ditches and secondary dikes. This reduced the salinity required by these plants, reducing the spread and allowing native species to take over the lands within a span of three years (An, 2003).

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6. Strengthening monitoring protocols

External stressor addressed by the measure: Lack of data available on the wetland

Proposed implementation time: Short/medium term

Description:

To prepare for the climate change impacts in the years to come, the wetland must be monitored for any signs of ecosystem change

- Installation of automatic weather stations can help monitor the aforementioned climatic parameters, such as temperature, rainfall, wind and evaporation
- Hydrological parameters such as water level, evaporation rate, soil and water pH, salinity, conductivity and turbidity need to be also recorded, on an annual or half-yearly basis
- Floral and faunal assessments could be conducted on a predetermined frequency (annual frequency is recommended)

All identified changes would help postulate and improve management strategies.

7. Human activity diminution

External stressor addressed by the measure: Human activities including agriculture, fishing, cattle rearing and grazing

Proposed implementation time: Short/medium term

Description:

Land use and resource depleting activities, such as agriculture, cattle rearing and grazing, fishing and man-made developments, must be identified and reduced, particularly in the Gosabara wetland. Farming practices require water that is provided by both the surface and ground water of the wetland.

With models predicting a decrease in the level of both water sources, alternative farming practices or farming lands must be provided. Cattle should also not be permitted to enter the wetland as they devour new saplings and prevent the wetland from thriving and increase soil erosion rates. Development activity within and near the wetland could be halted as it tampers with the ecosystem and introduces a variety of issues including soil contamination from construction material and disturbance to native and migratory birds, especially during the breeding season.

8. Financial incentives

External stressor addressed by the measure: Human activity

Proposed implementation time: Short/medium term

Description:

To promote the conservation of the wetland and prevent development and resource exhaustion, land owners as well as land use practitioners can be financially incentivised to protect the wetland and its biodiversity. This measure is particularly significant for Gosabara wetland, where human conflicts around wetland have been found to be prominent.

Case Study: Creation of alternactive income sources for fishermen for wetland conservation

An interesting case of use of alternative sources of income to motivate wetland conservation is that of East Kolkata Wetlands, a threatened Ramsar site in Eastern India, spread across 136 sq. km, which is renowned as a model of multiple use wetland. The wetland has a natural resource recovery system developed and maintained by the local communities supporting 104 wetland species including endemic marsh mongoose and mud turtle. The project used ecotourism as a means of poverty alleviation and sustainable environment development through community partnership.

The initiative made use of a public private partnership model along with community participation. Self Help Groups (SHGs) were established within the communities, with support from South Asian Forum for Environment (SAFE) and National Bank for Agriculture and Rural Development (NABARD). The fisherwomen were provided with training and visit programmes, and young men were trained with marketing skills. The capacity building exercises provided significant confidence to the community members to carry out eco-tourism initiatives. The ecotourism leveraged on the ecosystem services such as the landscape of the site, rich biodiversity and unique aquatic species and water birds.

A micro-insurance scheme was also designed for the people, with support from TATA-AIG group, an insurance company, to ensure that that their initial contribution remains an investment and the premium money is returned with bonus on completion of the tenure of the insurance, in case there is no claim for accidental benefits.

The revenue collected from eco-tourism was an alternative economic opportunity for sustenance of the community members. A portion of the excess revenue went for premium of group micro-health insurance coverage. This motivated the fishermen and other community members to contribute to protection of wetlands. The project was based on the concept of "biorights", which stresses on protection of areas of global environmental importance by compensating poor people who live near these areas, and are dependent on these areas for cash generating activities.

Source: http://doc.teebweb.org/wp-content/uploads/2013/01/Conserving-wetlands-through-microfinance-programs-India.pdf

9. Open channels between researchers and policy makers

External stressor addressed by the measure: Lack of awareness about wetland conservation and its importance

Proposed implementation time: Medium term

Description:

Annual and/or bi-annual seminars should be conducted where researchers can present their findings and recommend climate mitigation strategies to the relevant authorities to implement these potential strategies.

10. Shoreline control measures

External stressor addressed by the measure: Sea level rise, soil erosion, habitat destruction

Proposed implementation time: Medium/long term

Description:

To protect the wetland from sea-level rise, erosion, and storms, the managing authorities of Gosabara wetland complex, along with the respective state agencies, must research, plan and regulate the design and installation of structures including dikes, tidal gates, bunds, setback lines and buffer zones.

Some examples of shoreline control measures to prevent coastal erosion are provided below. However, a detailed feasibility study is required to be carried out to ensure propoer selecton of the most suitable measure depending on the coastline conditions at the time of implementation.

Measure	Description
Groyne	• Coastal structure constructed perpendicular to the coastline from the shore into the sea to trap longshore sediment transport or control longshore currents • Easy to construct but requires regular maintenance and may cause erosion downdrift
Sea wall	• A structure constructed parallel to the coastline to shelter the shore from wave action • can be used to protect a cliff from wave attack and improve slope stability • should be constructed along the whole coastline; if not, erosion will occur on the adjacent coastline
Offshore breakwater	• A structure that parallels the shore (in the nearshore zone) and serves as a wave absorber • Large structures and relatively difficult to build
Artificial headland	• A structure is constructed to promote natural beaches because it acts as an artificial headland. • Relatively easy to construct and little maintenance is required • Relatively unstable against large waves
Beach nourishment	• Used to create a wider beach by artificially increasing the quantity of sediment on a beach experiencing sediment loss • Requires regular maintenance with a constant source of sediment and could be economical in severe wave climates • Can be used in conjunction with hard structural/engineering options, i.e. offshore breakwaters, headlands and groynes
Coastal revegetation	• Presence of vegetation in coastal areas improves slope stability, consolidates sediment and reduces wave energy moving onshore; thus, protecting the shoreline from erosion • Types of vegetation should be selected carefully after studying the coastline environment conditions

