Current Journal of Applied Science and Technology

Volume 42, Issue 41, Page 28-47, 2023; Article no.CJAST.108508
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Geomorphologic Changes and Ethnobotany Losses of Indian Sundarbans in Anthropocene

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2023/v42i414265

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/108508

Original Research Article

Received: 03/09/2023
Accepted: 07/11/2023
Published: 10/11/2023

ABSTRACT

People in the inter-tidal zones of the Ganga-Brahmaputra-Meghana Delta regions are reliant on mangroves for food, medicine, protection, and livelihood. The present Anthropocene epoch has a deteriorated impact on people's societal, fiscal, and demography due to the climate change loss of agriculture and land use. The mangrove vegetation of Indian Sundarbans is declining in the South 24-Praganna district, West Bengal, the world's largest estuarine forest, and the UNESCO Heritage, site.

Remote sensing (RS) and geographic information systems (GIS) techniques were used to download data of the Landsat 8 OLI from USGS/GLOVIS of SOUTH 24 Parganas, West Bengal and analysed by ERDAS IMAGINE applications for speculation of the land use/land cover dynamics

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from the year 2015 to 2020. Ground truthing was conducted by site visits and compiled the medicinal use of plants to investigate the sustenance of SDG-3 and SDG-14.2 and SDG 14.5 of life in the Sundarbans.

The distribution of various mangrove species was identified in the core, buffer and manipulation zones of the Sundarbans Biosphere Reserve, their stratification along the cross-sections, zoning, and use as folk medicines. The research reveals mangrove vegetation is dwindling along the coasts of the South 24 Parganas. There is subsidence, emergence and submergence of land in the archipelago of nearshore Islands. The mangrove loss has been transformed into settlements or agricultural land. Recommendations are made to sustain the inter-tidal vegetation.

Keywords: GBM delta; Sundarbans; mangroves; GIS; South-24-Parganas; ethnobotany.

1. INTRODUCTION

The large deltas of the east coast (EC) of India are undergoing sinking, shrinking and subsidence, regional sea level rise (RSLR), sedimentation, coastal erosion, and tidal inundations also the globally largest, Ganga Brahmaputra Meghana delta (GBMD). Mangroves, the halophytic plants grow in the transitional interface in Sundarbans in South 24 Parganas housed in the southern zone between the sea and the land. They are the tidal influencing areas comprising standalone flora (epiphytes, shrubs, ground ferns, grasses and trees) and brackish water fauna. It was a tiger reserve in the year 1973, declared as a wild sanctuary in the year 1977 and later a national park in 1984. This mangrove ecosystem is of late Cretaceous origin [146 - 100 Mya]. Its expanse is ever-changing with the transgression and retrogression of the Bay of Bengal coast. The evergreen blue carbon ecosystem is in Jeopardy due to Anthropogenic stress, climate changes in climate and is not compatible with Sustainable development goals, SDG 3 and SDG-14, [1-3].

Anthropocene: Homosapiens governed the biome, and fragmented the land, from states to districts grounded on nature's conformation in the Anthropocene (the human epoch) probably from 1950, and a larger scale from its golden spike period (1980). Presently, sustaining human life has urged for an incremental menace to humans, biodiversity, ecology, and the environment due to population density, modernization, urbanization, industrialisation, and land use strategies [4-7].

Sustainable Development Goals: SDGs 1 to SDG 17 were officially recognised by India among 193 members of the United States on 15th Sept. 2015. SDG 3 encourages people's health whereas SDG 14 promises to guard, reestablish and endorse sustainability of land-ocean usage of terrestrial ecosystems. The importance is emphasized in sustainably dealing with forests, combating desertification, Eco-system losses, and halting setbacks of degraded biodiversity loss [8-10].

Sundarbans and mangrove forests: Mangroves are halophytic plants that grow in the transition zones in coastal low-lying intertidal zones comprising aerophytes, shrubs, coastal ferns, grasses and trees. The Indian coast covers 4992 sq. km of mangroves out of 713789 km^2 global figure. https://geographyhost.com/forest-cover-in-india-important-statistics/.The Sundarbans (India and Bangladesh), the archipelago of islands, are housed in the Ganga Brahmaputra Meghna delta (GBMD). The largest mangrove delta is housed in about 10200 km2 (4200km^2 in India and the rest in Bangladesh) out of which about 2112.11 km2 of India's lower Gangetic delta (FSI, [11] and https://sundarbanresidency. com/history. html). True Mangrove covers 257.10 sq. km in the South 24 Parganas. The well-diversified vegetation has developed certain morphological, biological, physiological, and ecological common adaptability to thrive along tropical coasts or creeks having climatological, biological, ecological, and economic importance. Sundarbans Wetland has an International Status, ranking 27th (*Ramsar Site no. 2370*) [12-14].

Blue carbon: The coastal system consisting of salt marshes, plankton, and seagrass ecosystems, that efficiently store carbon, maintain the carbon balance and are called blue carbon. The ecosystem pertaining to blue carbon shields the coast from erosion, augments accretion, and regulates oceanic water standards, marine life and forestry. Presently this ecosystem is in jeopardy due to its resource over-exploitation, pollution, and anthropogenic intervention in its geomorphology. To sustain the role and maintain of concentration of CO_2 as per

SDG-13 (climate action). It warrants devoted insistence to restore the coastal blue carbon ecosystem to convert as a lasting carbon sink and to reduce carbon sequestrations. iucn.org/resources/issues-brief/blue-carbon.

MNG and MNA ecosystems can store and sequester huge quantities of blue carbon (Corg) but are area-specific. The CO2 emissions through coastal vegetation systems bear only 0.2% of total global CO2 emissions but about 18% of CO2 emissions from the tropical coastal ocean [40]). The Sundarbans, mangrove forest stores around 26.62 Tg of blue carbon [70].

Study Area: The Population of 24 Parganas (S) was 1.38million in 1951 whereas the present population has risen to 9.022million only in south 24 Parganas (North 24 Parganas not taken), [42]. Census India, [43]. During the Meghalayan period (≈4.1k YBP) of the Holocene epoch, there were the Sundarbans mangroves. The Sundarbans, the largest mangrove, house between 88°55 E to 89° E and 21°30' N to 23°30' N, i.e., between the Hooghly River (Kolkata) to Baleswar River (Khulna). The Indian mangroves have an area of about 3800 km2. Sundarbans Biosphere Reserve (SBR) of India is located within 21° 32′–22° 40′N and 88° 05′–89°51′E in districts of south 24- Parganas. The present study area is within 21° 32′–22° 14′N and 88° 10′–89° 05′ E. Indian SBR has an area of about 2,400 km^2.

