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Status of Land Conversion and Urban Sprawling Over Coastal Tract of West Bengal: a Study on Haldia Municipality Area

***Dipankar Mondal[1]; Subrata Jana[2] and Ashis Kr. Paul[3]**

[1] & [3] Department of Geography, Vidyasagar University, Midnapore, West Bengal
[2] Department of Geography, Belda Collge, Belda, Medinipur, West Bengal

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ABSTRACT

The fragile coastal areas are facing tremendous challenges in response to the recent trend of population growth and urbanization in the context of global and regional climate change and related events. The Haldia municipality area is imposed to coastal inundation and associated vulnerability as it is situated in the low-lying fragile littoral deposition of a soft sedimentary surface. The accelerated rate of flourishing urban infrastructural development ensures over the muddy surface, low-lying areas, wetland, coupled with the degradation of agricultural land and natural vegetation in conjunction with the magnitude of population growth. The haphazard urban infrastructural development leads to tidal inundation and storm rainwater logging, which also creates drainage problems in most of the urban areas. The land use and land cover (LULC) changes and landscape alteration has produced the environmental problems associated with ecosystem destruction. The six major types of LULC classifications have been done using the geospatial techniques in the four different Landsat images of 1991, 2001, 2011 and 2018. The LULC conversion has also been analyzed during 1991–2018 for the entire study area. After the establishment of the port-industry based urban centre in 1967, the urban infrastructural development concentrated over the elevated levee landscape in the IOC, Durgachack and Township areas during 1991. Afterwards, the built-up areas significantly increased in the low-lying areas of the central and western part through land-filling. The built-up area has tremendously grown from 4.72 km^2 to 29.36 km^2 during the study period, mostly occupying the agricultural land, muddy fields and vegetation areas.

Introduction:

More than 75 percent of the total population of the world is living within the coastal areas (Vernberg & Vernberg, 2001; Small & Nicholls, 2003; McGranahan et al., 2007; Waite et al., 2014) depending on the plenty of resources and livelihood options (Francisco, 2008; Bunce et al., 2010; Hussain, 2013). In this concern, coastal urban areas are dramatically sprawling over the unstable wetlands, low-lying areas after the landfilling and converting the agricultural lands (Jelgersma et al., 1993; Aber et al., 2012). The flourishing urban infrastructural development and population growth mostly over the soft sedimentary landscape, creating a boomerang effect to the coastal urban society after degrading the entire natural setup (Creel, 2003; Bulleri & Chapman, 2010). Illegal constructions are encouraged for generating amenities (Ganguly & Bagri, 2014; Baitalik & Majumder, 2018). The immense population pressure in the coastal urban areas produces a large volume of waste and pollutants associated with the socio-economic development which is deteriorating the coastal environmental quality (Lakshmi & Rajagopalan, 2000; Burak et al., 2004; Long et al., 2009; Surya et al.,

Correspondence to Dipankar Mondal
Cartographer, Department of Geography, Vidyasagar University, Midnapore, West Bengal
E-mail address : dipankargeo@gmail.com

2020). The huge extraction of groundwater allows the saline seawater to encroach into the groundwater aquifers (Pareek et al., 2006). The over-extraction is also liable to regional and local land subsidence (Galloway & Burbey, 2011; Bhattacharya, 2013). Moreover, the escalating rates and intensities of hydrometeorological hazards swelling the threats to the coastal societies at present and it will be magnified in the near future (Shamsuddoha & Chowdhury, 2007). With such effects, the coastal habitat and ecosystems are degrading and become more and more vulnerable. Therefore, the coastal areas remain under threat and they will be more fragile and vulnerable in time perspective with due effects of extending urbanization (Senapati & Gupta, 2014). Therefore, the goal of sustainable development is somehow impossible to achieve without protecting the environment for the present as well as a future generation by controlling our present stage of development at a certain level (Cicin-Sain, 1993; Sum & Hills, 1998; Sathaye et al., 2006; Ray et al., 2019).

