CMPA Technical Report Series

46

Hydrology Study and Climate Change Vulnerability Assessment to inform Management Planning of Khijadiya Wildlife Sanctuary in Gujarat

August 2017

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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 Khijadiya Bird Sanctuary in Jamnagar district of Gujarat, and explore potential solutions for their informed management planning. The carbon sequestration potential of the wetland was also assessed.

Khijadiya Bird Sanctuary (KBS) is located at a distance of about 12 km from Jamnagar city in Gujarat. It is an outcome of two earthen reclamation bunds constructed to restrict rapid flow of fresh water from draining into the Gulf of Kutch and to control salinity ingress from sea tides. The measured annual rainfall near the wetland area for the period from 2011 to 2016 was found to be- 660 mm, 348 mm, 1211 mm, 262 mm, 303 mm and 435 mm respectively. The hydrological assessment has been carried out assuming the rainfall level of the lowest rainfall year, that is, 2014-15, amongst the past six years.

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 = 10km^2 Average depth = 30cm	2.55
2	Bottom surface area = 10km^2 Average depth = 50cm	4.26
3	Bottom surface area = 12km^2 Average depth = 30cm	2.75
4	Bottom surface area = 12km^2 Average depth = 50cm	4.59

The total water inflow to Khijadiya Bird Sanctuary comprises of inflow due to surface run-off from catchment (downstream of the reservoirs), and inflow due to direct rainfall over the wetland. The monthly total inflow to the wetland was estimated as follows:

Month	Rainfall (mm)	Total magnitude of water generated in the catchment below reservoirs (m^3)	Inflow due to run-off from catchment d/s of reservoirs (21% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)
	(a)	(b)	(c)	(d)	(e)
June 2014	7	2,026,220	425,506.2	108,500	534,006.2
July	136.5	39,511,290	8,297,370.9	2,115,750	10,413,120.9
August	85	24,604,100	5,166,861	1,317,500	6,484,361
Sept	33	9,552,180	2,005,957.8	511,500	2,517,457.8
Oct	0	0	0	0	0
Nov	0.5	144,730	30,393.3	7,750	38,143.3
Dec	0	0	0	0	0
Jan 2015	0	0	0	0	0
Feb	0	0	0	0	0
March	9	2,605,140	547,079.4	139,500	686,579.4
April	0	0	0	0	0

Month	Rainfall (mm)	Total magnitude of water generated in the catchment below reservoirs (m^3)	Inflow due to run-off from catchment d/s of reservoirs (21% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)
May 2015	0	0	0	0	0
Total	**271**	**78,443,660**	**16,473,168.6**	**4,211,060**	**20,684,228.6**

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 for the low rainfall year, 2014-15 (as given below).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total evaporation during the month (cm)	11.99	14.64	19.12	24.48	27.77	26.19	18.35	15.03	14.37	16.12	12.87	11.84

During the post monsoon period, the total evaporation losses from October to January were estimated to be about 53 cm, and from October to November, about 29 cm. Therefore, if the average water depth of Khijadiya Bird Sanctuary is assumed to be 30 cm, the wetland shall more or less be dry by the end of November. Similarly, if the average depth is assumed to be about 50 cm, the wetland shall be dry by the end of January. Since the depths are not same at all the locations across the sanctuary, the availability of water varies from one point to another after November. The following measures have been recommended to improve the water retention capacity of the wetland during the post monsoon period:

- Dredging in selected locations to trap the overflowing water from the wetlands during monsoons
- Regulating the level of siltation entering the wetland from the catchment run-off through sediment or silt traps
- Construction of rainwater storage structures to store water during monsson period and utilizing it 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. A sharp increase in temperature within the range of 0.9°C and 1.2°C is projected in the months of March and December. The temperature levels across the region are projected to increase across most months within the range of 0.4°C and 1.12°C across the year. A sharp increase in rainfall in the range of 0.6mm and 1.5mm per day is projected in the month of August, which has also been one of the wettest months in the region historically. However, a sharp fall in the rainfall level, in the range of 0.2mm and 0.6mm per day, is also projected in the following month of September.

The sea level near the coasts adjoining Khijadiya Bird Sanctuary 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
- Creating open channels between policymakers and researchers
- Development of migration corridors in the long run

Since Khijadiya Bird Sanctuary is a partially flooded wetland, it sequesters carbon dioxide and releases methane into the atmosphere. The combination of these two factors determines whether these offsetting processes make a wetland system an overall contributor to the greenhouse effect. Maximising permanent vegetation in Khijadiya could provide an increase in the carbon sequestration potential. Increasing the carbon sequestration potential for Khijadiya while ensuring that its ecological character is not disturbed would require:

- A systematic improvement of the Mangroves of Khijadiya wetland
- 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

The carbon sequestration potential of Khijadiya 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.

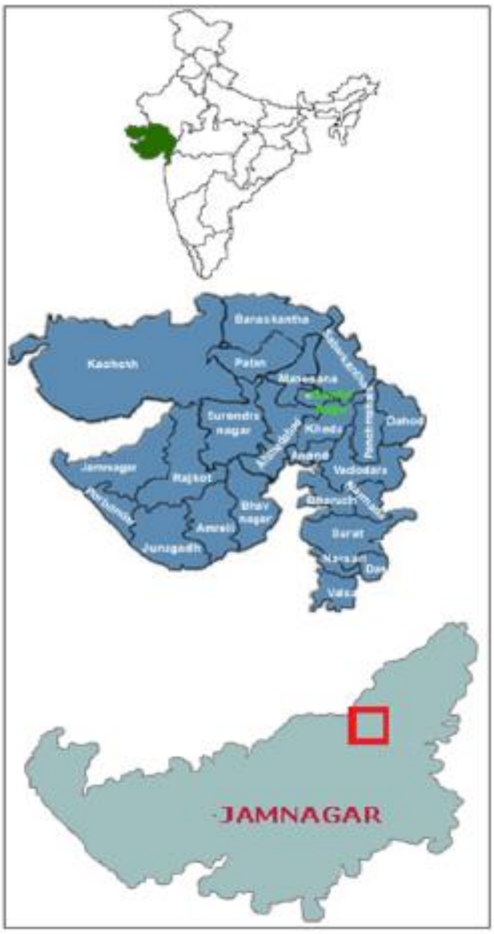
The project is funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB), and implemented by the Ministry of Environment, Forests and Climate Change (MoEFCC), and GIZ, on behalf of BMUB. Under this project, the following research study is being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

1.1 Objective and scope

The overarching aim of this study is to support integrated management planning of Khijadiya Bird Sanctuary 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 wetland to climate change and identifying adaptation options
- Assessing carbon sequestration potential and flux of the wetland

1.2 Overview of Khijadiya Bird Sanctuary



Khijadiya Bird Sanctuary (KBS) is located at a distance of about 12km from Jamnagar city in Gujarat. It is an outcome of two earthen reclamation bunds constructed to restrict rapid flow of fresh water from draining into the Gulf of Kutch and to control salinity ingress from sea tides. Except Vibhapar, all the other three villages (Jambuda, Khijadiya and Dhunvav) share boundaries with KBS. Although Jamnagar district is drought prone, four villages around Khijadiya Sanctuary used to have fertile land with high productivity due to the natural drainage of rivers flowing into the sea.

Khijadiya wetland in Jamnagar district has a unique geographical peculiarity, as a combination of a sweet water lake and coastal saline water marshland. Declared as a sanctuary on 6 November 1982, it is the biggest of its kind in Gujarat with an area of $6.05km^2$. It adjoins the oldest marine protected area of India, the Jamnagar Marine National Park.

About 300 species of birds visit this wetland every year. The wetland hosted eight bird species falling under ‘Globally Threatened / Nearly Threatened’ as per the criteria of International Union for Conservation of Nature (IUCN). During the period between 2012 and 2014, rainfall was very low and the number of birds reduced to 11,601 and 10,044, respectively.

Under the centrally sponsored scheme of ‘National Wetland Conservation Programme’ (NWCP), eight wetlands in Gujarat have been identified as wetlands of national importance, of which one is Khijadiya Wildlife Sanctuary[1].

[1] Source: Report of the Comptroller and Auditor General of India on Economic Sector for the year ended 31 March 2015, Government of Gujarat.
http://www.cag.gov.in/sites/default/files/audit_report_files/Gujarat_Economic_Sector_Report_5_2015.pdf

2. Hydrological assessment

2.1 Hydrological characterisation of the wetland

The Khijadiya wetland and Bird Sanctuary is located at 22°31'27"N latitude and 70°07'17"E longitude at a distance of about 12kmnortheast of Jamnagar city on the southern coast of the Gulf of Kutch in the Saurashtra region of the western state of Gujarat. Khijadiya wetland is a shallow, freshwater wetland with extensive marshes, adjacent to a large area of saltpans and salt marsh on the south shore of the Gulf of Kutch. The location of the Khijadiya Bird Sanctuary and its major catchment areas are shown in Figure 1.

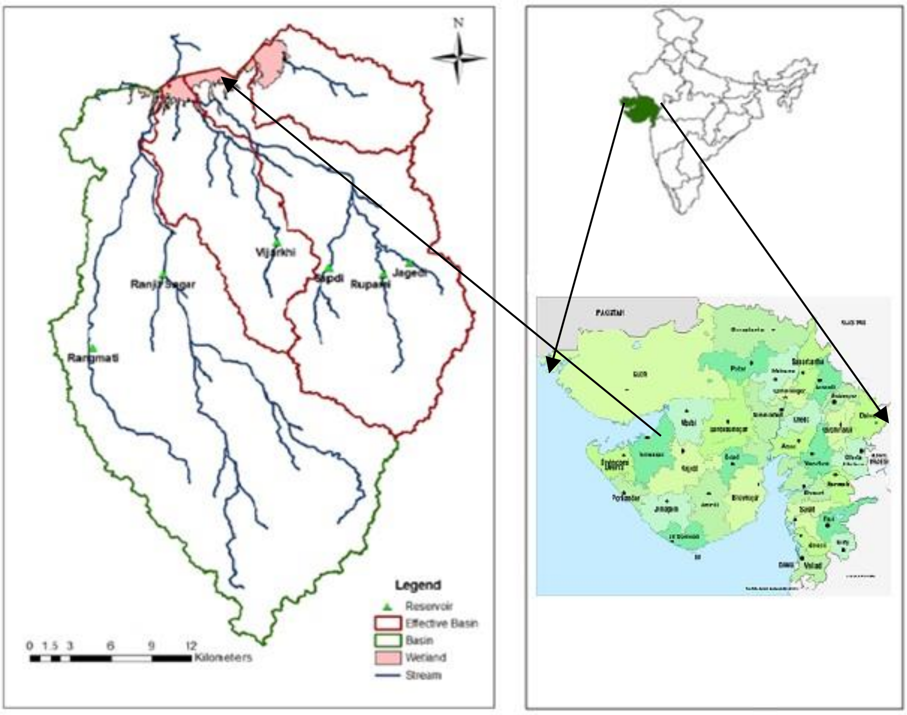


Figure 1 Location of Khijadiyawetland, its effective and total catchment area

Khijadiya sanctuary is basically a result of two non-linked man-made reservoirs, compositely forming a wetland complex due to two reclamation bunds, which were built with the objective of arresting salinity ingress from the sea-side,and thus, preventing freshwater from draining into the sea. Earlier, Khijadiya Bird Sanctuary was a sea coast and the marshy wasteland of the revenue villages —Khijadiya, Jambuda and Dhunvav— of Jamnagar district. To prevent salinity ingress and to reclaim the land, the erstwhile ruler of Navanagar State in 1920, and subsequently the Government of Gujarat, in 1956, constructed a reclamation bund along the coast to store water from Ruparel and Kalindirivers. This resulted in the restriction of freshwater flow of small rivers and salt-water inflow during high tides. Before the construction of the earthen bunds prior to India's independence, part of the sanctuary was intertidal zone of the Gulf of Kutch. The sanctuary area is just above the high tide level and the tidal water reaches up to the boundary of the sanctuary. The boundary of marine sanctuary extends into the freshwater lake area of the Khijadiya sanctuary and also constitutes the boundary of the sanctuary towards the Gulf of Kutch. Thus, as the salinity decreased in the 1940s and 1950s, the lakes were colonisedby aquatic plants, and extensive reed-beds developed. Gradually, over the years, a variety of vegetation types grew leading to an increase in wildlife, especially birds and, in particular, the waterfowl that started flocking and roosting in the region. By this time, however, the need for fresh water had become more important than the requirement for agricultural land, and the plans to drain the area were abandoned.

Instead, four pumping stations were installed at the east of the main Khijadiya Lake to supply fresh water to nearby villages.

The sanctuary and its surrounding environment, thus, represent a mosaic of ecosystems largely comprising freshwater wetlands, brackish water impoundments, mangroves, salt pans, intertidal mudflats, a creek, surrounding agricultural land and the large area as wasteland with *Prosopis*dominant vegetation. Khijadiya Lake Complex, thus, not only includes the two lakes, but also has extensive marshes on the southern shore of the Gulf of Kutch (Sanjeev Kumar, 2013). . A stretch of creek and salt pans, adjoining the freshwater wetland complex, has a direct bearing on the ecosystem of Khijadiya wetlands.

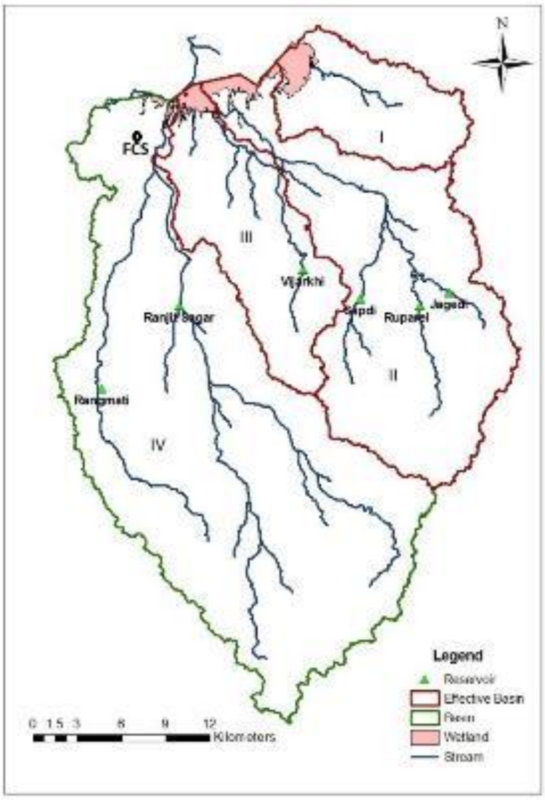


Figure 2 Sub-watershed delineation and location of Full Climatic Station (FCS)

2.2 Climate

The area is relatively dry, having a tropical monsoon climate, and rainfall mainly concentrated in July and August. The mean maximum temperature is 40°C, and the minimum is 7°C. The seasons of the year are: monsoon (middle of June to middle of October), winter (November to February) and summer (March to June). From March onward, the temperature starts rising till it reaches the maximum i.e., as high as 45°C in some parts of the state. January is the coldest month of the year in all parts of the state, with maximum temperature never exceeding 30°C and the minimum temperature remaining between 8°C and 10°C. The Khijadiya Bird Sanctuary area is characterized by very hot summers and severely cold winters. The temperature varies from 6°C to 45°C. Maximum rainfall occurs during the monsoon period, which is mainly from June-July upto September. Rainfall is erratic and scanty, due to which frequent drought conditions arise. Relative humidity of the Khijadiya Lake and Bird Sanctuary area varies from 20 per cent to 70 per cent. Winds are generally light to moderate, and increase in intensity during the late summer and monsoon seasons. High wind is experienced at the sanctuary, which blows mainly from north-east to north-west direction from October to April. South-west winds blows during monsoon and chilly wind direction keeps on changing in winters from south-west to south-east. Coastal areas experience stronger winds. The important observed climatic parameters of average monthly rainfall and pan evaporation for a period of six years (2011–16) are given in Figure 3. The data have been collected from the meorological observatory located at Krishi Vigyan Kendra, Jamnagar. .

