Goa University

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Zoology

Conservation and management of mangroves and intertidal mudflats along the coastline of Goa, India

Final Report

Report submitted to:

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Conservation and management of mangroves and intertidal mudflats along the coastline of Goa, India

Chapter I: Introduction

Goa is situated in the Central-West Coast of India, borders the Arabian sea, and extends from North to South. The total length of Goa coast is approximately 105 km. Goa lies in the WG region and is the smallest state of India having area of 3701 sq. km. Goa shares its boundaries with Maharashtra in North, Karnataka in South & East and Arabian sea in West. Goa's seven major rivers are the Mandovi, Zuari, Terekhol, Chapora, Galgibag, Cumbarjua canal, Talpona, and the Sal. The Zuari and the Mandovi are the most important rivers, interspaced by the Cumbarjua canal, forming a major estuarine complex. These rivers are fed by the Southwest monsoon rain and their basin covers 69% of the state's geographical area. Goa has more than 40 estuarine, eight marines, and about 90 riverine islands. The state is divided into two civil districts—North Goa and South Goa and 12 talukas namely Pernem, Bardez, Bicholim, Sattari, Tiswadi, Ponda, Mormugao, Salcette, Sanguem, Quepem, Dharbadora and Canacona (Figure 1).

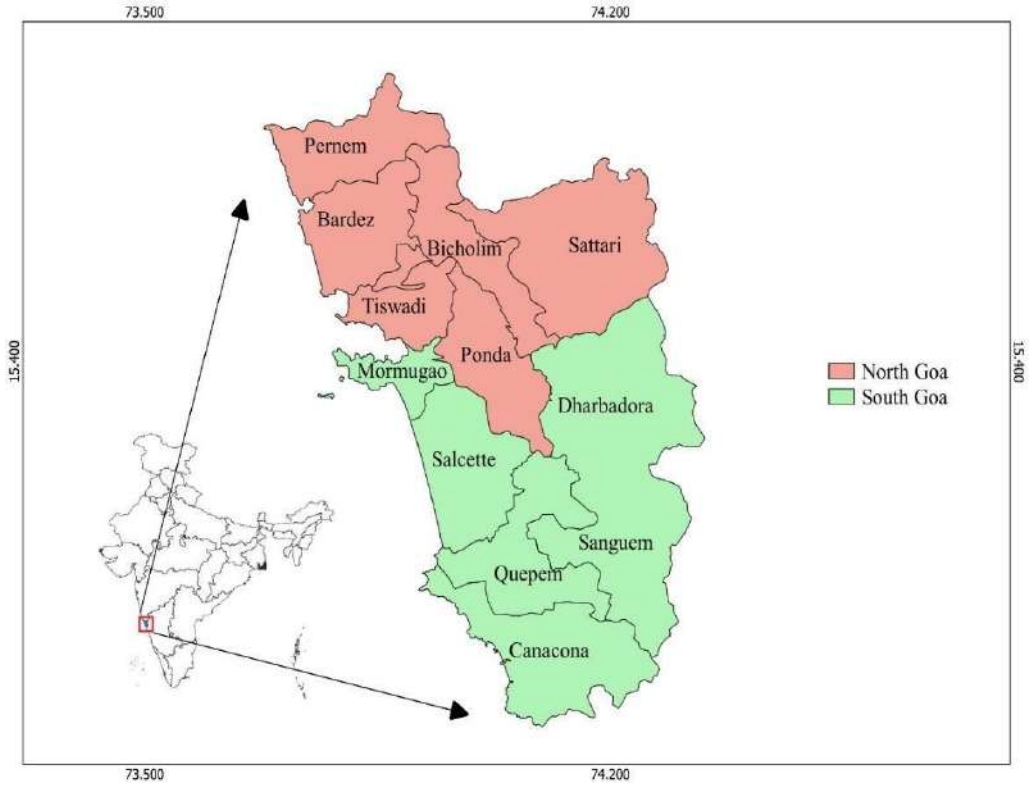

Figure 1: Map showing District and Taluka's of Goa state.

Mangroves are salt tolerant plant communities found in tropical and sub-tropical intertidal regions of the world. Such areas are characterized by high rainfall (between 1,000 to 3,000mm) and temperature (ranging between 26 degree C to 35 degree C). Mangrove species exhibit a variety of adaptions in morphology, anatomy, and physiology to survive in water logged soils, high salinity and frequent cyclonic storms and tidal surges. Mangroves are important refuges of Costal bio-diversity and act as bio-shields against extreme climatic events. Large populations, primarily rural, depend on mangrove ecosystems for a wide variety of biomass dependent livelihoods.

As per Global Forest Resource Assessment, 2020 (FRA 2020), world over 113 countries have Mangrove forests covering an estimated 14.79 million hectares. The largest mangrove area is reported in Asia (5.55 million hectares), followed by Africa (3.24 million hectares), North and Central America (2.57 million hectares) and South America (2.57 million hectares). Oceania has reported the smallest area of Mangroves (1.30 million hectares). More than 40% of the total area of Mangroves was reported to be in just four countries: Indonesia (19% of the total), Brazil (9%), Nigeria (7%) and Mexico (6%).

Various functional types of mangrove forests can be briefly described as:

1. Over wash mangrove forest: These are small islands covered with mangroves that are frequently washed by the tides. The dominant species is *Rhizophora sp*.
2. Fringing mangrove forests: These strips of mangrove are found along the borders of the waterways and influenced by tidal activities. These are sensitive to erosion and mostly exposed to marine environment. The dominant species is *Rhizophora sp*.
3. Riverine mangrove forests: These are luxuriant stands of mangroves found along the tidal areas and creeks with a good input of freshwater and fluvial nutrients. Often

composed of *Rhizophora sp.* and *Avicennia sp.*

4. Basin mangrove forests: These are stunted mangroves located in the interior swamps and in drainage depressions. Often dominated by *Avicennia sp.*
5. Scrub mangrove forests: A dwarf stand of mangroves found on flat costal fringes due to high salinity.

There are around 82 described species of mangroves in the world, 60 of which exist exclusively on coasts between high and low tide lines. About 16 mangroves and few associated species have been recorded from the Goa coast. There are seven estuaries fringed with mangroves along the Goa coast. There exist an intricate network of creeks and backwaters. Mangroves grow from small bushes to 40- to 60-meter-high trees found in Ecuador. Mangroves are remarkably very sturdy species growing in muddy soil, but some also grow on sand, peat and coral rocks. They grow in water up to 100 times saltier the most plants.

Mudflats or mud flats, also known as tidal flats or, in Ireland, slob or slobs, are coastal wetlands that form in intertidal areas where sediments have been deposited by tides or rivers. Intertidal mudflats are prominent sub environments found on the fringe of estuaries and in lower relief sheltered costal environments (O'Brien et al. 2000). The fine-grained sediments of the intertidal mudflats are derived from terrestrial and marine regions (Shi and Chen 1996; Lesueur et al. 2003). Mudflats acts as a major sink for trace metals and a very important habitat for wading avifauna (Cearreta et al. 2000; Baidya and Bhagat 2018). Marine bivalves and gastropods are sedentary, filter-feeders, feeding on suspended particles in these mudflats (Phillips, 1980). The mudflats have been identified and studied one present on the mouth of river Zuari (Dias and Nayak 2016). Several other mudflats have gained importance in the recent years but have not been identified and quantified in-terms of area.

A global analysis published in 2019 suggested that tidal flat ecosystems are as extensive globally as mangroves, covering at least 127,921 km2 (49,391 sq mi) of the Earth's surface. Mudflats may be viewed geologically as exposed layers of bay mud, resulting from deposition of estuarine silts, clays and aquatic animal detritus. Most of the sediment within a mudflat is within the intertidal zone, and thus the flat is submerged and exposed approximately twice daily. Tidal flats, along with intertidal salt marshes and mangrove forests, are important ecosystems. They usually support a large population of wildlife, and are a key habitat that allows tens of millions of migratory shorebirds to migrate from breeding sites in the northern hemisphere to non-breeding areas in the southern hemisphere. They are often of vital importance to migratory birds, as well as certain species of crabs, mollusks and fish.

The maintenance of mudflats is important in preventing coastal erosion. However, mudflats worldwide are under threat from predicted sea level rises, land claims for development, dredging due to shipping purposes, and chemical pollution. In some parts of the world, such as East and South-East Asia, mudflats have been reclaimed for aquaculture, agriculture, and industrial development. It is estimated that up to 16% of the world tidal flats have disappeared since the mid-1980s.

Mudflat sediment deposits are focused into the intertidal zone which is composed of a barren zone and marshes. Within these areas are various ratios of sand and mud that make up the sedimentary layers. The associated growth of coastal sediment deposits can be attributed to rates of subsidence along with rates of deposition. Barren zones extend from the lowest portion of the intertidal zone to the marsh areas. Beginning near the tidal bars, sand dominated layers are prominent and become increasingly muddy throughout the tidal channels. Common bedding types include laminated sand, ripple bedding, and bay mud. Bioturbation also has a

strong presence in barren zones.

The present study aims to understand the extent change of mangroves across various estuaries and river network in Goa and to locate the intertidal mudflats and study their extent during low tides.

Objectives of study:

1) Identification of degraded areas conducive for mangrove plantation to be taken up.
2) Identification of mudflats/ new areas of to be taken up for mangrove plantation.
3) Identification of existing mangrove areas requiring supplementary plantation or enrichment.

Chapter II:
Objective 1: Identification of degraded areas conducive for mangrove plantation to be takenup.

Methodology

Study area

The work was carried out in the state of Goa. Goa encompasses an area of 3,702 square km (1,429 square miles). It lies between the latitudes 14°53′54″ N and 15°40′00″ N and longitudes 73°40′33″ E and 74°20′13″ E. In the state of Goa Mangrove lies along the major rivers *viz.* Mandovi, Zuari, Terekhol, Chapora, Galgibag, Cumbarjua canal, Talpona, and the Sal.

Image procurement

High resolution of Satellite and Landsat images were procured from United States geological survey (USGS), Earth Explorer; 2023; FS; 083-00; Geological Survey (U.S.). To map the mangrove cover change imagery from USGS Landsat 8 Level 2, Collection 2, Tier 1, USGS Landsat 7 Level 2, Collection 2, Tier 1 and NASA SRTM Digital Elevation 30m were procured and processed.

Mapping mangrove cover change

Mangrove extent change was done by considering its extent during two periods with a difference of 10 years between it (year 2012 and year 2022). It was carried out using Google Earth Engine platform and QGIS. Following programme was generated in Google Earth Engine. The following programme was processed using Google Earth Engine platform which uses Python and JavaScript. Following which the generated files were transferred to QGIS in the GeoTIFF format for further analysis and generation of maps.

Following assets were used for the mangrove extent map generation

1. roi: Region of Interest
2. L8: USGS Landsat 8 Level 2, Collection 2, Tier 1
3. L7: USGS Landsat 7 Level 2, Collection 2, Tier 1
4. SRTM: NASA SRTM Digital Elevation 30m
5. Mangrove2012: Mangrove sample points from year 2012 for training programme
6. Non-mangrove2012: non-mangrove sample points from year 2012 for training programme
7. Mangrove: Mangrove sample points from year 2022 for training programme
8. Non-mangrove: non-mangrove sample points from year 2022 for training programme

Link for the Google Earth Engine Code editor:
https://code.earthengine.google.com/04d48615832888b47649496d7913472b
(Refer page XX for the programme in the report)

Results

The mangrove extent in the state of Goa in the year 2012 was 21.2537 square km. (Figure 3) while in the year 2022 it got increased to 34.0998 square km. (Figure 2). There is an increase of 12.8461 square km. with respect to the year 2012 (Figure 4). While at many places the mangrove cover has increased, there are places observed wherein the mangrove areas are degraded or destroyed over the years from 2012 to 2022 (Figure 5). It has been observed from the data obtained from the extent change that Bardez taluka have highest increase of mangrove cover in 2022 w.r.t 2012 which is of 4.51 square km. while in Tiswadi taluka degradation of mangrove cover has been observed the highest which is of 0.10 square km. (Table 1, Figure 6).No mangrove cover is recorded in the Sanguem and Sattari Taluka (Table

1, Figure 6). In theyear 2012 higest mangorve extent was recorded in the Salcete taluka while lowest is recordedin Bicholim and Canacona talukas (Table 1).

