

SPATIO-TEMPORAL CHANGE OF DRAINAGE NETWORK AT HUMAN-NATURE INTERFACE AND ITS FUTURE IMPLICATION TO THE ESTUARINE ENVIRONMENT IN GOSABA ISLAND, SUNDARBAN, INDIA

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ABSTRACT. Gosaba C.D. Block is an active tidal island of the Indian Sundarban. In this island, human-induced modification of the natural drainage system poses serious threats to the estuarine environment. It was started during the British colonial period through the construction of embankment to protect the reclaimed coastal land from saline water ingress. The rapid growth of population over the last few decades has triggered the changes in the drainage network and also altered the land use land cover of the study area. The human encroachment on the drainage area has hampered the sedimentation process as well as water circulation in the delta. As a result, the island is gradually transforming into saucer-shaped form, which aggravates various coastal threats like flood inundation, waterlogging and embankment breaching during extreme environmental events. To study the spatio-temporal change of the drainage network pattern from 1955 to 2018, different multi-temporal satellite images, US Army Toposheet, Census of India Report (2001 and 2011) and Human Development Report (2014) have been used as a source of secondary data for the analysis in ArcGIS environment. In addition to this, instrumental surveying has been done to measure the slope direction in relation to land use land cover and a questionnaire survey was conducted to understand the livelihood status of people influenced by various coastal threats and risks due to the drainage congestion. The study reveals that population density has gradually increased in recent decades and is negatively correlated with the drainage density on the island. The choking of the surface drainage canals has increased the problem of waterlogging in agricultural fields, which affected their productivity. Therefore, a strategy for management of the drainage network needs to be urgently implemented in order to protect the life and livelihood of rural people from various coastal threats.

KEY WORDS: Drainage system, Human encroachment, Population growth, Drainage congestion, Coastal threats

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INTRODUCTION

The Gosaba Island is a tidally active deltaic plain of Indian Sundarban. Topographically, the delta is a flat alluvial plain lying below the high tide level and crisscrossed by several interlinking rivers and creeks. This drainage system plays a significant role in maintaining the morphological balance of the delta (Mistri 2014). The human being, the most dominant species on the earth surface is continuously modifying the natural environment into the world of artifacts (De 2006). This ceaseless

transformation of the estuarine environment is more prominent in the modification of the drainage network, which started since the period of land reclamation (from the 1870s onward). The massive deforestation of mangrove forests during the British colonial period (1870–1947) and unsystematic construction of the embankments along the river have disturbed the fluvio-morphological system of the delta over time. However, is this alteration of natural drainage system at the human-nature interface good or bad? This is a matter of serious concern and needs to be critically reviewed from the environmental perspective

(Bandyopadhyay 2000; Danda 2007; Mistri 2014). In the second half of 20th century, the increasing population pressure exerted a serious threat to the natural resources of the delta and the balance between conservation and utilization of natural resources has posed a serious threat to the life and livelihood of the rural people. The haphazard construction of closures, choking of the drainage canals due to human encroachment and obstruction of the free flow of water has hampered the delta formation processes (O'Malley 1914). As a result, the island gradually develops a saucer shape due to uneven supply and distribution of sediment over the entire delta. The intensive waterlogging in the agricultural fields owing to the mismanagement of the drainage system is responsible for declining economic productivity of the agricultural land (Bannerjee 1988). These constraints aggravate the economic crisis and entrap farmers in pervasive poverty (Mandal 1995). Poverty affects different aspects of social livelihood and creates livelihood conflicts. To address these issues, the present research work focuses on three major objectives. Firstly, the study describes the scenario of human interference in the estuarine environment since the period of land reclamation. Secondly, the research highlights the spatio-temporal change of the drainage network at human-nature interfaces and associated changes in land use land cover. Thirdly, it examines the future threats and risks due to mismanagement of the inland drainage system as well as land-use practices.

THE STUDY AREA

The Indian Sundarban delta is a part of the Gangetic delta, which originated from the recent alluvial deposition by the Ganga-Brahmaputra river and their distributaries (Bandyopadhyay 2003). The development of the delta continues for more than 49.5 million years to the present. The initial 'proto delta' experienced a strong regression of the sea and the coastline shifted southward taking almost the present configuration. The rapid deposition took place during the later part of the tertiary period when the 'modern delta' took its present shape (Sanyal 1999). The initial delta building processes are still active but have been interrupted by various human activities. The present study area, Gosaba C.D. Block is one of the major blocks of Indian Sundarban, it lies within Canning Sub- Division of South 24 Parganas district of West Bengal, India. The areal extension of Gosaba is 21°54'N to 22°08' N and 88°29'E to 88°49' E (Fig. 1). The region is bounded by the River Bidya in the west and the Gomar and Raimangal Rivers in the east. The Gosaba Island consists of 14 Gram Panchayats (Amtali, Bali I, Bali II, Bipradaspur, Chhota Mollakhali, Gosaba, Kachukhali, Kumirmari, Lahiripur, Pathankhali, Radhanagar-Taranagar, Rangabelia, Satjelia and Sambhunagar) and 50 inhabited villages (District Human Development Report 2009). The total area of the block is 296.43 sq. km and the population density is 830 people/sq. km (Census of India 2011). In Gosaba, 44% of the population is living below the poverty level and 87% of people suffer from food shortages (Halder and Dennath 2014).