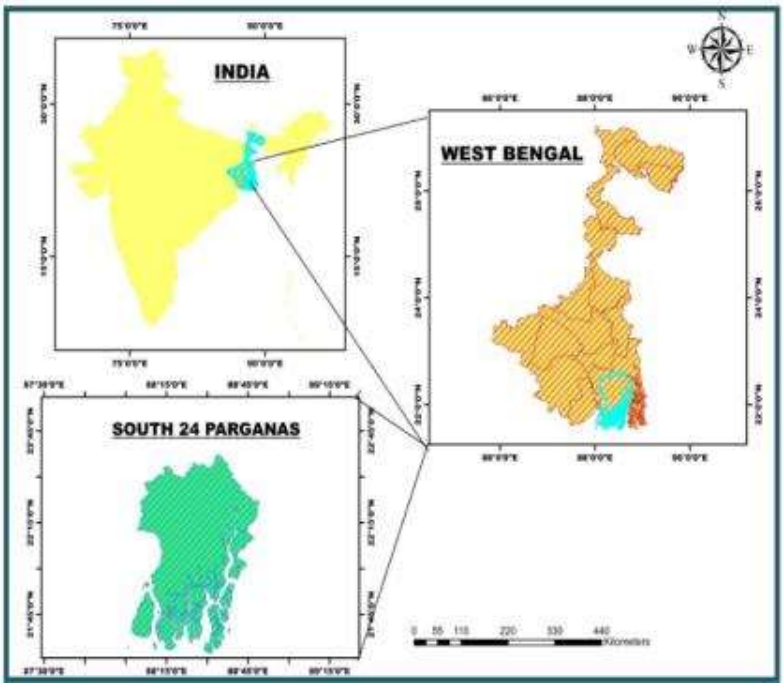
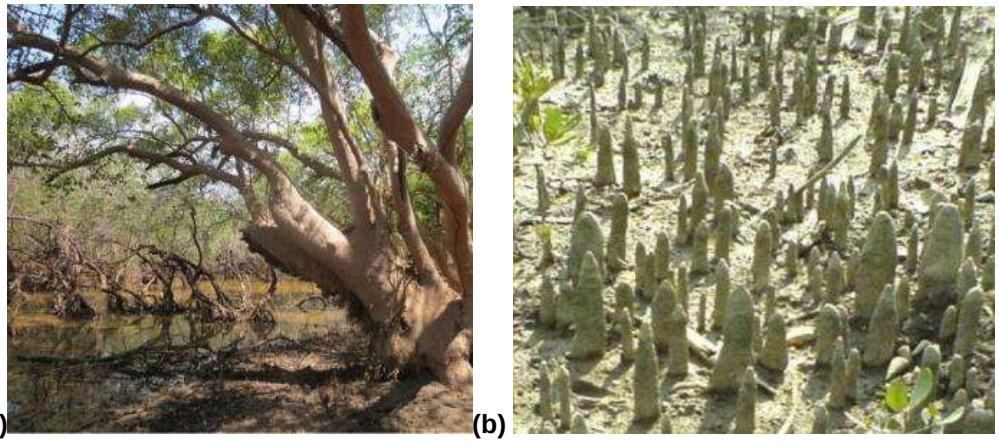
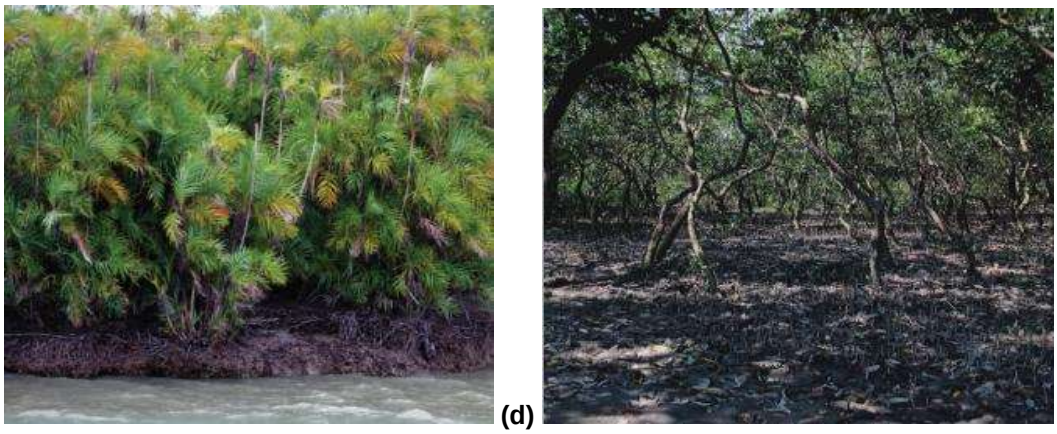


Fig. 1. The Index map of the South 24 Parganas district in West Bengal part of GBM delta





(c) **(d)**

Fig. 2 (a) Sundari plant in Hooghly estuary (b): Knee roots in Passur or Pitamari (*Xylocarpus mekongensis)* mangroves (c) The Hental in Matla River in S-24-Parganas (d) Hental forests

The 'Sundarbans' are named after the main mangrove species 'Sundari' (Heritiera fomes) which is endangered due to cutting, and top-dying diseases. The other attraction of Sundarbans is the Royal Bengal tiger (Panthera Tigris ssp. Tigris), which is endangered now, [15]. The irrigation demand in Sundarbans is about 2784 MCum. The waterbodies (small or large) are 70000 in number and supplemented by 8,000 shallow tube wells that cannot cater for the demand [16]. Food security is at stake for 87.5% of the low-income people in Sundarbans. Present changes in climatic, unsafe food security warrant an increase in the irrigation network, (Figs. 2 a,b,c,d).

2. REVIEW OF LITERATURE

The 24-Parganas was established on 15th July 1757 by Mir Jafar, the first Nawab of Bengal. The South 24 Parganas was formed on 1st, March 1986. Which was later bifurcated into subdivisions- (Alipore and Diamond Harbour) and divided into 30 blocks (GoWB and South 24 Parganas website [47]). The Multidimensional Rural Poverty Index Score of the South 24 Parganas as per NITI Ayog, 2023 in the year 2015-16 and 2019-21 were 0.116 and 0.064 respectively [18].

Mangroves are developed in ≈150000 sq. km globally [17]. India shares 4975 km2, (0.15% of the globe) along the country's east, west, and AN Islands. Coasts. The largest man-groves in West Bengal cover 42.45%, followed by Gujarat (23.66%) (FSI, [11]). Indian Sundarbans have enumerated 27 pure mangrove species out of 46 true global and 40 mangrove The east coast of India has species, while the west coast has 27 species [19], Nandi et al., [20], Chanda et al., [21]). MSL is a proxy for mangrove area delineation), [22], [23].

Geomorphologic study of Sundarbans and south Parganas is difficult for ground survey due to in accessibility and tough terrain. Remote sensing (RS) is one of the proper tools for mapping and monitoring inaccessible topography, and natural resources [24-28]. The on-ground survey is hard, time-consuming, and laborious in mangrove tidal swamps, Remote sensing (RS) methodology can be conducted for the mapping and monitoring of the ground truthing and up-to-date information [29,30,21].

RS techniques have the potential to recognize, map, and monitor changes in the mangrove forests in coastal areas, using hyper-spectral satellite images and information for digital image processing to classify mangrove bowls [31-34]. Landsat TM, SPOT XS, IRS LISS-III, CARTOSAT-1 (2.5m), and Sentinel-2, are common sensors used for Mangrove species. Identification is more helpful in high-resolution multispectral images than in coarser-resolution images [35,36,20].

The effective management of a holistic blue carbon ecosystem can refurbish the strategy to bridge the inmates to protect stakeholders' risk from deterioration of ecology, community, lifeline, society, and economy. There is a lag between coordination between its stakeholders, achieving suitable restoration goals and prescribing SOP (standard operating procedures), which are essential for the restoration of degraded mangrove areas.

2.1 Objectives:

Since 2016, there have been few literature studies against land use change estimation literature available for the study area. The objectives of the present geospatial study to investigate:

1. The study of geomorphology of the Indian Sundarbans.
2. To access the multidimensional ethnobotanical folk drugs of the aboriginals of the area.
3. To speculate the functions of Sundarbans ecology, the current changes in the land use (LU) of South 24 Parganas in the last eight years (2015-2022).
4. The impact of the mangrove ecosystem on its stakeholders in the last two decades.