In the year 2022 higest mangove cover is recorded in the Salcete taluka while lowest is recorded in Pernem taluka (Table 1). Since at most of the places the mangrove cover has increased at a very high rate, there are no major areas wherein new plantation of mangroves is required in the study area.

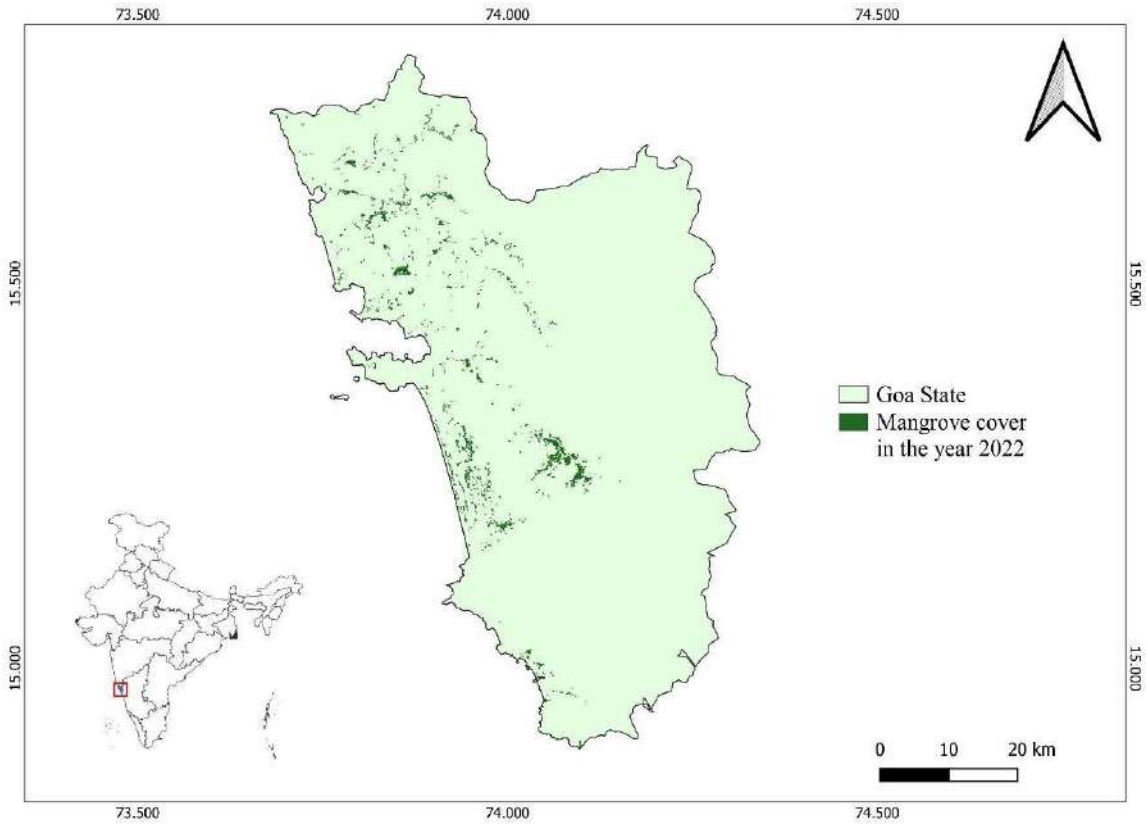

Figure 2: Map showing mangrove cover of Goa in the year 2022.

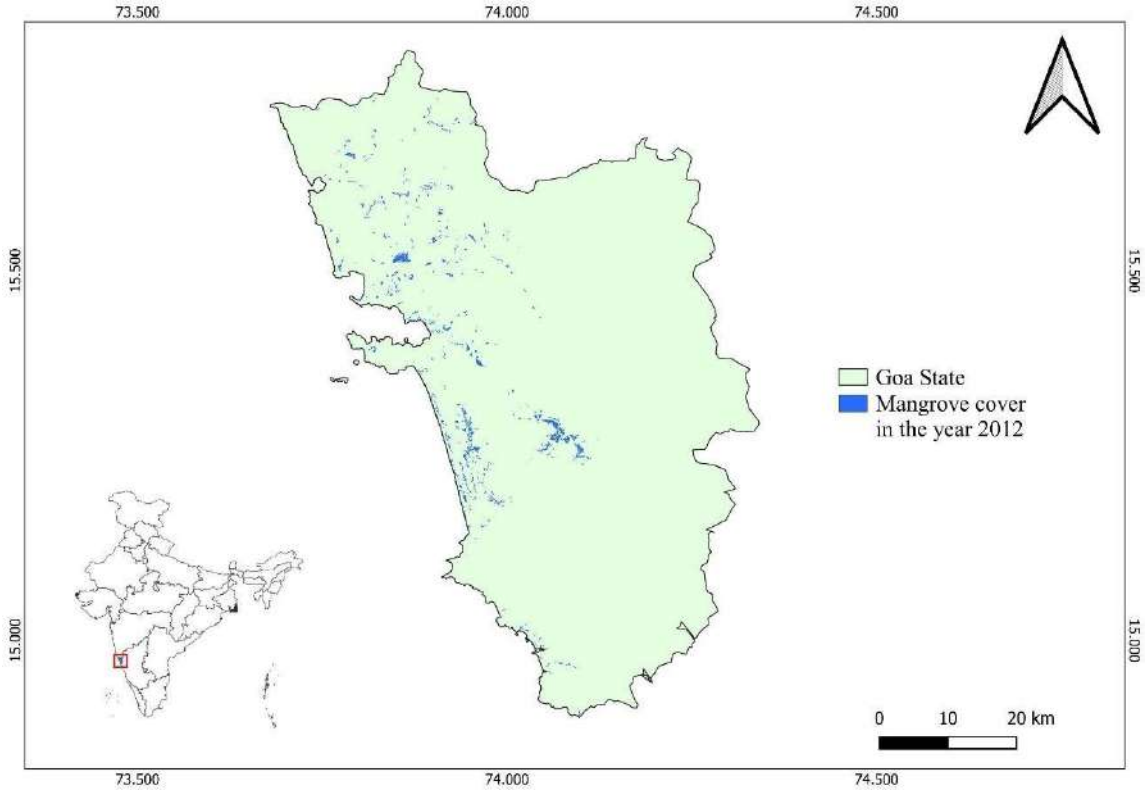

Figure 3: Map showing mangrove cover of Goa in the year 2012.

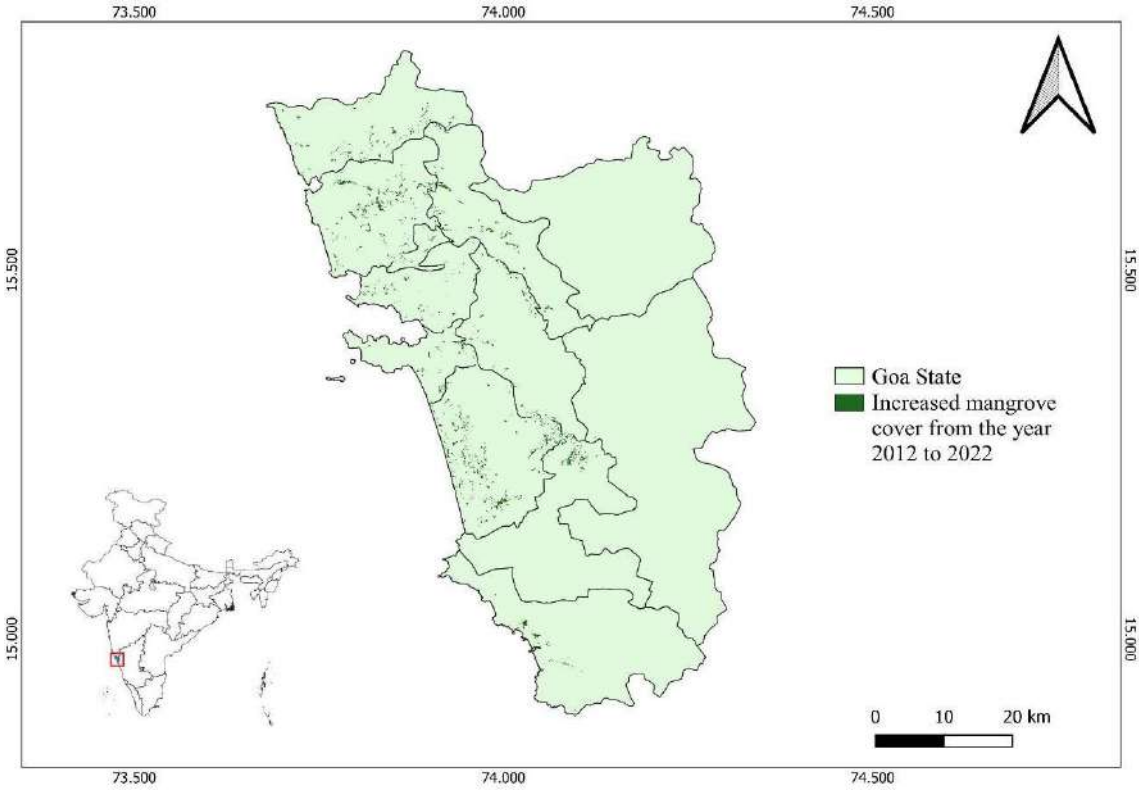

Figure 4: Map showing increased mangrove cover across Goa in the year 2022 with respect to year 2012.

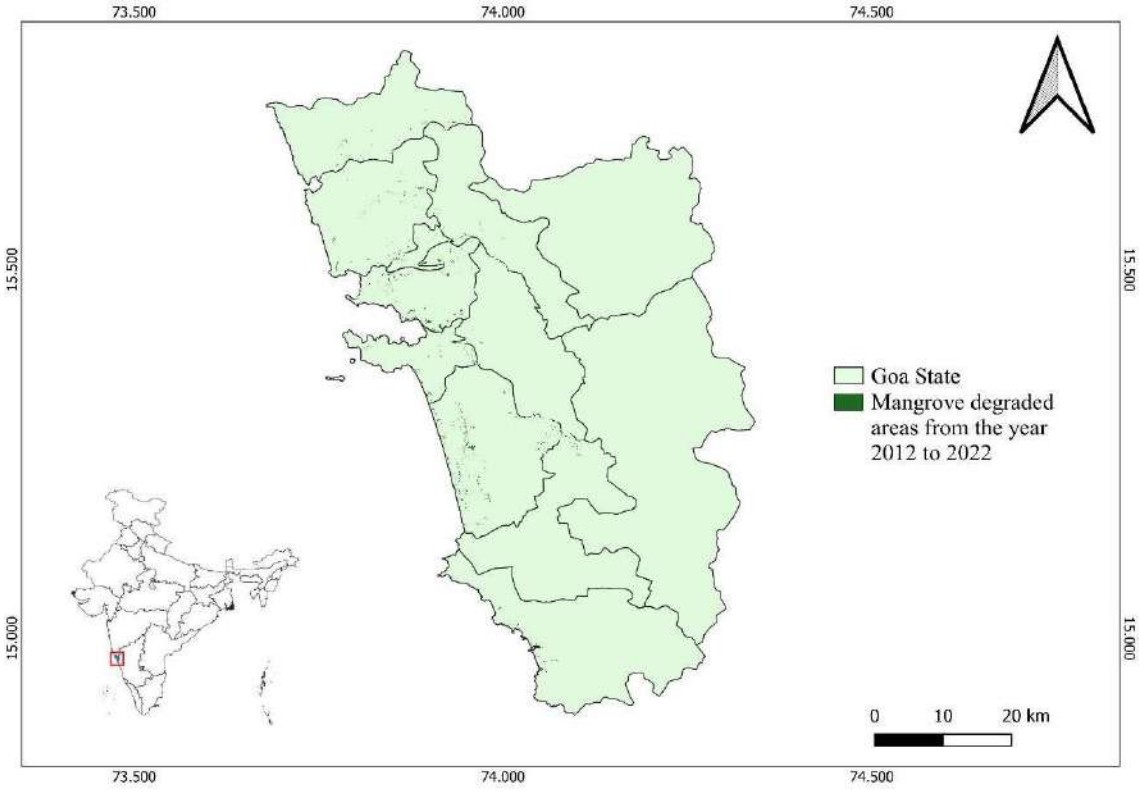

Figure 5: Map showing mangrove degraded areas of Goa in the year 2022 with respect to year 2012.