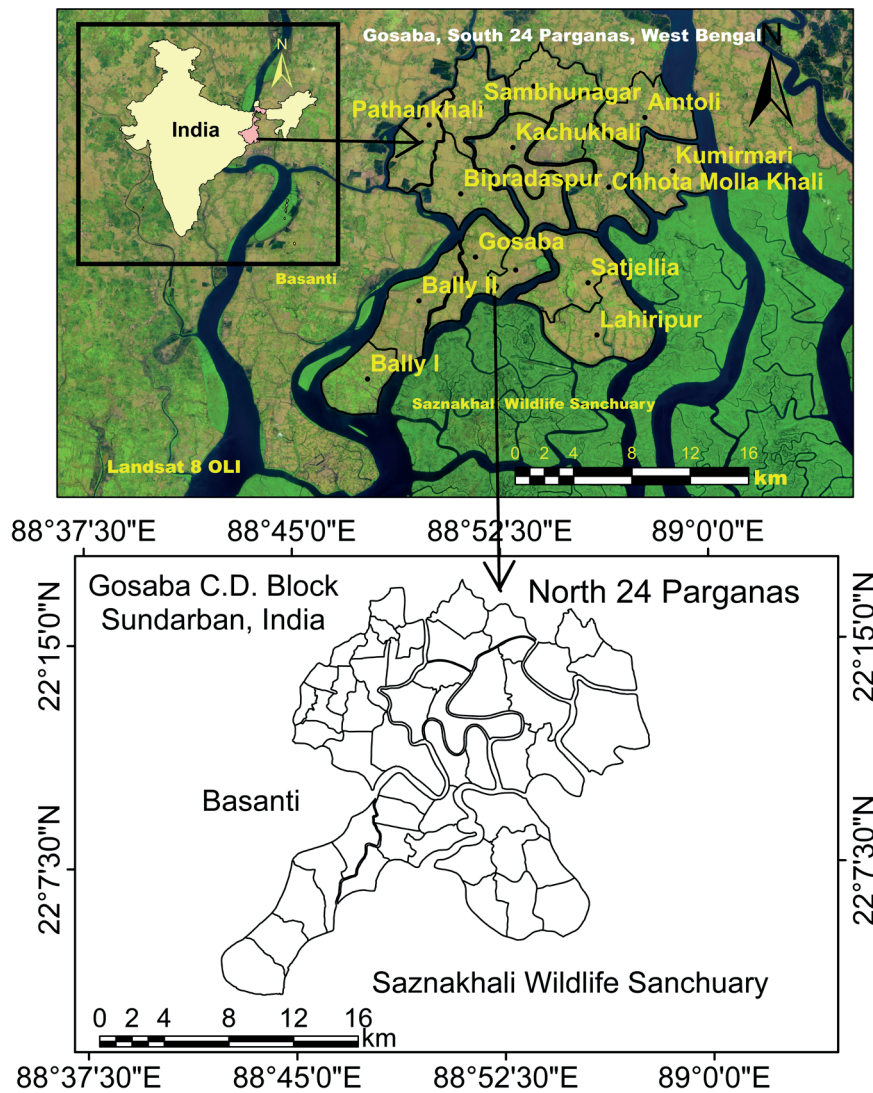


Fig. 1. Location of the study area

Table 1. Details description of data sets for the study

Data Sets	Description	Spatial and Temporal Resolution		Path and Row	Source
		Size of Pixel	Date of Acquisition		
Satellite Data	Landsat MSS	60 m	05-Nov-1972	148 & 45	United States Geological Survey https://earthexplorer.usgs.gov
	Landsat TM	30 m	01 Nov-1997	138 & 45	
	Landsat 8 OLI	30 m	08-Nov-2018	198 & 45	
	LISS III	23.5 m	25-Nov-2017	108 & 56	NRSC, Bhuban http://bhuvan.nrsc.gov.in/data/download/index.php
Population Related Data				Census of India, 2001 and 2011 Human Development Report, 2014	

DATABASE AND METHODOLOGY

The present research work has been done based on both primary and secondary data. Primary data was collected through field surveying along with the questionnaire method. Some field photographs were also collected to show the human intervention on the drainage system. The geo-historical change of Gosaba Island has been studied from various books, journals, and articles. To identify the spatio-temporal change of the drainage network, different multi-temporal satellite images have been used in a GIS environment (Table 1). The on-screen digitization method using polyline feature was adopted for digitizing the drainage network from each satellite image. Thereafter, Image overlay analysis has been done to identify the changing pattern of the drainage network.

Drainage density is an important attribute of the drainage system both from morphological as well as hydrological viewpoints. Drainage density is calculated based on the following formula

$$D_d = \frac{L_u}{A} \quad \text{..... Equation 1 Horton (1945)}$$

Drainage density (D_d) = Stream length (L_u)/Basin area (A)

To understand the population pressure of the study area, population density is calculated based on the following formula

$$D_p = \frac{N}{A} \quad \text{..... Equation 2}$$

Population density (D_p) = Number of people (N)/ Land area (A)

To understand the spatial relationship between population density and drainage density, Pearson correlation is calculated and the statistical significance of this correlation value is also verified using the Student's t-test.

To show the land use land cover changes in the study area, multi-temporal Landsat images of 1972, 1997 and 2018 have been incorporated in the GIS environment. The maximum likelihood classification method has been used for supervised classification of each satellite image. Altogether five LULC classes have been chosen based on the field experience and the author's prior knowledge about the study area.

Gosaba is a flat alluvial island, facing intensive waterlogging problem due to mismanagement of the drainage and land-use system. To understand the minute change of the slope in such a flat alluvial plain, Dumpy level survey has been conducted within a small plot of Gosaba mouza to identify the direction of slope change. The

average surface elevation is considered to be 2 meters as collected from the adjacent Gosaba Irrigation Sub-Division Office. The location point data ('X' represents longitude and 'Y' represents latitude) have been collected using GPS receiver. The ground elevation (denoted by Z value) data was surveyed using a Dumpy Level. After getting XY and Z values, the Reduced Level (RL) has been calculated based on collimation method. The DEM is prepared using the spatial analysis tool in the ArcGIS environment incorporating XY and Z values. The contour map is also prepared from DEM to understand the change of the slope direction.

A land-use map has also been prepared using the Georeferenced Google Earth Image (US Dept. of State Geographer, Imagery date 12/8/2018) and cadastral map (Gosaba mouza, Gosaba, Scale-1:2500) in the GIS environment. The horizontal positional accuracy (RMSEr) of Google Earth high-resolution rural imagery is 4.2 meter (Mean-3.4 meter; SD-2.3 meter) from 2008 onward which is reliable for scientific study (Paredes-Hernandez et al. 2013). The following equation was used for the calculation of RMSEr, taken from Federal Geographic Data Committee (FGDC 1998).

$$RMSE_x = \sqrt{\frac{\sum_i (x_{data,i} - x_{reference,i})^2}{n}} \quad (1)$$

$$RMSE_y = \sqrt{\frac{\sum_i (y_{data,i} - y_{reference,i})^2}{n}} \quad (2)$$

$$RMSE_r = \sqrt{RMSE_x^2 + RMSE_y^2} \quad (3)$$

Where, $x_{data,i}$, $y_{data,i}$ are the co-ordinates of the i^{th} point in the evaluated dataset

$x_{reference,i}$, $y_{reference,i}$ are the co-ordinates of the i^{th} point in the independent reference dataset of higher accuracy

'n' is the number of checkpoints; 'i' is an integer that ranges from 1 to n. This land-use map was compared with the previous elevation and slope map to understand the problem of surface slope modification and the extent of human encroachment on abundant channels, locally known as khals, at the human-nature interface.