11. Migration corridors

External stressor addressed by the measure: Effects of climate change

Proposed implementation time: Long term

Description:

Wetland vegetation and aquatic populations are limited to the area the wetland encompasses, i.e., they are isolated. Corridors and land expansion options would have to be considered as they may be the last line of defence for these organisms against extreme climate change. These options would help preserve and increase biodiversity resistance to climate change and allow organisms to migrate and settle to more suitable ecosystem.

Examples of migration corrdorrs across the world

Although migration corridors are a relatively newer concept for coastal eco systems, certain adaptation plans such as Michigan Adaptation Plan and Maryland Wetland Conservation Report have recommended development of migration corridors as a long term measure to adapt to the effects of climate change.

In Northeast Bavaria, Southern Germany, three fish passes (corridors) were constructed in the three rivers of the main river system. The corridors have been made as a means to recompense the detrimental effects caused by the three overdrift mills, such as the changes to the natural flow system of the rivers which lead to habitat fragmentation and a decline in population of riverine fish species. The fish bypass, reportedly, improved the biodiversity of the river in the small habitat areas around the bypass, as these migration corridors increased fish movements during periods of high discharge and during spawning periods. High species richness and abundance was also observed in areas near the bypass. Further, it was indicated that to improve the biodiversity of the whole river system, variables such as river flow rate and flood events must also be taken into account while designing such corridors. (Pander et. al. 2013).

Reference: Pander, J., Mueller, M. and Geist, J., 2013. Ecological functions of fish bypass channels in streams: migration corridor and habitat for rheophilic species. River Research and Applications, 29(4), pp.441-450.

4. Carbon sequestration assessment

Wetland ecosystems have unique characteristics as they often lie at the centre of a complex inter-linkage of culture, ecological diversity and economic activities. Wetlands exist in a wide variety, ranging from freshwater standing ecosystems influenced by riparian water systems, such as lakes and reservoirs to downstream marsh land estuarine ecosystems, sharing an active interaction with marine ecosystems (Adhikari Shalu, 2009).

Gosabara can be characterised as reclaimed estuarine marsh lands exhibiting reduced interactions with the proximal marine ecosystem. Gosabara is the result of dykes constructed for the management of floods. Gosabara wetland's interactions with the marine ecosystem has been restricted at the surface and exists only at the subterranean level, where sub-surface sea water interacts with the water table. Surface level hydrological pulsing is seen at an extreme with both wetlands losing almost all of their surface water during the dry season.

Under such circumstances, characterising wetlands to showcase their carbon sequestration potential is complex, since it is influenced by multiple pathways of carbon. These carbon pathways in turn encapsulate various loops of carbon fluxes which have resulted in both wetlands, simultaneously acting as carbon sinks and sources. The process of locking carbon dioxide away from the atmosphere is called carbon sequestration.

Photosynthesis along with the resulting decomposition reactions are the primary drivers for carbon compounds to be introduced within Gosabara wetland. The potential for carbon introduction due to photosynthesis of land-based vegetation has been captured in a quantifiable manner. The decomposition reactions, through which captured carbon is released back to the atmosphere, and take place under aerobic and anaerobic conditions, are complex and were found to be challenging to attribute quantitatively at a system-wide scale.

Since Gosabara wetland is fed from upstream water sources and rainwater, carbon compounds are introduced under both in-situ and ex-situ conditions. In-situ carbon presence within the wetland ecosystem is driven by local vegetation (trees, shrubs, and herbs) along with micro-faunal and micro-floral organisms, such as algal colonies present within the water column. Ex-situ carbon compounds are introduced due to introduction of detritus and decomposition reactions taking place in the water soures upstream of the wetland ecosystem.

The end-of-life carbon compound contributions by micro-organisms are less than 1 per cent of the gross carbon compound introduction to the wetland ecosystem. Additionally, it would be challenging for a wetland manager to directly influence micro-organism fauna within the wetland ecosystem. Hence for the purpose of carbon flux study, their influence is not considered due to the extremely high amount of complexity involved in managing their presence and the extremely low amount of impact on the carbon fluxes operating at the wetland.

The following sections present a description of the carbon flux system in action at and the carbon sequestration potential of Gosabara wetland. The section is based on the field study carried out by KPMG in India and refers to the satellite mapping prepared as part of the floral baseline study. The annual carbon sequestration potential of manageable sub-habitats of the wetland is provided as an aid for the wetland manager to intervene and increase the carbon being sequestered at the wetland. This information is provided in the form of the existing carbon sequestration potential of these sub-habitats within Gosabara. The wetland manager would thus be able to take modular decisions to influence sub-habitats of the wetland complex.

4.1 Carbon fluxes in Gosabara wetland

In Gosabara, organic carbon is converted into compounds including carbon dioxide and methane and/or stored in plants, dead plant matter, and microorganisms. Organic matter typically contains between 45 per cent and 50 per cent carbon. Gosabara wetland contains five main carbon reservoirs, which interact with each other leading to the carbon flux action. (Fig. 39).