Taluka	Mangrove cover in year 2012 (sq. km.)	Mangrove cover in year 2022 (sq. km.)
Pernem	0.6318	0.9382
Bardez	0.7649	5.2812
Bicholim	0.1876	2.0574
Canacona	0.1	1.6708
Mormugao	0.8091	1.6792
Ponda	0.7976	1.0443
Quepem	3.1154	6.4122
Salcete	12.0296	12.2992
Sanguem	0	0
Dharbandora	0	0
Sattari	0	0
Tiswadi	2.8177	2.7173
Total	**21.2537**	**34.0998**

Table 1: Table showing mangrove cover from year 2012 and 2022

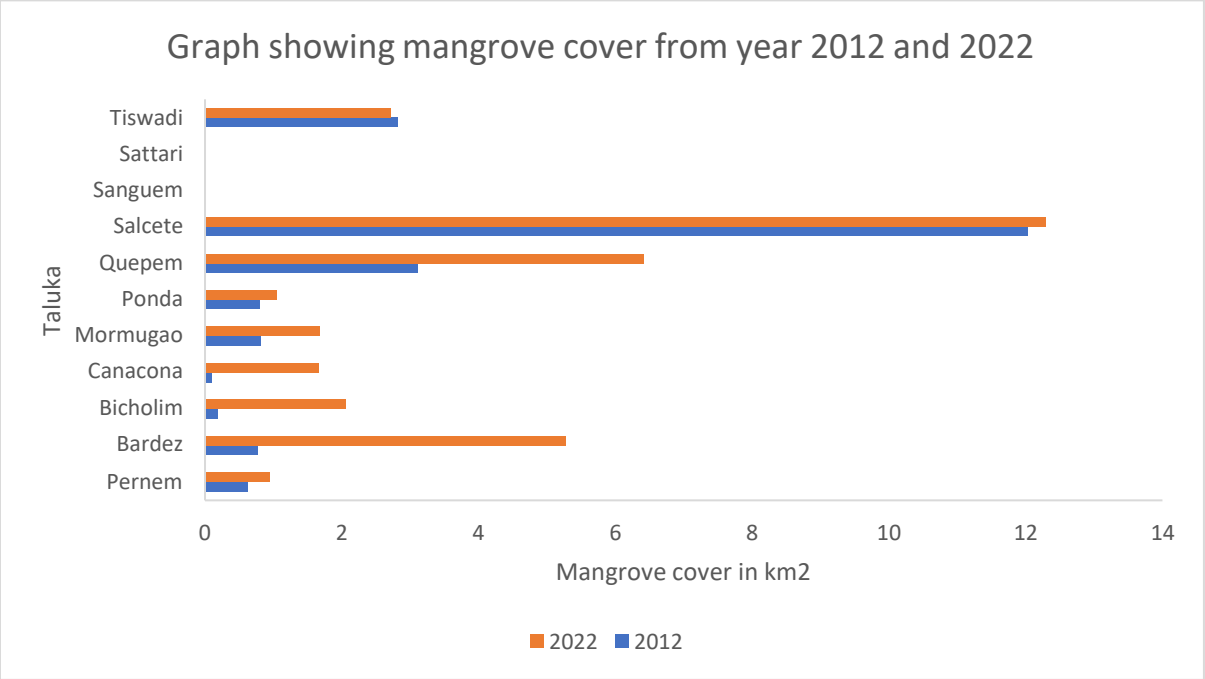

Figure 6: Graph showing mangrove cover from year 2012 and 2022

Chapter III
Objective 2: Identification of mudflats/new areas of to be taken up for mangrove plantation.

Methodology

Study area

The work was carried out in the state of Goa. Goa encompasses an area of 3,702 square km (1,429 square miles). It lies between the latitudes 14°53′54″ N and 15°40′00″ N and longitudes 73°40′33″ E and 74°20′13″ E. In the state of Goa Mangrove lies along the major rivers *viz.* Mandovi, Zuari, Terekhol, Chapora, Galgibag, Cumbarjua canal, Talpona, and the Sal.

Identification of Inter-tidal mudflats

A questionnaire was prepared to know the locations of intertidal mudflats across Goa, and was circulated in the coastal panchayats of Goa. Following assessment of answers given by the respective panchayat members, a through oral survey was conducted with random fisherman and fisherwomen from respective panchayat areas from coastal zone. Following both the survey assessment a shortlisting of areas was done for identifying inter-tidal mudflats across Goa.

Mapping of Mudflats

Identified areas were visited during lowest tides and then photographed using DJI Mavic Mini drone, with attached 12MP camera to it. Images were captured with reference points in it for georeferencing them. Further which by using Bosch CST-302R Total Station machine mudflats were surveyed, boundaries were marked and georeferenced shapefiles were created for further analysis. These shapefiles then were plotted on map by using QGIS and the downloaded imagery and maps were created.

Results

A total of ten mudflat groups were identified in entire Goa state, five in North Goa district and five in South Goa district (Table 2, Figure 7-14). The biggest mudflat is the Chicalim mudflat with an opening area of 2.74 sq. km. followed by Agaciam mudflat with an opening area of 1.13 sq. km. The smallest mudflat is the Galgibag mudflat with an opening area of 0.02 sq. km (Table 2). Identified mudflats are feeding grounds for various faunal species and hence are not suggested to be taken up for mangrove plantation. Many of the species are listed under IUCN red list and were found in these mudflats. It has been also observed that these mudflats are dynamic in nature and the extent changes continuously due to activities like flooding and erosion caused by flow of water. Maintaining the integrity of these mud flats is of utmost important as it is not only ecologically fragile but has high economic value.

Sr. No.	Mudflats	Area (Sq. Km.)
1	Morjim-chapora	0.78
2	Ribandar	0.29
3	Chorao	0.28
4	Siridao	0.35
5	Agaciam	1.13
6	Zuari	0.95
7	Chicalim	2.74
8	Betul	0.2
9	Talpona	0.58
10	Galgibag	0.02

Table 2: Table showing mudflats in Goa state along with its area during low tide.

Figure 7: Map showing location and extent of Morjim-Chapora mudflat in Goa

Figure 8: Map showing location and extent of Ribandar and Chorao mudflat in Goa

Figure 9: Map showing location and extent of Agaciam and Siridao mudflats in Goa

Figure 10: Map showing location and extent of Chicalim mudflat in Goa

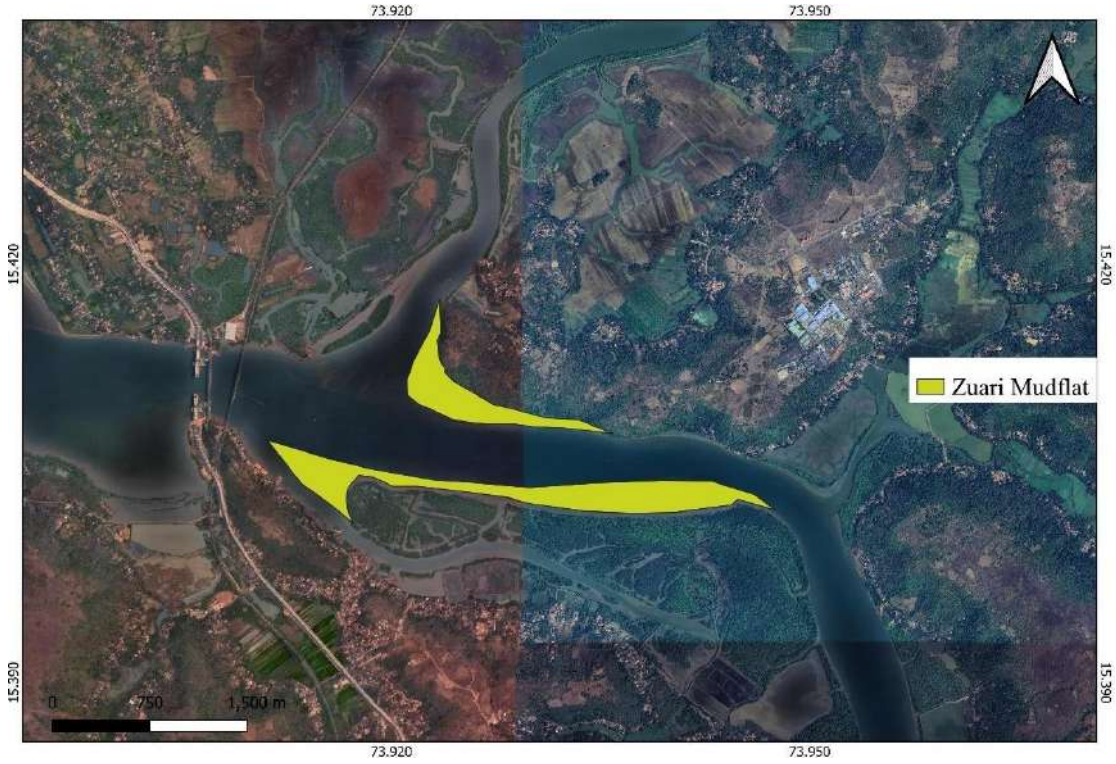

Figure 11: Map showing location and extent of Zuari mudflat in Goa

Figure 12: Map showing location and extent of Betul mudflat in Goa

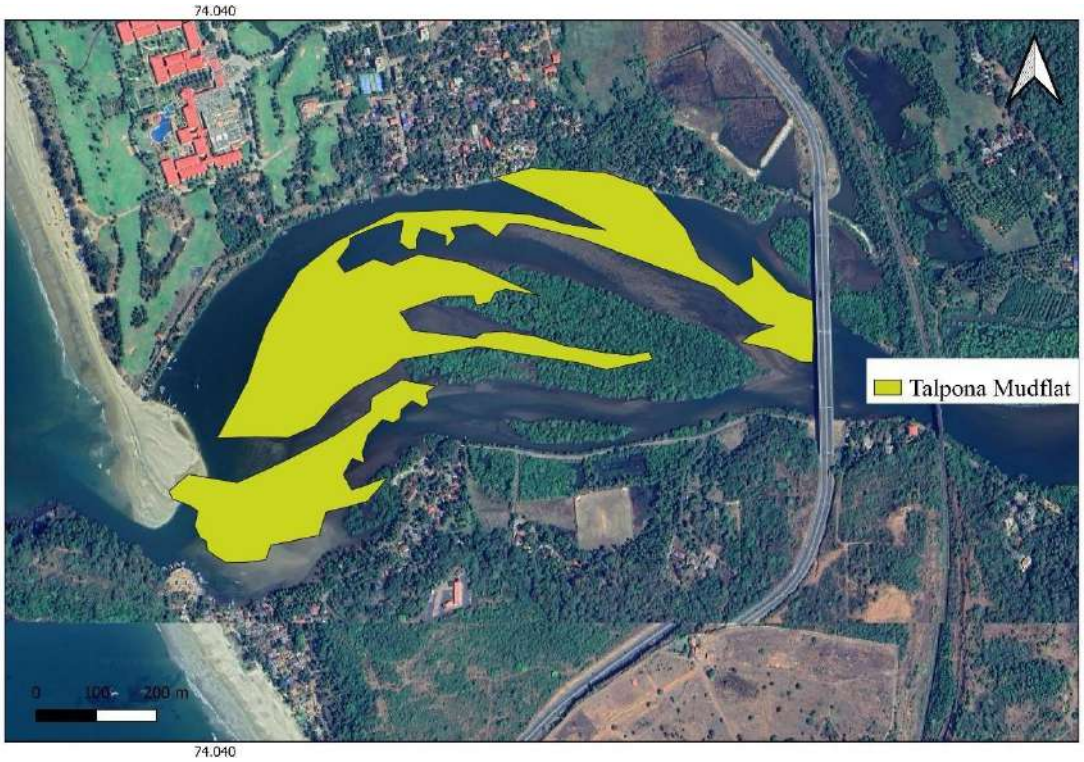

Figure 13: Map showing location and extent of Talpona mudflat in Goa

Figure 14: Map showing location and extent of Galgibag mudflat in Goa

Chapter IV:

Objective 3: Identification of existing mangrove areas requiring supplementary plantation orenrichment.