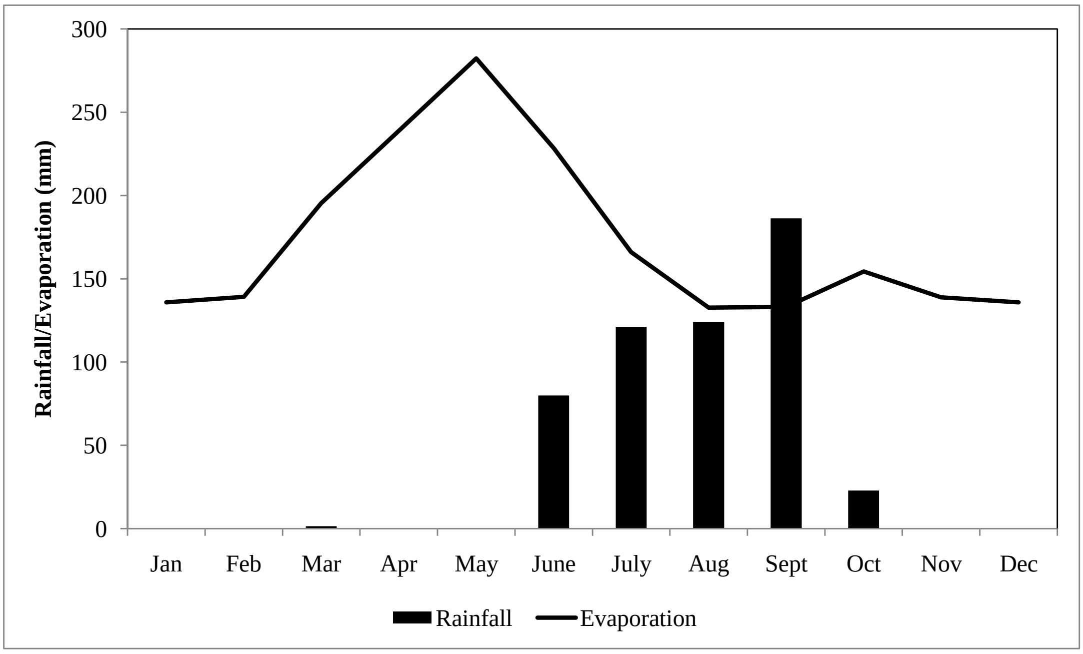


Figure 3 Observed average rainfall and pan evaporation (2011–16) nearby study area

3.1.2 Geology and soils

Geologically, Saurashtra basin consists of mostly Mesozoic and Cenozoic rocks, and stratigraphically the sequence begins with Cretaceous to be followed upward by the Deccan volcanics, Tertiary and the Quaternary. The area is largely covered and prominently exposed by the Deccan Trap (basaltic rocks), the thickness varies from few hundreds to thousands of metres. Traps are underlain by thick Mesozoic sediments (100–4,000m), which can form potential source rocks. The soil texture varies throughout the Khijadiya Lake and Bird Sanctuary. The soil texture of Khijadiya freshwater wetland has less gravel, coarse sand and comparatively more fine sand, silt and clay with increased water holding capacity. Thus, good vegetation exists towards Khijadiya freshwater wetland. The principal emergent macrophytes species include *Typhaangustata*, Scirpus sp., Cyperus sp., and *Saccharumspontaneum*. Submerged aquatic plants include *Hydrillaverticillata*, *Vallisneriaspiralis*, and *Najas minor*. Screens of *Prosopisjuliflora* have been planted along the bunds. There is some scrubby mangrove in the adjacent salt marsh, but all the mangrove trees have been cut down. *Avicennia marina* still thrives in the channels, but grazing camels and constant cutting prevent trees to attain maximum height. The natural vegetation in surrounding areas include*Acacia nilotica*, *Capparis decidua*, and Phoenix sp. The wetland and marshes are fed by monsoon run-off in several seasonal streams. A deep channel connects the outflow from the lakes with a tidal channel running down to the sea.

The two seasonal streams flow from south to north and drains into the sanctuary area and bring a lot of silt. The siltation in turn has led to reduction of water storage capacity of the lakes. Not having a perennial river, the freshwater wetlands face water scarcity in the summer months, as water is retained till the month of March. The southern part of the Khijadiya wetland towards Dhunvav and Khijadiya side normally found to be 4–5 feet, which at places is over 6 feet. Towards the eastern side at Jambuda, the water depth on an average remains 2–3 feet.

The wetland is an extremely important staging and wintering area for a wide variety of waterfowl. Almost 300 species of birds have been recorded in the sanctuary, including about 94 species of water birds. Various freshwater turtles are reported to exist and many visitors come to observe birdlife in the sanctuary. Khijadiya lakes provide water for irrigation and domestic use, while salt is extracted from the two neighbouring salt works; as water levels recede, local villagers cultivate vegetables on the exposed beds of the lakes. Cattle and other domestic livestock graze the edge of the reed-beds, and up to 150 camels graze the adjacent salt marsh at neap tides. The Government of Gujarat through the State Forest Department has taken initiative to conserve the wetland from biodiversity viewpoint under the Wildlife (Protection) Act, 1972. The Ministry of Environment and Forest, New Delhi, has identified the Khijadiya Wetland and Bird Sanctuary for conservation under the NWCMP Programme. The bird sanctuary and nearby wetland area is shown in Figure 4.

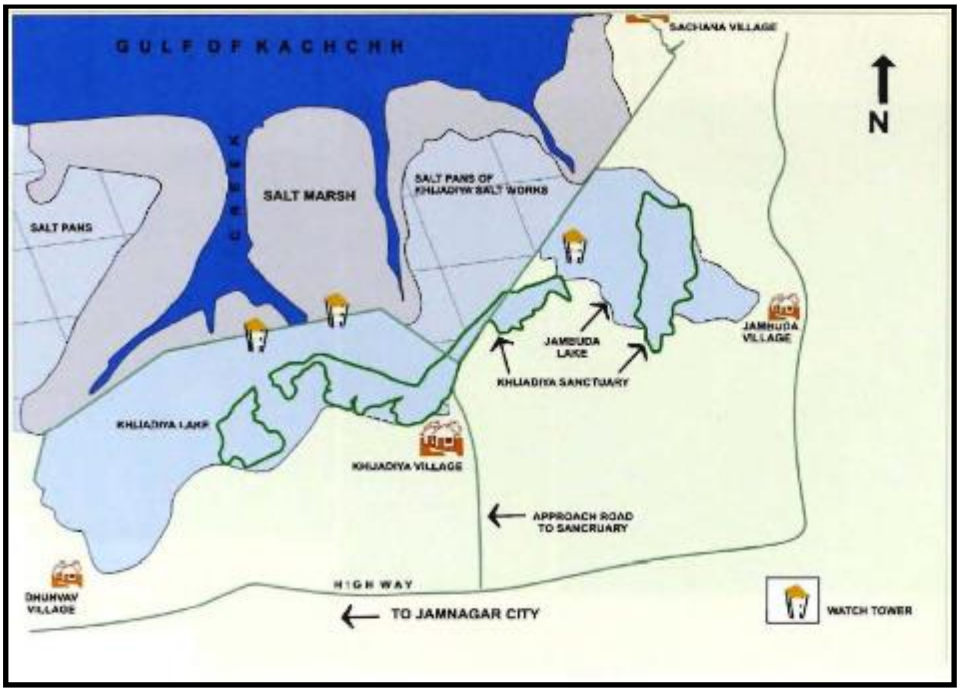


Figure 4 Map of Khijadiya wetland and bird sanctuary (Source: Zoological Survey of India, 2013)

3.1.3 Land use and cover

Jamnagar district consists of 73.62 per cent agricultural land, 17.28 per cent wasteland, 2.7 per cent built-up and remaining 6.40 per cent area covers forest, prosophisand quarry. The major land use categorisationsfound within wetland catchment area are: agriculture, built-up, forest, grass land, water bodies, waste land and wetland. The synoptic view of the satellite image (IRS-LISS-III) of the wetland catchment area is shown in Figure 5.

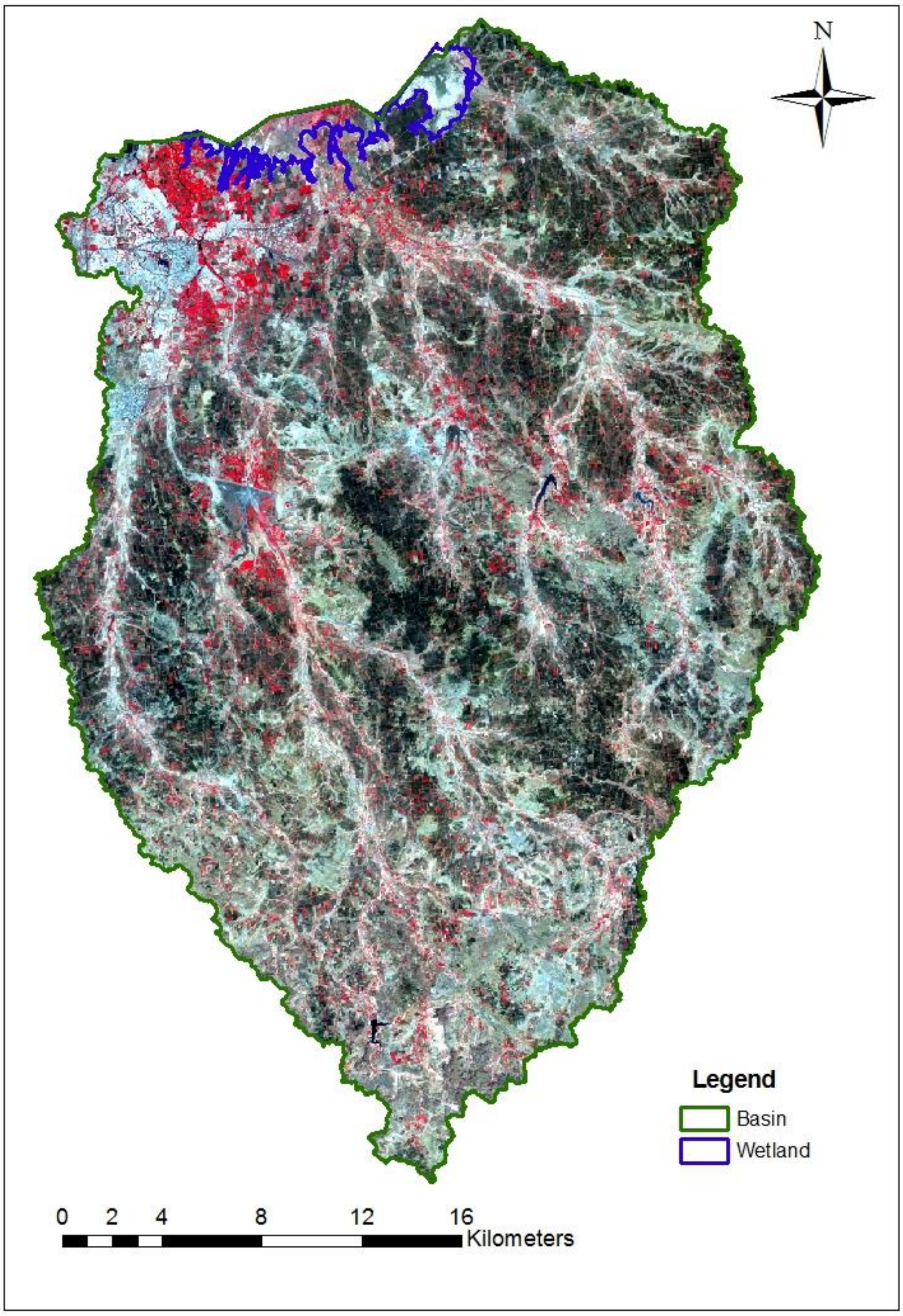


Figure 5 Synoptic view of the satellite image (IRS LISS III) of Khijadiya wetland catchment area, 23-02-2012

2.3 Assessment of water quality profiles

An intensive field survey was conducted in the month of March 2017. A few water samples were collected within the wetland and analysed for physical parameters in the field using micropocessor-based electrodes (pH and electrical conductivity). The chemical and trace metal analysis was carried out at Deltaic Regional Centre, National Institute of Hydrology, Kakinada. The location of the samples collected from the wetland is shown in Figure 6 and chemical analysis data is shown in Table 1. The water quality data indicated that samples are fresh water and this water is floating on saline water except at sample KH4. The physical, chemical and trace metals in KH1, KH2 and KH3 are within BIS(2012) drinking water limits.

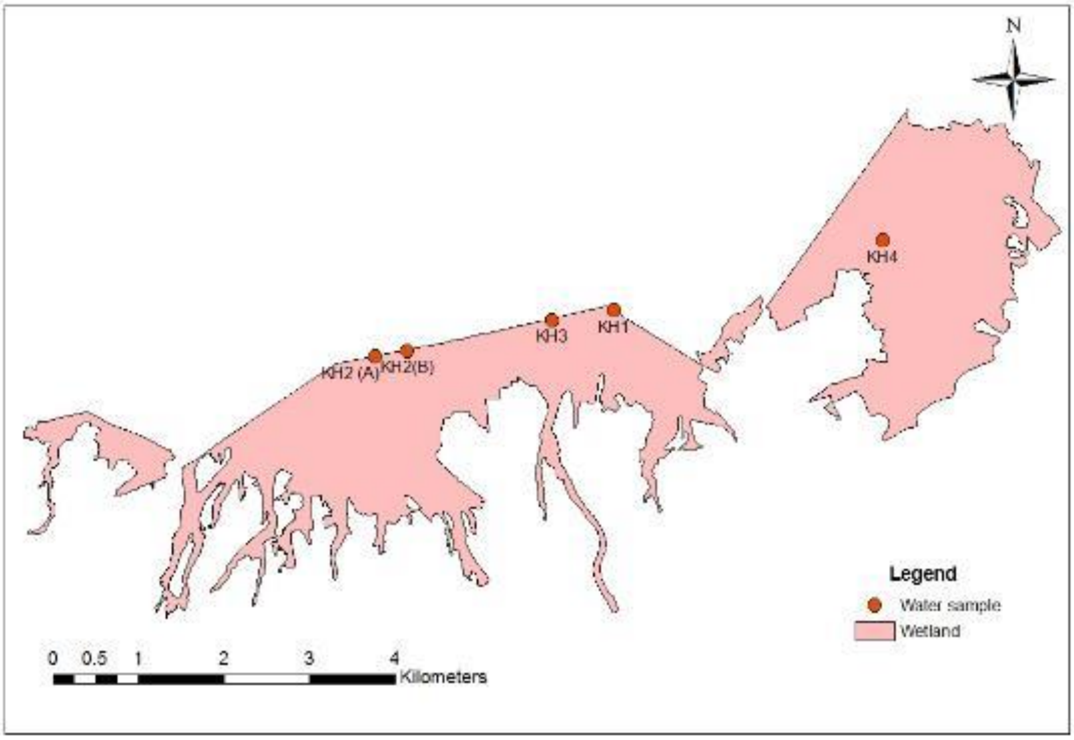


Figure 6 Location of water samples collected within the wetland in the month of March 2017

Sample Id	Temp in ^{0}C	pH	EC	Ca	Mg	Na	K	Cl	HCO_3	SO_4	NO_3	Cd	Li	Zn	Fe
KH1	30.20	8.70	2200	120	2	500	50	680	400	77	13	NA	NA	NA	NA
KH2 (A)	25.00	8.80	1650	40	39	450	45	290	510	82	34	0.0416	BDL	0.1761	1.0601
KH2(B)	23.50	8.70	1640	20	39	480	40	300	530	72	30	0.0416	0.5031	0.1667	0.3367
KH3	26.70	8.10	1800	48	44	415	45	360	290	179	11	0.0441	1.0054	0.0431	BDL
KH4	28.00	9.40	8600	52	158	2475	90	3160	180	267	12	0.0441	1.5257	0.0633	BDL

Table 1 Physical, Chemical and Trace Metal analysis of water samples collected from site in March 2017
**Electrical Conductivity (µmhos/cm) and all units are in mg/L. BDL: Below Detectable Limit*

2.4 Run-off modelling

There are many methods available to estimate run-off from a catchment area. However, these methods are based on lumped and distributed approaches. If the stream gauge/discharge data or inflow measurement into reservoir/pond is available, an advanced calibrated rainfall-run-off modelling can provide good estimation of run-off from the catchment. In the present study, widely used SCS-CN method has been used for run-off estimation. The SCS-CN curve number method is based on the water balance equation and two fundamental hypotheses, which are stated as: 1) ratio of the actual direct run-off to the potential run-off is equal to the ratio of the actual infiltration to the potential infiltration; and, 2) the amount of initial abstraction is some fraction of the potential infiltration.

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{for } P > Ia\ (0.2S) \qquad (1)$$

Where Q is run-off in mm and P is precipitation in mm, S = potential infiltration after the run-off begins given by:

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Where CN is Curve Number, The *CN* (dimensionless number ranging from 0 to 100) is determined from a table, based on land-cover, Hydrological soil groups (HSG), and Antecedent Moisture Content (AMC). HSG is expressed in terms of four groups (A, B, C and D), according to the soils infiltration rate. AMC is expressed in three levels (I, II and III), according to rainfall limits for dormant and growing seasons. CN value was adopted from Technical release (TR-55).

$$CNw = \frac{\sum(CNi + Ai)}{A} \quad (3)$$

Where *CNw* is the weighted curve number, while *CNi* is the curve number from 1 to any number; *Ai* is the area with the curve number CNi, and *A* is the total area. This methodology was applied to estimate annual run-off from Jamnagar district by Shay (2015) for a period of 20 years (1991–2010). The relation between annual rainfall and run-off for Jamnagar district is shown in Figure 7. The average run-off from Jamnagar district was found to be around 21 per cent of the annual rainfall. The same percentage has been adopted for the current investigation.