In the Indian coastal areas, the mega-cities like Mumbai, Kolkata and Chennai are recently devastated by rainwater flooding (Kamini et al., 2006; Nath et al., 2008; DownToEarth, 2012; Selvaraj et al., 2016, The Times of India, 2021). The unplanned urban infrastructural development leads to the urban sewerage and water-logging problem which intensified during the storm rainfall (Mowla & Islam, 2013). In West Bengal, the coastal areas of Purba Medinipur district, as well as the Haldia municipality area is situated over the littoral deposition of soft sedimentary surface (PLMLS, 2015; LU&DCP, 2015; Duari, 2019). Gradual alterations and degradation of wetlands and agricultural area (Jana & Paul, 2019; Maity et al., 2021), drainage control measures (Bandyopadhyay et al., 2014) and over extractions of groundwater (Maity et al., 2017, 2018), problems of urban waste treatment and their dumping (Arceivala & Asolekar, 2006; Yang et al., 2019) will create additional threats to the uncontrolled urban sprawling within the coastal zones in the near future (Rahman et al., 2010; Franci et al., 2015; Khan et al., 2021). The satellite image-based temporal analysis of land use and land cover (LULC) change is the key aspect to understand the trend of land use conversion. The accelerated rate of built-up area increases after converting the natural landscape as well as the natural habitable areas of the indigenous species. The required space for natural habitat is squeezing with accelerated area enhancement for more compact urban infrastructures (Mondal, 2021). Most of the agricultural land, wetlands and low-lying area are converted into a profitable urban landscape (Jana & Paul, 2018). Therefore, the natural habitats of the floral and faunal species have been endangered with time (Naskar & Mandal, 1999; Roy-Basu et al., 2020). The agricultural land is also converted into built-up areas (Nanda, 2001; Ojha & Chakrabarty, 2018). With due effects, the environment quality has deteriorated in tremendous form. The Remote Sensing and Geographic Information System (GIS) techniques are used to evaluate the spatial and temporal growth of the urban centre and also to estimate the rate of land conversions and resource uses by such sprawling in the sensitive coastal environment (Shaw & Das, 2018). The alterations of the landscape and LULC changes are promoting the degradation of natural ecosystems and habitats (Abdullah et al., 2019; Mondal et al., 2021).

In the present scenario of population growth and anthropogenic activities, people cannot able to minimize and someway control their daily life and activities (Rahman, 1993; Paul et al., 2021). So, they are compelled to adjust the nature of degradation, and such kind of tendency promotes rapid urban expansion and environmental degradation. A suitable action plan is to be required on an urgent basis for sustaining the densely populated urban areas (Revi, 2008; Viero et al., 2019). Also, there need to find out the best suitable and easy ways which can minimize the risks and future vulnerability of the coastal urban society. In this aspect, the main goal of this study is to break down the previous 27 (1991–2018) years of data of nature and land use land cover (LULC) changes in the Haldia municipality area, West Bengal and to differentiate the main cause overdue the changes.

2. Study area

Haldia municipality area is located on the supralittoral tract of the estuarine floodplain surface at the confluence of the river Hugli and Haldi. This area extended within the coordinates of 22°00'52.98" N to 22°08'35.76" N and 88°01'24.93" E to 88°11'49.95" E with the areal coverage of 99.97 km^2 (Fig. 1). Initially, in 1967, this urban centre was established over the relatively elevated natural levee surface depending on the port and allied activities. But, the urban area is gradually expanding over the remaining levee surfaces and also over the low-lying areas occupying the agricultural land and wetlands for supporting the areas of industries, market complex and residential complex. The lowland filling is intensively adopted for the preparations of suitable land for urban infrastructural development. Recently, the new accrue area of Haldia municipality and extended Haldia planning area's urban infrastructure has been planned and implemented in the low-lying area which is liable to more vulnerable (PLMLS, 2015; LU&DCP, 2015).