RESULTS AND DISCUSSION

Evolution of the Drainage and Land Use at the Human-Nature Interface

Rivers act as a lifeline for the sustenance of the daily livelihood in the estuarine Sundarban. The interconnected network of the drainage pattern has been modified and encroached by various human activities for their short-term benefits. This intervention on the drainage system

was started during the British colonial period (from the 1870s onward) by the clearing of dense mangrove forests and the land reclamation after the construction of the embankment. (Kanjilal 2000; Bandyopadhyay 2000; Danda 2007). However, large scale land reclamation in Gosaba Island was initiated in the late nineteenth century by Sir Daniel Hamilton, A Scottish businessman who took lease around 9000 acres of land in Sundarban (lots no 143 and 149) (Das 2016). Initially, there were only 900 people (Census of India, 1909) living in this Island, that migrated from neighboring states like Jharkhand, Odisha and surrounding districts. In each phase of the land reclamation, people have neglected the role and importance of the river to the estuarine environment and modified the drainage system according to their own needs. During the early 19th century, frequent flooding was a curse for the sustenance of the livelihood of the people who initially settled in this island. So, an initiative was taken to construct a large-scale embankment along the rivers to prevent saline water intrusion in the agricultural land, which has stopped the natural process of delta building and changed the morphological appearance of the delta (Dhara and Paul 2016). The average elevation (6m from mean sea level) of the island remains below the high tide and storm surge levels, therefore this delta is always prone to several hazards such as saltwater intrusion and coastal flooding because of the embankment breaching and overtopping (Hazra et al. 2002). During the post-colonial period (1955–2018), the characteristics of the land use have rapidly changed due to the fast growth of the decadal population which reaches 10.67% from 2001 to 2011. During the field survey, it was observed that encroachment of the creek estuary,

haphazard construction of closures and transformation of land use characteristics exert huge pressure on land use land cover (Fig. 2). The transformation of land use is more prominent in the conversion of agricultural and fisheries-related land during the last four decades. Numerous creeks of this island have been disconnected from their parent source and transformed by human activities into sweetwater ponds for irrigation as well as fisheries-related activities. These types of changes in land use have altered the morphological as well as hydrological equilibrium of the delta with time.

Spatio-temporal Change in the Drainage Network

The large-scale transformation of the drainage channels into water bodies, that are mainly used for fisheries, and subsequent disappearance of creeks from the delta at the human-nature interface are quite common in entire Sundarban but in the present study, these spatio-temporal changes of the drainage network were analyzed for Gosaba Island over the periods of 1955–1972, 1972–1997 and 1997–2018. Different layers of the drainage network were overlaid to understand the sequential change of the drainage pattern over the last six decades (1955–2018) and these changes are shown in Fig. 3. Before the land reclamation, the island was fully covered by dense mangrove forests but after human footprint on the delta in the late nineteenth century, the pattern of the surface drainage has been immensely modified at the human-nature interface. The haphazard construction of closures and illegal encroachment on the drainage has modified the lateral connectivity of the drainage network. The drainage density has also decreased over time. The total area of the



Land reclamation by construction of embankment during British colonial period (Early Nineteenth Century)



Human encroachment on drainage and transformation of land characteristics (Post British colonial period)

Source: Field Photographs in Gosaba (October, 2018 to February 2019)

Fig. 2. Human interventions on drainage channel

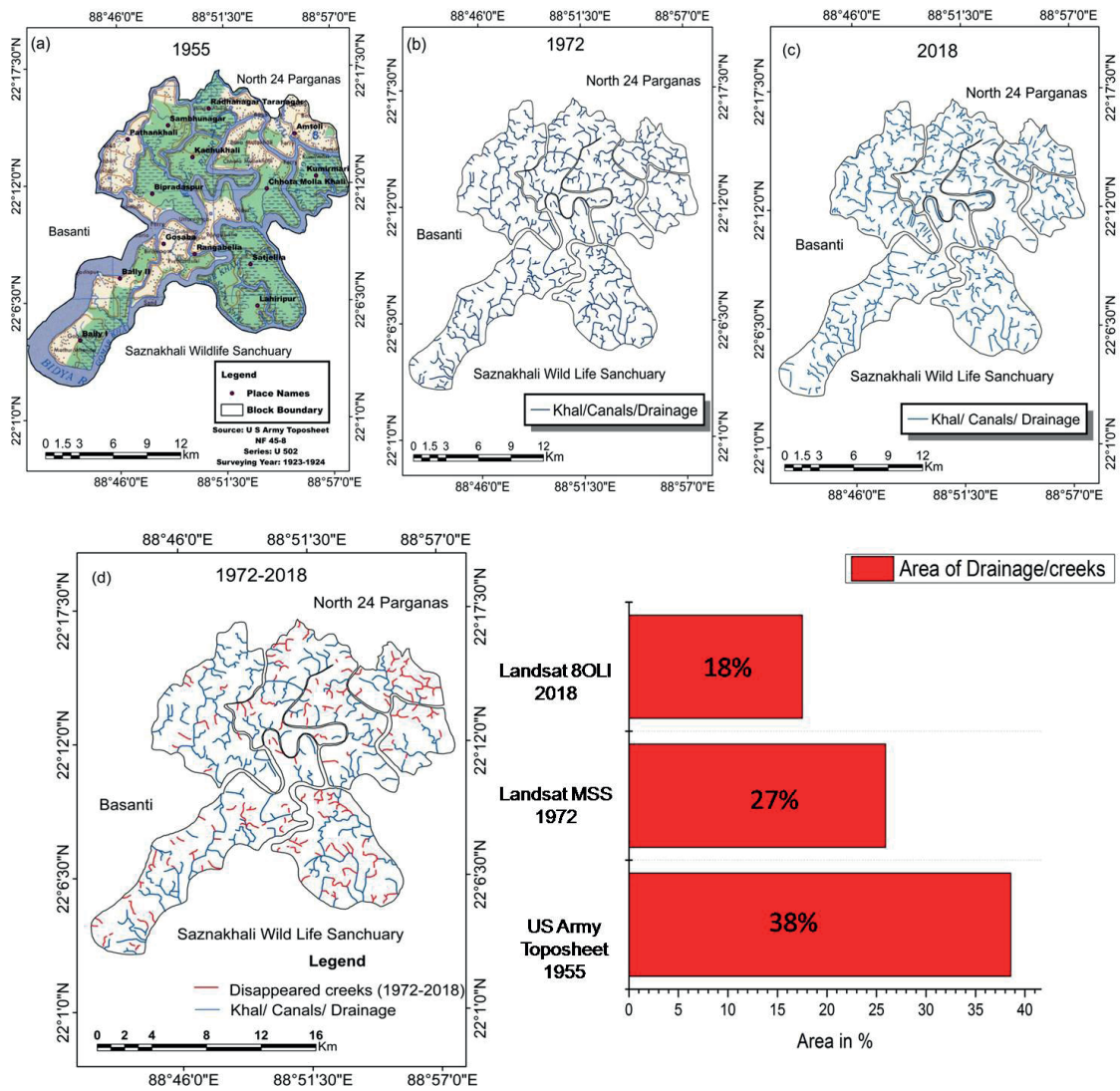


Fig. 3. Spatio-temporal change of the drainage network (1955–2018)