Carbon reservoirs at Gosabara

- Plant biomass carbon
- Particulate organic carbon
- Dissolved organic carbon
- Microbial biomass carbon
- Refractory carbon — Gaseous Carbon products (CO_2,

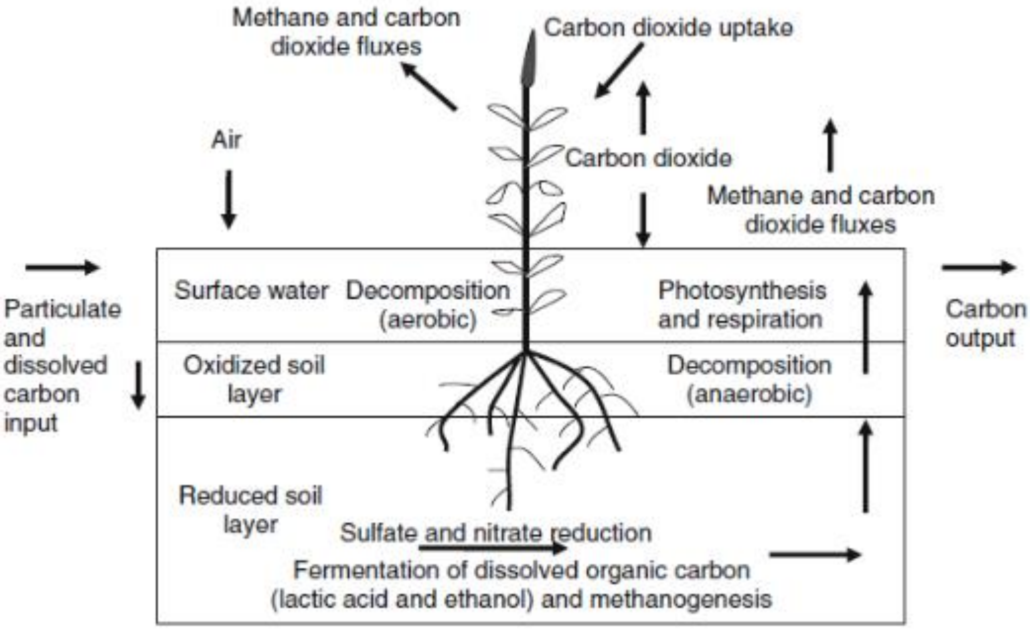

Figure 26 Carbon cycle for wetlands (Kayranli Birol, 2010)

Apart from carbon dioxide (CO_2) and methane (CH_4), the other four components present in the wetland are water, active biomass, detritus, and soil. Active biomass comprises of wetland plants and periphyton (microorganisms and detritus embedded within submerged surfaces), and contributes to the transformation of inorganic carbon, such as carbon dioxide to organic carbon through photosynthesis. Photosynthesis through active biomass is the primary action through which refractory carbon is converted to organic carbon (Hensel PF, 1999).

As a result, the presence of vegetation is a crucial segment in the carbon uptake flux. Vegetation has a direct relationship with the amount of water available in the wetland system. The total variability of the amount of organic carbon production capability of Gosabara wetland varies due to the time of the year, nutrient input status and the type of vegetation.

These factors are in turn dependent on the amount of water available in the wetlands. Thus Gosabara wetland can be considered to have two primary carbon phases based on the meteorological and the resultant hydrological conditions in vogue.

As dicussed in the earlier sections, water is introduced within the system when the monsoon rainfall is active during the brief period of four months. During this time, vegetation rapidly increases, and beyond the ‘wet season’, it continues to decline resulting in a simultaneous release of carbon captured throughout the ‘dry season’.

Season	Water availability	Carbon sequestration	Carbon release
Wet	High	High	Low
Dry	Low	Low	High

Gosabara can be characterised in separate vegetation sub-habitats, which have been adequately characterised in the floral baseline survey conducted at the start of the project. These sub-habitats increase or decerease in geographical spread based on water availability in the wetland.
The sub-habitats were demarcated using satellite images from the USGS site with the following steps:

- Image acquisition from USGS site
- Geometric rectification with the help pf Google Earth map
- Subset creation using Boundary
- Unsupervised classification
- Image recoding
- Raster to Vector conversion
- Contexual editing
- Map finalising and Area statistics

The following sub-section provides influencers of carbon flux within Gosabara wetland. Considering the fluctuating character of the wetland, the study has found that when evaluated for carbon flux activities at a sub-habitat level, carbon uptake or release actions varied considerably; however, at a system-wide scale and within the annual time frame, their influence on the sum total carbon sequestration of the wetlands relatively decreased.

4.1.2 Carbon flux influencers in Gosabara wetland

Gosabara has six sub-habitats classified as follows:

- Water
- Wetland vegetation
- Salt marsh vegetation
- Land vegetation
- Barren land
- Agricultural land