(Excel) 2013 etc. All the results have been prepared in the form of tables and diagrams based on the compiling data sets mentioned in Table 1. The main aspect of this research is to analyse LULC classification and changing patterns. Therefore, satellite data in Thematic Mapper (TM) and Operational Land Imager (OLI) sensors of Landsat 5 and 8 satellites have been collected and used for different purposes. The ward maps of Haldia were collected from the Haldia municipality office (Table 1).

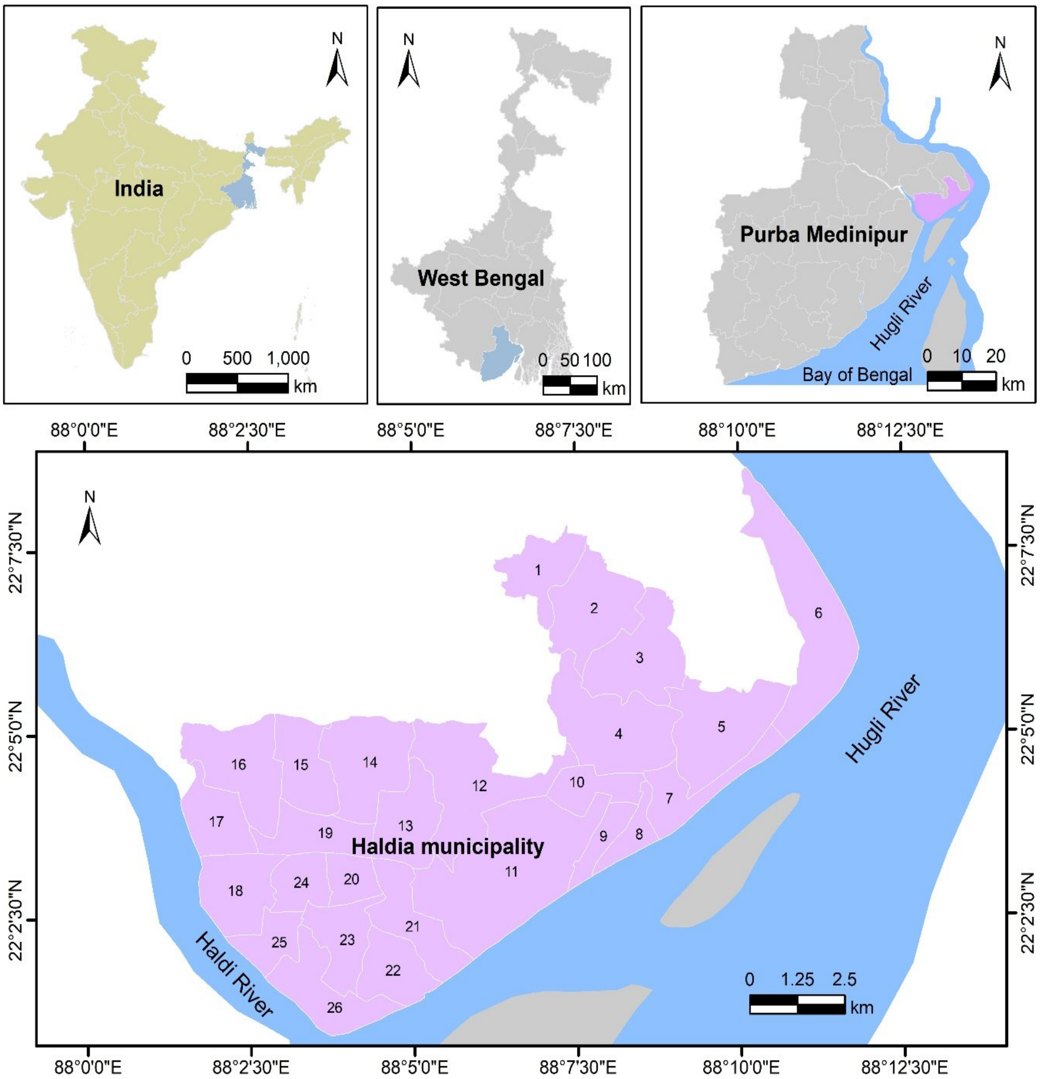

Fig. 1: Location of the Haldia municipality area at the confluence of Hugli and Haldi rivers