Methodology

Study area

The work was carried out in the state of Goa. Goa encompasses an area of 3,702 square km (1,429 square miles). It lies between the latitudes 14°53′54″ N and 15°40′00″ N and longitudes 73°40′33″ E and 74°20′13″ E. In the state of Goa Mangrove lies along the major rivers *viz.* Mandovi, Zuari, Terekhol, Chapora, Galgibag, Cumbarjua canal, Talpona, and the Sal.

***The methodology for identification of areas for supplementary plantation is same asthe methodology for objective 1**

Identification of areas

Ground truthing was carried out (physical surveys) in all the areas which showed mangrove degradation in the study area. With surveys and interaction with locals only those areas are selected where maximum damage to the mangrove extent is seem and supplementary plantation can be carried out without conflict of interest.

Result

Upon surveying entire mangrove areas, a total number of 15 places across goa have been identified (Table 3, Figure 15), wherein supplementary plantation can be taken up in the future. In these places either the mangroves have grown old and have died or are eroded over the course of time. However, while carrying out plantation due care to be taken to select appropriate species of plat as every species occupy its own level within the strata.

sr. no.	Place	latitude	longitude
1	Paliyem	15.717937	73.725671
2	Merces	15.483222	73.848144
3	Chorao	15.516021	73.858489
4	Divar	15.512555	73.915241
5	Divar	15.50804	73.892711
6	Narve	15.545508	73.919317
7	Dongrim	15.44394	73.943775
8	Agaciam	15.420751	73.920123
9	Agaciam	15.416406	73.912605
10	Pomburfa	15.531277	73.873598
11	Nerul	15.50223	73.774789
12	Thivim	15.602553	73.863639
13	Marcel	15.54837	73.949518
14	Adpai	15.373867	73.959599
15	Galgibaga	14.965703	74.053882

Table 3: coordinates/location of areas for supplementary plantation

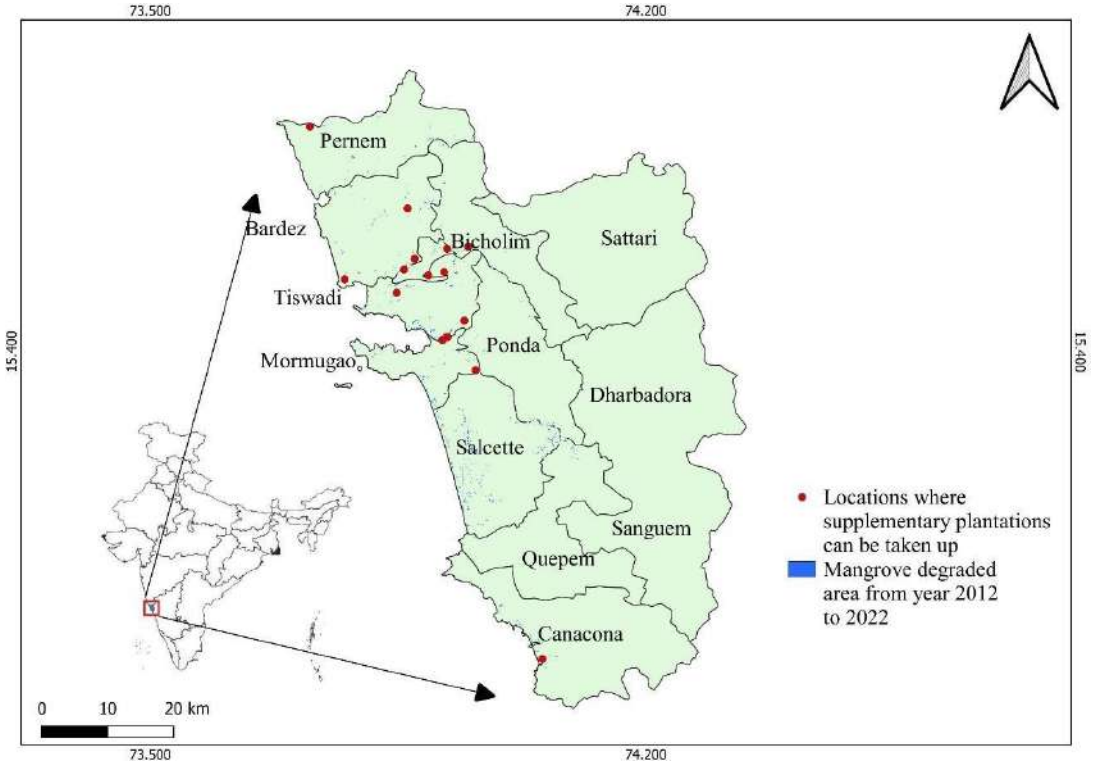

Figure 15: Map showing areas suggested for supplementary plantation

Chapter V

Faunal and floral assessment ofmangroves and mudflats

Methodology

Transact surveys were carried out to enlist species of mangroves found in the study area. Along with mangrove species faunal surveys were also carried out to enlist species like mammals, aves, amphibians, reptiles, fishes inhabiting the mangroves and mudflats. The methodology used were transact surveys and visual encounter sampling method to carry out the work (Burnham et. al. 1981; Anderson et. al. 2015).

Result

A total of 16 species of mangroves are recorded from the state of Goa (Table 4). Amongst all the estuaries in Goa, Mandovi estuary has the highest diversity with 13 species recorded while Talpona and Galgibag has the lowest diversity with nine species of mangroves recorded (Table 4). Mangrove associated trees recorded includes *Derris heterophylla, Clerodendrum inerme, Salvodora persica* and *Dolichandrone spathacea.*

Sr. No.	**species**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
1	*Rhizophora mucronata*	X	X	X	X	X	X	X	X
2	*Rhizophora apiculata*			X		X			X
3	*Ceriops tagal*	X							
4	*Bruguiera gymnorhiza*			X	X	X	X	X	X
5	*Bruguiera cylindrica*			X	X	X			
6	*Kandelia candel*	X	X	X	X	X			
7	*Sonneratia caseolaris*	X	X	X	X	X	X		
8	*Sonneratia alba*	X	X	X	X	X	X	X	X
9	*Avicennia marina*	X	X	X	X	X	X	X	X

10	*Avicennia officinalis*	X	X	X	X	X	X	X	X
11	*Lumnitzera racemosa*	#	#	#	#	#	#	#	#
12	*Xylocarpus moluccensis*	#	#	#	#	#	#	#	#
13	*Excoecaria agallocha*	X	X	X	X	X	X	X	X
14	*Aegiceras corniculatum*	X		X	X		X	X	
15	*Acrostichum aureum*	X	X	X	X	X	X	X	X
16	*Acanthus ilicifolius*	X	X	X	X	X	X	X	X

Table 4: Table showing distribution of mangrove species across the major estuaries of Goa in the year 2022, a: Terekhol, b:Chapora, c: Mandovi, d: Zuari, e: Cumbarjua canal, f: Sal, g: Talpona, h: Galgibag, X: Present, #: Status Unknown

Fauna associated along the mangroves involves various species of vertebrates and invertebrates. 8 species of Mammals were observed based on direct and indirect evidences in the Mangrove habitat of Goa of which *Lutrogale perspicillata* is listed in Vulnerable category of IUCN Red List (Table 5). 154 species of Aves of which *Numenius arquata, Limosa lapponica, Ciconia episcopus, Mycteria leucocephala, Anhinga melanogaster, Threskiornis melanocephalus, Anthracoceros coronatus* and *Psittacula eupatria* belongs to Near threathened category of IUCN red list, *Sterna aurantia, Leptoptilos javanicus, Clanga clanga* and *Ocyceros griseus* belong to vulnerable category of IUCN Red List, were observed along the mangrove habitat of Goa (Table 6). 16 species of reptiles were observed in the Mangrove habitat of Goa of which *Crocodylus palustris* and *Python molurus* were listed in the Vulnerable category of IUCN Red List (Table 7). 10 species of Amphibians were observed in the mangroves of Goa of which *Pseudophilautus amboli* and *Raorchestes bombayensis* are listed in the Critically Endangered and Vulnerable category of IUCN Red List respectively (Table 8). A total of 16 species of Fishes are recorded from the mangroves of Goa (Table 9).

Sr. No.	Species	IUCN Status
1	Bonnet Macaque *Macaca radiata*	Least Concern
2	Common Palm Civet *Paradoxurus hermaphroditus*	Least Concern
3	Grey Mongoose *Herpestes edwardsii*	Least Concern
4	Indian Jackal *Canis aureus*	Least Concern
5	Three-striped Palm Squirrel *Funambulus palmarum*	Least Concern
6	Smooth-coated Otter *Lutrogale perspicillata*	Vulnerable
7	Wild Boar *Sus scrofa*	Least Concern
8	Flying fox *Pteropus giganteus*	Least Concern

Table 5: List of Mammals recorded from Mangroves of Goa

Sr. No.	Species	IUCN Status
1	Lesser Whistling Duck *Dendrocygna javanica*	Least Concern
2	Rock Pigeon *Columba livia*	Least Concern
3	Spotted Dove *Streptopelia chinensis*	Least Concern
4	Orange-breasted Green Pigeon *Treron bicinctus*	Least Concern
5	Grey-fronted Green Pigeon *Treron affinis*	Least Concern
6	Greater Coucal *Centropus sinensis*	Least Concern
7	Blue-faced Malkoha *Phaenicophaeus viridirostris*	Least Concern
8	Pied Cuckoo *Clamator jacobinus*	Least Concern
9	Asian Koel *Eudynamys scolopaceus*	Least Concern
10	Banded Bay Cuckoo *Cacomantis sonneratii*	Least Concern
11	Grey-bellied Cuckoo *Cacomantis passerinus*	Least Concern
12	Common Hawk Cuckoo *Hierococcyx varius*	Least Concern
13	Jerdon's Nightjar *Caprimulgus atripennis*	Least Concern
14	Indian Swiftlet *Aerodramus unicolor*	Least Concern
15	Common Swift *Apus apus*	Least Concern
16	Slaty-breasted Rail *Lewinia striata*	Least Concern
17	White-breasted Waterhen *Amaurornis phoenicurus*	Least Concern
18	Ruddy-breasted Crake *Zapornia fusca*	Least Concern
19	Black-winged Stilt *Himantopus himantopus*	Least Concern
20	Grey-headed Lapwing *Vanellus cinereus*	Least Concern
21	Red-wattled Lapwing *Vanellus indicus*	Least Concern