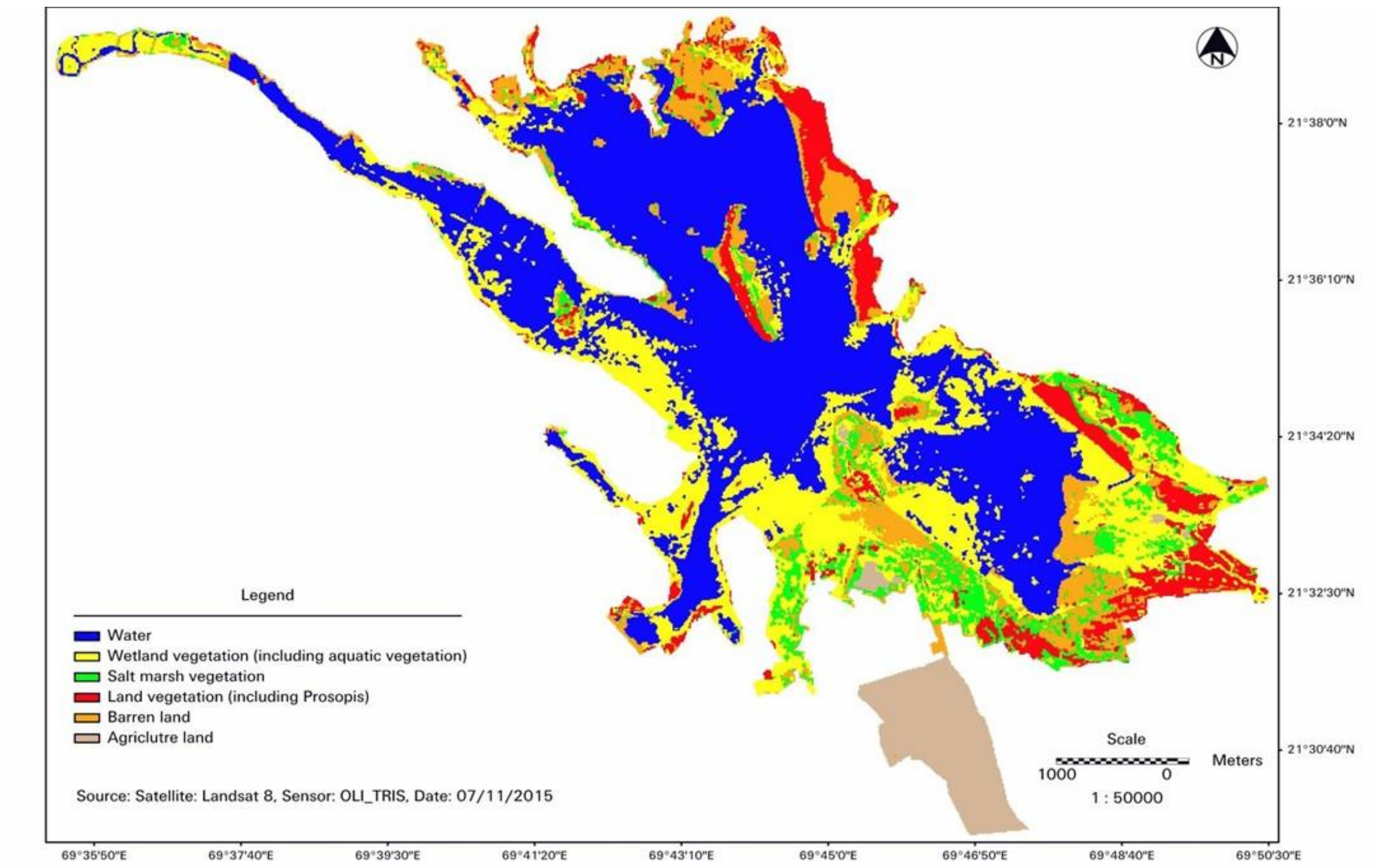

Figure 27 Wetland habitat Map of Gosabara complex – Wet season 2015, (Nagar, 2016)