Ganga-Brahmaputra Meghana (GBM) Delta: The GBM delta is the world's largest and wildest budding delta of Asia spread over six states, i.e., India, Bangladesh, Bhutan, China, Myanmar and Nepal. The GBM canopy covers 1.7 million km2 of India and Bangladesh. The delta covers an area of about 100,000 sq. km and is fertile and agriculturally potential. The 355km long delta runs parallel to the Bay of Bengal (BoB) coast. It is shaped by the regular deposition of sediment through GBM rivers (~1 BT/annum). The Ganga R. only carries about 150 to 590 MT/Y, the Brahmaputra 135 to 615 MT/y and the Meghana (6-12 MT/ annum) have a decreasing trend (data 1960-2008). The ephemeral rivers and the longshore drift of about 260km long swampy coast have an average annual subsidence of 3-7mm/year [37-41].

South 24 Pargana (West Bengal): The south 24 Parganas is a district (formed March 1st, 1986) adjacent to Kolkata city of area 9960 km^2, comprising 8.153 million people (2011 Census). The district falls under Survey of India Topo Sheet No. 79B/2 to 6, 79B/10 to 12, 79B/15 and 16, 79C/1 to 6, 79C/9, and C/10. The lower part is housed in the Sundarbans, the largest mangroves of the globe. The connectivity is lacking due to a highly anastomosed drainage network, hilly land, and mangroves. The district is fed by the rivers Matla (wide estuary), the Raj Mangal (tidal estuary), the Saptamukhi (tidal estuarine), the Hooghly (260km long, treated as holy Ganga), the Vidyadhari(estuarine), the Thakuran (called Jamira, tidal estuarine) and the Piyali (a connector between Bidyadhari and Matla).

The South 24 Parganas district is trifurcated as (i) The marshy Sundarbans (Zone I) (ii) The Non-Sundarbans(countryside) (Zone II), and (iii) The Urban areas around Kolkata city, (Zone III). Zone II is composed of anastomosis of 1st-order drainages emerging the 2nd-order distributaries by bifurcation within both mangrove swamps, Levees, and marshes with mangrove associates. The Zone I areas are the coastal belt consisting of creeks and Sundarbans with pure MNG. Irrespective of zones, the land is highly fertile and has high yields of rice, timber, fish, honey, sugarcane, beetle nuts etc, (Bagchi 2017[44]). Indian Sundarbans in the phytosociological study had five zones but presently transformed into four zones (loss of a few species of mangroves). It is due to the impact of Tides (Low and High), Regional Sea level changes (RSLR), the impact of cyclones and human interventions, between 2017-2021(Chowdhury et al, 2023[45]).

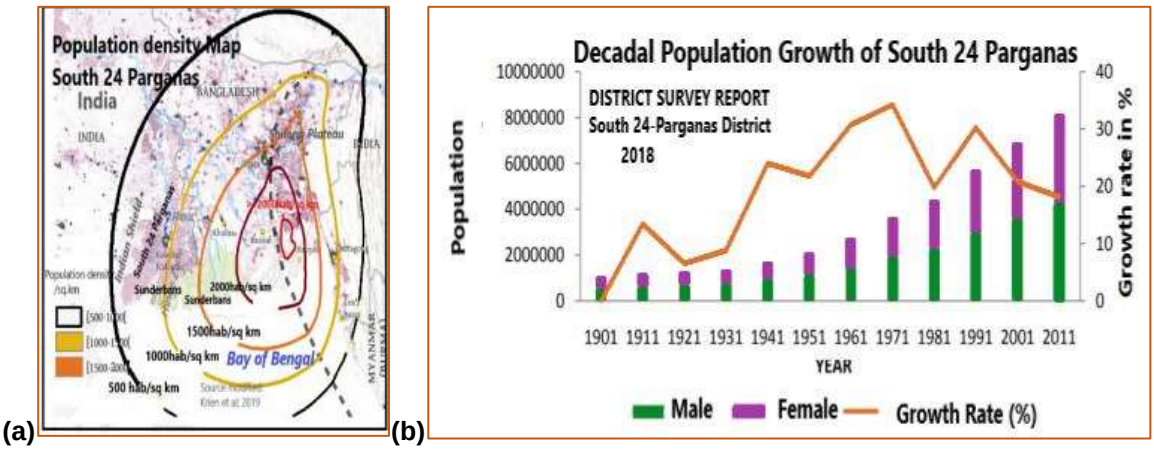


Fig. 3(a): Demographic study of South 24 Parganas Fig 3(b): The decadal population map of South 24 Parganas (source modified: https://s24pgs.gov.in/assets/webdoc/mediauplo)

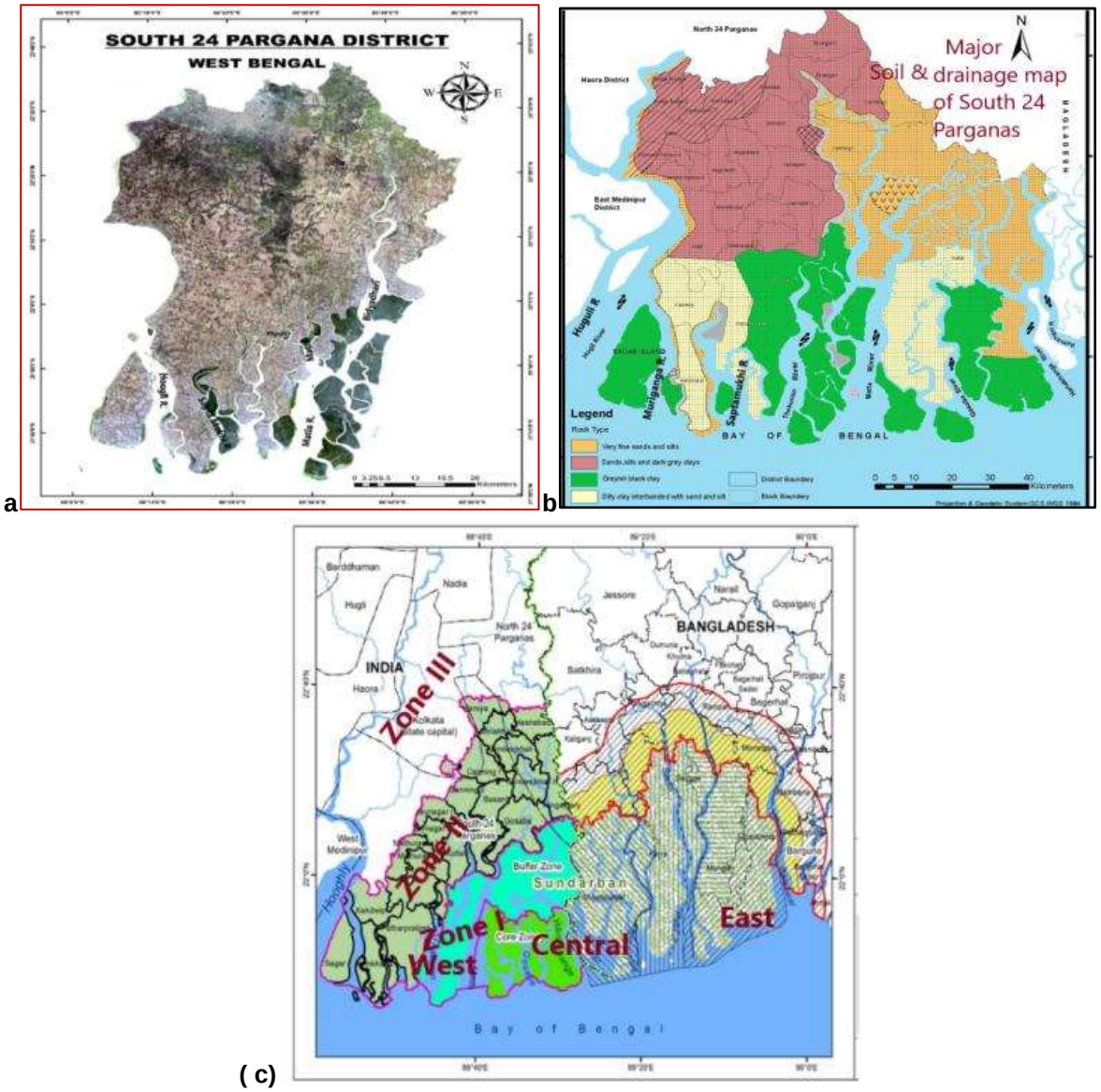


Fig. 4(a): GIS Terrain map 24 Parganas (S),Fig 4(b): The soil map of 24 Parganas(S) Rivers (Sou mod: GoWB; Dist. Survey Report -2018) Fig (c): Zoning of 24 ParganasS) (Sour: The World Bank, the IWA modified)