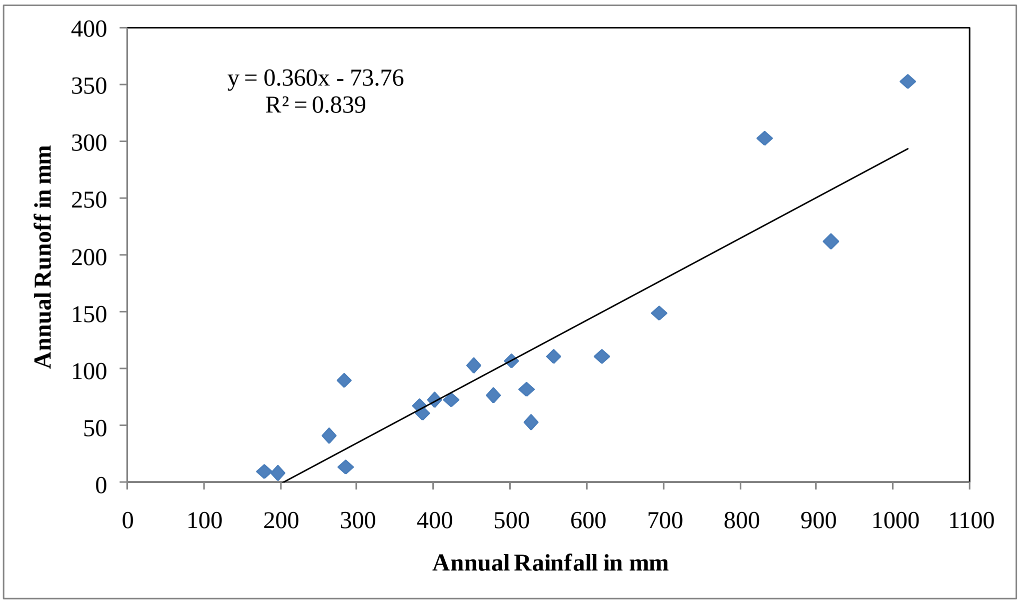


Figure 7 Relation between annual rainfallrun-off from Jamnagar district (1991–2010)

2.5 Water balance of Khijadiya

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:

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

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 Khijadiya 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

a. Water year

The data of various meteorological parameters for Jamnagar have been collected from KrishiVigyan Kendra, Jamnagar, from 2011 to 2016. The monthly average of rainfall and pan evaporation have been computed and shown in Figure 3. The measured annual rainfall near to wetland for the period from 2011 to 2016 was found to be- 660mm, 348mm, 1,211mm, 262mm, 303mm and 435mm respectively. The dry year or deficit rainfall year has been chosen for formulating management plan for the wetland. This is because if the management plan is prepared for the worst scenario, it can work for the lesser rainfall years also. Accordingly the water year of 2014–15 has been considered for the analysis, as it was the year with lowest rainfall during the period 2011–16 for which the data were available. The total annual rainfall for the water year 2014–15 was only 271mm and the monthly rainfall is given in the following Table 2.

Month	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	March-15	April-15	May-15
Total rainfall (in mm)	7	136.5	85	33	0	0.5	0	0	0	9	0	0

Table 2 Measured monthly rainfall in mm for the water year 2014–15

b. 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 8 (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.

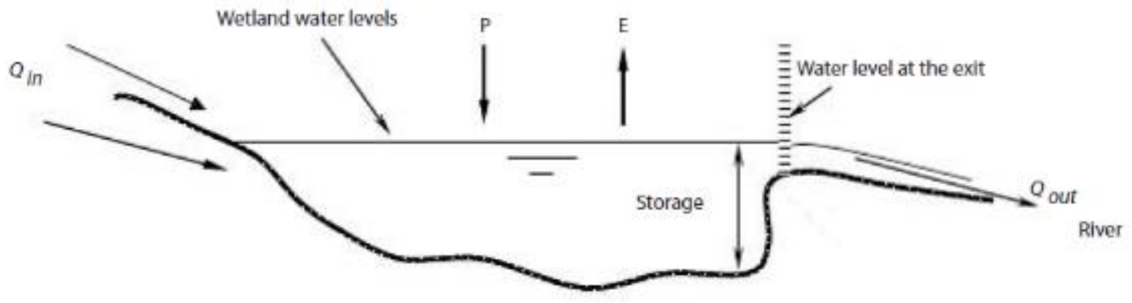


Figure 8 Seasonal wetland and water balance components

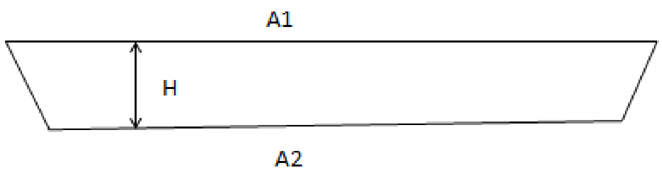


Figure 9 Cross-section of a hypothetical wetland

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. As far as Khijadiya wetland is concerened, its reported maximum surface area is 15.54km^2. Therefore, the bottom surface area of the Khijadiya wetland can be assumed to be somewhere between 10km^{2}and 12km^2.
Thus,

A1 = 15.54km^2

A2 = 10km^2 to 12km^2

Bathymetry data of the Khijadiya wetland are not available, As such, exact dimensions of its morphometry are not known. While a deeper water body like a lake or a dam has the deepest point located somewhere on its bottom, its bottom most surface (deepes point) respresents a point, making its cross section look like a cone. Therefore, for estimating volume of a lake or a dam, the shape of the lake or dam is assumed to be a cone in the bathymetric studies. The Khijadiya wetland has three basins with different depths. However, from the observations made in the field, there is not significant variation in the depths of the three basins of the Khijadiya wetland. Further more, being a very shallow wetland, the bottom surface can not be considered as a point but a surface. Also, from the field observations it is clear that the average depth for the Khijadiya wetland can be assumed to be 1ft or, at the most, half a metre (30cm or 50cm). Thus, a wetland can be assumed to be a conical frustrum, with a cross sectional view as shown in Fig. 9 above. .

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

$$V = \frac{1}{3} \times H\left(A1 + A2 + \sqrt{(A1 \times A2)}\right) \quad (5)$$

Where A1, A2 and H are surface area of the top surface, surface area of the bottom surface and average depth of wetland, respectively. Based on the assumption of bottom surface ($10km^2$ or $12km^2$) and depth (30cm or 50cm), as explained above, the storage capacity of the Khijadiya wetland has been estimated using the equation 5 for volume of a conical frustrum. The estimated capacities of the the wetland are given in Table 3.

Assumptions		Storage capacity (Million cubic metres)
1	Bottom surface area = $10km^2$ Average depth = 30cm	2.55
2	Bottom surface area = $10km^2$ Average depth = 50cm	4.26
3	Bottom surface area = $12km^2$ Average depth = 30cm	2.75
4	Bottom surface area = $12km^2$ Average depth = 50cm	4.59

Table 3 Various combinations of wetland storage capacity

c. Estimation of total inflow

Total inflow to the wetland is the sum of inflow due to surface run-off from catchment (downstream of the reservoirs) + inflow due to direct rainfall over the wetland. Total inflow into wetland has been calculated as 21 per cent of the rainfall falling over the catchment downstream of the reservoirs, based on the runoff coefficient of 21% for Jamnagar area as reported by Shah (2015). The catchment area downstream of the reservoirs is $305km^2$ including the wetland area. The maximum water spread area of the wetland is $15.54km^2$, and therefore, the area of the catchment area of the wetland downstream of the reservoirs is $289.46km^2$. The computed monthly inflows into the wetland are given in Table 4. Thus, the total water received by the wetland during 2014–15 as inflow was only 20.7Mcum, of which 16.5Mcum was contributed by the catchment downstream of reservoirs and 4.2Mcum was contributed by the Inflow due to direct rainfall over wetland. Most of the water was received during the four monsoon months of June to September in 2014. Thus, about 19.9Mcum was received during monsoon 2014 of which about 15.9Mcum was from the catchment and about 4.0Mcum from direct rains over the wetland.

Month	Rainfall (mm)	Total magnitude of water generated in the catchment below reservoirs (m^3)	Inflow due to run-off from catchment d/s of reservoirs (21% of b) (m^3)	Inflow due to direct rainfall over wetland (m^3)	Total inflow to wetland (c+d) (m^3)
	(a)	(b)	(c)	(d)	(e)
June 2014	7	2,026,220	425,506.2	108,500	534,006.2
July	136.5	39,511,290	8,297,370.9	2,115,750	10,413,120.9
August	85	24,604,100	5,166,861	1,317,500	6,484,361
Sept	33	9,552,180	2,005,957.8	511,500	2,517,457.8
Oct	0	0	0	0	0
Nov	0.5	144,730	30,393.3	7,750	38,143.3
Dec	0	0	0	0	0
Jan 2015	0	0	0	0	0
Feb	0	0	0	0	0
March	9	2,605,140	547,079.4	139,500	686,579.4

Month	Rainfall (mm)	Total magnitude of water generated in the catchment below reservoirs (m³)	Inflow due to run-off from catchment d/s of reservoirs (21% of b) (m³)	Inflow due to direct rainfall over wetland (m³)	Total inflow to wetland (c+d) (m³)
April	0	0	0	0	0
May 2015	0	0	0	0	0
Total	271	78,443,660	16,473,168.6	4,211,060	20,684,228.6

Table 4 Computed wetland inflows for the water year 2014–15

Based on the assessment of storage capacity of the wetland (Table 3), which is 2.55 Mcum to 4.59Mcum, the wetland cannot hold more than this capacity and rest of the water overflows. However, it may be noted that even the deficit rainfall of 271mm would be sufficient to fill the wetland capacity completely during monsoon. 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 this capacity shall be able to survive the evaporation losses during the post monsoon period, is the main issue of investigations. For this we need estimates of evaporation.

d. Estimation of evaporation losses

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–Monteithmethod. The Penman–Monteithequation as per Allen et al.(1998), is:

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

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 (γ) 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). The estimated daily evaporation rate of wetland is shown in Figure 10.

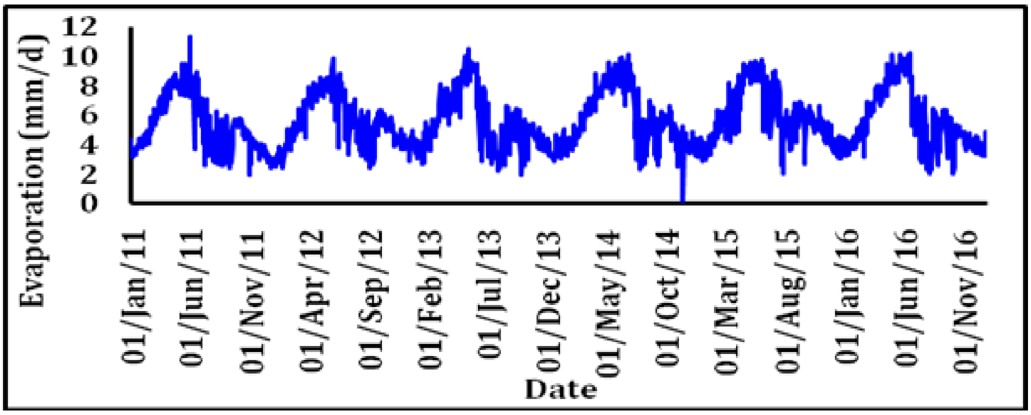


Figure 10 Computed daily wetland evaporation rate

Based on the daily evaporation rates of the wetland (2011–16), the average daily evaporation rates have been computed for different months. These values are shown in Table 5 and the average daily evaporation for the water year 2014–15 is given in Table 6.

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 5 Average daily evaporation from wetland (2011–16)

Month	Average daily evaporation (mm/d)	Total evaporation during the month (mm)
June 2014	8.73	261.9
July 2014	5.92	183.52
August 2014	4.85	150.35
September 2014	4.79	143.7
October 2014	5.20	161.2
November 2014	4.29	128.7
December 2014	3.82	118.42
January 2015	3.87	119.97
February 2015	5.23	146.44
March 2015	6.17	191.27
April 2015	8.16	244.8
May 2015	8.96	277.76

Table 6 Average evaporation rate for the year 2014–15

The average depth of water in wetland is 30cm or 50cm, the capacity of wetland would be full by the end of the monsoon period. During the post monsoon period, the total evaporation losses from October to January was about 53cm and from October to November, about 29cm. Therefore, if the average water depth is 30cm in wetland, the wetland shall more or less dry by the end of November and if the average depth is about 50cm, the wetland shall dry by the end of January.

From the on-field discussions, it was found that the wetland starts drying more or less during January-end and some water is left only during the deeper parts. This is because depths are not same at all the locations. Thus, it appears that the average depth is more or less 50cm (which appears a reasonable assumption compared to 30cm). For estimation of evaporation in volume terms, data on surface area corresponding to various depths in the wetland is required. Evaporation loss in a specific period, in volume terms, is estimated by multiplying the average surface area by average evaporation rate during that period. The storage capacities and water spread areas of the wetland are shown in Figure 11. The capacity of the wetland starts increasing from bottom to top. At the bottom, the storage capacity is zero where as the capacity is maximum at top surface, which corresponds to maximum water spread area of the wetland. The storage capacity of the wetland varies between this maximum and zero storage capacity. As the depth of water from bottom increases, the volume of water in the wetland increases. At different depths the surface areas (i.e. the water spread area) also variy. The surface area increases from bottom to top. To determine the change in surface area and change in volume at different depths, depth-surface-area curves are needed. This has been developed for the wetland and shown in Fig. 11. Since surface areas and volume are known only for bottom and top of the wetland (i.e. minimum and maximum conditions), the remaining values have been interpolated from these values.

Volume of evaporated water has been estimated by applying evaporation rates to the water spreas area represented by the surface area of the wetland. For example, in October 2014, the average daily evaporation rate was 5.20 mm/d. This has been multipled by the 31 number of days of October to get the total evaporation depth in that month. This comes out to be 161.2 mm (16.2 cm). Thus, the total evaporation loss from the wetland during October, 2014 was 16.12cm. Based on the earlier explaination, assuming the water depth of the wetland was at maximum water depth (50cm) at the end of monsoon, that is, on 30th September, 2014, a loss of 16.12cm shall bring the depth down to 33.88cm (say 34cm) by the end of October, 2014. From Figure 11, the corresponding volume for the assumption of 10km^2 bottom area shall be about 2.9Mcum. The total evaporation loss in volume terms comes out to be (4.26 - 2.9 = 1.36Mcum). For the 12km^2 bottom area assumption, the corresponding volume comes out to be 3Mcum and the total evaporation loss comes out to be (4.59 -3.1= 1.49Mcum). Similarly, it can be estimated for the month between November 2014 and January 2015, etc.

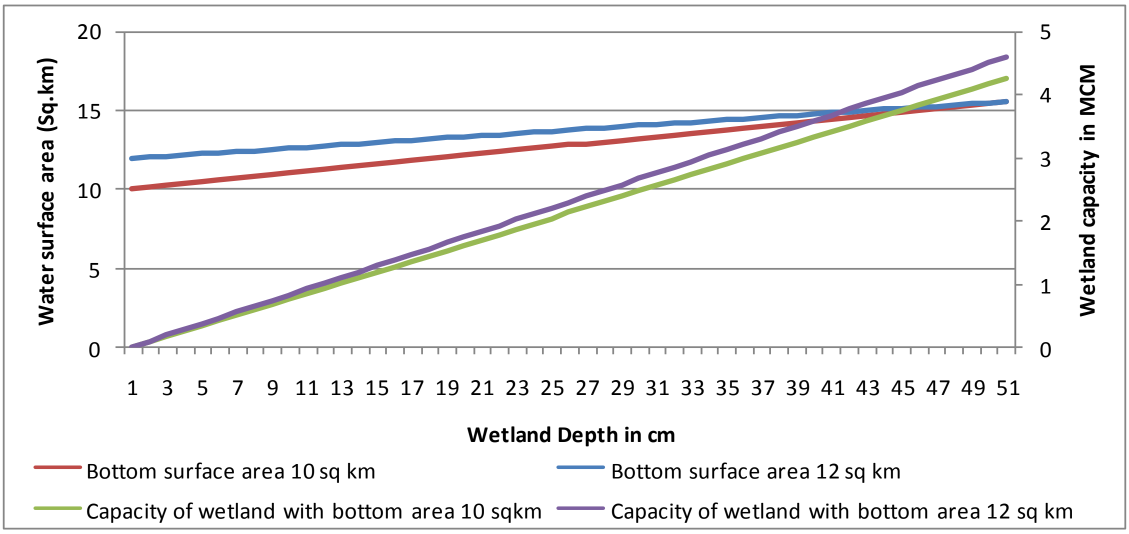


Figure 11 Wetland water spread area and capacity at different depths of the wetland

From the average evaporation rates for the post monsoon period from 1 October to 31 May (based on the averages for 2011–16), the evaporation during the post monsoon period is as follows:

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Average. daily evaporation rate (mm/d)	5.16	4.22	3.69	3.75	4.66	6.5	7.88	8.73
Total evaporation in cm	16.00	12.66	11.44	11.63	13.05	20.15	23.64	27.063

Table 7 Evapaoration across the year

Thus, from the above table, it is clear that the total evaporation during October and November shall be about 29cm and during October–January it shall be about 52cm. Since the average depth of wetland is only about 50cm, the water can last only, say, by the end of January.