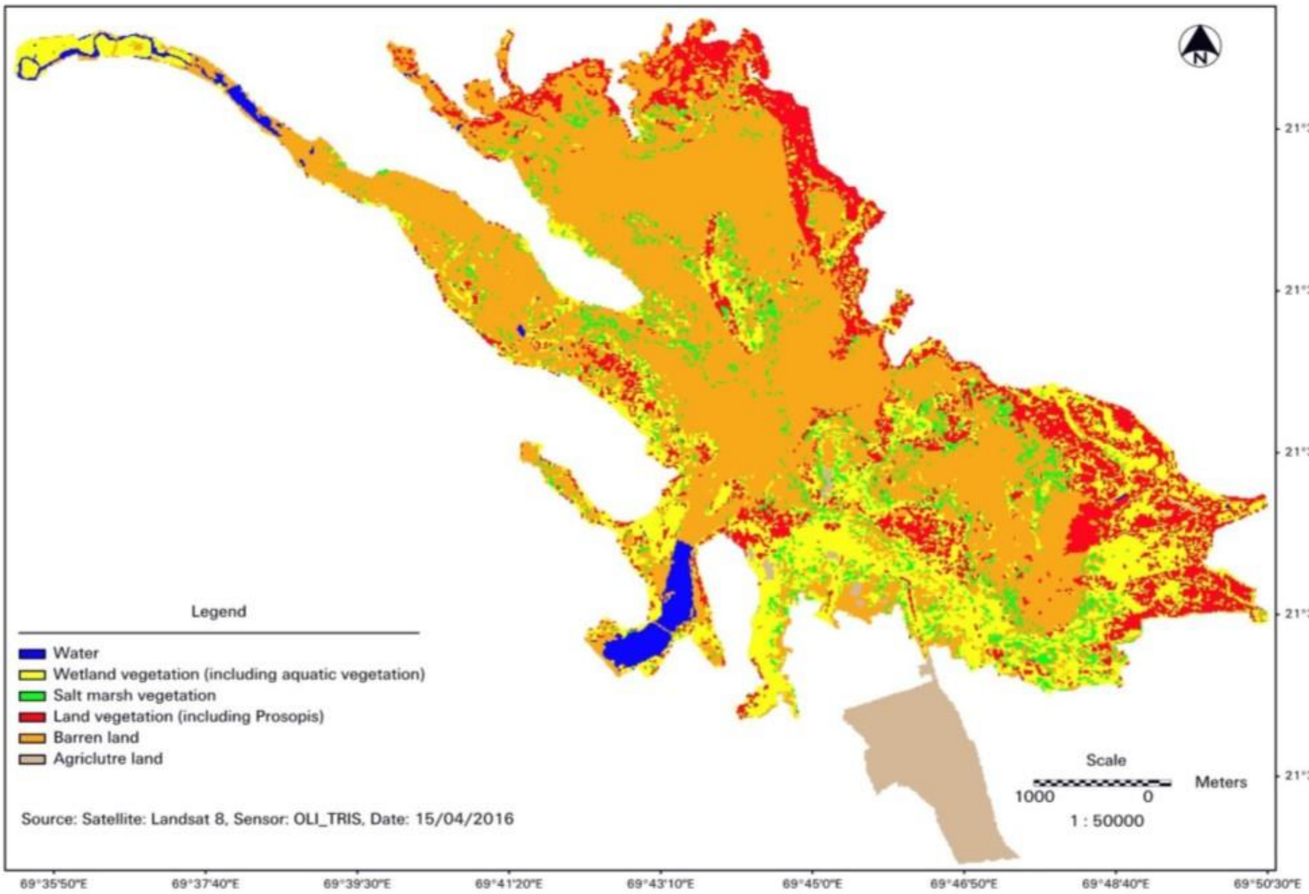

Figure 28 Wetland habitat Map of Gosabara complex – Dry season 2016, (Nagar, 2016)

There is a wide annual fluctuation in the area under each sub-habitat over a year. The study found that the overall influencers of the annual carbon flux are net positive, being influenced by a very small proportion of tree vegetation (terrestrial and marshland — mangrove) that occurs on less than 10 per cent of the total area of the wetland ecosystem. The remaining vegetative influencers of carbon show a nearly equal flux over an annual timeframe.

The sub-habitas demarcated using the GIS maps provided above are categorized in Table 17. The area of sub-habitats is referred from the floral baseline assessment while the net-change (wet season to dry season) is the calculated percentage change in area.

Sub-habitats	Wet season 2015		Dry season 2016		Net change (wet to dry)	
	In km^2	Total area (%)	In km^2	Total area (%)	Change in area (%)	Status
Water	56.4	43.7	2.5	1.9	-95.6	Decrease
Wetland vegetation	32.6	25.3	27.9	21.6	-14.4	Decrease
Salt marsh vegetation	7.8	6.0	6.9	5.3	-11.5	Decrease
Land vegetation	11.3	8.8	19	14.7	68.1	Increase
Barren land	14	10.9	65.4	50.7	367.1	Increase
Agricultural land	6.9	5.3	7.3	5.7	5.8	Increase
Total area	129		129			

Table 17 Sub-habitat driven carbon flux in Gosabara (Source: Nagar, 2016 and KPMG analysis)

The study found that influence of dissolved organic carbon within the water sub-habitat was redundant since the water sub-habitat almost disappears, decreasing by almost 96 per cent resulting in a concurrent increase in the barren land sub-habitat.[5] This annual conversion means that the net contribution of carbon sequestered versus carbon released is almost equivalent. It is important to note that the floral baseline study does not record any tree vegetation on this barren land sub-habitat, which could contribute to long-term carbon uptake.

From a management perspective, ensuring a decreased conversion to barren land would allow a higher net gain in carbon sequestered due to increased availability of water to propagate vegetation in the surrounding land areas.

The relatively smaller variability on wetland, salt marsh and agricultural land has resulted in an annual net addition to the amount of carbon being sequestered by the chief vegetation present in these sub-habitats. The floral baseline records the following major vegetation in the two seasons for these three sub-habitats.

Sub-habitat	Wet season	Dry season
Wetland vegetation	Schoenoplectus, Bolboschoenus, Phragmites Mangroves - Avicennia	Schoenoplectus (Dried), Bolboschoenus, Phragmites Mangroves – Avicennia
Salt marsh	Suaeda, Arthrocnemum, Aeluropus, Cressa	Suaeda, Arthrocnemum (Dried), Aeluropus (Dried), Cressa, Salicornia
Agricultural land	Various Agricultural cultivations	Ingress of Cressa weed in the barren fields

Table 18 Season-wise sub-habitats

Apart from the mangrove vegetation present in the salt marsh sub-habitat, all other plants encountered are either herbs or grasses, and in the case of agricultural land these are annuals and semi-annual plants that are harvested and thus removed from the wetland system.

The occurrence of trees is recorded only in the land vegetation and to some extent wetland vegetation (mangroves) sub-habitat. These sub-habitats contribute to the longer term carbon sequestration flux, since unlike other vegetation types, trees present here have the highest influence in the net carbon sequestered within the Gosabara wetland system.

In the land vegetation sub-habitat, five species of trees have been recorded: *Acacia nilotica* ssp. *indica Prosopis juliflora*, *Leucaena leucocephala*, *Salvadora persica* var. *indica*, *Azadirachta indica,* with *Prosopis julifloria* being the major species (Nagar, 2016). These trees are found in areas that remain above the water line of the wetland leading to an acumulation of carbon within the existing trees. This carbon is not cycled through the wetland readily and is not released to other aspects of wetland ecosystem, thereby, not becoming available for release through decomposition fluxes.