The south 24 Parganas is disaster-wise very sensitive. Cyclones with a return period of 4.62 years/cyclone, the flood of 22events, average lightning days/ year 48days, cold wave days of 20 days/year that confronted between 1969 to 2019 The av. rainfall of 1750mm/year, and the maximum temperature of 48°C [46,47].

Sundarbans; The world's largest mangroves: Sundarbans is 260km long coast along the shoreline with Rhizophora mangroves species (largest Sundari), mangrove associates, and saltwater swamps formed at the lower Ganges Delta,https://s24pgs.gov.in/historical_background . Sundarbans halophytes are under threat/ endangered and are included under the Red List of Ecosystems (Sievers et al., [48]. The evergreen Sundarbans canopy accommodates halophytes like the Sundari, Kakra, Keora, Garan, Hental, Golpata, Dhundul, Passur, Garjan varieties, etc. The distributaries small or large like Malta, the Hatania and Doania, the Go Saba, the Piyali, the Raiman gal, the saptamukhi, and the Thakuran, and the muddy islands such as Sagar, Ghoramara, Henery, and the Locha Achara Islands situated in the district [13]. Species like rotundifolia, Aegialitis Heritiera fomes, S. Griffith, and Sonneratia apetala have turned up endemic due to Anthropogenic stress,

westerly Tectonic uplift, and subsidence. The mangroves protect the inmate's livelihood and its ecosystem from devastating floods, tides and cyclonic storms. In the 21st century, the cyclones had an impact on the south 24 Parganas but moderated by the mangrove ecosystem. They are Gonu (2007); Sidr (2007); Phailin (2013), Hudhud (2014), Mora (2017), Fani (2019), Amphan (2020); YAAS (2021); Sitrang (2022), and Mocha (2023) [49].

Indian Sundarbans: The Indian Sundarbans are part of the GBM subaqueous delta covering 19 blocks out of 30 blocks of the district. The Indian fabric of mangroves, a complex ecoregion had 6402 sq. km. in 2001 which has shrunk to 6385 sq. km in 2009, (erosion of 64.16 sq. km, accretion of 20.12 sq km) in a decade, [49]. Near the coast, the forest enters the mangrove swamp; which shelters many desolate animals, brackish water species, and amphibians like crocodiles. It is the last zoonotic sanctuary of the Royal Bengal tigers (≈400 in number) and 30000 spotted deer. The rare bovines existing are sheep (Garole breeds), Muscovy ducks (China Hans), etc.

Ecosystem Services: The fiscal and livelihood services obtained from Sundar Ban mangroves are added by fishing nurseries, aquaculture, fuel for the poor, honey, traditional medicines, etc. There is a transformation from wetland/forest to aquaculture farming and agricultural fields. The South 24 Parganas is enrolled on “The UNESCO World Heritage” list and named “The Sundarbans and Sundarbans National Park” respectively.

Sundarbans forests house 17 folk medicinal plants in its MNG (true mangroves), 24 types of MNA (Mangrove Associates), 57 varieties of NMG (Non-Mangrove terrestrial species), 13 varieties of Fabaceae, 5 species of Lamiaceae and Compositae [50]. The dominant *Mangrove Species in Sundarbans is Heritiera, Avicennia, Xylocarpus, Sonneratia, Bruguiera, Cereops, Aegicera, and Rhizophora. Nipa, etc.*

Sundarbans Biosphere Reserve (SBR): People in the SBR area are financially backward and are directly reliant on bit-resources like fish, crabs, prawns, timber, honey, and fuel wood from SBR. This eco-region has high yields, from land, rivers and diverse biodiversity. The weather remains humid and the active monsoon (June to Sept.) provide an average annual rainfall of 1750mm. The av. Maximum Temperature is 35 °C and water bodies are allochthonous types, tide-dominated mangrove wetlands. The mangroves are in the estuarine, funnel-shaped linear tidal mud flats with anastomosed channels falling in BoB. Tidal level in high tides also varies from 3 to 6.5 m seasonally and water pH from 7.2 to 7.9. 24 numbers. The heart of the Sundarbans biosphere reserve has dwindled due to erosion, submergence and human over-exploitation of land, vegetation, and water resources.

The core area of SBR is restricted to human access lest they deteriorate the ecosystem. The buffer area is admissible for honey, folk medicines collection, fishing, and limited dry wood cutting. Poaching and theft of forest products are prohibited from being protected by armed forest guards on patrol or in motorised boats. There is no nocturnal trespass within the river/forest. Forest bit houses and camps are set at vulnerable positions within the park. Location-wise the distribution of flora is in Table 1.

Ethno-medicinal utility of Sundarbans mangroves: *Arious reports say the common and popularly available MNG and MNA mangrove varieties available in Indian Sundarbans possess antiviral, antibacterial, antifeedant antioxidant, antileukemia, antidiarrheal, and antitumor pharmacological properties and also* behave excellently as antioxidants, anti-microbial, antihyperglycemic, antinociceptive, and anti-malignant. Phytochemical studies revealed they contain chemical ingredients i.e., saponins, glycosides, alkaloids, steroid tannins, flavonoids, gums, phytosterols, and antidiabetic, [51,52] [Table 2].

LU/LC m**ethods and methodology:** The present study has focused on investigating the LU/LC changes in the mangrove forest area due to natural causes, and the hydrological regime, substantial variations in topography, salinity, erosion, and tidal current inundations, in spite of species species-specific plantation to sustain the MNG and MNA. Baseline information is collected as a pre-requisite for identifying, mapping and estimating mangroves by experienced survey staff, hydrology, geomorphology, the amplitude of tides, inundation area, and the existence of predators. Due to their inaccessibility and inundation, it is a herculean task to conduct field surveys within the tidal swampy mangrove forests with tigers, crocodiles etc. So, GIS methodology is preferred but a species-specific afforestation program is necessary for Sundarbans for an exact survey [24].