22	Lesser Sand Plover *Charadrius mongolus*	Least Concern
23	Greater Sand Plover *Charadrius leschenaultii*	Least Concern
24	Kentish Plover *Charadrius alexandrinus*	Least Concern
25	Little Ringed Plover *Charadrius dubius*	Least Concern
26	Whimbrel *Numenius phaeopus*	Least Concern
27	Eurasian Curlew *Numenius arquata*	Near Threatened
28	Bar-tailed Godwit *Limosa lapponica*	Near Threatened
29	Ruff *Calidris pugnax*	Least Concern
30	Temminck's Stint *Calidris temminckii*	Least Concern
31	Little Stint *Calidris minuta*	Least Concern
32	Terek Sandpiper *Xenus cinereus*	Least Concern
33	Common Sandpiper *Actitis hypoleucos*	Least Concern
34	Spotted Redshank *Tringa erythropus*	Least Concern
35	Common Greenshank *Tringa nebularia*	Least Concern
36	Marsh Sandpiper *Tringa stagnatilis*	Least Concern
37	Wood Sandpiper *Tringa glareola*	Least Concern
38	Common Redshank *Tringa totanus*	Least Concern
39	Slender-billed Gull *Chroicocephalus genei*	Least Concern
40	Black-headed Gull *Chroicocephalus ridibundus*	Least Concern
41	Brown-headed Gull *Chroicocephalus brunnicephalus*	Least Concern
42	Lesser Black-backed Gull *Larus fuscus*	Least Concern
43	Little Tern *Sternula albifrons*	Least Concern
44	Gull-billed Tern *Gelochelidon nilotica*	Least Concern
45	Whiskered Tern *Chlidonias hybrida*	Least Concern
46	River Tern *Sterna aurantia*	Vulnerable
47	Greater Crested Tern *Thalasseus bergii*	Least Concern
48	Lesser Crested Tern *Thalasseus bengalensis*	Least Concern
49	Asian Openbill *Anastomus oscitans*	Least Concern
50	Woolly-necked Stork *Ciconia episcopus*	Near Threatened
51	Lesser Adjutant *Leptoptilos javanicus*	Vulnerable
52	Painted Stork *Mycteria leucocephala*	Near Threatened
53	Oriental Darter *Anhinga melanogaster*	Near Threatened
54	Little Cormorant *Microcarbo niger*	Least Concern

55	Indian Cormorant *Phalacrocorax fuscicollis*	Least Concern
56	Cinnamon Bittern *Ixobrychus cinnamomeus*	Least Concern
57	Grey Heron *Ardea cinerea*	Least Concern
58	Purple Heron *Ardea purpurea*	Least Concern
59	Great Egret *Ardea alba*	Least Concern
60	Intermediate Egret *Ardea intermedia*	Least Concern
61	Little Egret *Egretta garzetta*	Least Concern
62	Western Reef Egret *Egretta gularis*	Least Concern
63	Cattle Egret *Bubulcus ibis*	Least Concern
64	Indian Pond Heron *Ardeola grayii*	Least Concern
65	Striated Heron *Butorides striata*	Least Concern
66	Black-crowned Night Heron *Nycticorax nycticorax*	Least Concern
67	Glossy Ibis *Plegadis falcinellus*	Least Concern
68	Black-headed Ibis *Threskiornis melanocephalus*	Near Threatened
69	Eurasian Spoonbill *Platalea leucorodia*	Least Concern
70	Osprey *Pandion haliaetus*	Least Concern
71	Oriental Honey Buzzard *Pernis ptilorhynchus*	Least Concern
72	Crested Serpent Eagle *Spilornis cheela*	Least Concern
73	Greater Spotted Eagle *Clanga clanga*	Vulnerable
74	Western Marsh Harrier *Circus aeruginosus*	Least Concern
75	Shikra *Accipiter badius*	Least Concern
76	Black Kite *Milvus migrans*	Least Concern
77	Brahminy Kite *Haliastur indus*	Least Concern
78	White-bellied Sea Eagle *Haliaeetus leucogaster*	Least Concern
79	Spotted Owlet *Athene brama*	Least Concern
80	Malabar Grey Hornbill *Ocyceros griseus*	Vulnerable
81	Malabar Pied Hornbill *Anthracoceros coronatus*	Near Threatened
82	Common Kingfisher *Alcedo atthis*	Least Concern
83	Stork-billed Kingfisher *Pelargopsis capensis*	Least Concern
84	White-throated Kingfisher *Halcyon smyrnensis*	Least Concern

85	Black-capped Kingfisher *Halcyon pileata*	Least Concern
86	Collared Kingfisher *Todiramphus chloris*	Least Concern
87	Pied Kingfisher *Ceryle rudis*	Least Concern
88	Green Bee-eater *Merops orientalis*	Least Concern
89	Blue-tailed Bee-eater *Merops philippinus*	Least Concern
90	Coppersmith Barbet *Psilopogon haemacephalus*	Least Concern
91	Eurasian Wryneck *Jynx torquilla*	Least Concern
92	Speckled Piculet *Picumnus innominatus*	Least Concern
93	Heart-spotted Woodpecker *Hemicircus canente*	Least Concern
94	Brown-capped Pygmy Woodpecker *Yungipicus nanus*	Least Concern
95	Yellow-crowned Woodpecker *Leiopicus mahrattensis*	Least Concern
96	Greater Flameback *Chrysocolaptes guttacristatus*	Least Concern
97	Rufous Woodpecker *Micropternus brachyurus*	Least Concern
98	Black-rumped Flameback *Dinopium benghalense*	Least Concern
99	Alexandrine Parakeet *Psittacula eupatria*	Near Threatened
100	Rose-ringed Parakeet *Psittacula krameri*	Least Concern
101	Plum-headed Parakeet *Psittacula cyanocephala*	Least Concern
102	Vernal Hanging Parrot *Loriculus vernalis*	Least Concern
103	Small Minivet *Pericrocotus cinnamomeus*	Least Concern
104	Orange Minivet *Pericrocotus flammeus*	Least Concern
105	Indian Golden Oriole *Oriolus kundoo*	Least Concern
106	Black-hooded Oriole *Oriolus xanthornus*	Least Concern
107	Common Iora *Aegithina tiphia*	Least Concern
108	Spot-breasted Fantail *Rhipidura albogularis*	Least Concern
109	Ashy Drongo *Dicrurus leucophaeus*	Least Concern
110	Greater Racket-tailed Drongo *Dicrurus paradiseus*	Least Concern
111	Indian Paradise-flycatcher *Terpsiphone paradisi*	Least Concern
112	Long-tailed Shrike *Lanius schach*	Least Concern
113	House Crow *Corvus splendens*	Least Concern
114	Indian Black-lored Tit *Machlolophus aplonotus*	Not Evaluated
115	Common Tailorbird *Orthotomus sutorius*	Least Concern

116	Grey-breasted Prinia *Prinia hodgsonii*	Least Concern
117	Jungle Prinia *Prinia sylvatica*	Least Concern
118	Ashy Prinia *Prinia socialis*	Least Concern
119	Plain Prinia *Prinia inornata*	Least Concern
120	Zitting Cisticola *Cisticola juncidis*	Least Concern
121	Booted Warbler *Iduna caligata*	Least Concern
122	Paddyfield Warbler *Acrocephalus agricola*	Least Concern
123	Blyth's Reed Warbler *Acrocephalus dumetorum*	Least Concern
124	Barn Swallow *Hirundo rustica*	Least Concern
125	Wire-tailed Swallow *Hirundo smithii*	Least Concern
126	Red-rumped Swallow *Cecropis daurica*	Least Concern
127	Streak-throated Swallow *Petrochelidon fluvicola*	Least Concern
128	Red-vented Bulbul *Pycnonotus cafer*	Least Concern
129	Red-whiskered Bulbul *Pycnonotus jocosus*	Least Concern
130	Green Warbler *Phylloscopus nitidus*	Least Concern
131	Jungle Babbler *Argya striata*	Least Concern
132	Rosy Starling *Pastor roseus*	Least Concern
133	Chestnut-tailed Starling *Sturnia malabarica*	Least Concern
134	Jungle Myna *Acridotheres fuscus*	Least Concern
135	Orange-headed Thrush *Geokichla citrina*	Least Concern
136	Indian Blackbird *Turdus simillimus*	Least Concern
137	Oriental Magpie Robin *Copsychus saularis*	Least Concern
138	Tickell's Blue Flycatcher *Cyornis tickelliae*	Least Concern
139	Thick-billed Flowerpecker *Dicaeum agile*	Least Concern
140	Pale-billed Flowerpecker *Dicaeum erythrorhynchos*	Least Concern
141	Nilgiri Flowerpecker *Dicaeum concolor*	Least Concern
142	Purple-rumped Sunbird *Leptocoma zeylonica*	Least Concern
143	Crimson-backed Sunbird *Leptocoma minima*	Least Concern
144	Purple Sunbird *Cinnyris asiaticus*	Least Concern
145	Loten's Sunbird *Cinnyris lotenius*	Least Concern
146	Jerdon's Leafbird *Chloropsis jerdoni*	Least Concern
147	Baya Weaver *Ploceus philippinus*	Least Concern

148	White-rumped Munia *Lonchura striata*	Least Concern
149	Scaly-breasted Munia *Lonchura punctulata*	Least Concern
150	Tricoloured Munia *Lonchura malacca*	Least Concern
151	House Sparrow *Passer domesticus*	Least Concern
152	Yellow-throated Sparrow *Gymnoris xanthocollis*	Least Concern
153	Western Yellow Wagtail *Motacilla flava*	Least Concern
154	White-browed Wagtail *Motacilla maderaspatensis*	Least Concern

Table 6: List of Aves recorded from Mangroves of Goa

Sr No	**Species**	**IUCN Status**
1	Mugger crocodile *Crocodylus palustris*	Vulnerable
2	Indian black turtle *Melanochelys trijuga*	Least Concern
3	Indian flapshell turtle *Lissemys punctata*	Least Concern
4	*Hemidactylys sp.*	NA
5	Common keeled skink *Eutropis carinata*	Least Concern
6	Bengal monitor *Varanus bengalensis*	Least Concern
7	Roux's forest lizard *Moelisaurus rouxii*	Least Concern
8	Indian garden lizard *Calotes versicolor*	NA
9	Whitaker's boa *Eryx whitakeri*	NA
10	Indian rock python *Python molurus*	Vulnerable
11	Dog-faced water snake *Cerberus rynchops*	Least Concern
12	Glossy marsh snake *Gerarda prevostiana*	Least Concern
13	Checkered keelback *Fowlea piscator*	NA
14	Green vine snake *Ahaetulla borealis*	NA
15	Common bronzeback *Dendrelaphis tristis*	NA
16	Indian Rat snake *Ptyas mucosa*	NA

Table 7: List of Reptiles recorded from Mangroves of Goa

Sr. No.	**Species**	**IUCN Status**
1	*Euphlyctis aloysii*	NA

2	*Euphlyctis cyanophlyctis*	Least Concern
3	*Hoplobatrachus tigerinus*	Least Concern
4	*Minervarya caperata*	NA
5	*Minervarya gomantaki*	NA
6	*Minervarya syhadrensis*	Least Concern
7	*Hydrophylax malabaricus*	Least Concern
8	*Polypedates maculatu*s	Least Concern
9	*Pseudophilautus amboli*	Critically Endangered
10	*Raorchestes bombayensis*	Vulnerable

Table 8: List of Amphibians recorded from Mangroves of Goa

Sr. No.	**Scientific Name**	**English Name**	**Local Name**
1	*Etraplus suratensts*	Pearl spot	Kalundra
2	*Scatopherns argus*	Spotted scat	Bannsire
3	*Plectorhirchus gibbosus*	Black sweet lips	Harvil
4	*Gerres filamentosus*	Whip fin silver biddy	Shetka
5	*Acanthopagnes serda*	Black sea bream	Paloo
6	*Letes calcaris*	Giant Perch	Chonok
7	*Mugil cephal:*	Mullet	Shevte
8	*Sillago sihama*	Sand whiting	Muddosi
9	*Lutjamus lineolatus*	Red Snapper	Tamso
10	*Epinephalus malabaricus*	Grouper	Gobro
11	*Eleutheronama tetradatylus*	Thread fin	Rawas
12	*Hemiramphus xanthopterus*	Half beak	Tonki
13	*Opisthopterus tardoore*	Herring	Patchall
14	*Carageides oblongus*	Oblong Trevally	Konkar
15	*Usteogeneiosus militaris*	Cat fish	Sangot
16	*Anchoviella commersonii*	Anchovy	Motiyali

Table 9: List of fishes recorded from Mangroves of Goa

Chapter VI
Mangrove Extent in the year 2023

Methodology

Using High resolution of Satellite and Landsat images were procured from United States geological survey (USGS), Earth Explorer; 2023; FS; 083-00; Geological Survey (U.S.) and the digital signature obtained while extracting results for objective 1 and 3 mapping was done to evaluate the extent of mangroves in the year 2023. Further ground truthing was carried out in all the river networks to verify the maps and necessary correction were done. Further Shapefiles were obtained of the extent, and using software QGIS analysis was done.