The floral baseline study, however, noted instances of anthropogenic pressure on the trees (Nagar, 2016). This leads to harvesting of good standing stock of trees meaning that the sequestered carbon

[5] Organic carbon dissolved in the water sub-habitat comprises of dissolved biochemical oxygen demand and other carbon components in solution. Since dissolved organic carbon typically represents less than 1 per cent of the total organic carbon in soil, it has been ignored as part of this carbon sequestration potential assessment.

from these trees is being removed from the system, which results in only a small non-measurable regenerative growing stock of trees.

4.2 Assessing carbon sequestration potential Gosabara wetland

In a wetland, the process of carbon sequestration is driven by vegetation through the addition of carbon compounds. There are also various carbon leakages pathways through which carbon is released back into the atmosphere.

The chief carbon capture pathway is photosynthesis reactions and release pathway is through aerobic and anaerobic decompositions. Depending on the net addition or subtraction and the type of carbon compounds being sequestered or released back to the atmosphere a wetland is considered to be either a source or sink of carbon.

When Gosabara wetland has conditions of high water table, and thus low decomposition rates, it sequester more carbon than released, since at the same time carbon is also being captured through vegetative growth. However, when conditions of low water table exist, leading to decerease photosynthesis and a higher decomposition (aerobic and anaerobic) rate, Gosabara releases back the carbon captured (Kayranli Birol, 2010).

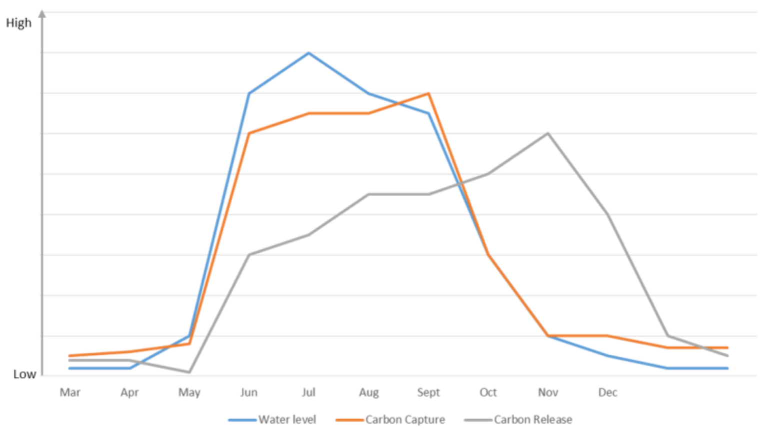

Figure 29 Indicative Water level, Carbon Capture, Carbon Removal processes (Source: KPMG Analysis)

Having a high water table results in more anaerobic decomposition of matter which is much slower than aerobic decomposition. However, there is a degree of complexity within the two types of decomposition because anaerobic decomposition results in the release of methane that is a more potent greenhouse gas[6] than carbon dioxide, which gets released through aerobic decomposition.

Because of the large amount of annual variance within the highest and lowest points in the accumulated water at Gosabara, the primary driver at the wetland is aerobic decomposition of plant matter.

Because of the existing fluctuating ecological characteristics of the wetland, the net carbon sequestration potential of the wetland is low. Only with targeted management interventions that could seek to retain water presence across the wetland can aid in net addition and long-term storage of organic carbon.

In Gosabara, organic matter accumulates when primary productivity is faster than the corresponding decomposition rate (Brinson Mark, 1981), leading to a net accumulation of organic matter. Due to slower nature of anaerobic decomposition rates, organic matter and, thus, carbon continue to accumulate in multiple stratum over the soil structure (Kayranli Birol, 2010).

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[6] The Global Warming Potential of Methane is 21. That means that methane is 21 times more potent that carbon dioxide in contributing to the albedo effect.

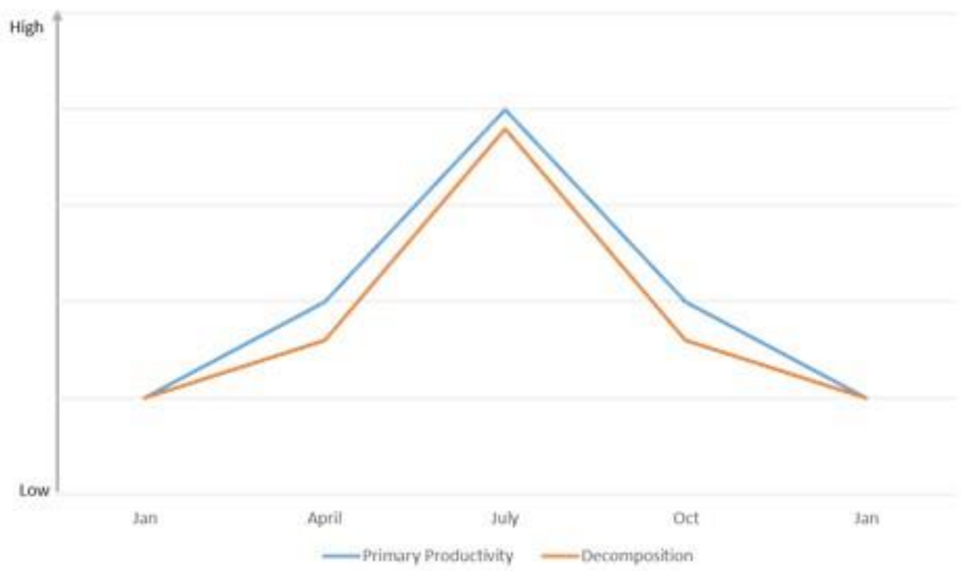

Figure 30 Indicative Productivity and aerobic Decomposition Rate variance and differential (Source: KPMG Analysis)

While in perennial wetlands, this results in a shift from aerobic to anaerobic processes due to lack of oxygen in the wetland sediment, which drastically reduces the decomposition rates. This leads to the strata being eventually broken down leading to storage of carbon due to the microbial actions, which actively convert organic carbon to inorganic forms albeit over a decadal time frame.