3. Database and methodology

3.1. Data used

The present work has been carried out based on the secondary data, and their proper analysis through the geospatial and statistical environment, adopting different methods of analysis using models and suitable software like ENVI 5.2, ArcGIS 10.4, Microsoft Office

Table 1: Different Satellite data and Ward maps are used in the study.

Satellite data	Acquisition date	Path/Row	Purpose of use	Data source
Landsat 5 (TM)	06/03/1991	138 / 045	Shoreline and bankline shifting, LULC classification, and urban sprawling	USGS, Earth Explorer (https://earthexplorer.usgs.gov/)
	13/02/2001	138 / 045		
	09/02/2011	138 / 045		
Landsat 8 (OLI)	27/01/2018	138 / 045		
	18/01/2018	139 / 045		
Ward map	-	-	Study area demarcation	Haldia Municipality office

3.2. Methodology

3.2.1. Image correction

The Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) atmospheric correction has also been done after the radiometric corrections (ENVI, 2009). The FLAASH model is used to remove or minimize the influence of atmospheric noise from the object reflectance.

The radiometric corrections of the TM and OLI sensors have been done on the satellite images of Landsat 5 and 8. In this process, the Digital Numbers (DNs) have been converted to radiance value for the Landsat 5 and 8 images respectively using Eq. 1 and 2 (Chander et al., 2009; Mishra et al., 2014).

$$L_{\lambda} = \left(\frac{L_{MAX\lambda} - L_{MIN\lambda}}{Q_{cal\max} - Qcal\min}\right)(Q_{cal} - Q_{cal\min}) + L_{MIN\lambda} \quad (1)$$

where L_{λ} is the spectral radiance at the sensor's aperture, Q_{cal} is the quantized calibrated pixel $Q_{cal\min}$ is the minimum quantized calibrated pixel value corresponding to $L_{MIN\lambda}$ (DN), $Q_{cal\max}$ is the minimum quantized calibrated pixel value corresponding to to $L_{MAX\lambda}$ (DN) to $L_{MAX\lambda}$ is the spectral at-sensor radiance that is scaled to $Q_{cal\max}$ $L_{MIN\lambda}$ is the spectral at-sensor radiance that is scaled to $Q_{cal\min}$

$$L_{\lambda} = (M_L \times Q_{cal}) + A_L$$

where L_{λ} is the spectral radiance, M_L is the radiance multiplicative scaling factor for the band, A_L is the radiance additive scaling factor for the band, and Q_{cal} is the pixel value in DN of the level 1 (L1) product image.

The reflectance rescaling coefficient factor is used to convert the Top of Atmospheric (TOA) planetary reflectance of multispectral bands of the satellite data. Eq. 3 is considered to switch the spectral radiance to TOA reflectance for Landsat data (NASA, 2016).

$$\rho_p = \frac{(\pi \times L_{\lambda} \times d^2)}{(ESUN_{\lambda} \times \cos\theta_s)} \quad (3)$$

where, ρ_p is the unit less planetary reflectance, which is the ratio of reflected versus total power of energy (NASA, 2016); L_{λ} is the spectral radiance at the sensor's aperture (at satellite radiance); d is the earth-sun distance in astronomical units (provided with Landsat 8 metadata file; $ESUN_{\lambda}$ is the mean solar exo-atmospheric irradiances; θ_s is the solar zenith angle in degrees, which is equal to $(\theta_s = 90^{o} - \theta_e)$, where θ_e is the sun elevation; *ESUN* is the $(\pi^2 \times d^2) \times$ radiance maximum and reflectance maximum.