Results

A total of 14 river networks were surveyed to map the mangrove extent. Mandovi river had the highest mangrove extent followed by Zuari river while Baga river had the least mangrove extent (Table 10, Figure 16-29).

Sr. no.	River Network	Area (Square Km)
1	Terekhol River	0.20
2	Mandrem River	0.04
3	Ashwem River	0.04
4	Chapora River	3.27
5	Baga River	0.02
6	Nerul River	1.29
7	Mandovi River	17.17
8	Siridao River	1.25
9	Zuari River	11.21
10	Sal River	3.02
11	Agonda River	0.07

12	Palolem River	0.13
13	Talpona River	0.30
14	Galgibaga River	0.41
	Total	**38.42**

Table 10: Table showing mangrove cover area of individual river network based on ground truthing done in 2023

Figure 16: Map showing mangrove extent around Terekhol river in year 2023

Figure 17: Map showing mangrove extent around river at Mandrem in year 2023

Figure 18: Map showing mangrove extent around river at Ashwem in year 2023

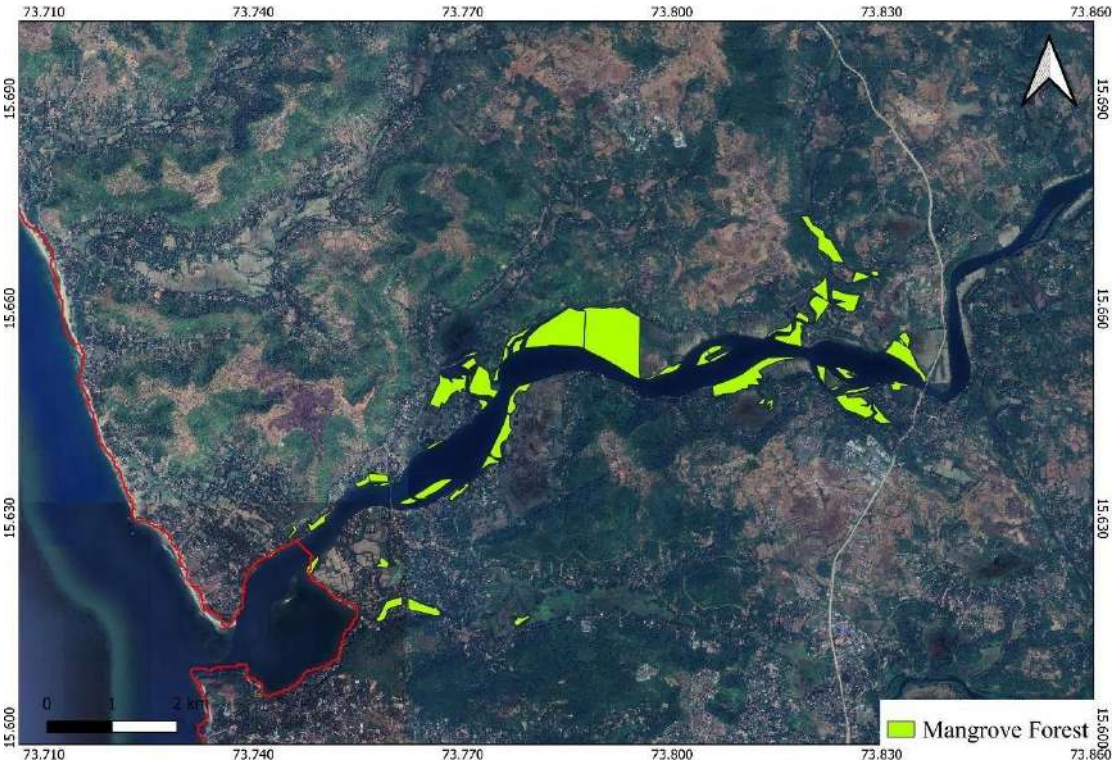

Figure 19: Map showing mangrove extent around Chapora river network in year 2023

Figure 20: Map showing mangrove extent around Baga river network in year 2023

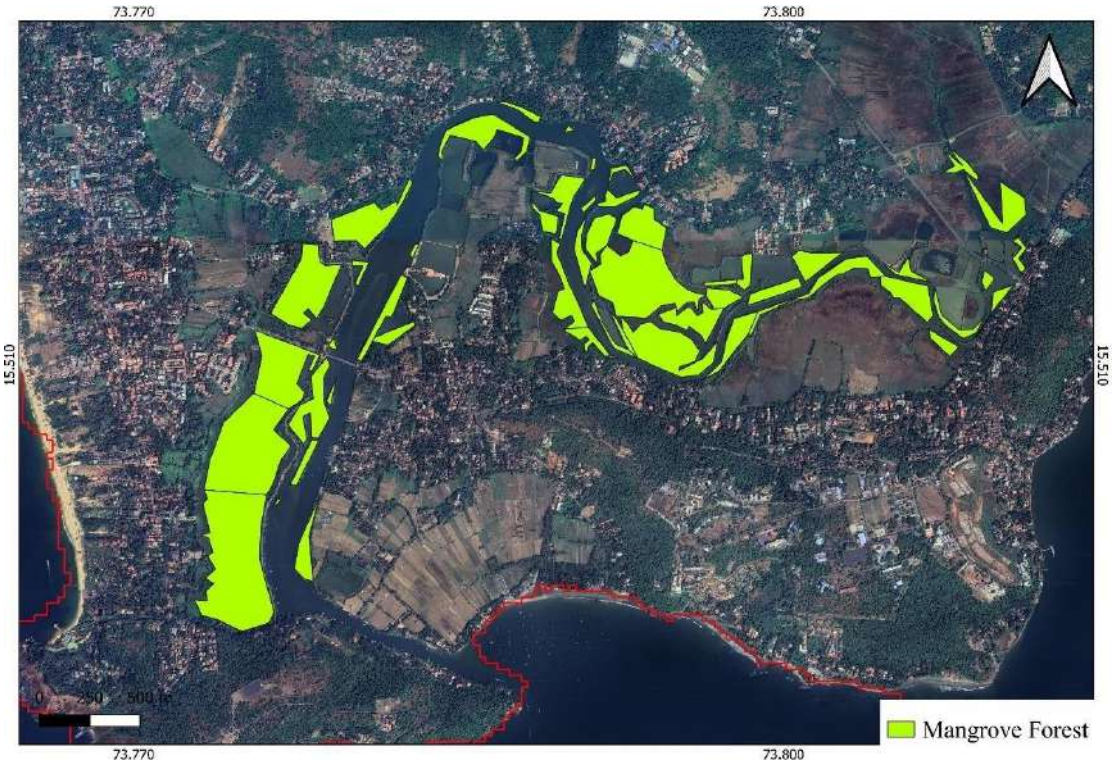

Figure 21: Map showing mangrove extent around Nerul river network in year 2023

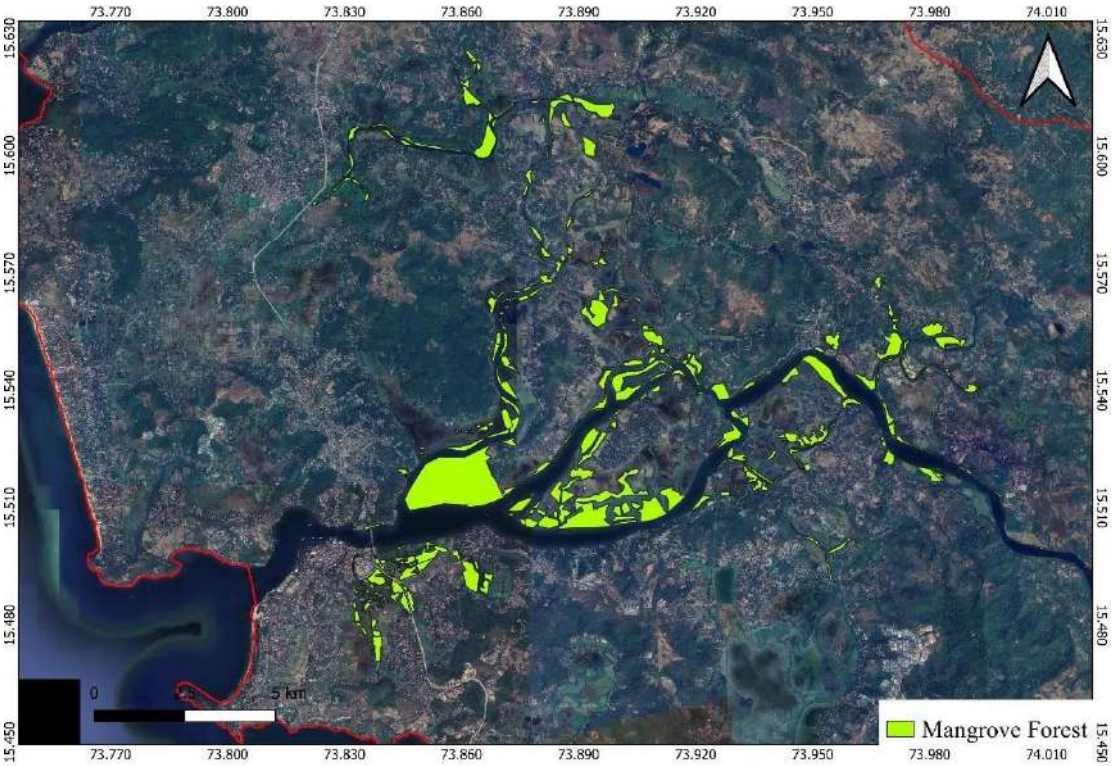

Figure 22: Map showing mangrove extent around Mandovi river network in year 2023

Figure 23: Map showing mangrove extent around Siridao river network in year 2023

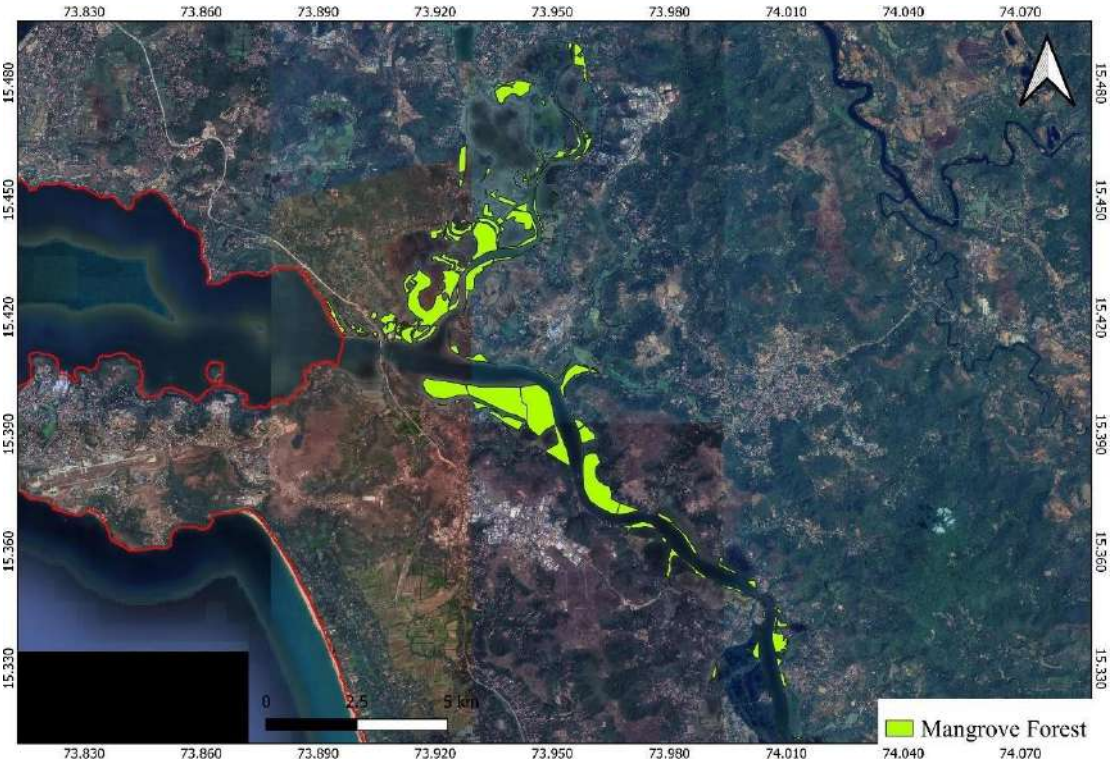

Figure 24: Map showing mangrove extent around Zuari river network in year 2023

Figure 25: Map showing mangrove extent around Sal river network in year 2023

Figure 26: Map showing mangrove extent around Agonda river network in year 2023

Figure 27: Map showing mangrove extent around Palolem river network in year 2023

Figure 28: Map showing mangrove extent around Talpona river network in year 2023

Figure 29: Map showing mangrove extent around Galgibaga river network in year 2023