Table 1. The dominating MNG, MNA and NMG species found in Sundarbans

#	Location of the place	Local name	Botanical Name
1	*Estuarine zone, Tidal zone,* banks, River mouths; swamps new sedimentation; sub-aqueous soil (Highly saline tolerant)	Jatbaen; Pairabaen; Kalabaen Kripa Garia Tora	Avicennia officinalis Avicennia alba Avicennia marina Lumnitzera racemosa Kandelia candel Aegialitis rotundifolia
2	Low salinity, Tidal current passing; channels in highland, Creeks in *Mid Estuarine zone*	Garjan Goran Math Goran Bakul Keora	Rhizophora apiculata Ceriops Decandra Ceriops Tagal Bruguiera cylindrica Sonneratiapetala
3	*Inner estuarine Zone:* river inflow, less saline; elevated inland, Compact soil	Genwa Kankara Khalsi Ora Hental	Excoecaria agallocha Bruguiera gymnorrhiza Aegiceras corniculatum Sonneratia caseolaris Phoenix paludosa
4	*Rare(R), endemic (E), Sporadic (S)* restricted to specific salinity	Amur (E) Dhundul (E) Passur (E Sundari(R) Golpata (R) Palm-swamps (S)	Agalia domestica Xylocarpus granatum Xyclocarpus mekongensis Heritiera fomes Nypa fruticans Palm-swamps
5	*Freshwater Mangroves*, dense and discontinuous, bushy and dwarf, even bushy	Hargoza Ban Lebu Lata Sundari	Acanthus ilicifolius Merope angulates Brownlowia tersa

Table 2. Majore mangrove species used as ethnobotany

Local name	Botanical name	Part used	Mode of attempt	Disease attempted /uses	Sources
Sundari	*Heritiera fomes:*	Leaves, seeds,	Extraction by decoction	Diarrhoea, dysentery, colic, acidity, indigestion, constipation, stomach ache, bloating, lack of appetite and Gastrointestinal disorders	
		woods,	Powder	Piles, Laxatives	
		Stem bark	Paste	Eczema, abscess, boils, aches, rash, infections, scabies, itch, dermatitis, sores, scar, and warts	Mehmud et al, [53]
		Bark	decoction	Diabetes & Goitre	
		Twig	Toothbrush	Toothache; oral infection	
Indian mangrove 8types	Avicennia (Officinallis L. or Marina)	Leaves roots & barks	Paste or decoction	Injuries or inflammation (alkaloids); cancer, diabetes, malaria, rheumatism, asthma, smallpox and ulcer	Patra et al., [54]; Namaji et al, [55]
Acanthaceae, JATbaen (such 8 varieties)	*Avicennia officinalis; Avicennia marina*	Leaves roots, flowers bark, twigs	Diabetic and diuretic, immunity developer	rheumatism, asthma, tumour, dyspepsia, paralysis	Thatoi et al, [56]
Hental	Phoenix paludosa; Arecaceae	Upper soft part	Bark	To Control Cough	
Dhundul (tree)	Xylocarpus granatum	Bark	paste	dysentery, diarrhoea and other abdominal troubles, Febrifuges.	
		Seed ash	seed ash+ sulfur & coconut oil	Allergy; Itching	Alamgir et al, [57]
		Fruit	Direct or maceration	Antiinflamatory, antidiarrhoeal,	
Caw Phal (Climber)	Sarcolobus globosus	Fruit, leaves	Extract or maceration	antimicrobial activity, rheumatism, dengue	Alamgir et al, [57]
Math Garan	Ceriops tagal	Bark and wood	Extract and treat wood	Antioxidant and anticorrosive, Construction material, dying and tanning	Shamsuzzaman et al., [58]
Genwa (blind your eye mangrove)	Excoecaria agallocha	Leaves, flowers, twigs	Latex is poisonous so	antioxidant, antimicrobial, anti-inflammatory, analgesic, antiulcer, anticancer, anti-reverse, anti-filarial, transcripts, antihistamine-release, DNA damage protective, antidiabetic, antitumor	Mondal et al, [59]
Garjan	Rhizophora mucronata	Leaves, flowers twigs	Extract or maceration	Antidiabetic and antioxidant activity; antifungal activity	Adhikari et al, [60]
Keora	Sonneratia apetala	Fruit, leaves,	Seed power/	Antibacterial, Anti-Diarrhoeal, Analgesic,	Hossain et al.,

Local name	Botanical name	Part used	Mode of attempt	Disease attempted /uses	Sources
		seed	extraction	Antioxidant, Cytotoxic Activities; asthma ulcers, febrifuge, swellings, sprains, bleeding, haemorrhages, piles	[61]
Kankra	Bruguiera gymnorrhiza	bark; leaves	Extract	abortifacient; Liver disorders	Sur et al, [62]
Khalsi (Odiya-Teluni)	Aegiceras corniculatum	Leaves, bark	decoction	Antidiabatic, , analgesic, asthma, Diarohea, and rheumatism.	Gurudeeban et al, [63]
Pasur	Xylocarpus mekon-genesis (3 species)	seeds, fruits, stem bark, leaf, twigs	Seeds power/ extraction, decoction	Anti-oxidant, anticancer, anti-diabetic, antimicrobial, anti-malarial, antifeedant, neuro-protective diarrhoea, cholera, dysentery, fever, viral infections	Nabeelah Bibi et al, [64]; Dey et al., [65]
Jele Goran	Ceriops decandra	Leaves	Extract	Antidiabetic, antimicrobial; inflammation, and cancer.	Mahmud et al., [66]
Tora	Ding Hou & Tora Senna Tora	Leaves	Extract	Antioxidant, antibacterial, anti-inflammatory; bronchitis, itches, rheumatism, ringworm, leprosy, dyspepsia, liver & heart disorders.	Rahman et al., [67]
Bhola	Hibiscus tiliaceus	Flowers	extract	Antibiotic; bronchitis, fevers, antihistaminic; coughs, ear infections, abscesses, postpartum disorders, skin diseases	Abdul Awal et al., [68]
Golpata	Nypa fruticans	Fruit	Extract	land scaping, antidiabetics and antioxidant, less toxic; healing gout, seeds creamy flavour	Yossuf et al., [69]

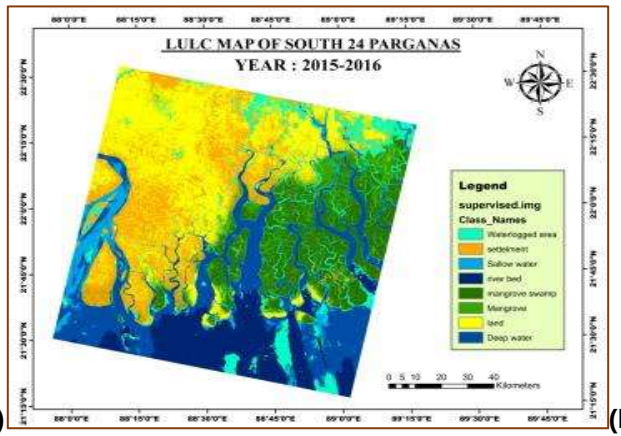
The tree Sundari in Sundarbans, a major medicinal plant is gradually becoming “endangered” on the IUCN Red List

GIS Methodology to detect LULC changes: The remote sensing (RS) technique has increasingly emerged as an emerging innovative tool for mapping and timely change of land use (mangroves), though downloaded RS data cannot replace the field survey data, the classification and the change detection for planning, managing and monitoring land utilization. The RS claims the advantage of synoptic coverage, free/ low-cost, time-saving, accurate and repetitive coverage, during watershed, mangrove, coastal, and disaster management [71,17,72].