2.1.5 Conclusion

The analysis of water balance carried out for the year 2014-15, which was the driest year with the lowest rainfall, among all the years of the period 2011-16, clearly indicates that the wetland can get enough water during the monsoon and its capacity is filled completely during the monsoon, even if the rainfall is very deficit. The major issue is that the wetland is not able to sustain the water till the end of summer, because of heavy evaporation losses. Since evaporation is a natural phenomena and hence can not be easily controlled, if the water of the wetland has to last till May-end, following management plans can be taken up:

i) At present, a significant amount of water is overflowing from the wetland during monsoon because the wetland does not have adequate capacity to hold the water. Thus, it is recommended to increase the storage capacity of the wetland through dredging, to trap the overflowing water. This will increase the capacity of the wetland and it can hold more volume of water.

ii) Evaporation is a major factor and it is a surface phenomena. This means that evaporation losses would depend upon water spread area of the wetland. This, in other words, means that if the water spread area is more, evaporation losses would be more. So, dredging should be done in such a way that top surface area is not increased, but depth is increased. This would mean more water, without increasing the top water spread area. In other words, it means that the water may be stored depth-wise and not laterally, so that it can last for more days by reducing the volume of evaporation losses.

iii) If we want to maintain a specific depth say 30cm (of the average depth of 50cm) throughout the summer months, then we have to work out the total evaporation loss of water during the post monsoon season for this depth. The corresponding water spread area for the 30cm depth for assumed 10km^2 bottom condition is 13.32km^2 and for 12km^2 bottom surface assumption it comes out to be 14.12km^2 from the interpolation curves. Now, the average evaporation for the post monsoon period of October–May is 5.57mm/d. So the total evaporation losses would come out to be 0.074Mcum per day for the assumed 10km^2 bottom condition and 0.079 for the 12km^2 assumed bottom condition. Since there are 243 days from 1 October to 31 May, the total evaporation loss for these 243 days comes out to be 18.02–19.11MCM. This means that about 18–19Mcum (say, about 20Mcum) of water shall be required for the post monsoon period to maintain the 30cm depth in the wetland throughout the summer (if there is no increase in the present capacity)

iv) Some of this water may be supplied by preventing the overflow and storing the water in a reservoir. However, since there would be evaporation losses from such reservoirs, it is likely to be a challenge to fulfil the above demand. Increasing depth of the wetland through dredging may not be able to fulfill the requirement. This is because the present capacity of the wetland is about 5 Mcum at the average depth of about 50 cm. 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 ground water.

v) Thus, it is obvious that additional water may have to be brought from other sources, such as the reservoirs located upstream of the wetland to meet the water requirements of the wetland for the period of January to May. This requirement could be around 19 Mcum, if no dredging of the wetland is carried out or less, depending upon the depth of dredging, if it is carried out.

2.6 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 brackish/saline ground water. Since the groundwater surrounding Khijadiya Bird Sanctuary 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 wetland. However, siltation is also an essential ecological feature of wetlands, and removing siltation process can lead to loss of certain ecosystem characteristics. But certain temporary siltation prevention measures to regulate the level of silt entering the wetland can be explored, such as siltation traps. A temporary sediment or silt trap can be formed by excavating or by constructing a small embankment of stone, stone-filled bags, or other material to retain sediment.

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 that the sediment can settle out. The outlet can be a rock-lined depression in the containment berm.


Figure 12 Examples of temporary silt traps
Source: http://transportation.ky.gov/Environmental-Analysis/Environmental%20Resources/5-Sediment%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 wetland, 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– 20 Mcum of 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 Khijadiya Bird Sanctuary 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).[2] 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.[3]

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.[4]

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 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

[2] Source: IPCC, https://www.ipcc.ch/ipccreports/tar/wg1/518.htm
[3] 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
[4] Source: https://unfccc.int/resource/docs/publications/impacts.pdf

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 13 below.

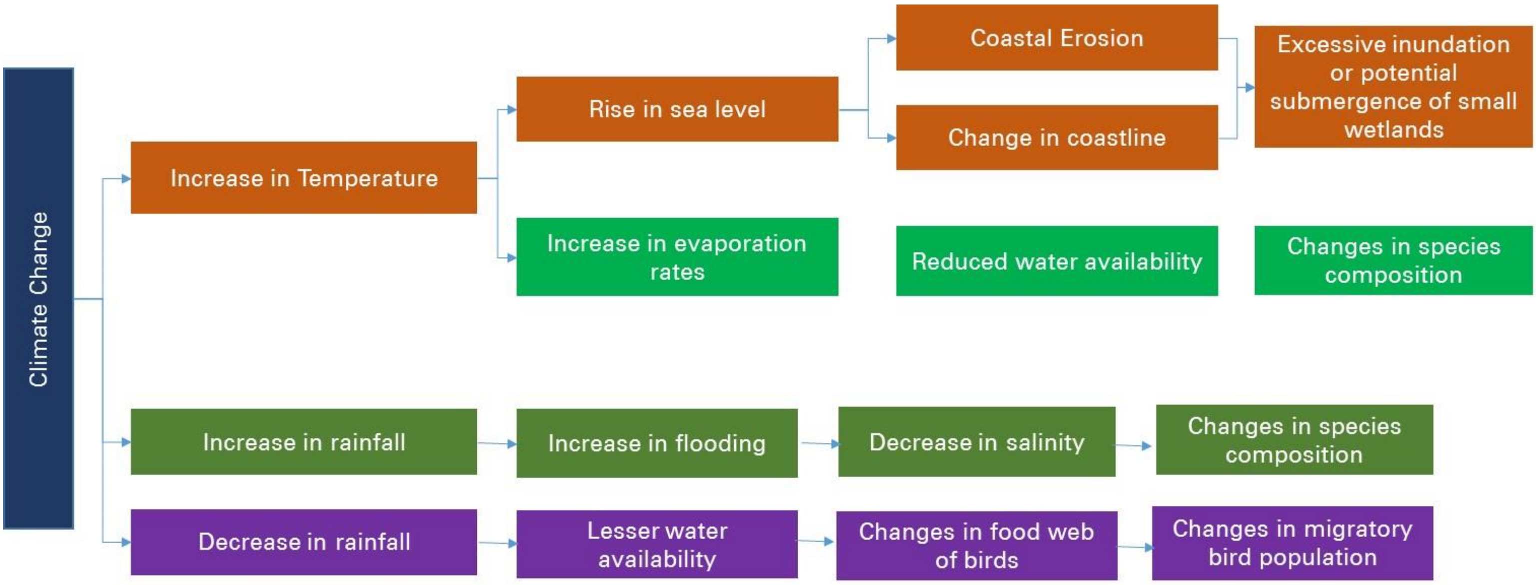


Figure 13 Potential impacts of climate change on coastal wetlands

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 wetland.

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

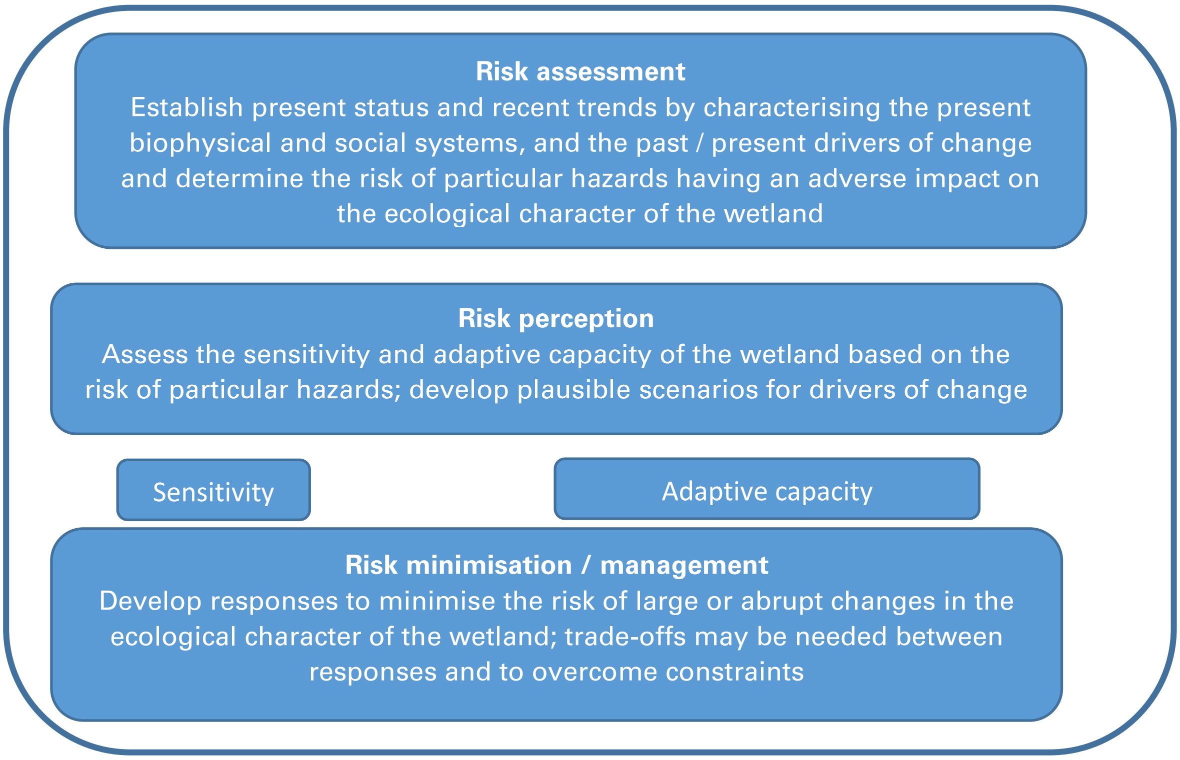


Figure 14 Approach to climate risk and vulnerablity assessment

Based on this framework, the climate vulnerability of Khijadiya Bird Sanctuary 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.[5] 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 15, 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

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

and the corresponding concentration peak (seen from Figure 15) do not occur at the same time due to the storage and subsequent release of gases like CO_2 by the land and ocean reservoirs as a part of the carbon cycle.

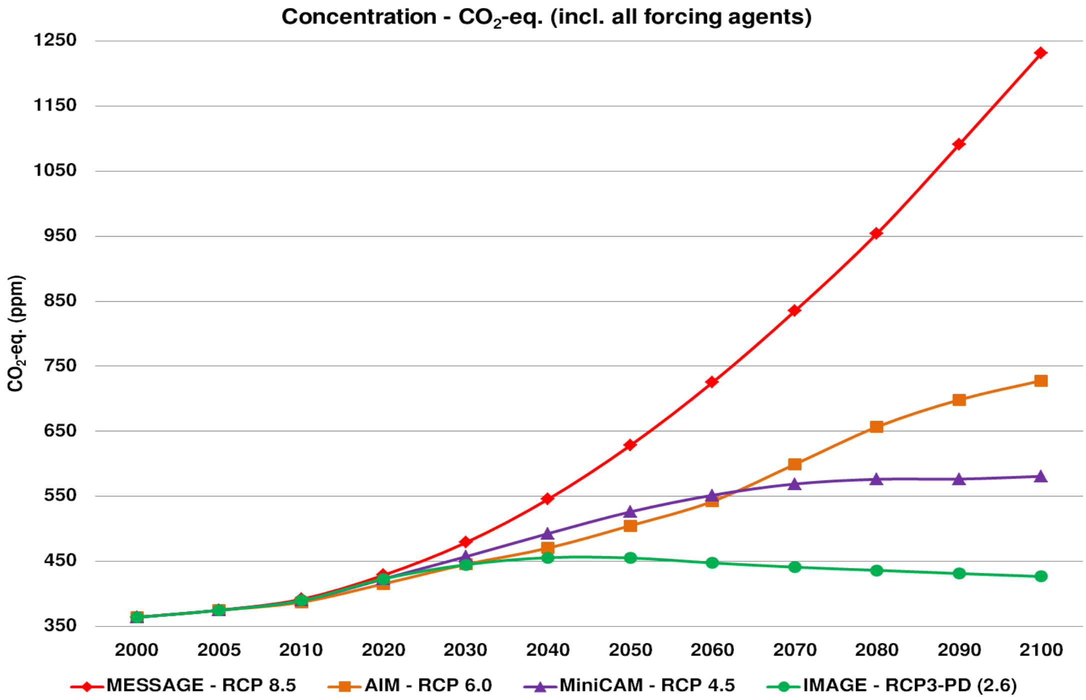


Figure 15 Atmospheric CO2-equivalent concentrations (ppmv) of all forcing agents in RCP Scenarios (IPCC AR5)

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 Khijadiya Bird Sanctuary.

3.3 Climate change assessment, projections and vulnerability of Khijadiya Bird Sanctuary

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 Khijadiya 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 Khijadiya wetland in the current climate

An analysis of the historical dataset for temperature from 1979–2016 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. It is to be noted that Figure 16 below illustrates the average temperatures in the grid boxes, and the actual temperatures observed over a specific location inside a given grid box could be somewhat higher or lower than the grid box mean value.

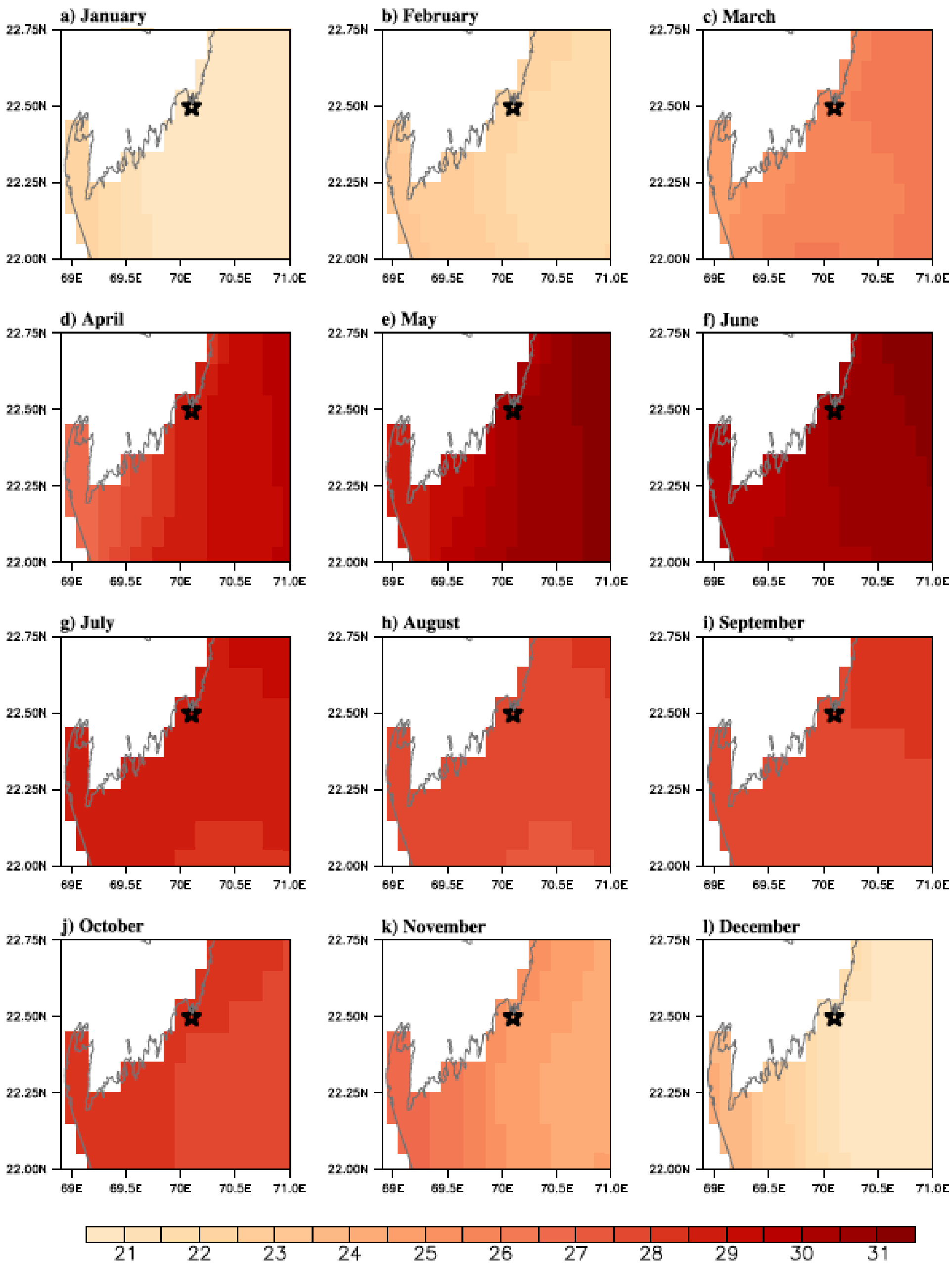


Figure 16 Climatological mean 2m air temperature (degree C) over the Khijadiya wetland region (marked by a star) from ERA-Interim reanalysis dataset for the period 1979–2016 for individual months

The results of the trend analysis of observed historical dataset for air temperature are illustrated in Figure 17. The stippled (dotted) regions in the graph represent a significant variation in temperature over time, and the colours representing the trend in T2m in degree C per 38 years. It can be seen that there has been a significant change in temperature in the region around Khijadiya, especially in the months of March and November at a rate of around 1.6°C per 38 years (approximately 0.4°C per decade).