Chapter VII
Discussion

The mangrove cover has been increasing over the years. This is due to the fact that people have stopped practicing agriculture and bunds are left abandoned/unrepaied because of which mangroves are infiltrating these fields. This is also due to the fact that mangroves have high regenerative capacity if left unattended. This has been observed in several places in entire Goa (Figure 30, Figure 31). This infiltration has been mostly observed in the agricultural lands wherein mangroves were present on the fringes. Mangroves have been reported to be able to help by acting as a buffer against Tsunami, cyclones and other storms. This was observed in areas in Tamil Nadu when tsunami had a hit at the state. Along with the growth of mangroves it also harbours various threats due to manmade and natural elements.

Mangroves provide various ecosystem services in the form of Shoreline stabilization, Costal protection, Animal habitat and breeding and feeding grounds, pollution control and costal water quality improvement, service to local community, mangrove fisheries, carbon sequestration and ecotourism.

Figure 30: Mangrove Forest patch of an area at Chorao in year 2012

Figure 31: Mangrove Forest patch of an area at Chorao in year 2022

Threats

1. Urbanization: the urban development includes the construction of man-made structures for which mangrove forests are cleared. This is mainly due to the fact that mangroves were potentially understood to be non-productive lands and hence were reclaimed for urbanization.

2. Agriculture: the conversion of mangrove lands for agriculture purpose begun in 1770 and is continued till date. Converting mangroves into agriculture land involves cutting of mangroves and digging a canal, the soil of which is piled on both sideways on which various vegetables like okra, brinjal, cucumbers are grown.

3. Aquaculture: Recent growth of aquaculture business is harming mangroves in quite a way. Owners prefers places which are in close proximity to the waterbodies to set up their shrimp ponds and hence cut the mangroves on fringes to build canals or ponds.

4. Recently many mangrove areas are explored for ecotourism an activity which has certainly gained attention from different stakeholders and potential economic gain. However, some impacts are experienced to the ecology.

5. Sewage and industrial effluent: Mangrove habitat serves as a dumping ground for solid waste and for discharging the effluents from various sources. Industrial waste water and are sometimes discharged without treating it into mangrove habitats. Increased accumulation of pollutants in mangrove ecosystem, especially through food chains is likely to occur due to coastal developmental activities. In aquaculture, antibiotics and chemicals are widely used to disinfect and adjust the water quality which in turn harms mangroves. Several human settlements of banks are also seen releasing sewage directly into these water bodies. Several economically important bivalve species are highly impacted.

6. Oil pollution: Various oil spills have been recently observed along the coastline of Goa, these oil spills enters the estuarine systems wherein mangroves are abundantly present and cover their roots. This process usually occurs during high tides when water from sea enters the estuaries.

7. Cutting of mangroves: Due to the decrease in firewood recently it has been observed that some people collect it from mangrove habitats. Since the trees are small and easy to handle, they cut off the plants and leave them for drying overtime and them collect it.

8. Overfishing: Mangrove serve breeding ground for several fishes and aquatic life. Recent innovation in fishing gears and rising demand for fish has created major decline in fishes associated to mangroves. In many places these mangroves are cut off to create space to tie or set the fishing gears like line nets etc.

9. Sand and iron ore mining: Movement of heavy boats gives rise to strong waves which sometimes damage the seedlings.

10. Natural threats to mangroves include flooding, grazing, poor natural regeneration, biofouling, cyclones and climate change.

Recommendations for Conservation & Management formangroves:

Considering the outcome of short-term study carried out to understand the mangrove status, following recommendations are listed for its better management and conservation. However detailed management plan may be worked out subsequently.

- Identification of crucial mangrove habitats for conservation.
- Promotion of scientific research to understand diversity of flora and fauna.
- Multidisciplinary approach involving government, non-government, educational institution and local communities for better conservation outcome.
- Assessment of suitability as reserve forest.
- Conservation awareness programmes and ecotourism practices
- Afforestation of degraded mangrove areas shown in the present study.
- Avoid unplanned sand extraction to prevent further degradation of crucial mangrove habitats.
- Regular monitoring/repair of traditional bunds to avoid saline water intrusion and invasion of mangroves into agriculture land.
- Soft measures or traditional methods may be adopted to repair these bunds to avoid destruction of important mangrove habitats.

- During afforestation, appropriate plant species should be selected, as every species occupies distinct location in the mangrove forest.
- Avoid dumping of construction debris and release of sewage water

Recommendations for Conservation & Management for inter-tidal mudflats:

Intertidal mudflats are invisible during the high tide, however the un-vegetated ground is exposed as tide retreats. Although little oxygen penetrates the sediment, it is full of hidden treasure. Present study confirms 7.32 sq. km. area is contributed by mudflats. These mudflats are randomly formed along the estuary banks and river banks and are of dynamic nature which is said to be due to continuous changes in the flow and current in the water columns of the coastal waters. Following are the recommendations for its conservation and better management.

- Mud flats are crucial feeding grounds for several resident and migratory avian diversity. Mudflats being ecologically sensitive habitat should not be indiscriminately used for mangrove plantation. Mangrove plantation activities should be done in the areas from where they have been destroyed. Mudflats shall not be converted into mangroves habitats

- Microorganisms also play vital role to drive food chain as well as fertility of mud flats for growth and development of mangroves. Mudflat are categorized as ecologically sensitive habitat as different from mangroves in latest CRZ notification (2011).

- Several mangrove fauna such as Crocodiles, Mud clams, Molluscs, Crustaceans, Worms etc harbours on these mud flats. It is this clandestine life, coupled with

twice-daily saturation that softens silty sediment sufficiently for shorebirds to probe, that rendersmudflats mighty feeding stations for millions of shorebirds worldwide.

- These mudflats support several fisher-folk communities and full fills their daily need, which should be maintained and conserved at all cost.

- Mud flats serves as a breeding and feeding ground for several fish species, mud crabs, mud skipper, migratory and resident birds etc.

- Improvements in both knowledge and actions are required to realize the conservation and sustainable use of intertidal mudflats and salt marshes in Goa, specifically in terms of decision-making.

- This study can be a base to carry out further detailed scientific research for better understanding of ecological functioning and to initiate best conservation practices.

- All the concern line departments need to work together while planning any developmental activities.

Plate 1: Mammals

Three Striped Palm Squirrel

Indian Grey Mongoose

Indian Jackal

Bonnet Macaque

Plate 2a: Aves

Collard Kingfisher

Stork-billed Kingfisher

Little Cormorrant

Orange Breasted Green Pigeon

Osprey

White-bellied Sea Eagle

Plate 2b: Aves

Painted Stork

Great Egret

Black-headed Ibis

Western Reef Egret

Common Greenshank

Indian Pond Heron

Plate 3: Reptiles

Mugger crocodile

Indian garden lizard

Rat Snake

Checkered Keelback

Dog-faced Water Snake

Bengal Monitor

Plate 4: Amphibians

Hoplobatrachus tigerinus

Euphlyctis aloysii

Polypedates maculatus

Minervarya gomantaki

Euphlyctis cyanophlyctis

Hydrophylax malabaricus

Plate 5: Plants

Sonneratia alba

Acanthus ilicifolius

Kandelia candel

Salvodora persica
(Mangrove associate)