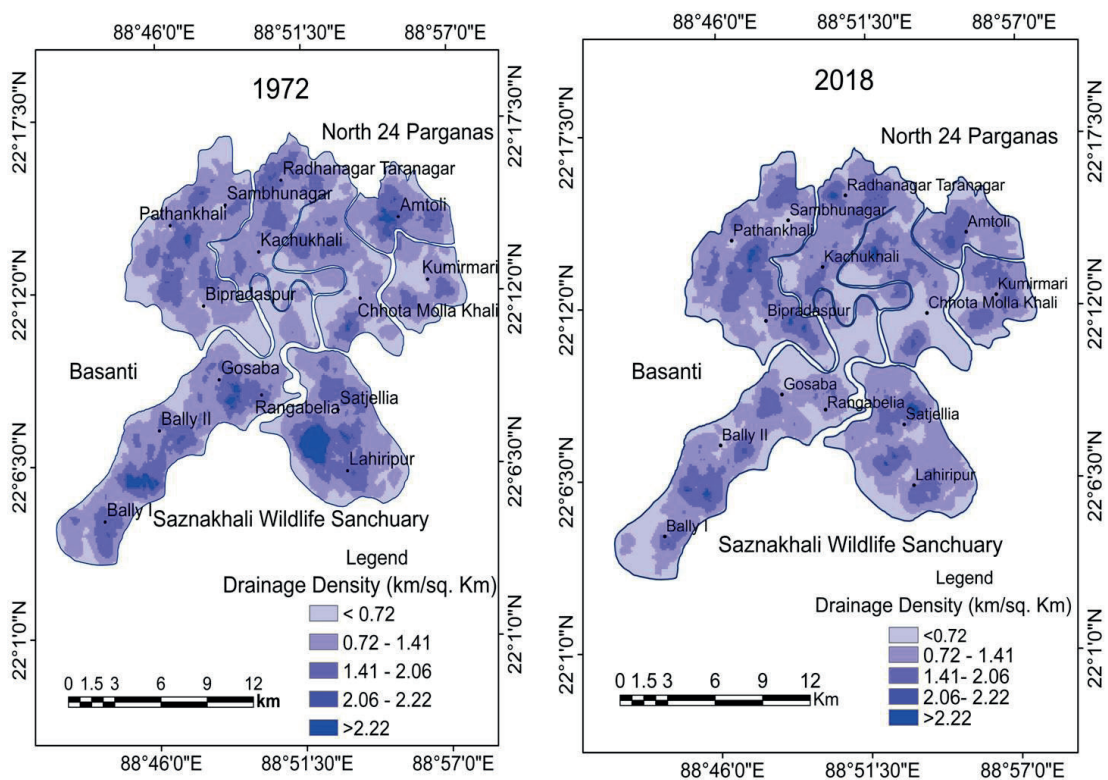


Fig. 4. Spatio-temporal change of drainage density

drainage network in 1955 stood at 38% and has gradually declined to 18% in 2018. The lack of interconnectivity within the drainage network creates drainage congestion, which induces the waterlogging problem in several places within the island.

Spatio-temporal Change in the Drainage Density

Drainage density was first used by Horton (1945) to understand different hydrological parameters. The drainage density depends on the pattern and arrangement of the

drainage network and determines the efficiency of the drainage system (Gray 1965). As the spatial arrangement of the drainage network has been continuously modified at the human-nature interface, the drainage density shows a continuously decreasing trend from 1.13 km/sq. km in 1972 to 0.91 km/ sq. km in 2018 (Table 2, Fig. 4). Thus, the drainage density shows a negative change of -0.21 km/sq. km from 1972 to 2018. The change of drainage density was the highest in Gosaba G.P. (-0.29), Lahiripur G.P. (-0.41), Bally I G.P. (-0.34). Chotomollakhali G.P. (-0.30) and Bipradaspur G.P. (-0.29). The medium rate of change was observed

Table 2. Change of the drainage density in different Gram Panchayats of Gosaba C.D. Block

Sl. No.	G.P. Name	Drainage Density (km/sq. km)		Change of Drainage Density (km/ sq. km)
		1972	2018	
1	Bipradaspur	1.20	0.91	-0.29
2	Sambhunagar	1.01	1.00	-0.01
3	Pathankhali	1.05	0.90	-0.15
4	Radhanagar Taranagar	1.23	1.00	-0.23
5	Kachukhali	1.26	1.05	-0.21
6	Amtoli	0.91	1.10	0.19
7	Kumirmari	1.19	1.16	0.03
8	Bally I	1.15	0.81	-0.34
9	Bally II	1.27	1.19	-0.08
10	Lahiripur	1.24	0.83	-0.41
11	Satjelia	0.84	0.74	-0.10
12	Chotomollakhali	1.27	0.97	-0.30
13	Gosaba	1.28	0.41	-0.87
14	Rangabelia	0.92	0.78	-0.14
Average		1.13	0.91	-0.21

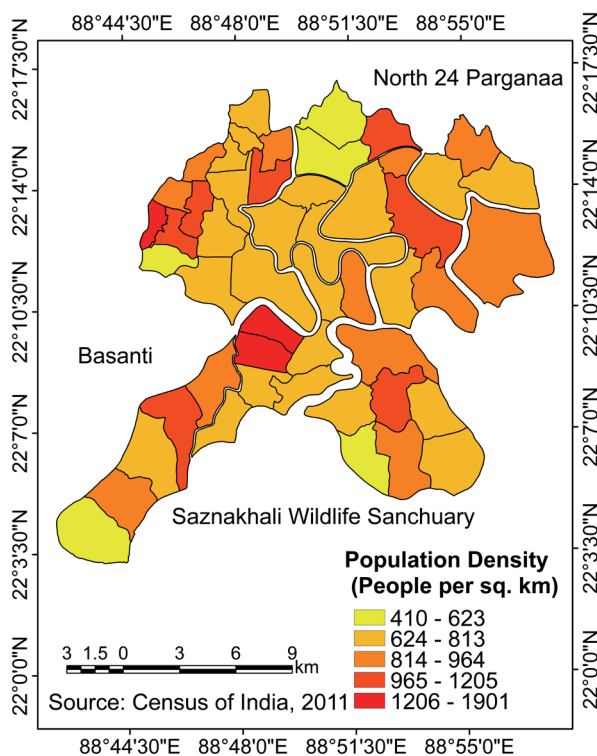


Fig. 5. Population Density in 2011

for Radhanagar Taranagar G.P. (-0.23), Kachukhali G.P. (-0.21), Pathankhali G.P. (-0.15) and Rangabelia G.P. (-0.14). Sambhunagar G.P. (-0.01), Bally II G.P. (-0.08) and Kumirmari G.P. (-0.03) are characterized by the low change of the drainage density. During the field survey, it was observed that different types of human activities, started primarily through land reclamation and embankment construction, were the major cause of the drainage system decay and human encroachment along with unsystematic land-use practices exert massive stress on functioning of the drainage system of the delta in the recent decades.