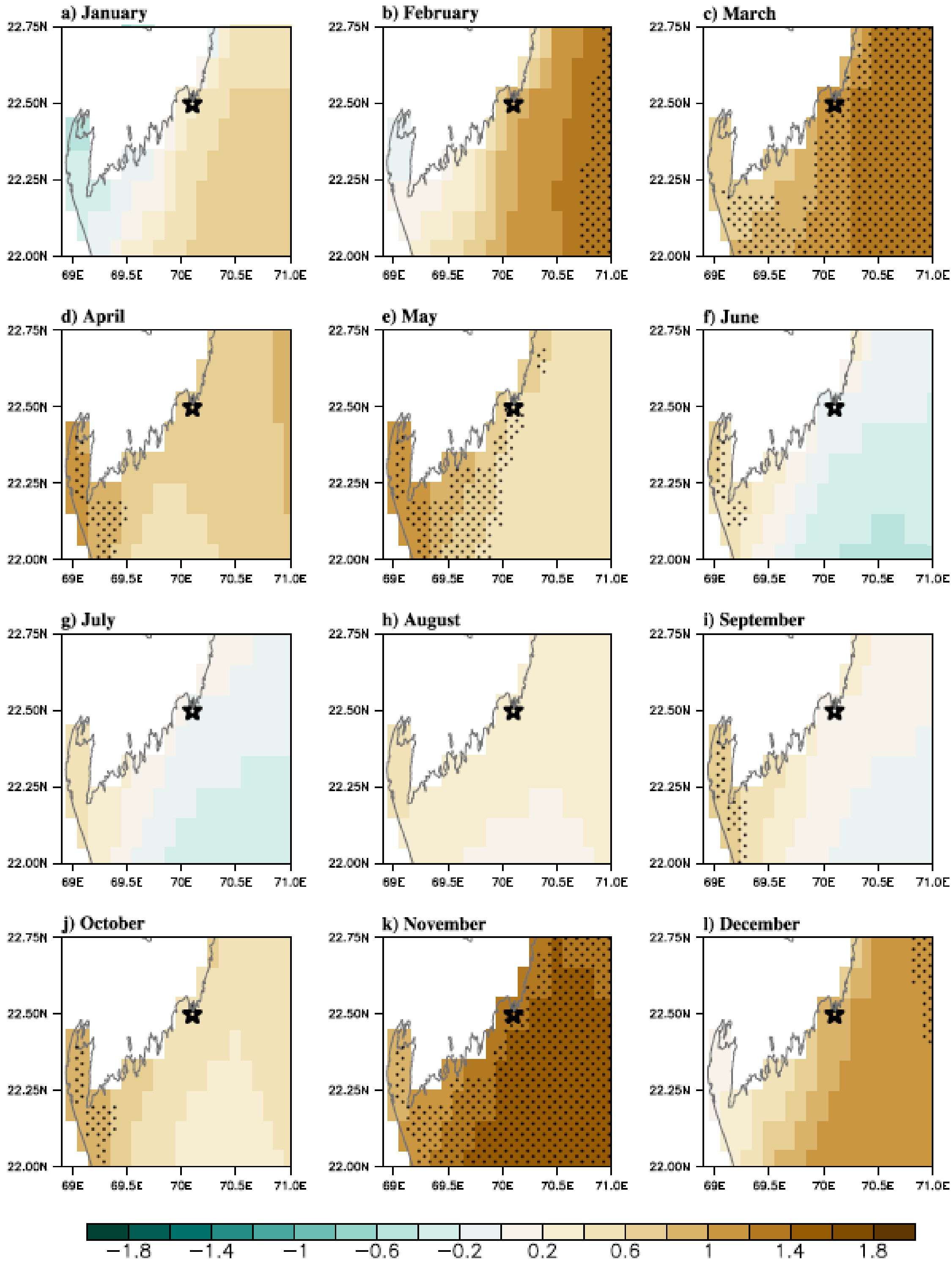


Figure 17 Observed trend in the mean 2m air temperature (degree C per 38 years) over the Khijadiya wetland region (marked by a star) from ERA-Interim reanalysis dataset for the period 1979–2016 for individual months

3.3.2 Temperature characteristics over the Khijadiya wetland under global warming

The 20-year projected change (compared to the baseline period of 1985–2005) in air temperature in the region around Khijadiya is illustrated in Figure 18. It can be seen that a sharp increase in temperature within the range of 0.9°C and 1.2°C is projected in the months of March and December. This is in line with the increasing trend seen in the historical data for temperature in the month of March in this region between 1979 and 2016, as illustrated in Figure 16.

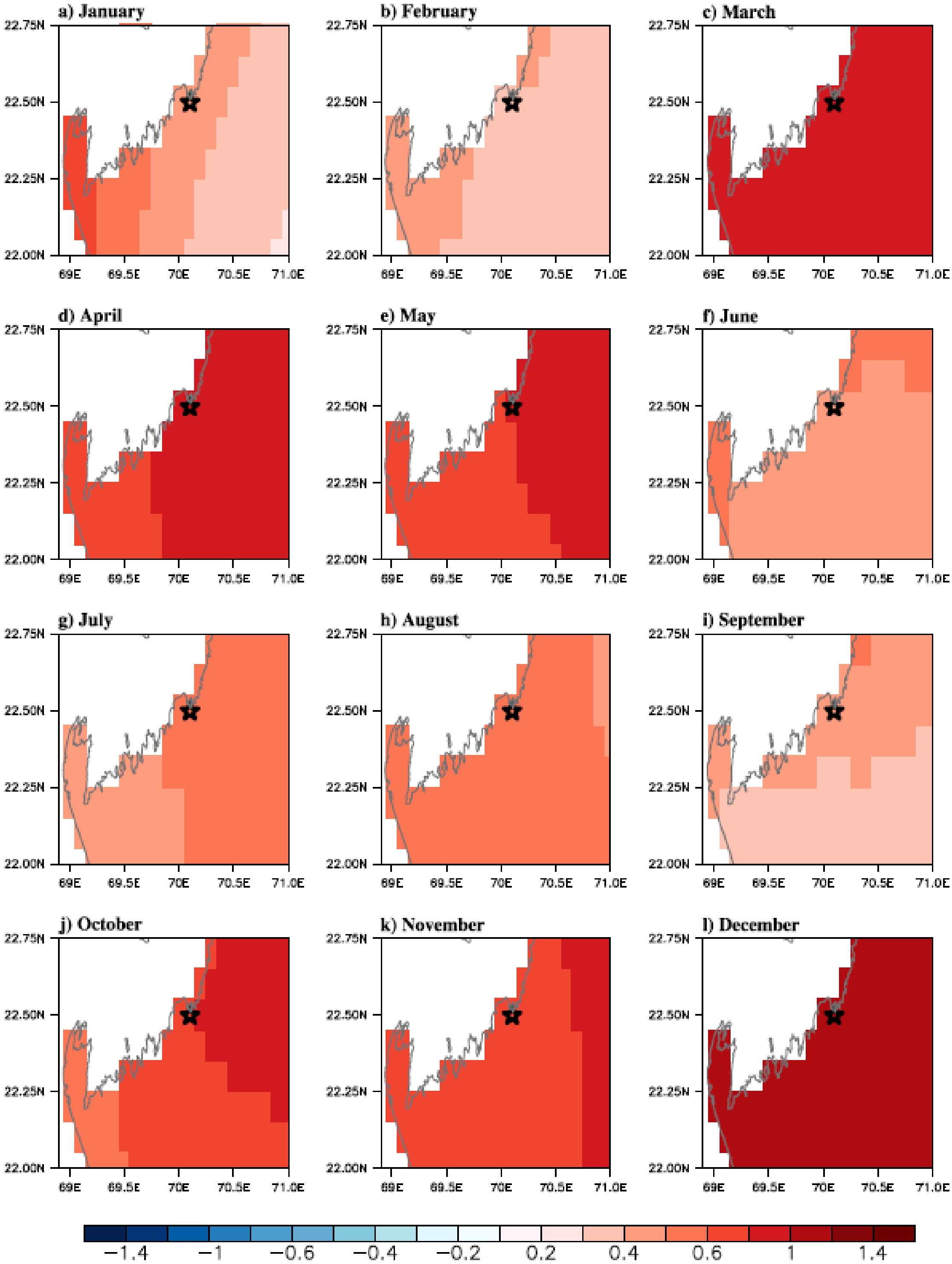


Figure 18 Projected change in 2m-air temperature (degree C) over the Khijadiya wetland region (marked by a star) under the RCP8.5 global warming scenario for the near-term (2016–36) for individual months as compared to the baseline period of 1985–2005

It can also be seen from Figure 18 that the temperature levels across the region are projected to increase across most months within the range of 0.4°C and 1.12°C across the year. This implies that an overall increase in temperature is projected for the Khijadiya wetland region for the next two decades.

3.3.3 Rainfall characteristics over the Khijadiya wetland in the current climate

An analysis of the historical dataset of rainfall patterns for the period from 1998 to 2014 shows that July is the wettest month with the maximum average monthly rainfall, followed by August and September.

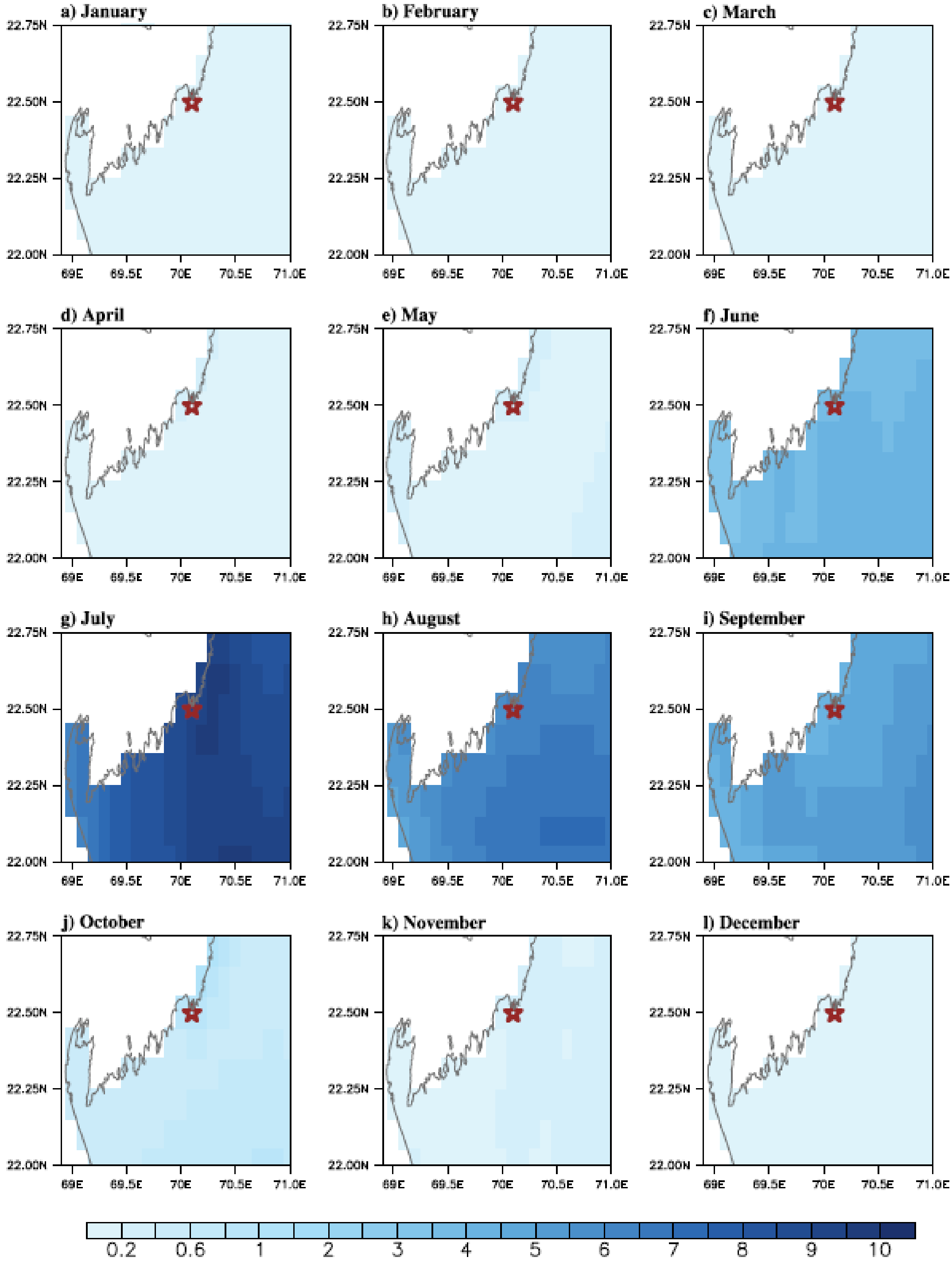


Figure 19 Climatological mean rainfall (mm/day) over the Khijadiya wetland region (marked by a star) from TRMM satellite retrievals for the period 1998–2014 for individual months

3.3.4 Rainfall characteristics over the Khijadiya wetland under global warming

Figure 20 illustrates the 20-year projections for spatial rainfall distribution in the region around Khijadiya wetland. It can be seen that a sharp increase in rainfall in the range of 0.6mm and 1.5mm per day is projected in the month of August, which has also been one of the wettest months in the region historically. However, a sharp fall in the rainfall level, in the range of 0.2mm and 0.6mm per day, is also projected in the following month of September.