So, the Landsat 8 images are made available with band-specific rescaling factors which allow for the straight conversion from Digital Number (DN) to TOA reflectance. On the other hand, the property of the atmosphere (i.e. Disturbance on the reflectance that varies with the wavelength) should be considered to calculate the reflectance at the surface (Eq. 4) so, it is described by the land surface reflectance (ρ) (Moran et al., 1992).

$$\rho = \frac{\{\pi \times (L_{\lambda} - L_p) \times d^2\}}{[T_v \times \{(ESUN_{\lambda} \times \cos\theta_s \times T_z\} + E_{down}]} \quad (4)$$

where L_p is the path radiance; T_v is the atmospheric transmittance in the viewing direction; T_z is the atmospheric transmittance in the illumination direction; E_{down} is the downwelling diffuse irradiance.

3.2.2. Image classification

The supervised classification techniques, Spectral Angle Mapping (SAM) and Support Vector Machine (SVM) algorithm are applied in the four different Landsat images from 1991, 2001, 2011 and 2018 of the selected sites for the LULC classification (Bouaziz et al., 2017). In this study, based on the spatial coverage of the study areas, about 15 points of each class were demarcated depending on the on-field knowledge for the LULC classification. The classified images (2018) were further validated with the field verification, and the LULC classification was finally considered for this study when the classification was more than 89 percent accurate based on the Kappa coefficient. Moreover, year to year LULC conversions has been estimated using a conversion matrix (Deng et al., 2008).

4. Results and discussion

4.1. LULC changes

The study area was classified into six major LULC classes for the years 1991, 2001, 2011 and 2018. Although the municipality has been established in 1997, the LULC of 1991 has also been considered to understand the nature and comparison of LULC changes of the Haldia municipality area.

The LULC classification of 1991 reveals that before the Haldia was considered as a municipal area the built-up areas have mainly remained in three parts near the Durgachak, Indian Oil Corporation (IOC) complex, and Township areas in a patchy form (Fig. 2), an area of 4.72 km^2 (Table 2). Also, scattered distribution of built-up areas has been observed in different areas as it is commonly observed in rural areas. Other five types of LULC classes are accounted as water bodies (4.68 km^2), vegetation (22.56 km^2), muddy field (20.78 km^2), agricultural land (43.83 km^2) and fallow land (3.39 km^2) (Fig. 2; Table 2). Ward number 6 is situated on the bank margin of the river Hugli. The major part of this ward is inundated during the high tide. Therefore, depending on the tide level, the area of the muddy field and water bodies has been significantly changed in the different LULC classification maps. Moreover, the municipality area has been situated in the Holocene fluvial deposit, mature swamp and mudflat areas. A muddy field has also been observed in the interior part.