Impact of Population Density on Drainage Density

The rapid growth of population had an adverse impact on the drainage density in the study area. In the present study, the population density map was prepared based on the latest data of Census of India, 2011 to understand the spatial concentration of the population with relation to the drainage density in various Gram Panchayats (Fig. 5). The study reveals that there is a negative relationship between the population density and drainage density, which means that higher population density corresponds to lower drainage density and vice versa. To understand the relationship between these two variables in quantitative terms, the Pearson Correlation analysis was performed. In the scatter plot, the values of population density are shown on the X-axis as it is considered an independent variable and the values of the drainage density are shown on the Y-axis as it is considered a dependent variable. The position of these paired values shows a graphical correlation between the studied variables. The correlation values were used to draw the best fit line. Here, the type of polynomial regression was used as it better depicts the correlation. The correlation coefficient value here is negative ($r = -0.49$, $r^2 = 0.245$) (Fig. 6). This value indicates that the growth of population has negatively influenced the drainage density of the Gosaba C.D. Block. To test the significance of the 'r' in

the present study, the Student's t-test has been performed in MS Excel 2007 platform. The details are presented in Table 3. To perform the Student's t-test, the alpha value was set to 0.05 and the calculated P-value was equal to 0.00, which is less than 0.05 (Table 3). Therefore, this statistical analysis clearly shows that there is a significant difference between the means of the two selected variables.

Dynamics of the Land Use Land Cover Change

To assess the land use land cover change of the study area, different multi-temporal satellite images have been used in the Remote Sensing and GIS environment. Five LU/LC categories were identified i.e. (1) River and Water Bodies (2) Agriculture with Fallow Land (3) Agriculture without Fallow Land (4) Settlement with Vegetation and (5) Mangrove Forest. The LU/LC change was estimated for the years 1972, 1997 and 2018. The study shows that the percentage of area of river and water bodies has rapidly decreased over the years, it was estimated at 14.10% in 1972, 10.11% in 1997 and 7.29% in 2018. This decrease is mainly due to rapid growth of population (10.67% from 2001 to 2011, Census of India), illegal encroachment of khals and conversion of water bodies into the land. The total area of agricultural land has also decreased from 1972 to 2018. The area of agricultural land with fallow stood at 40.54% in 1972, 44.28% in 1997 and 45.87% in 2018 whereas the area of agricultural land without fallow has reduced from 23.97% to 14.69%. Interaction with the farmers during the field survey revealed that extreme weather events in recent years and increasing salinity of the soil after severe cyclone Aila in 2009 has led to a decrease in agricultural production, so much that certain farmers intend to engage in alternative economic activities. Most of the agricultural land remains fallow during Boro season mainly due to lack of irrigation facilities and accumulation of salt in surface soil due to active capillary process. The area of settlements has rapidly increased from 18.42% in 1972 to 28.41% in 2018.

Table 3. Calculation table of the t-test

Variables	Mean	Variance	Pearson Correlation	N	df	Alpha Value	Remarks
Population Density (2011)	855.07	20443.16	-0.44	14	13	0.05	Statistically Significant
Drainage Density (2018)	0.92	0.0406					