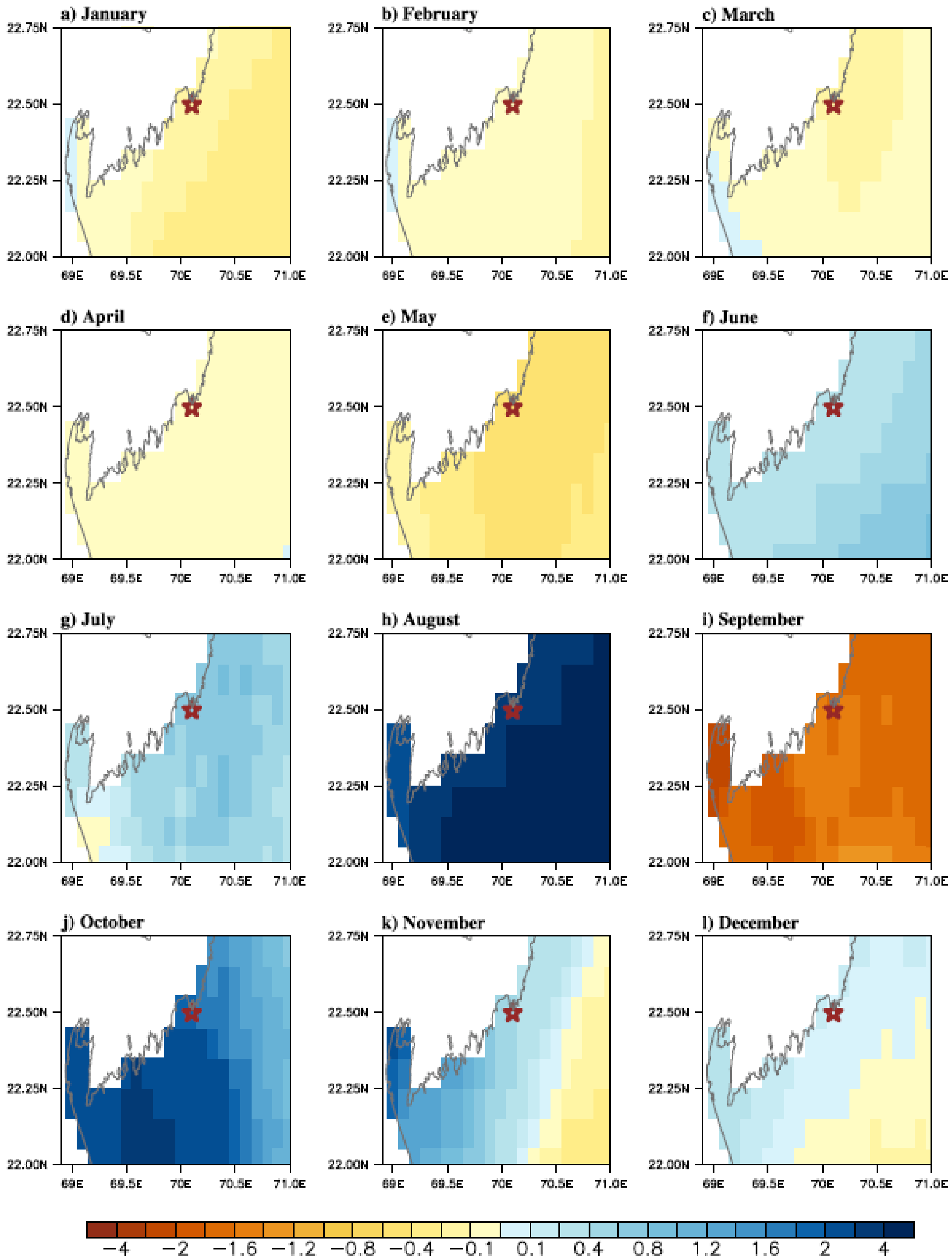


Figure 20 Projected change in rainfall over the Khijadiya wetland complex region (marked by a star) under the RCP8.5 global warming scenario in the near-term (2016–36) as compared to the baseline period of 1985–2005

While rainfall is projected to be decreasing from January to May, a small increase in the range of 0.2mm and 0.6mm per day is projected in the month of June, followed by a decreasing trend again in July, historically the wettest month of the year over the region. Thus, the overall projection trend for rainfall across the year remains unclear. However, it can be ascertained that the rainfall patterns are expected to be unevenly spread, and a likely shift in the wettest months can be expected.

The average monthly changes in temperature and rainfall levels in Khijadiya wetland and its catchment have been summarised in the Tables 8 and 9 below.

Month	Change in temperature (ºC)	Change in rainfall (mm/month)
January	0.46	-3.94
February	0.38	-0.02
March	0.96	-3.56
April	0.87	-0.46
May	0.80	-15.63
June	0.48	7.33
July	0.52	18.88
August	0.53	109.97
September	0.44	-46.85
October	0.78	58.42
November	0.73	15.44
December	1.12	3.24

Table 8 Projected temperature and rainfall changes in Khijadiya wetland, 2016–36

Month	Change in temperature (ºC)	Change in rainfall (mm/month)
January	0.42	-6.31
February	0.37	-0.01
March	0.96	-3.29
April	0.86	-0.28
May	0.79	-16.29
June	0.46	11.13
July	0.52	19.28
August	0.53	130.86
September	0.40	-46.59
October	0.77	68.50
November	0.73	9.96
December	1.12	1.22

Table 9 Projected temperature and rainfall changes in Khijadiya catchment, 2016–36

3.3.5 Sea level rise projections for the coastlines neigbouring Khijadiya Bird Sanctuary

Given that the geographical location of the Khijadiya wetland 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, and especially important in the context of Khijadiya wetland. 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 the Khijadiya 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 Khijadiya Bird Sanctuary, the sea level timeseries available for the Mumbai coast is used as a proxy for estimating the corresponding SLR over the Khijadiya 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 10 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 Khijadiya wetlands, 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 11 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 Khijadiya Bird Sanctuary, 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 11 Sea level rise projections near Khijadiya wetland, 2020–35

Table 11 shows that the sea level near the coasts adjoining Khijadiya wetlands 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 base 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 12 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 the 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 Khijadiya Bird Sanctuary

The climate change scenarios for Indian conditions have been discussed in above sections and provided projections of daily precipitation and daily mean temperatures for Khijadiya Bird Sanctuary 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 the wetland. 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 Khijadiya Bird Sanctuary 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 in Khijadiya Bird Sanctuary

The projected rainfall data in Figure 21 for the 20-year period (2016–36) clearly shows that there is no declining trend in rainfall at Khijadiya catchment. As a matter of fact, there is an increasing trend in the annual rainfall. This means that the rainfall considered for hydrological analysis of the wetland (water balance previously reported in earlier section) is not going to get worsened. The rainfall considered as worst scenario for analysis was 271mm as reported in 2014–15. The projected data indicates that the worst (most deficit) water year in the next 20 years shall be year 2035–36 with an annual rainfall of 270.4mm, which is more or less the same as the year considered for analysis 2014–15 with annual rainfall of 271mm. Thus, inflow components for the most deficit projected year of 2035–36 is likely to be the same as has been reported already for the year 2014–15 in the analysis reported in the earlier section. However, since temperatures are likely to be more, therefore, it is important to see how this would affect the evaporation and, subsequently, the hydrology of the wetland. This aspect is analysed in the following sections.

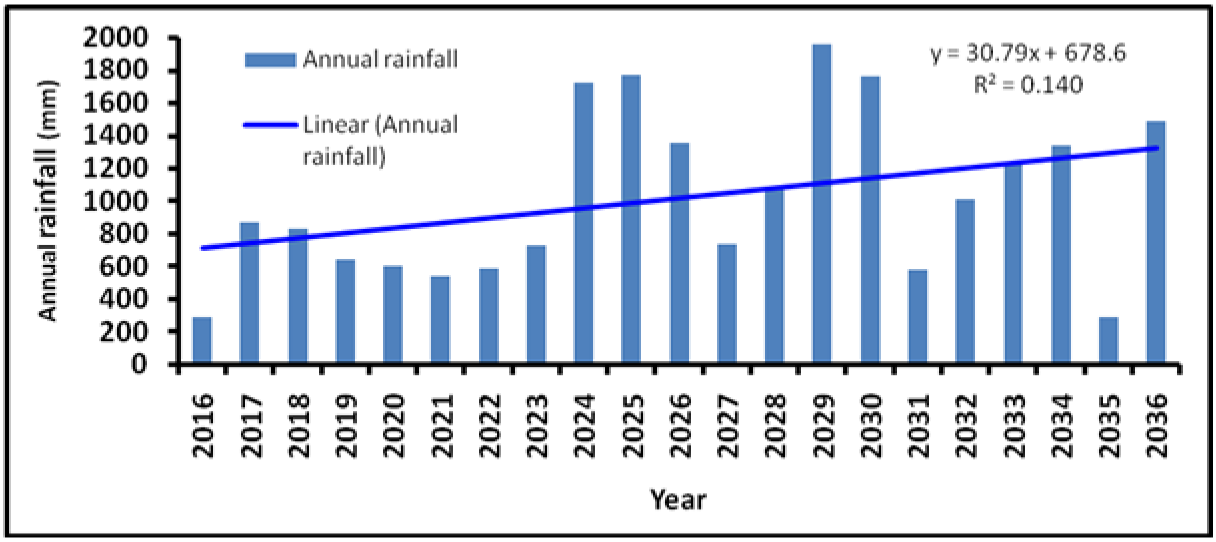


Figure 21 Projected annual rainfall of Khijadiya wetland for 2016–36

Temperature analysis of Khijadiya Bird Sanctuary

It was learnt that the mean temperature at Khijadiya 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 Khijadiya wetland for the 20-year period is available and is shown in Figure 22. 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).

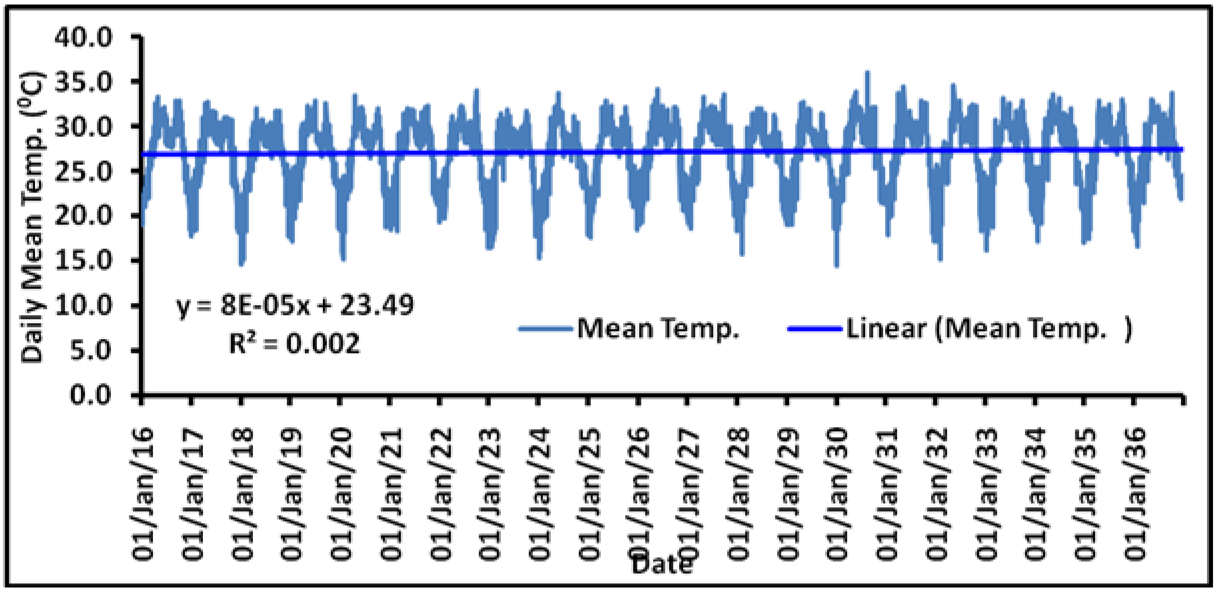


Figure 22 Projected temperature of Khijadiya wetland for 2016–36

Effect of temperature change on evaporation of Khijadiya Bird Sanctuary

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 Khijadiya 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 Khijadiya Bird Sanctuary

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 23. 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.

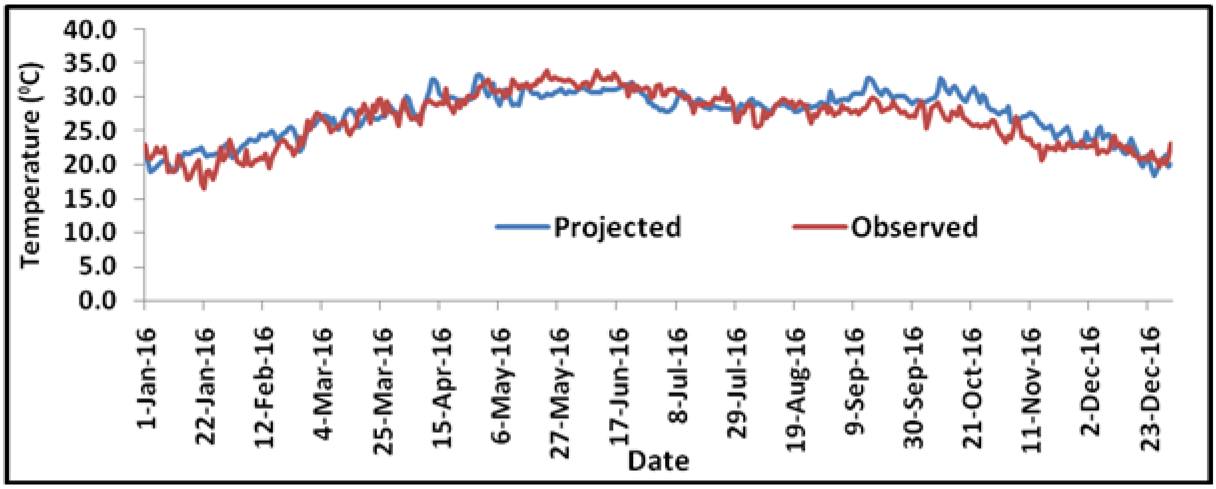


Figure 23 Observed versus projected mean temperature data for year 2016

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 24, 25, and 26, respectively. It can be seen 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 the Khijadiya wetland areas in specific months or specific seasons. On the other hand, evaporation appears to be decreasing for the area during many times of the years.

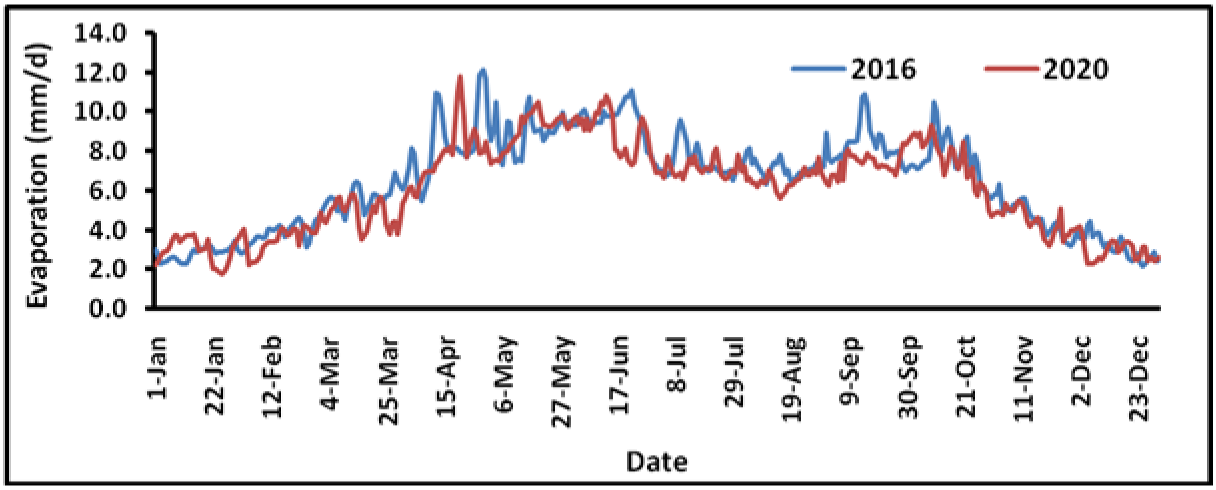


Figure 24 Comparison of projected evaporation rates of 2020 with the evaporation rates of 2016 for Khijadiya wetland

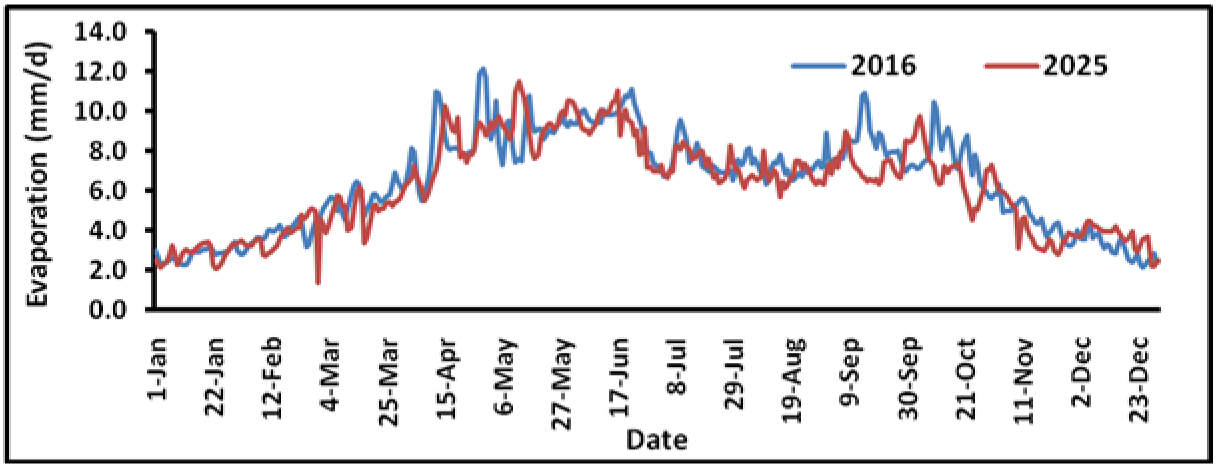


Figure 25 Comparison of projected evaporation rates of 2025 with the evaporation rates of 2016 for Khijadiya wetland

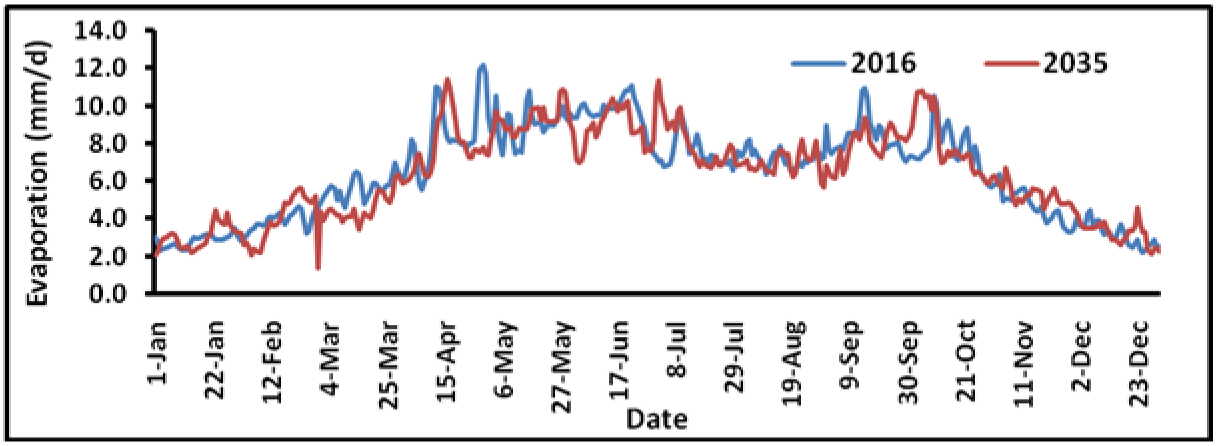


Figure 26 Comparison of projected evaporation rates of 2035 with the evaporation rates of 2016 for Khijadiya wetland

Decreasing characteristics of evaporation are further illustrated in Table 13, 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 13 Expected evaporation characteristics of different projected years

Table 14 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 14 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 14 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 Khijadiya Bird Sanctuary

As mentioned earlier, evaporation rate estimated from the Penman–Monteith model is considered as more precise, and was therefore used in the analysis of water balance for the wetland. The expected change in evaporation estimated from the projected data of evaporation shall be applied to this evaporation to get the average evaporation for the period 2016–35, as presented in Table 15.