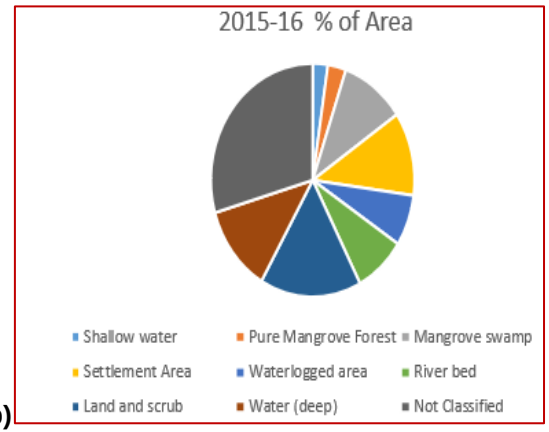
Data-Processing: The Landsat 8 OLI data for continuous data for the year 2015 to 2022 of SOUTH 24 Parganas is downloaded either 2nd quarter of Nov. or the first quarter of Dec.) of the year. After completing the transfer from USGS/GLOVIS was extracted in a zip file and was opened in TIFF files of diverse bands in ERDAS IMAGINE. The chronological processes followed are layer staking, subset imaging and supervised classification. Further, the steps are setting preferences (input and output directory), adding layers, inserting geometry, and identifying particular land features manually to have appropriate pixel accuracy. Then select the raster menu and select all signatures or classes. The Satellite image found five features- (i) Water bodies (ii) Agricultural land (iii) Vegetation (iv) Built and (v) Marshy land to have supervised classification and find the error data. To get an accurate supervised image decision rules can be tried one after other.

Present setup: MNG occurred in the study area from the years 2015-16, 2016-17, 2017-18, 2018-19, and 2019-20 (for five years). The cloud cover pictures were not considered and the error in processing within <5% is accepted. The classification method is applied for data analysis. The classification matrix is used to analyze urban growth. The classified images are interpreted to obtain several pixels for calculating area. Temporal analysis helps in studying the change detection for analysing the decrease in the number of water and vegetation image pixels. In the process of five years of data analysis, we can be able to find out the major changes in terms of land surface /land cover, vegetation and many more then we can easily interpret the analysis process with appropriate calculations and graphs that how much area gradually changed in percentage (%) is given below.

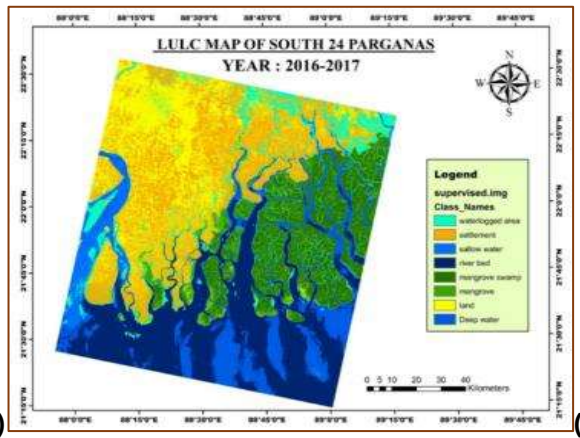
a)



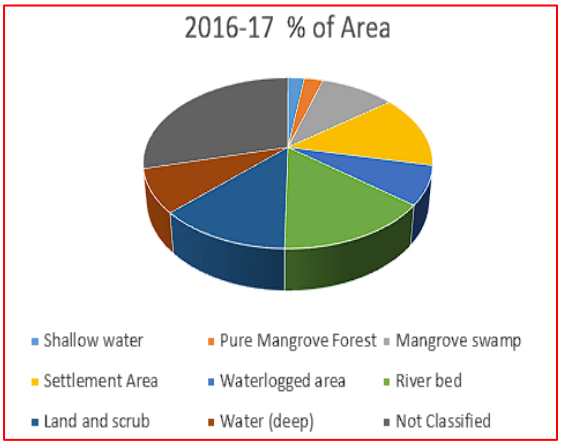
(b)

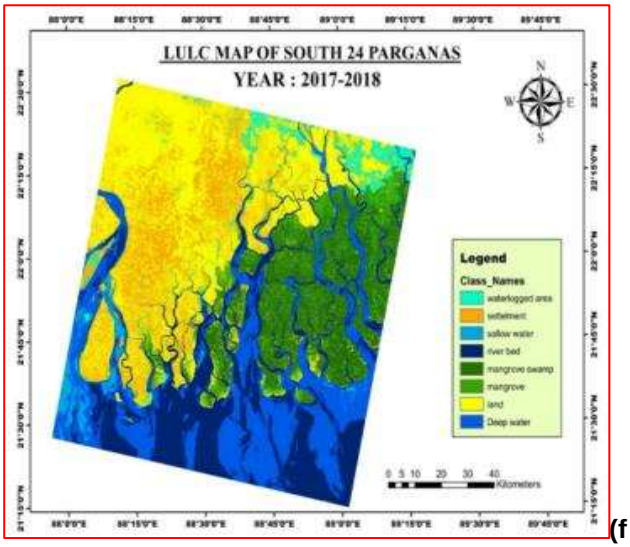


(c)

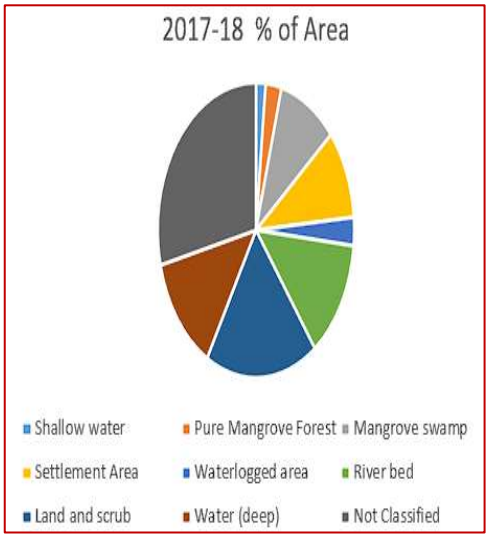


(d)

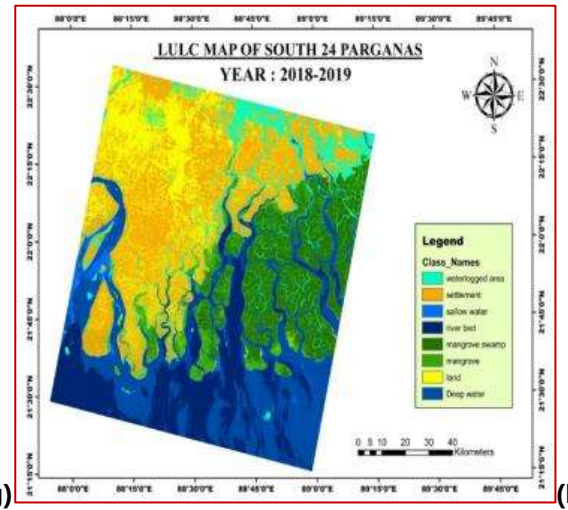




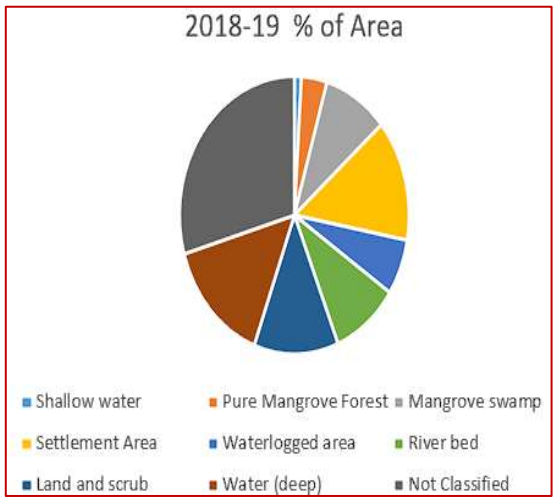
(e)