In a seasonal wetland, such as Gosabara, the anaerobic microbial action is absent during the dry season due to the absence of surface coverage by water. This leads to a fast aerobic decomposition pathway, which leads to almost all organic carbon being released back into the atmosphere.

Additionally, since aerobic decomposition in wetland systems is far more effective with respect to organic matter degradation than anaerobic processes, such as fermentation and methanogenesis, methane emission pathways for the Gosabara wetland is not a significant carbon emission pathway.

The water table level of wetland not only influences the amount of methane emitted to the atmosphere, but also the removal of methane from the atmosphere. Deep wetlands generally capture carbon dioxide from and release methane to the atmosphere. The combination of these two fluxes determines whether these countervailing processes make a wetland system an overall contributor to the greenhouse effect. The ratio of methane release to carbon dioxide consumption determines the carbon exchange balance with the atmosphere for any wetland ecosystem.

Gosabara, in particular, has a large dry spell during which time the various organic stratum accumulated during the wet season are exposed to the sun and not covered with water. This results in the wetlands operating as methane sinks. However, carbon is released into the atmosphere through the fast-acting aerobic decomposition process in the form of carbon dioxide.

Partially, flooded wetlands also have some area above the mean annual water table. This results in the soil strata to be well aerated leading to a decreased methanogenesis and an increase in the methane oxidation for all sub-habitats except drying wetland, salt marsh land and water type of sub-habitats.

4.3 Potential to increase carbon sequestration in Gosabara

Increasing the carbon sequestration potential for the Gosabara wetland while ensuring that the ecological character of the wetland is not disturbed would require:

— Replacement of the *Prosopis juliflora* occupied land vegetation sub-habitats with native species such as *Acacia nilotica*, *Azarithiracta indica, etc.,*

— Gap plantation using similar native species on the land vegetation sub-habitat for the wetland: Gap plantation only of the artificial natural regeneration type may be undertaken in the wetland since carrying out complete artificial regeneration and creation of plantations may have impacts on the land availability for the local and migratory avifauna

The carbon sequestration potential of the wetland can be increased through plantation of tree species on the land area that does not get submerged during the wet season. Preference needs to be given to non-invasive locally abundant species.

Plantations on the land vegetation sub-habitat of local species such as *Acacia nilotica* and of mangrove species such as *Avicennia marina, Avicennia officinalis* in possible mangrove sub-habitats can aid in increasing the carbon capture potential of the wetland.

Carbon sequestration potential of suggested species:

Land vegetation species	Carbon content (kg) to various height classes (cm)				
	1–150	150–200	200–250	250–300	>300
***Acacia nilotica*[7]**	2.0	9.9	13.5	36.5	80.7
Mangrove Species	Carbon content (kg) to various height classes (cm)				
	1–151	151–300	301–400	401–500	>500
***A. marina*[8]**	0.26	1.91	7.38	16.55	55.85
A. officinalis	0.013	0.280	3.725	6.174	65.657

Carbon sequestration potential for the land vegetation sub-habitat Gosabara over a 20-year period is provided as below: Gosabara land vegetation sub-habitat area — 11.3km^2

Acacia nilotica	***Gosabara***
Carbon Sequestration Potential (M. Tonnes)	272.4

Detailed year-on-year growth of sequestered carbon for the wetland has been provided in Annexure 1.

[7] Height and girth calculated based on age class from FRI Envis Darta base on Babul (*Acacia nilotica*). Brown's carbon sequestration equation used to arrive at the carbon values.
[8] Age Class and resultant carbon values obtained from the publication of GEER titled Carbon Sequestration by Mangroves of Gujarat.

Annexure 1: Carbon Sequestration

Carbon sequestration potential for developing a Mangrove sub-habitat in Gosabara is provided as below:

Planting geometry — 500 trees per Ha. (50,000 trees per km^2)

As a result the total carbon sequestration potential of the mangrove sub-habitat has been projected as below:

Year	Height class (Cm)	*A. marina* (Carbon Sequestration potential in Kgs)	Total carbon sequestration potential (Kg)	*A. officinalis* (Carbon sequestration potential in kg)
1	1–151	0.26	15,600	0.013
2	1–151	0.26	15,600	0.013
3	1–151	0.26	15,600	0.013
4	1–151	0.26	15,600	0.013
5	151–300	1.91	114,600	0.28
6	151–300	1.91	114,600	0.28
7	151–300	1.91	114,600	0.28
8	151–300	1.91	114,600	0.28
9	301–400	7.38	442,800	3.725
10	301–400	7.38	442,800	3.725
11	301–400	7.38	442,800	3.725
12	301–400	7.38	442,800	3.725
13	401–500	16.55	993,000	6.174
14	401–500	16.55	993,000	6.174
15	401–500	16.55	993,000	6.174
16	401–500	16.55	993,000	6.174
17	401–500	16.55	993,000	6.174
18	401–500	16.55	993,000	6.174
19	>500	55.85	3,351,000	65.657
20	>500	55.85	3,351,000	65.657