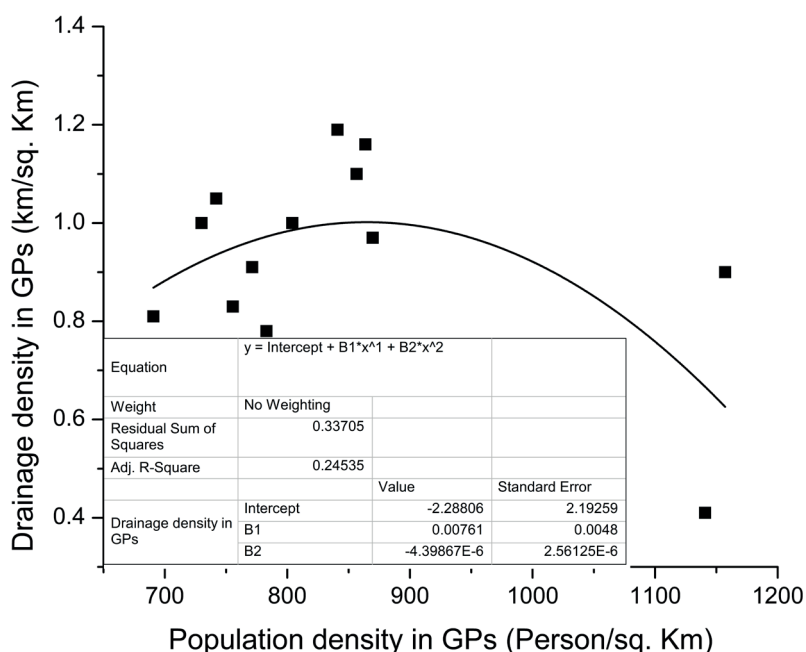


Fig. 6. Relation between population density and drainage density

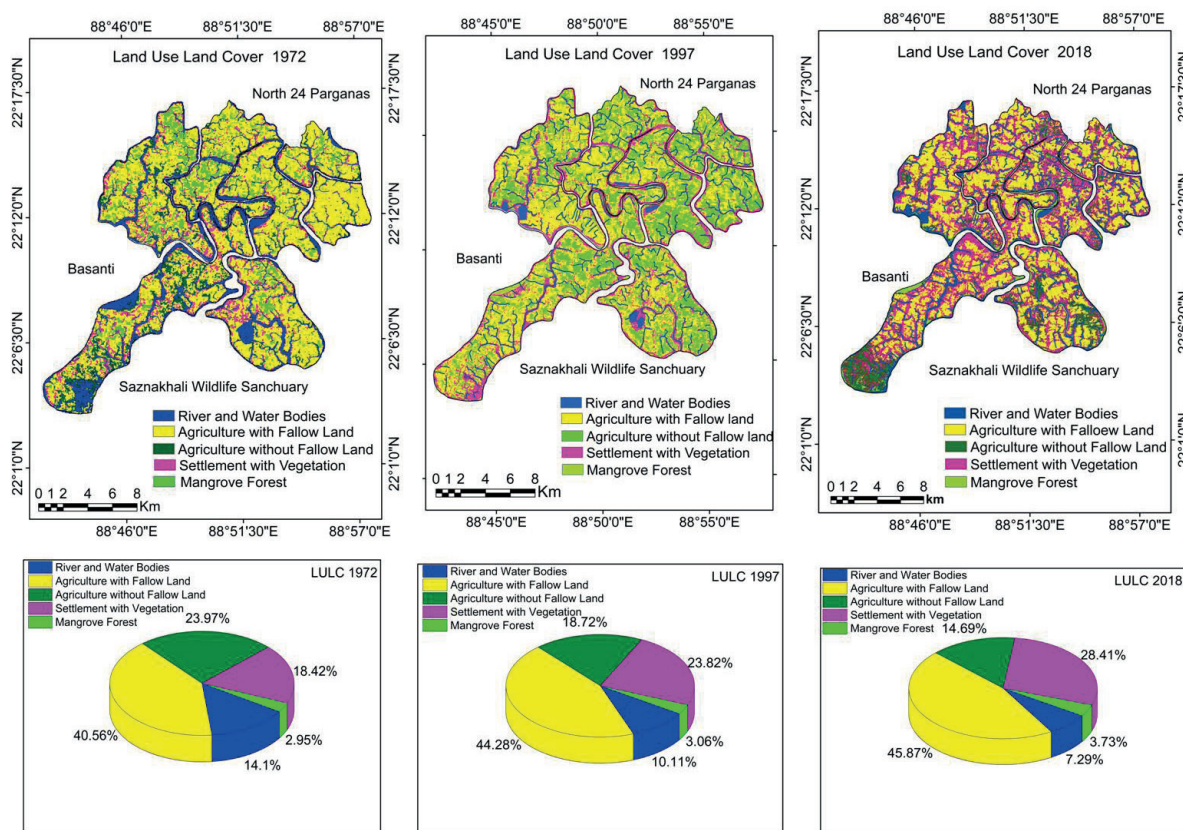


Fig. 7. LU/LC classes in 1972, 1997 and 2018

Table 4. LU/LC classes of the study area in 1972, 1997 and 2018

LU/LC Classes	1972		1997		2018		1972–2018 Change of area (%)
	Area (sq. km)	Area (%)	Area (sq. km)	Area (%)	Area (sq. km)	Area (%)	
River and Water Bodies	41.50	14.10	29.75	10.11	21.46	7.29	-6.81
Agriculture with Fallow Land	119.31	40.54	130.32	44.28	135.00	45.87	5.53
Agriculture without Fallow Land	70.56	23.97	55.09	18.72	43.24	14.69	-9.28
Settlement with Vegetation	54.21	18.42	70.13	23.83	83.62	28.41	9.99
Mangrove Forest	8.68	2.95	9.01	3.06	10.98	3.73	0.83

There is a significant growth observed in mangrove forest cover in newly formed river chars and channel bars. The share of mangrove forest cover was 2.95% in 1972, 3.06% in 1997 and has slightly increased up to 3.73% in 2018 (Table 4, Fig. 7).

Future Threats and Risks

Being located in the low-lying coastal region makes the Gosaba Island more vulnerable to various coastal hazards like floods, cyclone, embankment breaching and sea-level rise. The large-scale modification of the natural drainage pattern due to human interference and subsequent disappearance of the drainage network from the delta is a triggering factor of various coastal vulnerabilities and creates potential threats as well as risks for the livelihood of rural people.

Risk of Flood Inundation

Most of the area in Gosaba Island is lying below the high tide level. Since the period of land reclamation, the linear pattern of settlement has been built up

primarily along the embankment for easy access to water and transportation facilities. Embankment acts as a coastal safeguard for local inhabitants, despite that coastal region adjacent to rivers and creeks have been frequently inundated due to embankment breaching and resultant overtopping of tidal water. During the field survey, it was observed that height of the embankment is not enough to protect people from water inundation during catastrophic rainfall and cyclones as observed during severe cyclone Aila in May 2009 and more recent Bulbul in November 2019. Some field observations in Rangabelia, Birajnagar and Bagbagan mouzas in Gosaba C.D. Block have shown that there are locations (Fig. 8) where the height of the embankment is less than half a meter above the high tide level. As a result, people who are living adjacent to the coast, are frequently flooded and the risk of inundation as well as the duration of inundation has increased multiple times due to poor drainage condition of the delta. The drainage, haphazard construction of closures and lack of sufficient sluice gates create obstructions in the water circulation system, which increases the risk and vulnerability of the area to coastal flooding during catastrophic events.