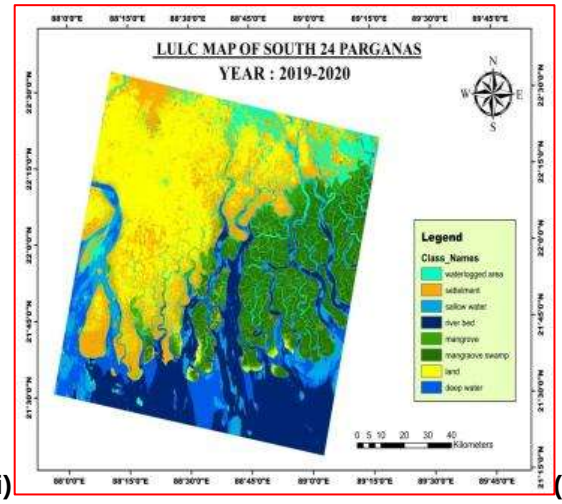
(f)



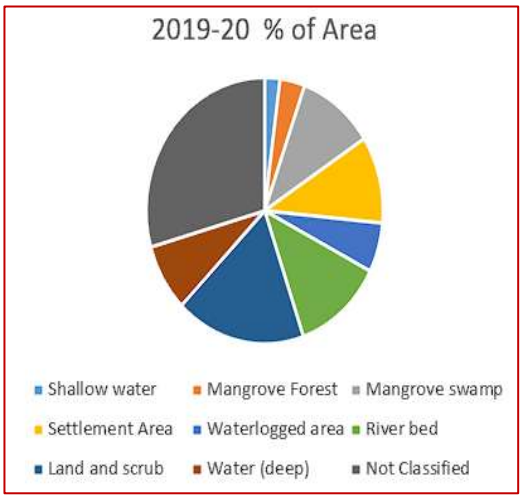
(g)



(h)



(i)



(J)

Fig. 5. (a) to (J): The year-wise areas for land use for mangroves, mangrove associates and inland taxa in Sundarbans, S-24-Parganas

The result reveals that as the Sundarbans area is populous, People have exploited the edges of the land for either settlements or agriculture at the cost of mangroves or mangrove Swamps, (Fig 5 ((a-f) and (Table 3).

Table 3. The land use and land cover of the classified study area in % of South 24 Parganas

Class	2015-16	2016-17	2017-18	2018-19	2019-20
Classified	% of Area	% of Area	% of Area	% of Area	% of Area
Shallow water	2.4	2.2	1.6	1.0	2.1
Mangrove Forest	2.9	2.5	2.6	3.6	3.4
Mangrove swamp	10.2	9.9	9.6	9.1	9.4
Settlement Area	11.6	13.8	10.8	14.2	10.6
Waterlogged area	7.1	7.3	3.1	6.5	6.0
River bed	8.1	14.6	13.1	9.4	12.2
Land and scrub	16.1	12.5	17.5	11.9	17.7
Water (deep)	12.1	8.2	10.9	14.8	09.2
Not Classified	29.5	29	28.8	29.5	29.4

Considering the mangrove forest: The LULC map for Sundarbans in south 24 Parganas was constructed and the corresponding land utilisation changes were calculated**.**

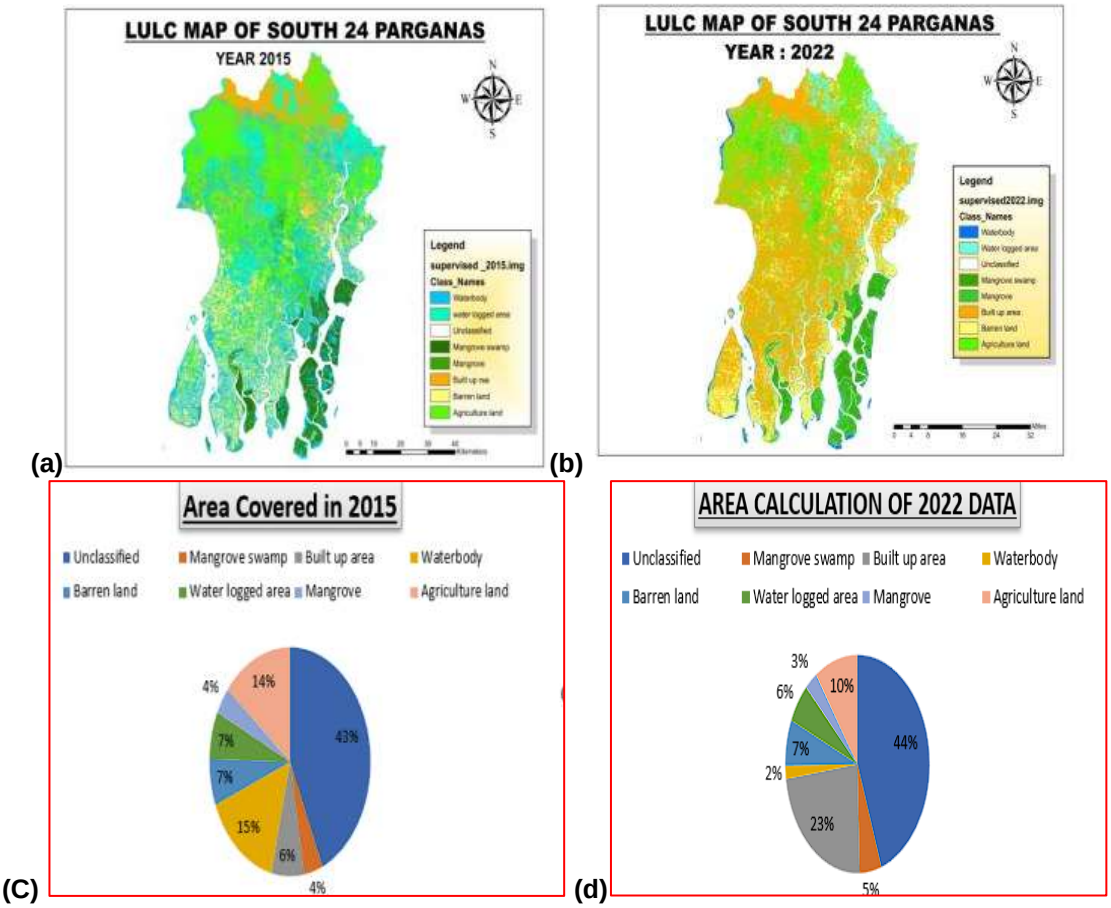


Fig. 6 a-d. Land use area changes in % for various features between the year 2015 and 2022

It is inferred from the satellite data study that one per cent of the study area has been converted from mangrove forests to mangrove swamps. The causes may be attributed to either increase in settlement area 5 (a to d).

Table 4. land use changes in % for various features in Sundarbans in South 24 Parganas, WB.

Class	2015	2022	% change (+/-)
Classified	% of Area	% of Area	
Mangrove Forest	4	3.0	(-) 1.0
Mangrove swamp	4	5	(+) 1
Settlement Area	7	24	(+) 17
Waterlogged area	7.1	6.0	(-) 1.1
Agricultural land	15	10.0	(-) 5
Land and scrub	7	7	0
Waterbody	16	2	(-)14
Not Classified	40	43	--

The structure of the result of the analysis indicates that within seven years the built-up area and the transformed water bodies (ponds) to agricultural land. have surged by (17%), the cause being a rise in population. Due to the slamming of the extremely severe cyclonic storm Amphan 2020, there was great devastation to Sundarbans.