Table 19 Carbon sequestration potential for mangrove sub -habitat in the wetland

Carbon sequestration potential for the land vegetation sub-habitat in Gosabara is provided as below:

Planting geometry — 500 trees per Ha. (50,000 trees per km^2)

Gosabara land vegetation sub-habitat area — $11.3 km^2$

As a result the total carbon sequestration potential of the land vegetation sub-habitat has been projected as below:

Year	Height class	*Acacia nilotica* (Carbon sequestration potential in kg)	*Gosabara Carbon Sequestration Potential (Tonnes)*
1	1–150	2.0	1,130
2	1–150	2.0	1,130
3	1–150	2.0	1,130
4	1–150	2.0	1,130
5	150–200	9.9	5,594
6	150–200	9.9	5,594
7	150–200	9.9	5,594
8	150–200	9.9	5,594
9	200–250	13.5	7,631
10	200–250	13.5	7,631
11	200–250	13.5	7,631
12	200–250	13.5	7,631
13	250–300	36.5	20,623
14	250–300	36.5	20,623
15	250–300	36.5	20,623
16	250–300	36.5	20,623
17	250–300	36.5	20,623
18	250–300	36.5	20,623
19	>300	80.7	45,623
20	>300	80.7	45,623

Table 20 Carbon sequestration potential for land vegetation sub-habitat in Gosabara

Annexure 2: Field Visits

The team conducted two field visits to the wetland site, Gosabara Wetland Complex, in the months of February and March, respectively. The team consisted of professionals and researchers from KPMG, IIT, and NIH.

The objective of both visits was to initiate dialogue and collect data for conducting the hydrological assessment and climate risk vulnerability assessment study. Apart from carrying out a physical run-through of the site, discussions were held with various officials of relevant government departments and local authorities to understand key issues of the wetland and explore data availability for the study.

During the visits, discussions were held with the following authorities:

Porbandar
• Forest Department • Krishi Vigyan Kendra District Office • Salinity Ingression Control Department • Mokarsagar Wetland Conservation Committee

Further, we also met Bhaskaracharya Institute of Space and Application (BISAG), Gandhinagar to explore availability of maps and toposheets of the project site.

Data Collection:

A detailed meeting was held with the Forest Department of Porbandar on the first day of the visit to the site. These discussions were focused on understanding the history of the wetland and current hydrological, climatic and socio-economic regime of the wetland. The Forest Department officials pointed the team to other departments which may provide us with the data required for the study.

The following documents and datasets was collected during our interactions with various departments:

Data	Source
Management Plan for Porbandar Bird Sanctuary 2014-15 to 2023-24	Forest Department, Porbandar
Base map of Gosabara wetland complex in Porbandar District (in Gujarati)	Salinity Ingression & Control Department, Porbandar
Daily meteorological data (rainfall, min. and max. temperature, evaporation, wind speed, etc.) for Porbandar district for a period of past three years	Krishi Vigyan Kendra, Porbandar
District Annual Report on Irrigation, 2016	Forest Department, Porbandar
District Agriculture Plan for Porbandar district	Krishi Vigyan Kendra, Porbandar

In addition, a meeting was also held with the Mokarsagar Wetland Conservation Committee, Porbandar, a NGO working for conservation of Gosabara wetland complex, to understand their perspective of the hydrological and socio-economic issues related to the wetland.

Water samples were also collected for analysis of water quality. In-situ measurements of EC and pH were carried out, and samples are currently undergoing clinical laboratory tests for water quality. The details of water samples collected are as follows:

Table: Samples collected during field visit

S.N	Site ID	Study Area	Date of collection	Latitude	Longitude	Source
5.	MK-1	Gosabara	3/3/2017	21^{0}32.411’	69^{0}43.336’	Wetland
6.	MK-2	Gosabara	3/3/2017	21^{0}33.110’	69^{0}44.274’	Open Well
7.	MK-3	Gosabara	3/3/2017	21^{0}34.11’	69^{0}45’34.9’’	Wetland

<u>Illustrations from the Site Visit</u>

Some views of Gosabara wetland complex (March, 2017)

Water quality sampling of open well in study area of Gosabara wetland

A manmade channel in Gosabara wetland

Dry bed of Gosabara wetland

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About the Study

The study is part of the overall scientific and technical studies in Gujarat that the CMPA project supported towards effective and sustainable management of coastal and marine protected areas. The overarching aim of the hydrological, climate change and carbon studies was to support integrated management planning of Gosabara Wetland Complex via following specific objectives: conducting a hydrological analysis of the wetland, including the review of current water management practices and recommending measures for the maintenance of hydrological regime in support of biodiversity and ecosystem services; assessing vulnerability of the wetland to climate change and identifying adaptation options; and assessing carbon sequestration potential and flux of the wetland. The study was conducted by a team of experts from KPMG India, National Institute of Hydrology, and Indian Institute of Technology Delhi with support from the Wetlands International South Asia.

The CMPA Project

The Project "Conservation and Sustainable Management of Coastal and Marine Protected Areas" (CMPA) is a project of the Indo-German technical cooperation. It is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) and implemented by the Ministry of Environment, Forests and Climate Change (MoEFCC), Government of India, and the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of BMUB.*

Established to support the achievement of the Aichi targets of the Convention on Biological Diversity, the Project's overall goal is to contribute to conservation and sustainable use of biodiversity in selected areas along the coast of India. Taking into consideration the economic importance of the coastal zone for large segments of the population, the Project's approach is people-centered, thus ensuring the support for conservation by those depending on coastal ecosystems.

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Indo-German Biodiversity Programme
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