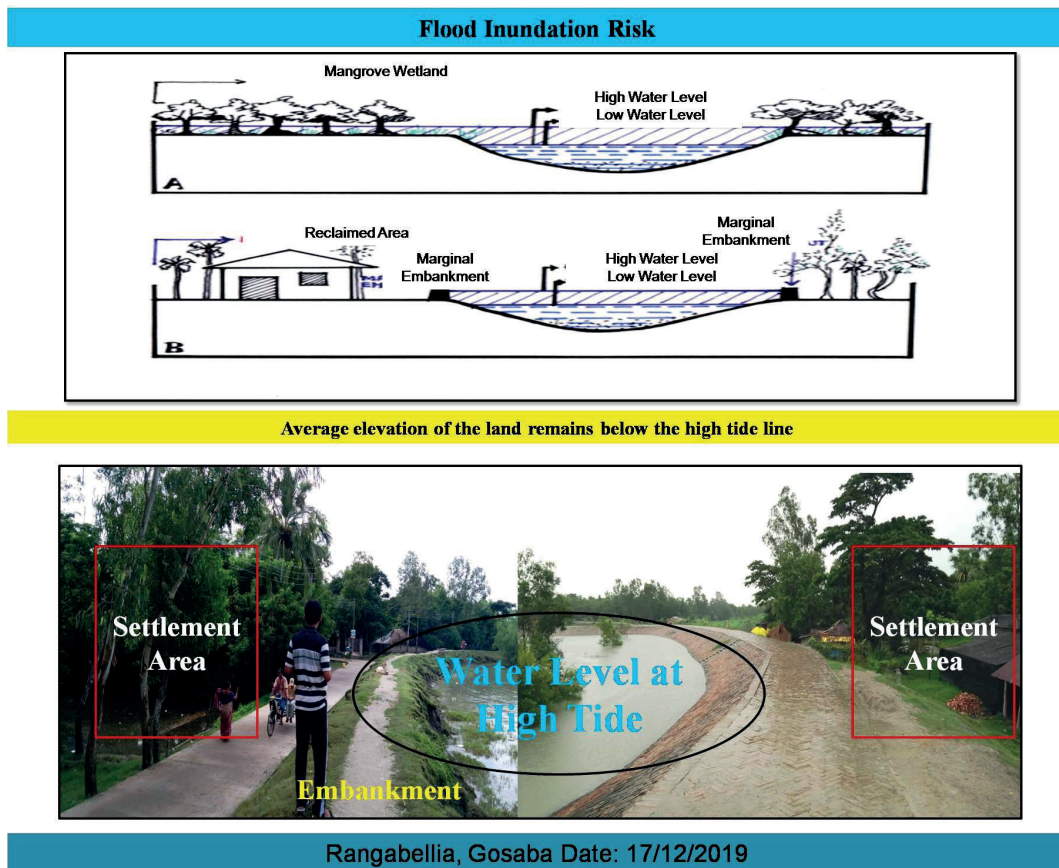


Fig. 8. Risk of flood inundation

The problem of Waterlogging in Agricultural Land

Gosaba is one of the worst suffering blocks in the Indian Sundarban facing acute problem in agriculture because of the poor drainage system. The profound human intervention on the drainage has interrupted the processes of delta building. The gradual human encroachment in various creeks of the estuary has disturbed the sediment as well as water circulation system within the delta. As a result, intensive siltation of the river bed and adjacent floodplains has gradually increased the elevation of the riverine floodplain as compared to the inward land of the island. The inward land is used for agriculture which is extremely prone to waterlogging especially during monsoon season. The change of surface slope direction with relation to land use land cover is presented in Fig. 9. To overview the slope change, a section of Gosaba Mouza was surveyed using dumpy level along with a GPS. The elevation profile shows that there is an inverse relationship between the slope and the distance from the canal within the surveyed section of the interfluvial zone. The profile depicts the presence of the saucer shape agricultural land within the delta. Some field photographs have been collected to understand the intensity of the waterlogging problem in agricultural fields caused by the drainage congestion. Almost 68% of the total cultivable land is low lying, mono-cropped and facing acute problem of waterlogging because of excessive rainfall coupled with poor drainage condition (Source: Field Survey in 2018). Management of the drainage system and the land-use practices have received scanty attention and the local people are least concerned about these types of changes despite the fact that disturbing the natural system without any environmental impact assessment may come out as a serious threat to the people’s livelihood.

Drainage Congestion and Livelihood Conflicts

Drainage is an important part of the sustainable livelihood of people from the very beginning of human civilization on earth. The role of rivers is unquestionable for human survival and there is no question of conflict at all. However, is the word «conflict» justifiable or not in the context of the present research? It is a matter of debate. The imprudent human intervention on the drainage as well as unsystematic land-use practices has affected the agricultural productivity of the island. There are 75% of people who depend on agriculture for their basic livelihood. It was estimated by the field survey (2018) that production of Aman paddy has decreased by almost 35% to 45% due to waterlogging in agricultural fields. People have very few options for alternative economic activities, which means that they have to rely on agriculture as their mainstay. Agriculture is not profitable at all and does not allow people to secure their minimum needs of a basic livelihood. As per field observations, the low income of farmers especially engaged in monocropping has led to a decline in their standard of livelihood (Table 5). Low literacy rate, early marriage and out-migration are the most common problems of people living on this island, which is also directly or indirectly correlated with their level of income. So, the poor drainage condition has led to a decline in the economic condition of people. The poor economic condition of people has also reinforced other social issues. The human-induced modifications of the natural drainage system will give rise to these conflicts and their future consequences if no management action plan is implemented immediately.

CONCLUSIONS

The life and livelihood of rural people are closely associated with the drainage system of the island. In the

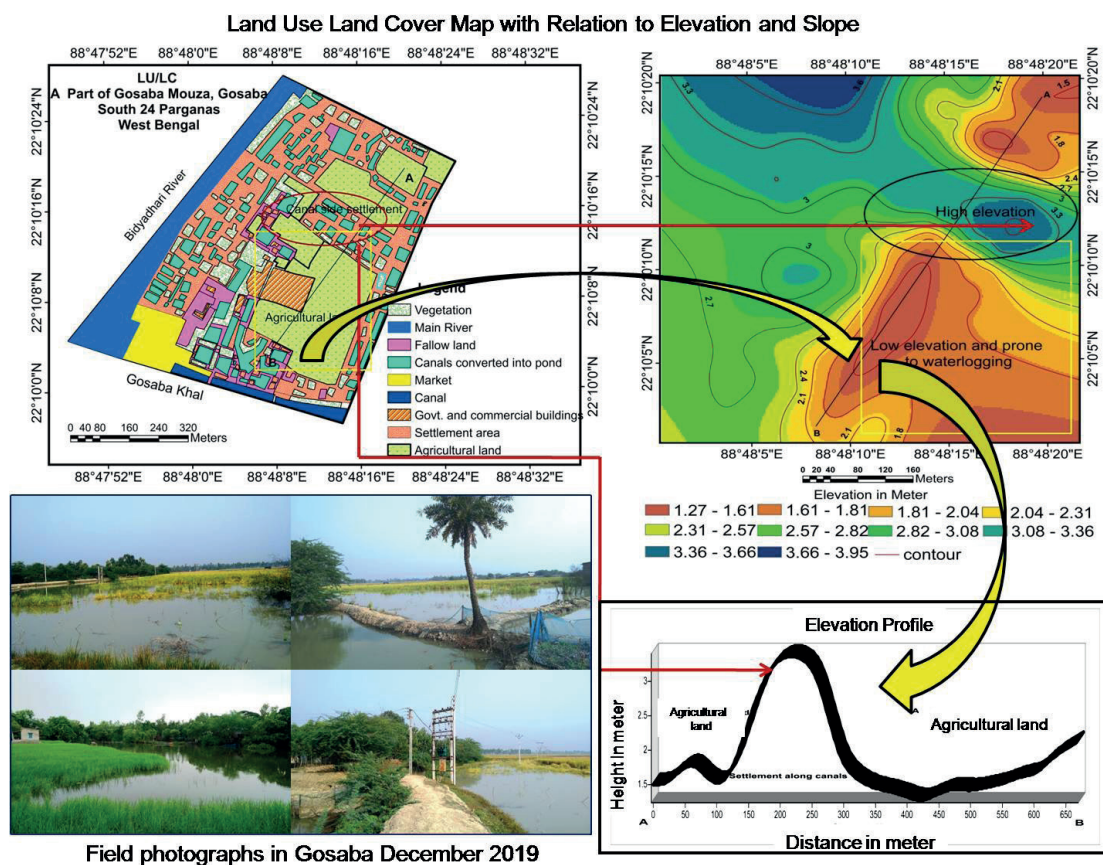


Fig. 9. Problem of waterlogging in agricultural field

Table 5. Livelihood aspects of the people engaged in the farming system

Aspects of Livelihood**	Monocropping (mainly rice farming)			Integrated Farming (Rice+fish or Rice+fish+on dyke horticulture)		
	Sample Size	Response	%	Sample Size	Response	%
Income level (<6,000 Rs./month)	80*	47	58.75	80*	38	47.50
Literacy Rate (able to read write and speak their mother tongue)		33	41.25		44	55.00
Early Marriage (below 18 for female and 21 for male)		32(F)	40.00		24(F)	30.00
		22(M)	27.50		15(M)	18.75
Rate of Migration		42	52.50		30	37.50

**Farmers surveyed (Field Survey: October 2018 - February 2019) those who are affected by waterlogging and engaged in monocropping or integrated farming system to sustain their livelihood.