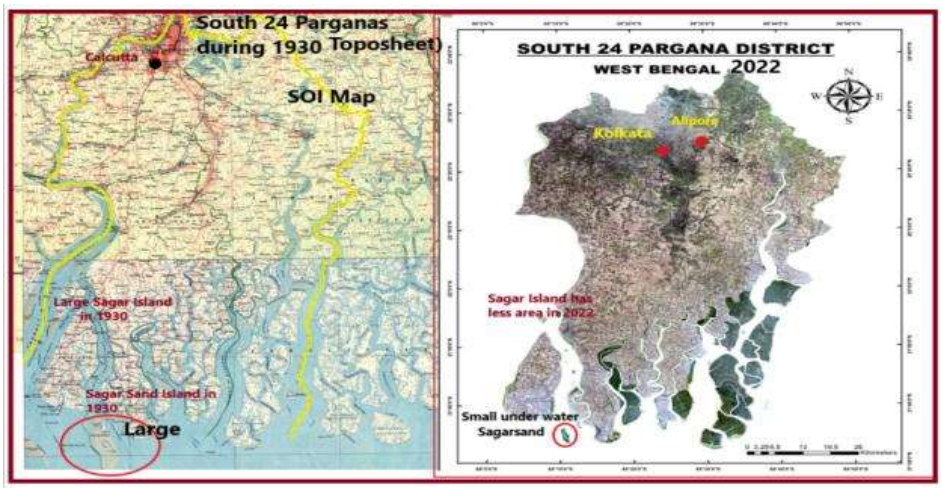


Fig. 7. The various islands existing (1930) within Indian Sundarbans are downsized in 2022

The topographical maps of 1930 of the Survey of India have been compared with the 2022 present map. Some larger islands within the Indian Sundarbans have been identified but later submerged totally or partly confirming coastal inundation by the BoB. The record reveals that 54 islands in the Indian Sundarbans are emerging, vanishing or helpless to submergence, (Table 5), https://www.Sundarbanaffairswb. in/home/page/islandsofsundarban.

Table 5. The status of various Islands under the Indian Sundarbans, India

#	Status of Islands	Name of the Islands
1	Islands disappeared from the present map	Lohachara, Bedford, Kabasgadi and Suparibhanga etc.
2	Islands under slow disappearance (vulnerable islands) to erosion are	Sagar, Ghoramara, Dakshin Surendranagar, Mousuni, Namkhana, Sagar sands, Dhanchi, Dalhousie, Bulchery, Bhangaduni, Mousini Lothian, Baliakhal Lothian, and Jambudwip
3	Islands emerged (in 1970 and later submerged in 2010).	South Talpatti after the Bhola (1970) cyclone, on the territory line and unhabitable.
4	Enlargement	Islands enlarging in eastern and northern margins of Indian Sundarbans Islands

Source: Mandal [73], www.sundarbanaffairswb.in/home/page/islands_of_sundarban

Spatial changes in the territory and outskirts are noticed in Sundarbans**.** The archipelago of islands mostly submerged or rarely emerged depending upon RSLR, littoral drift, and sedimentation in the estuaries. The area of the Islands was estimated from old SOI maps revealing that Indian Sundarbans mangroves inclusive of the waterbodies and drainage channels in the area were in 1773 (10064Km^2), in 1873 (7894 Km^2), 1973 (4277km^2), and 2016 (3576Km^2) @ 5.63% loss/year excluding the area of the riverine channels [74-76]

3. DISCUSSION

Mangroves grow along the sea-land interface. The mangrove forests are built up with diurnal tidal inundation. The Indian Sundarbans formed over a subaerial, subaqueous and tidal GBM delta. Mangroves survive within the elevation of the alluvial fans, paleo deltas and the Pleistocene terraces, and the fringe of the littoral drift or offshore current along the EC. The Himalayan rivers are ephemeral and carry huge amounts of sediment. The littoral sediment and the inland fluvial sediment get deposited along the flood plains, which act as a catalyst for the sustenance of MNG and MNA, [76].

Mangroves generally thrive in the most traumatic and unreceptive settings of highly saline, large tidal fluctuations, raised surface air temperature (SAT), high humidity, strong gusty winds and silty anaerobic soil. These are climate-tolerant plants and shrubs, that can protect stakeholders from erosion, adverse climate and cyclones, and there is insistent dwindling in the mangrove population. The various human services provided by these unique lifeline floral kingdom urge for its sustainable existence from nature and human cruelty. Its degradation **is** far higher in Asia than in other tropical and subtropical regions.

Human-based challenges are overfishing, tourism, food, medicine, fuel, shelter, deforestation, and construction materials are anthropogenic. Nature-based forces are subsidence, submergence, climate change, meteorological extremes, and ownership of land holdings of the swamps and mangroves. The main redressal actions are people's awareness, education, economic growth, clear landownership, distinct plans and proposals, the PPP mode development, participatory forest management.

The present study aims to detect the LU changes from 1773 to 2016 and especially (2015–2020) of Indian mangrove zones using the RS technique, The diminishing trend in Indian mangroves and Drainage Channels are inferred. The changes perceived are mangrove swamps, and fallow lands, transferred to agricultural fields, settlements, and waterbodies. It is high time to protect our coastal wealth either by legal interventions, people's participation, community involvement or PPP mode as one step to comply with SDG-15 i.e., life on land.

Regularly forming nurseries intermediate backwater inundation and species-specific afforestation are to be adopted to keep the mangrove forest sustainable. Baseline information about the rejuvenation of the existing mangroves is a criterion to identify, map, and estimate future mangroves' status. The constraint during the sustenance of maintenance of mangroves is strenuous and inaccessible to conduct field surveys amidst coastal creeks, swamps and mangrove forests.

The Sundarbans in South 24 Parganas have tried replantation programmes but are futile for adequate knowledge, communication, and documentation for the restoration of mangrove ecology. The national policy of food security (SDG-2) in changing climate, surged irrigation potential, and harnessing more water resources are essential. This is possible with more rainwater harvesting structures, rejuvenation and renovation of defunct and depleted drainage channels and recharging of UG aquifers are warranted.

SDG-15 cannot be ignored as the protection, restoration and promotion of forests demand its sustainable usage of telluric ecosystems. Actions are to manage the forest's sustainability, fight against desertification, stop and reverse gear the degradation and cease biodiversity loss to adhere to SDG-15.

Mangroves, that ensembles as significant asylums to coastal/ estuarine bio-diversity. They act as the bio-shields to extreme onshore events like gusty winds of cyclones, High tides, coastal erosion, high floods, and tsunami waves. These bio-shields never betray their ecosystem, zoonotic, sheltering avifauna, and biomass-dependant stakeholders and even add to the blue-carbon ecosystem, (ISFR [74].

4. CONCLUSION

Human activities have in recent years become recognised as a major force in shaping the

biosphere. The land use/land cover pattern of a region is an outcome of natural, socioeconomic factors and their utilization by man in time and space. Land is becoming a scarce resource due to immense agricultural and demographic pressure. Remote sensing (RS) and geographic information systems (GIS) techniques provide effective tools for analyzing the land use dynamics of the region as well as for monitoring, mapping and management of natural resources. The objective of the present study is to analyze the land use/land cover dynamics from the year 2015 to 2020. This project is mainly to study the satellite image and how it has changed in five years from date.

In the last 5 years duration (2015–2020) mangrove coverage has declined significantly and been replaced by waterbodies. The S-24-Parganas have lands in swamps and creeks available for mangrove plantations. Urbanization and agriculture land use/land cover features have a high rate of conversion against other land usages.

The apocalyptic future sea level rises in the study area, sediment-rich and active delta under erratic climate change, global warming and anthropogenic attack to nature has already deteriorated (≈75%) and cannot recoup. The present South 24 Parganas milieus cannot recuperate like the 19th-century biome but only can be maintained as it is today.

The district of South 24 Parganas houses the active delta of the Ganges, where its formation is still an ongoing process. The Sundarbans mangroves and their sustainability by adopting community contribution and spending social capital is the only successful technique to preserve UNESCO's World Heritage, and its vast bio-diversity of coastal lands, brackish water flora, fauna, avifauna, and aqua fauna.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/108508