Plate 6: Morjim-Chapora
Mudflat

a

b

Plate 7: Ribandar
Mudflat

a

b

Plate 8: Agaciam
Mudflat

a

b

Chapter VIII: References

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Google earth engine programme for compilation of mangrove cover maps of different time zones

```
var roi: Table users/mithilgawas0987/Goa
var L8: ImageCollection "USGS Landsat 8 Level 2, Collection 2, Tier 1"
var SRTM: Image "NASA SRTM Digital Elevation 30m" (1 band)
var L7: ImageCollection "USGS Landsat 7 Level 2, Collection 2, Tier 1"
var mangrove2012: FeatureCollection (7 elements)
var nonmangrove2012: FeatureCollection (10 elements)
var mangrove: FeatureCollection (12 elements)
var nonmangrove: FeatureCollection (35 elements)
```

```
//                    1) Set up the map                          //


//Center the map to the region of interest using the region shapefile
Map.centerObject(roi,7);
Map.setOptions('satellite');
```

```
//2.1) Cloud Masking
//////////////////////

//Landsat data includes a 'pixel_qa' band which can be used to create
//     a function to mask clouds

function maskClouds(image) {

  // Bits 3 and 5 are cloud shadow and cloud, respectively.
    var cloudShadowBitMask = ee.Number(2).pow(3).int();
    var cloudsBitMask = ee.Number(2).pow(5).int();

    // Get the pixel QA band.
    var qa = image.select('QA_PIXEL');

     // Both flags should be set to zero, indicating clear conditions.
    var mask = qa.bitwiseAnd(cloudShadowBitMask).eq(0).and(qa.bitwiseAnd(cloudsBitMask).eq(0));

  // Return the masked image, scaled to [0, 1].
  return image.updateMask(mask).divide(10000).copyProperties(image, ["system:time_start"]);
}
```

```
/2.2) Adding Spectral Indices
////////////////////////////////

/ This function maps spectral indices for Mangrove Mapping using Landsat 8 Imagery
ar addIndicesL7 = function(img) {
  // NDVI
  var ndvi = img.normalizedDifference(['SR_B4','SR_B3']).rename('NDVI');
  // NDMI (Normalized Difference Mangrove Index - Shi et al 2016 - New spectral metrics for mangrove forest identification)
  var ndmi = img.normalizedDifference(['SR_B7','SR_B2']).rename('NDMI');
  // MNDWI (Modified Normalized Difference Water Index - Hanqiu Xu, 2006)
  var mndwi = img.normalizedDifference(['SR_B2','SR_B5']).rename('MNDWI');
  // SR (Simple Ratio)
  var sr = img.select('SR_B4').divide(img.select('SR_B3')).rename('SR');
  // Band Ratio 54
  var ratio54 = img.select('SR_B5').divide(img.select('SR_B4')).rename('R54');
  // Band Ratio 35
  var ratio35 = img.select('SR_B3').divide(img.select('SR_B5')).rename('R35');
  // GCVI
```

```
  var gcvi = img.expression('(NIR/GREEN)-1',{
    'NIR':img.select('SR_B4'),
    'GREEN':img.select('SR_B2')
  }).rename('GCVI');
  return img
    .addBands(ndvi)
    .addBands(ndmi)
    .addBands(mndwi)
    .addBands(sr)
    .addBands(ratio54)
    .addBands(ratio35)
    .addBands(gcvi);
};
```

```
//2.3) Filter Landsat data by Date and Region
////////////////////////////////////////////////

// Temporal Parameters

// Select the desired central year here
var year = 2022;

// Start date will be set one year before the central year
var startDate = (year-1)+'-01-01';

// End date will be set to one year later than the central year.
var endDate = (year+1)+'-12-31';
```

```
//2.4) Apply filters and masks to Landsat 8 imagery
//////////////////////////////////////////////////

var l7 = L7.filterDate(startDate,endDate)
// Mask for clouds and cloud shadows
    .map(maskClouds)
//Add the indices
    .map(addIndicesL7);
```

```
//2.5) Composite the Landsat image collection
/////////////////////////////////////////////

//You can composite on a per pixel, per-band basis using .median()
// OR with quality bands like .qualityMosaic('NDVI')

var composite = l7
            // Uses the median reducer
            .median()
            // Clips the composite to our area of interest
            .clip(roi);
```

```
//2.6) Mask to areas of low elevation and high NDVI and MNDWI
/////////////////////////////////////////////////////////////

// Clip SRTM data to region
var srtmClip = SRTM.clip(roi);

//Mask to elevations less than 65 meters
var elevationMask = srtmClip.lt(10);

//Used the NDVI and MNDWI bands to create masks
var NDVIMask = composite.select('NDVI').gt(0.25);
var MNDWIMask = composite.select('MNDWI').gt(-0.50);

//Apply the masks
var compositeNew = composite
                    .updateMask(NDVIMask)
                    .updateMask(MNDWIMask)
                    .updateMask(elevationMask);
```

```
//2.7) Display results
//////////////////////

//Select bands and parameters for visualization
 var visPar = {bands:['SR_B4','SR_B5','SR_B3'], min: 0, max: 0.35};

//Add layer to map
Map.addLayer(compositeNew.clip(roi), visPar, 'Landsat Composite 2022');
```

```
////////////////////////////////////////////////////////////////
//          3) Construct Random Forest Model                  //
////////////////////////////////////////////////////////////////

//3.1) Prepare training data and predictors
////////////////////////////////////////////

//After drawing training polygons, merge them together
var classes = mangrove.merge(nonmangrove);

//Define the bands you want to include in the model
var bands = ['SR_B4','SR_B5','SR_B3','NDVI','MNDWI','SR','GCVI'];

//Create a variable called image to select the bands of interest and clip to geometry
var image = compositeNew.select(bands).clip(roi);

//Assemble samples for the model
var samples = image.sampleRegions({
    collection: classes, // Set of geometries selected for training
    properties: ['landcover'], // Label from each geometry
    scale: 30 // Make each sample the same size as Landsat pixel
    }).randomColumn('random'); // creates a column with random numbers
```

```
//Here we randomly split our samples to set some aside for testing our model's accuracy
// using the "random" column we created
var split = 0.8; // Roughly 80% for training, 20% for testing.
var training = samples.filter(ee.Filter.lt('random', split)); //Subset training data
var testing = samples.filter(ee.Filter.gte('random', split)); //Subset testing data


//Print these variables to see how much training and testing data you are using
    print('Samples n =', samples.aggregate_count('.all'));
    print('Training n =', training.aggregate_count('.all'));
    print('Testing n =', testing.aggregate_count('.all'));
```

```
//3.2) Begin Random Forest Classification
//////////////////////////////////////////

//.smileRandomForest is used to run the model. Here we run the model using 100 trees
// and 5 randomly selected predictors per split ("(100,5)")
    var classifier = ee.Classifier.smileRandomForest(100,5).train({
    features: training.select(['SR_B4','SR_B5','SR_B3','NDVI','MNDWI','SR','GCVI', 'landcover']), //Train using bands and landcover property
    classProperty: 'landcover', //Pull the landcover property from classes
    inputProperties: bands
    });
```

```
//3.3) Test the accuracy of the model
//////////////////////////////////////

    var validation = testing.classify(classifier);
    var testAccuracy = validation.errorMatrix('landcover', 'classification');
    print('Validation error matrix RF: ', testAccuracy);
    print('Validation overall accuracy RF: ', testAccuracy.accuracy());
```

```
//3.4) Classify the Landsat composite using the Random Forest model
/////////////////////////////////////////////////////////////////////

    var classifiedrf = image.select(bands) // select the predictors
                        .classify(classifier); // .classify applies the Random Forest

//The model results may be "noisy". To reduce noise, create a mask to mask
// unconnected pixels
    var pixelcount = classifiedrf.connectedPixelCount(100, false); //Create an image that shows the number of pixels each pixel is connected to
    var countmask = pixelcount.select(0).gt(25); //filter out all pixels connected to 4 or less

//Mask the results to only display mangrove extent
    var classMask = classifiedrf.select('classification').gt(0);
    var classed= classifiedrf.updateMask(countmask).updateMask(classMask);
```

```
//3.5) Map results
//////////////////////

//Add classification to map
Map.addLayer (classed, {min: 1, max: 2, palette:'blue'}, 'Mangrove Extent 2022');
```

```
//4.1) Adding Landsat 7 Spectral Indices
//////////////////////////////////////////////

// Both collections have different band numbers that are different, so I created two functions in regard to each individual set of bands

// This function maps spectral indices for Mangrove Mapping using Landsat 7 Imagery
var addIndicesL7 = function(img) {
  // NDVI
  var ndvi = img.normalizedDifference(['SR_B4','SR_B3']).rename('NDVI');
  // NDMI (Normalized Difference Mangrove Index - Shi et al 2016 - New spectral metrics for mangrove forest identification)
  var ndmi = img.normalizedDifference(['SR_B7','SR_B2']).rename('NDMI');
  // MNDWI (Modified Normalized Difference Water Index - Hanqiu Xu, 2006)
  var mndwi = img.normalizedDifference(['SR_B2','SR_B5']).rename('MNDWI');
  // SR (Simple Ratio)
  var sr = img.select('SR_B4').divide(img.select('SR_B3')).rename('SR');
  // Band Ratio 54
  var ratio54 = img.select('SR_B5').divide(img.select('SR_B4')).rename('R54');
  // Band Ratio 35
  var ratio35 = img.select('SR_B3').divide(img.select('SR_B5')).rename('R35');
  // GCVI
```

```
  var gcvi = img.expression('(NIR/GREEN)-1',{
    'NIR':img.select('SR_B4'),
    'GREEN':img.select('SR_B2')
  }).rename('GCVI');
  return img
    .addBands(ndvi)
    .addBands(ndmi)
    .addBands(mndwi)
    .addBands(sr)
    .addBands(ratio54)
    .addBands(ratio35)
    .addBands(gcvi);
};
```

```
//4.2) Filter Landsat data by Date and Region
//////////////////////////////////////////////

// Temporal Parameters

// Select the desired central year here
var year = 2012;

// Start date will be set one year before the central year
var startDate = (year-1)+'-01-01';

// End date will be set to one year later than the central year.
var endDate = (year+1)+'-12-31';
```

```
//4.3) Apply filters and masks to Landsat 7 imagery
////////////////////////////////////////////////////

var l7 = L7.filterDate(startDate,endDate)
// Mask for clouds and cloud shadows
    .map(maskClouds)  //We use the same function we used for Landsat 8
//Add the indices
    .map(addIndicesL7);
```

```
//4.4) Composite the Landsat image collection
////////////////////////////////////////////

//You can composite on a per pixel, per-band basis using .median()
// OR with quality bands like .qualityMosaic('NDVI')

var L7composite = l7
                  // Uses the median reducer
                  .median()
                  // Clips the composite to our area of interest
                  .clip(roi);
```

```
//4.5) Mask to areas of low elevation and high NDVI and MNDWI
////////////////////////////////////////////////////////////

//Used the NDVI and MNDWI bands to create masks
var L7NDVIMask = L7composite.select('NDVI').gt(0.25);
var L7MNDWIMask = L7composite.select('MNDWI').gt(-0.50);

//Apply the masks
var L7compositeNew = L7composite
                     .updateMask(L7NDVIMask)
                     .updateMask(L7MNDWIMask)
                     .updateMask(elevationMask); //We can use the same mask as before
```

```
//4.6) Display results
//////////////////////

//Select bands and parameters for visualization
//We use bands 4, 5, and 3 instead
var L7visPar = {bands:['SR_B4','SR_B5','SR_B3'], min: 0, max: 0.35};

//Add layer to map
Map.addLayer(L7compositeNew.clip(roi), L7visPar, 'Landsat Composite 2012');
```

```
//5.1) Prepare training data and predictors
//////////////////////////////////////////////

//After drawing training polygons, merge them together
var classes2012 = mangrove2012.merge(nonmangrove2012);

//Define the bands you want to include in the model
var L7bands = ['SR_B4','SR_B5','SR_B3','NDVI','MNDWI','SR','GCVI'];

//Create a variable called image to select the bands of interest and clip to geometry
var L7image = L7compositeNew.select(L7bands).clip(roi);

//Assemble samples for the model
var L7samples = L7image.sampleRegions({
    collection: classes2012, // Set of geometries selected for training
    properties: ['landcover'], // Label from each geometry
    scale: 30 // Make each sample the same size as Landsat pixel
    }).randomColumn('random'); // creates a column with random numbers
```

```
//Here we randomly split our samples to set some aside for testing our model's accuracy
// using the "random" column we created
var L7training = L7samples.filter(ee.Filter.lt('random', split)); //Subset training data
var L7testing = L7samples.filter(ee.Filter.gte('random', split)); //Subset testing data


//Print these variables to see how much training and testing data you are using
    print('Samples n =', L7samples.aggregate_count('.all'));
    print('Training n =', L7training.aggregate_count('.all'));
    print('Testing n =', L7testing.aggregate_count('.all'));
```

```
'/5.2) Begin Random Forest Classification
'//////////////////////////////////////////

'/.smileRandomForest is used to run the model. Here we run the model using 100 trees
'/ and 5 randomly selected predictors per split ("(100,5)")
    var L7classifier = ee.Classifier.smileRandomForest(100,5).train({
    features: L7training.select(['SR_B4','SR_B5','SR_B3','NDVI','MNDWI','SR','GCVI', 'landcover']), //Train using bands and landcover property
    classProperty: 'landcover', //Pull the landcover property from classes
    inputProperties: L7bands
    });
```

```
'/5.3) Classify the Landsat composite using the Random Forest model
'////////////////////////////////////////////////////////////////////////

    var L7classifiedrf = L7image.select(L7bands) // select the predictors
                        .classify(L7classifier); // .classify applies the Random Forest

'/The model results may be "noisy". To reduce noise, create a mask to mask
'/ unconnected pixels
    var pixelcount = L7classifiedrf.connectedPixelCount(100, false); //Create an image that shows the number of pixels each pixel is connected t
    var countmask = pixelcount.select(0).gt(25); //filter out all pixels connected to 4 or less

'/Mask the results to only display mangrove extent
    var L7classMask = L7classifiedrf.select('classification').gt(0);
    var L7classed= L7classifiedrf.updateMask(countmask).updateMask(L7classMask);
```

```
//5.5) Map results
//////////////////

//Add classification to map
Map.addLayer (L7classed, {min: 1, max: 2, palette:'yellow'}, 'Mangrove Extent 2012');
```

```
//6.1) Calculate Mangrove Area in 2012
//////////////////////////////////////

//Use reduceRegion with a Sum reducer to calculate total area
var get2012 = L7classed.multiply(ee.Image.pixelArea()).divide(10000).reduceRegion({
      reducer:ee.Reducer.sum(),
      geometry:roi,
      scale: 100,
      maxPixels:1e13,
      tileScale: 16
      }).get('classification');

print(get2012, 'Mangrove Extent 2012 in ha');
```

```
//6.2) Calculate Mangrove Area in 2022
//////////////////////////////////////

//Use reduceRegion with a Sum reducer to calculate total area
var get2022 = classed.multiply(ee.Image.pixelArea()).divide(10000).reduceRegion({
      reducer:ee.Reducer.sum(),
      geometry:roi,
      scale: 100,
      maxPixels:1e13,
      tileScale: 16
      }).get('classification');

print(get2022, 'Mangrove Extent 2022 in ha');
```