* Surveying method stratified random sampling in some selected GPs of the Gosaba block.

present study, some issues related to the human-induced drainage congestion and its future consequences are highlighted. Firstly, since the period of land reclamation, the pattern of the surface drainage system has been imprudently modified by various human-induced activities for some short-term benefits without considering its future adverse impact on the delta. The continuous human encroachment on the surface drainage system and subsequent disconnection from the Source River increased the coastal vulnerability during sudden environmental hazards and disasters. Secondly, the interconnectivity of the drainage network and drainage density has been gradually decreasing due to the rapid growth of population in the last few decades. As a consequence, long-duration water inundation caused by poor drainage system became a serious problem for the coastal dwellers, especially during catastrophic events. Thirdly, the saucer shape of the island causes the problem of waterlogging in the

agricultural fields, which is directly and indirectly affecting the socio-economic condition of rural people. Therefore, the protection of the natural drainage system is urgently needed in order to improve the livelihood of local people and minimize various threats of drainage congestion. The long-term management strategy for the drainage system is very important although, challenging task due to the conflict between the riot land and common property resources. Therefore, the management of agricultural land through the implementation of land reshaping techniques may emerge as an alternative solution for the farmers to reduce their monetary loss due to the drainage congestion and resultant waterlogging. They can adopt location-specific integrated farming activities like rich-fish-on dyke horticulture system to increase the agricultural productivity and efficiency of land use, which at the same time will increase the relative profitability and ensure better livelihood of the people. ■

REFERENCES

- Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal, India, Coastal Soils of West Bengal – Their Nature, Distribution and Characteristics, Bulletin No. 1/2003 by B. K. Bandyopadhyay, M. Maji, H. S. Sen, N. K.B. Tyagi, 2003.
- Bandyopadhyay S. (2000). Coastal changes in the perspective of long-term evolution of an estuary: Hugli, West Bengal, India. In: V. Rajamanickam and M.J. Tooley (Eds.), Quaternary Sea Level Variation, Shoreline Displacement and Coastal Environments, New Delhi: New Academic Publishers, 103-115.
- Banerjee A. (1998). Environment, Population and Human Settlement, New Delhi: Concept Publishing Company, 27-32.
- Census of India (2011). Provisional Population Totals. Registrar General and Census Commissioner of India, Ministry of Home Affairs, New Delhi, India. Available at: https://censusindia.gov.in/2011census/dchb/DCHB_A/19/1917_PART_A_DCHB_SOUTH%20TWENTY%20FOUR%20PARGANAS.pdf [Accessed on 15 March 2019].
- De K. (2006). Environmental impact of human Interface in the Sundarban Region of West Bengal. Burdwan: The University of Burdwan. Available at <http://hdl.handle.net/10603/64002> [Accessed 16 December 2019].
- Danda A.A. (2007). Surviving in the Sundarban: Threat and responses- An analytical description of life in an Indian riparian commons. The Netherlands: University of Twente. 1-195. ISBN: 90-365-2566-4.
- District Human Development Report South 24 Parganas, 2009. Development & Planning Department, Government of West Bengal. 1-20 Available at: http://www.undp.org/content/dam/india/docs/hdr_south24_parganas_2009_full_report.pdf. [Assessed on 12 November 2019].
- Das K. (2016). Sundarban embankments – a study along Suryaberiya River, Sambhunagar Island, Gosaba, West Bengal. International Journal of Current Research, 8(5), 32187-32195.
- Dhara S. and Paul A.K. (2016). Status of agriculture -a case study at Patharpratima Block of South 24 Parganas district. International Journal of Innovative Science, Engineering & Technology, 3(2), 239-246.
- Federal Geographic Data Committee (1998). Geospatial positioning accuracy standards. Part 3: national standard for spatial data accuracy. USA: U.S. Geological Survey. Available at <https://www.fgdc.gov/standards/projects/FGDC-standards-projects/accuracy/part3/chapter3> [Accessed on 16 December 2019].
- Gray D.M. (1965). Physiographic Characteristics and the Runoff Patterns: Proc.of Hydrol. Symp. No. 4, Research Watershed, National Research Council of Canada, 147-164.
- Halder A. and Debnath A. (2014). Assessment of climate induced soil salinity conditions of Gosaba Island, West Bengal and its influence on local livelihood. In: M. Singh et al. (Ed.), Climate Change and Biodiversity: Proceedings of IGU Rohtak Conference, 1, Advances in Geographical and Environmental Sciences Japan: Springer, 27-44, DOI: 10.1007/978-4-431-54838-6_3.
- Hazra S., Ghosh T., Das Gupta R., Sen G. (2002). Sea level and associated changes in the Sundarban. Science and Culture, 68(9), 309-321.
- Kanjilal T. (2000). Who killed the Sundarban. Calcutta: Tagore Society for Rural Development.
- Mistri B. (2014). Construction of Closure on tidal creeks and its effects: A case study of Patharpratima C.D. Block of Sundarban. Nature and Sustainable Development-Impact of Green Accounting, Published by Academic Staff College, The University of Burdwan. 111-124.
- O'Mally L.S.S. (1914). Rivers of Bengal, Bengal District Gazetteers. Calcutta: The Bengal Secretariat Book Depot.
- Mandal J. (1995). Implementation of Integrated Rural Development Programme – A Case Study of Sundarban, West Bengal. New Delhi: Jamia Millia University.
- Paredes-Hernandez C.U., Salinas-Castillo W. E., Guevara-Cortina F. and Martinez-Becerra X. (2013). Horizontal positional accuracy of Google earth's Imagery over rural areas: a study case in Tamaulipas, Mexico. Boletim de Ciências Geodésicas, 9(4), 588-601, DOI: 10.1590/S1982-21702013000400005 [Accessed on 22 December 2019].
- Sanyal P. (1999). Global warming in Sundarban delta and Bengal Coast. In: Guha Bakshi DN, Sanyal P, Naskar KR (eds), Sundarbans Mangal, Kolkata: Naya Prokash, 111–112.