Month	Present average rate of evaporation (2011–16) (mm/d)	Expected percentage change in evaporation during 2016–35	Expected average evaporation during 2016–35 (mm/d)
January	3.8	14.88	4.3
February	4.7	-0.28	4.6
March	6.5	-17.91	5.3
April	7.9	-4.78	7.5
May	8.7	3.95	9.1
June	7.6	-7.11	7.0
July	5.2	1.77	5.3

Month	Present average rate of evaporation (2011–16) (mm/d)	Expected percentage change in evaporation during 2016–35	Expected average evaporation during 2016–35 (mm/d)
August	4.4	-6.67	4.1
September	5.1	-11.72	4.5
October	5.2	-0.25	5.1
November	4.2	3.95	4.4
December	3.7	18.34	4.4
Mean	**5.6**	**-0.49**	**5.5**

Table 15 Expected average evaporation for the Khijadiya wetland for the period 2016–35

Table 15 indicates that the projected average evaporation rates are higher for the winter months of November, December and January. They are lower for the months of February, March and April, but are higher for the month of May. They are lower for the monsoon months of June, August and September, but are marginally more for July. They are also marginally lower for the transient month of October. However, it may be noted that the various monthly projected percentage change in evaporation give a net change in evaporation of -0.49 per cent, which means that average evaporation for the entire water year altogether shall be more or less the same as that of year 2016. Hence, no additional water is required for managing the water scarcity challenges of the Khijadiya wetland for the next 20 years, other than the requirement already specified under the water management plan discussed in the earlier sections.

3.5 Impacts of climate change on biodiversity of the wetland

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 Khijidiya Bird Sanctuary, 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.

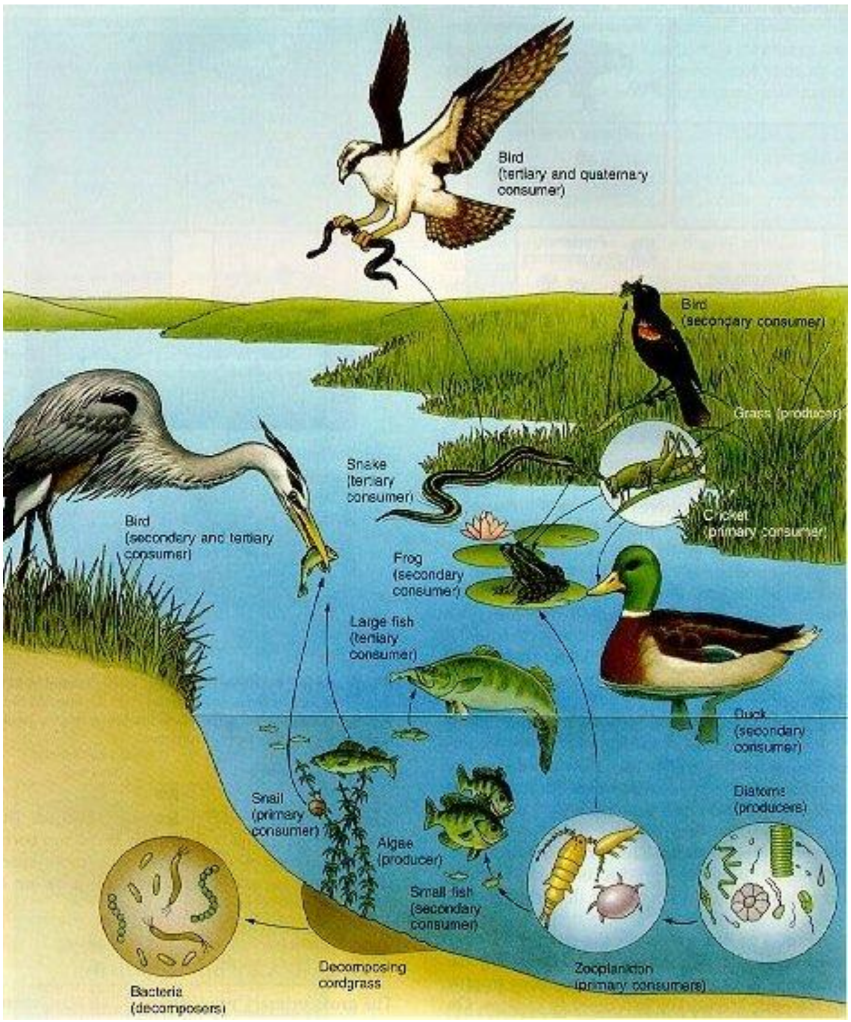


Figure 27 Illustration of a typical wetland food web. It consists of detritus (the decomposing cordgrass), nutrients produced by primary producers (algae, codgrass, diatoms) and a range of consumers (zooplankton, cricket, fish, frog, snake and birds)

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.

For example, in the Khijadiya Bird Sanctuary, the near-threatened Eurasian Curlewfeasts upon annelid worms and various insects such as beetles, locusts and crickets, along with mollusks, small crustaceans, polycheate worms, and the occasional tadpoles, frogs, fish, lizards, small birds and rodents (Johnsgard, 1981; del Hoyo et. al. 1996)). Another near-threatened bird, Black Tailed Godwit, is prominent in the sanctuary and also feeds on the adult and larvae of insects, like beetles, along with crustaceans, fish eggs and tadpoles (del Hoyo et. al. 1996).

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 Khijadiya Bird Sanctuary, water birds such as the Common and Demoiselle Crane and the majority of terrestrial birds (Figure 28) such as the Rosy Starling and Red vented Bulbul may be directly affected by such ecological responses of their prey.

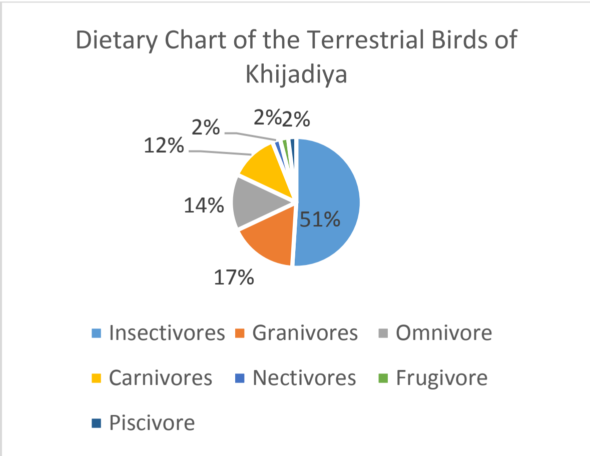


Figure 28 Dietary behaviours of the terrestrial birds in Khijadiya Bird Sanctuary.
It is to be noted that insectivores make up about half of the terrestrial bird population.
Source: Interim Report on Faunal Biodiversity Assessment, July 2016

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.

However, since the fish population in Khijadiya is not too significant due to limited water availability around the yeat, this risk is considered to be relatively less prominent than other biodicersity impacts.

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 Khijadiya Bird Sanctuary 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 would 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 Khijadiya Bird Sanctuary may disperse to a more favourable location in the long run.

To summarize, observed and projected trends in temperature and rainfall could be detrimental to the biodiversity of Khijadiya Bird Sanctuary. 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 wetlands 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 wetlands. Mangroves would also be disadvantaged with increasing temperatures and rainfall variation.

3.6 Recommendations for improving adaptive capacity of Khijadiya Bird Sanctuary

Based on the vulnerability assessment conducted, the following adaptation measures have been identified to respond to the imminent climate change impacts on Khijadiya Bird Sanctuary. 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. Khijdaiya village and Dhunvav village near the sanctuary)
- 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, needs to be identified and reduced. 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 wetlands from thriving and increase soil erosion rates. Development activity within and near both 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. 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.

9. Shoreline control measures

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

Proposed implementation time: Medium/long term

Description:

T To protect the wetland from sea-level rise, erosion, and storms, the Forest Department or the Salinity Control Department, 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

Measure	Description
	• 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

10. 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).

Khijadiya can be characterised as a reclaimed estuarine marsh land exhibiting reduced interactions with the proximal marine ecosystem. Khijadiya has come in to existence as a result of construction of a salinity ingression wall. 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 the wetland losing almost all of their surface water during the dry season.

The process of locking carbon dioxide away from the atmosphere is called carbon sequestration. 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 the wetland, simultaneously acting as carbon sink and source.

Photosynthesis along with the resulting decomposition reactions are the primary drivers for carbon compounds to be introduced within Khijadiya. 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 Khijadiya 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 Khijadiya. 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 wetlands are 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 Khijadiya. Thus allowing the wetland manager to take modular decisions to influence sub-habitats of the wetland complex.

4.1 Carbon fluxes in Khijadiya

In Khijadiya, 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. Khijadiya contains five main carbon reservoirs, which interact with each other leading to the carbon flux action. (Fig. 39).

Carbon reservoirs at Khijadiya

- Plant biomass carbon
- Particulate organic carbon
- Dissolved organic carbon
- Microbial biomass carbon
- Refractory carbon — Gaseous Carbon products (CO_2, CH_4)

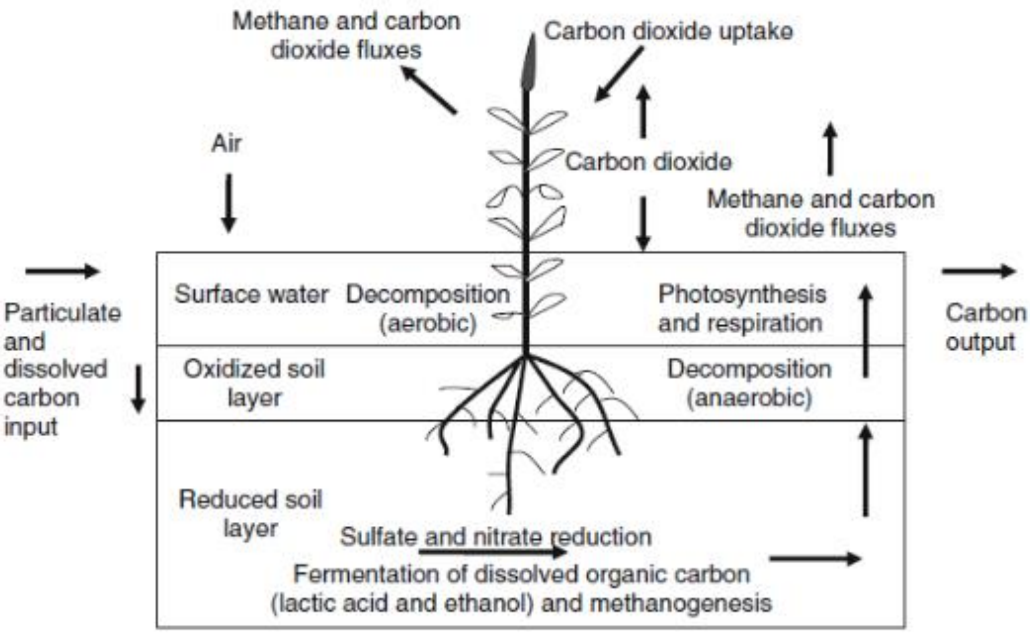

Figure 29 Carbon cycle for wetlands (Kayranli Birol, 2010)

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 Khijadiya 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 wetland. Thus, Khijadiya 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

The Khijadiya wetland 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 two sub-sections provide influencers of carbon flux within Khijadiya wetland. Considering the fluctuating character of Khijadiya, 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 wetland relatively decreased.

4.1.1 Carbon flux influencers in Khijadiya

Khijadiya has six sub-habitats classified as follows:

- Water
- Drying wetland
- Dried wetland
- Salt marsh vegetation
- Mangroves
- Land vegetation

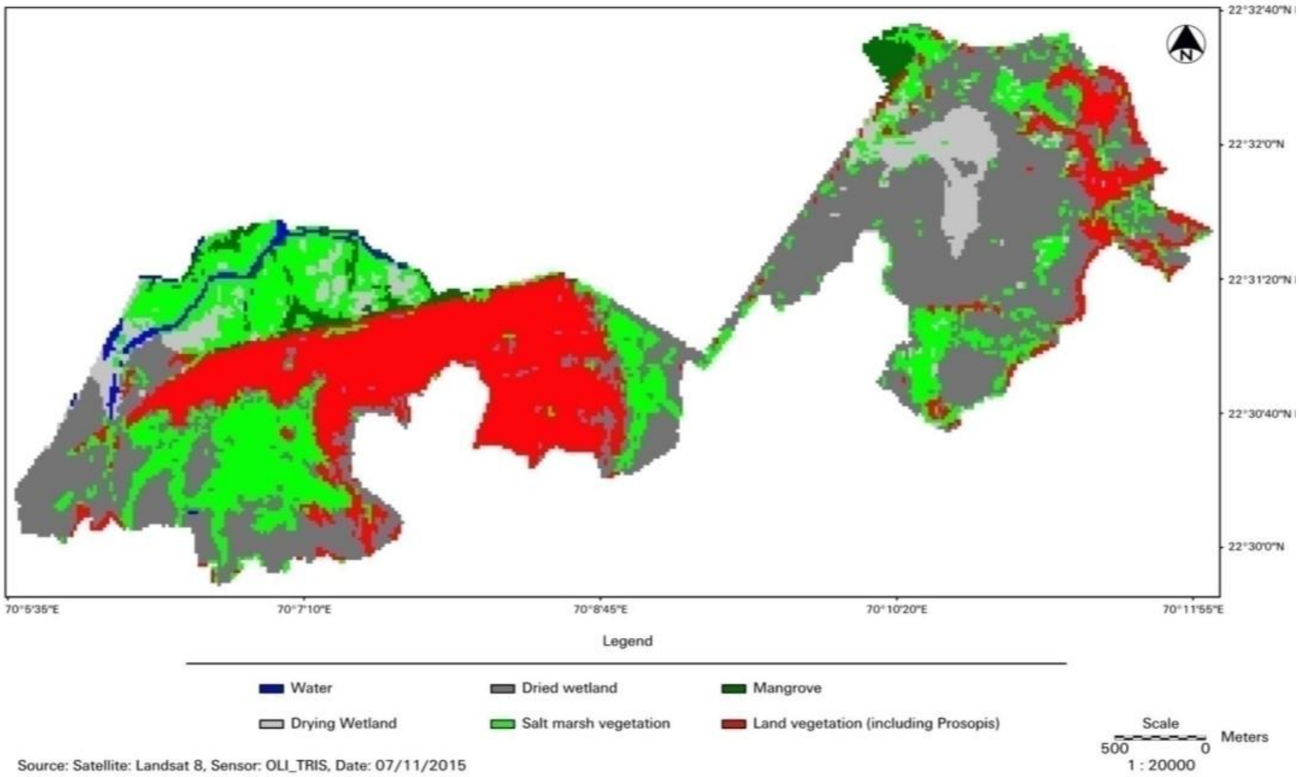

Figure 30 Khijadiya Wetland Habitat Map – Wet season 2015, (Nagar, 2016)

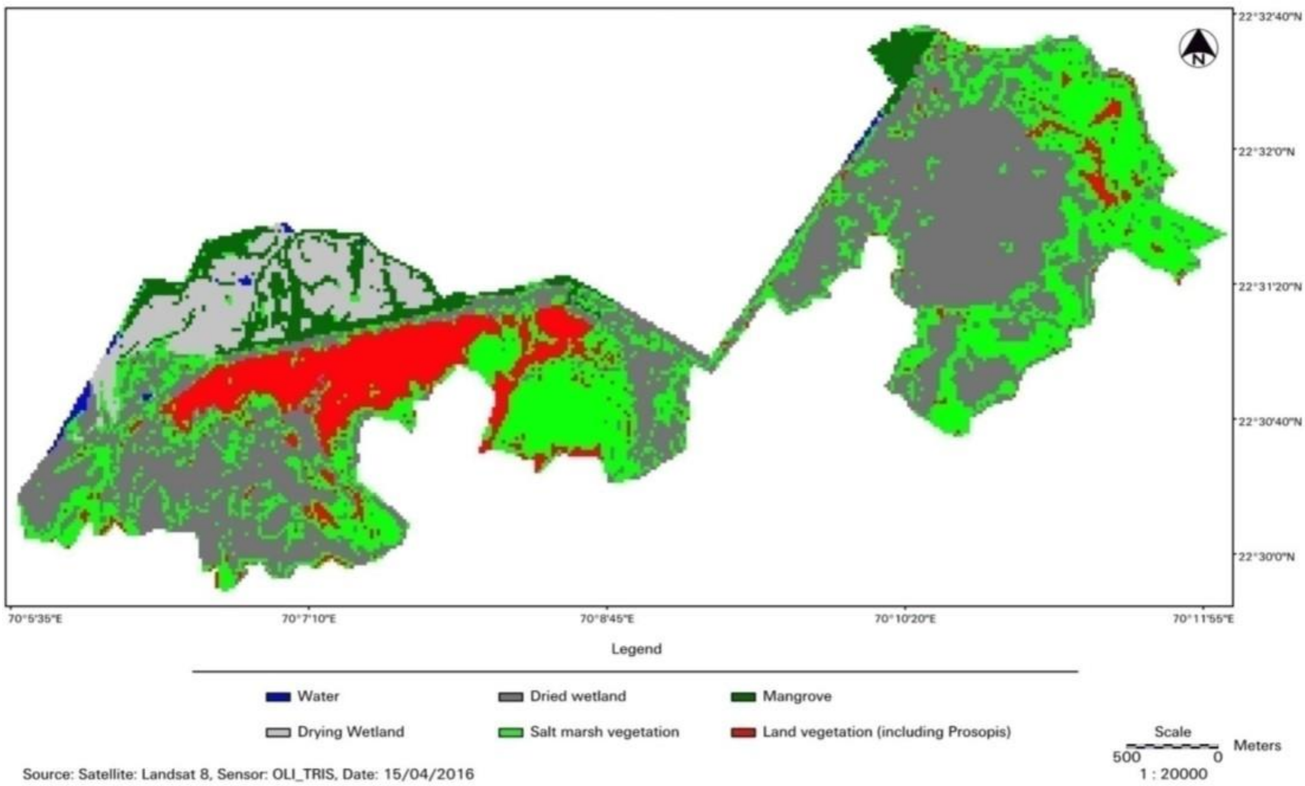

Figure 31 Khijadiya Wetland Habitat Map – Dry Season 2016, (Nagar, 2016)

There is a wide fluctuation in the area under only certain types of sub-habitats over a year. The study evaluated each sub-habitat separately by super-imposing carbon flux compositions that play an active role to sequester and or release carbon. The specific carbon fluxes taken into account are provided below. Overall the study found that the annual influencers of carbon flux are net negative, being influenced by the decrease of land vegetation by almost 50 per cent and the resultant conversion of this land to drying wetland and salt marsh vegetation. The study team observed methane release actions (through methanogenesis) in the drying wetland type of sub-habitat during the field visit.[6]

The sub-habitas demarcated using the GIS maps provided above are categorized in Table 16. 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	0.2	1	0.2	1	0	No change
Drying wetland	1.3	7	1.5	8	15	Increase
Dried wetland	7.9	41	7.9	41	0	No change
Salt marsh Vegetation	4.6	24	6.1	32	33	Increase
Mangroves	0.5	3	1.2	6	140	Increase
Land vegetation	4.8	25	2.3	12	-50	Decrease
Total	19.3		19.3			

Table 16 Sub-habitat driven carbon flux in Khijadiya (Source: Nagar, 2016 and KPMG analysis)

In Khijadiya, particulate organic carbon that is usually suspended in water columns and consists of decaying plant matter, microbial cells, particulate influent, and particulate organic substances were found deposited on the soil surface. Particulate organic carbon that exists in suspended water columns is released from the wetland through methane actions. However, since these were found directly exposed to air, methane actions were found to be largely restricted.

Water pockets existing on the wetlands comprise less than 1 per cent of the total wetland, and contained suspended microbes and microbial residues. Microbial biomass carbon, transforms organic carbon back to inorganic carbon, mineralised particulate organic carbon and, dissolved organic carbon.

However, this turnover of active biomass happens over a long term (decades) in submerged wetlands, considering the almost complete drying of the wetland during the dry season and retention of only 0.2km^2 water inundated area, this pathway of depositing carbon within the soil is almost absent for Khijadiya. It is also important to note that these trenches have been constructed only in the last two–three years and considering the decadal time frame over which this pathway produces any quantifiable inorganic carbon, the study was unable to quanitifiably represent this carbon flux pathway.

Carbon release in Khijadiya wetland environment is complex, and the various decomposition reactions within the drying wetland sub-habitat take place at different horizons; for example, respiration and methane oxidation occur in the aerobic zones while methanogenesis occurs in anaerobic zones. However, the highest rates of carbon release through decomposition are found closest to the wetland surface where there is an elevated input of fresh litter and recently synthesised labile organic matter.

[6] More research would be required to quantify the contribution of methane fluxes to the carbon release actions of Khijadiya.

Active plant growth during the wet season and the decomposition reactions over the dry season were the primary carbon flux in action at the Khijadiya wetland.

With the primary carbon accumulation being the long-standing vegetative influence from trees (*Prosopis juliflora, Acacia nilotica, Azathiracta indica, Leucaena leucocephala, Phoenix sylvestris, Tamarix indica*, *Avicennia marina,* etc.), the aerobic and anaerobic reactions resulted in carbon release in the form of CO_2 and methane.

4.2 Assessing carbon sequestration potential of Khijadiya

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 the Khijadiya wetland has conditions of high water table, and thus low decomposition rates, they sequester more carbon than they release, 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, they release back the carbon captured (Kayranli Birol, 2010).

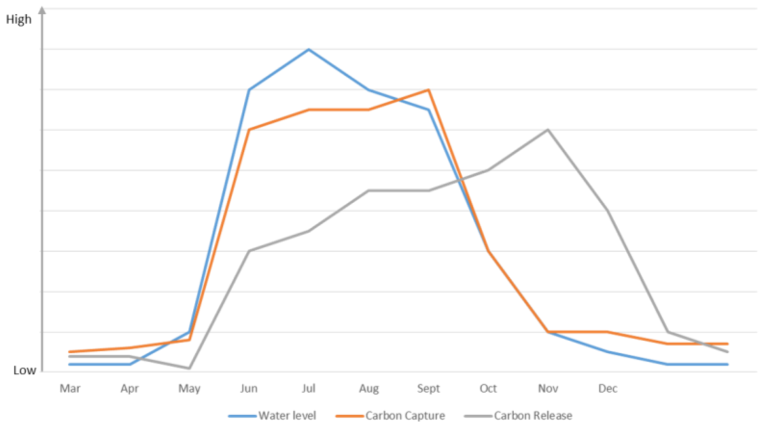

Figure 32 Indicative Water level, Carbon Capture, Carbon Removal processes (Source: KPMG Analysis)

Having a high water table results in more anaerobic decomposition of matter which is much slower thanaerobic 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[7] than carbon dioxide, which gets released through aerobic decomposition.

For Khijadiya, due to the primary presence of drying wetland sub-habitat and, both anaerobic and aerobic decompositions of matter are primary drivers for carbon release.

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.

[7] 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.

In Khijadiya, 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).

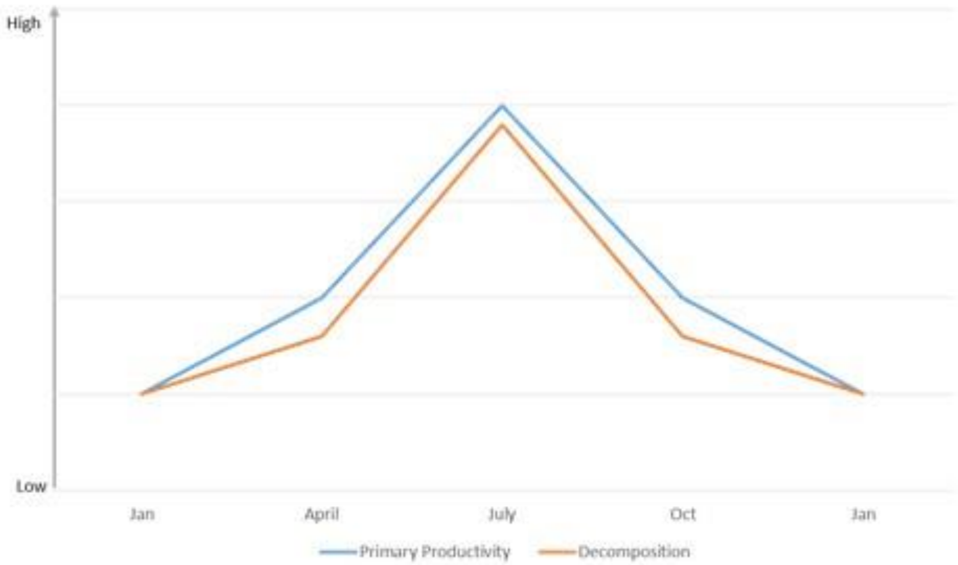

Figure 33 Indicative Productivity and aerobic Decomposition Rate variance and differential (Source: KPMG Analysis)

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 seasonal wetland, such as Khijadiya, 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 occur in the *water* sub-habitat area and is a carbon emission pathway for Khijadiya wetland.

The water table level of wetlands 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.

Khijadiya is a partially flooded wetland and hence sequesters carbon dioxide and releases methane into the atmosphere. The combination of these two factors determines whether these offsetting processes make a wetland system an overall contributor to the greenhouse effect. Maximising permanent vegetation in Khijadiya could provide an increase in the carbon sequestration potential.

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 of Khijadiya

Increasing the carbon sequestration potential for Khijadiya while ensuring that its ecological character is not disturbed would require:

- A systematic improvement of the Mangroves of Khijadiya wetland: The area on the seaward side of Part 1 and Part 2 of the sanctuary both have mangrove forests amounting to an area of 1.2 Km^2. These mangroves may be conserved and saplings may be planted in this area to ensure continued growth of the mangrove forests. The mangrove area has been demarcated in the Sub-habitat demarcation map (Figure 30 and 31)

- 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: 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 Khijadiya 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 the mangrove sub-habitats can aid in increasing the carbon capture potential of Khijadiya.

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*[8]**	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*[9]**	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 Mangrove sub-habitat in Khijadiya over a 20-year period is provided as below: Planting geometry — 500 trees per Ha, Khijadiya Mangrove sub-habitat area — 1.2km^2

Mangrove species	***Avicennia marina***	***Avicennia officinalis***
Carbon sequestration potential (M. Tonnes)	14.952	11.0658

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

Carbon sequestration potential for the land vegetation sub-habitat in Khijadiya over a 20-year period is provided as below: Khijadiya land vegetation sub-habitat area — 2.3km^2

Acacia nilotica	***Khijadiya***
Carbon Sequestration Potential (M. Tonnes)	55.22

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

Annexure 1: Carbon Sequestration

Carbon sequestration potential for the Mangrove sub-habitat in Khijadiya is provided as below:

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

Khijadiya Mangrove Sub-Habitat Area — $1.2 km^2$

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)	Total carbon sequestration potential (kg)
1	1–151	0.26	15,600	0.013	780
2	1–151	0.26	15,600	0.013	780
3	1–151	0.26	15,600	0.013	780
4	1–151	0.26	15,600	0.013	780
5	151–300	1.91	114,600	0.28	16,800
6	151–300	1.91	114,600	0.28	16,800
7	151–300	1.91	114,600	0.28	16,800
8	151–300	1.91	114,600	0.28	16,800
9	301–400	7.38	442,800	3.725	223,500
10	301–400	7.38	442,800	3.725	223,500
11	301–400	7.38	442,800	3.725	223,500
12	301–400	7.38	442,800	3.725	223,500
13	401–500	16.55	993,000	6.174	370,440
14	401–500	16.55	993,000	6.174	370,440
15	401–500	16.55	993,000	6.174	370,440
16	401–500	16.55	993,000	6.174	370,440
17	401–500	16.55	993,000	6.174	370,440
18	401–500	16.55	993,000	6.174	370,440
19	>500	55.85	3,351,000	65.657	3,939,420
20	>500	55.85	3,351,000	65.657	3,939,420

Table 17 Carbon sequestration potential for mangrove sub-habitat in Khijadiya

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

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

Khijadiya land vegetation sub-habitat area — $2.3km^2$

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

Year	Height class	*Acacia nilotica* (per tree Carbon sequestration potential in kg)	*Khijadiya carbon sequestration potential (Tonnes)*
1	1–150	2.0	230
2	1–150	2.0	230
3	1–150	2.0	230
4	1–150	2.0	230
5	150–200	9.9	1,139
6	150–200	9.9	1,139
7	150–200	9.9	1,139
8	150–200	9.9	1,139
9	200–250	13.5	1,553
10	200–250	13.5	1,553
11	200–250	13.5	1,553
12	200–250	13.5	1,553
13	250–300	36.5	4,198
14	250–300	36.5	4,198
15	250–300	36.5	4,198
16	250–300	36.5	4,198
17	250–300	36.5	4,198
18	250–300	36.5	4,198
19	>300	80.7	9,286
20	>300	80.7	9,286

Table 18 Carbon sequestration potential for land vegetation sub-habitat in Khijadiya

Annexure 2: Field Visits

The team conducted two field visits to Khijadiya Bird Sanctuary 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 project 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:

Jamnagar
• Forest Department • Salinity Ingression Control Department • District Statistics Office • District Agriculture Office • District Irrigation Office • Krishi Vigyan Kendra District Office • District Disaster Management Department • Public Works Department District Office • Interpretation Centre, Khijadiya

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

Data Collection:

A detailed meeting was held with the Forest Department of Jamnagar on the first day of the visit. 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
Daily meteorological data (rainfall, min. and max. temperature, evaporation, wind speed, etc.) for Jamnagar district for a period of past six years	Krishi Vigyan Kendra, Jamnagar
Annual rainfall data for Jamnagar for the past ten years	District Agriculture Office, Jamnagar
Statistical Yearbook of Jamnagar District, 2016 (in Gujarati)	District Statistics Office, Jamnagar
Readings for gauges installed in Khijadiya wetland for measuring water level	Forest Department, Jamnagar

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
1.	KH-1	Khijadiya	1/3/2017	22^{0}31’25.4”	70^{0}08’36.0”	Wetland
2.	KH-2	Khijadiya	2/3/2017	22^{0}31’10.2”	70^{0}07’11.3”	Wetland
3.	KH_3	Khijadiya	2/3/2017	22^{0}31.362’	70^{0}08.179’	Wetland
4.	KH-4	Khijadiya	1/3/2017	22^{0}31’52”	70^{0}10’25.6”	Wetland

Illustrations from the Site Visit

Team during field visit

Some views of Khijadiya wetland (March, 2017)

A view of the cause way in Khijadiya **In-situ measurement of some water quality parameters in Khijadiya**

Gauge for water level measurement in Khijadiya 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 Khijadiya Wildlife Sanctuary 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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FOREST DEPARTMENT GOVT. OF GUJARAT

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Indo-German Biodiversity Programme
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