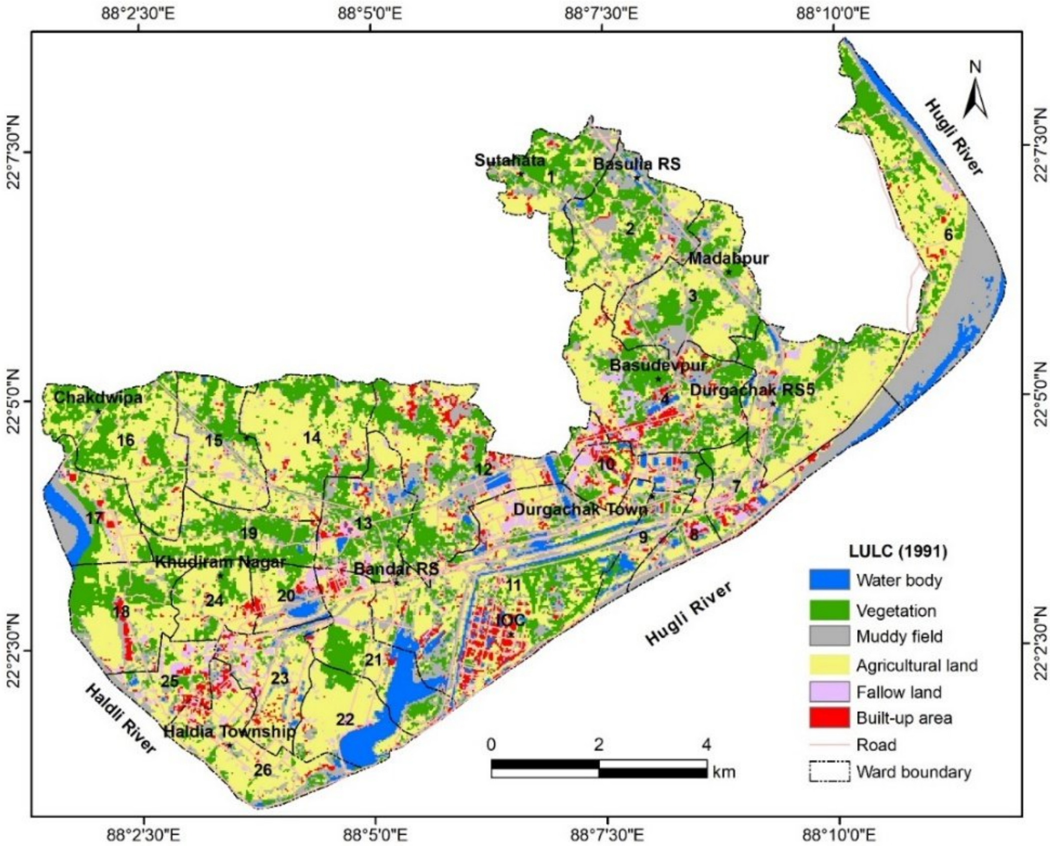

Fig. 2: Land use and land cover types of Haldia urban centre (1991).

During 2001, the dramatic enhancement of urban growth has been observed, which is reflected in the expansion of the built-up areas (Fig. 3). Within only 10 years (1991–2001), the built-up area increased (13.25 km^2) almost three times concerning the areas of 1991 (Table 2), and most of this increase was observed after 1997 in the following stage of municipality recognition. It is observed that most of the built-up areas have been established over the inland low-lying muddy fields after land conversion. The muddy fields have dramatically

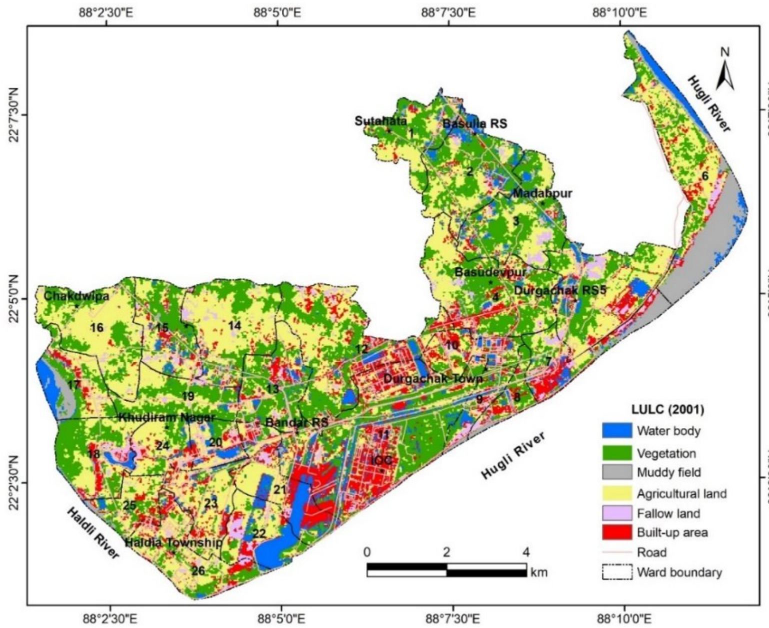

Fig. 3: Land use and land cover types of Haldia municipality area (2001)

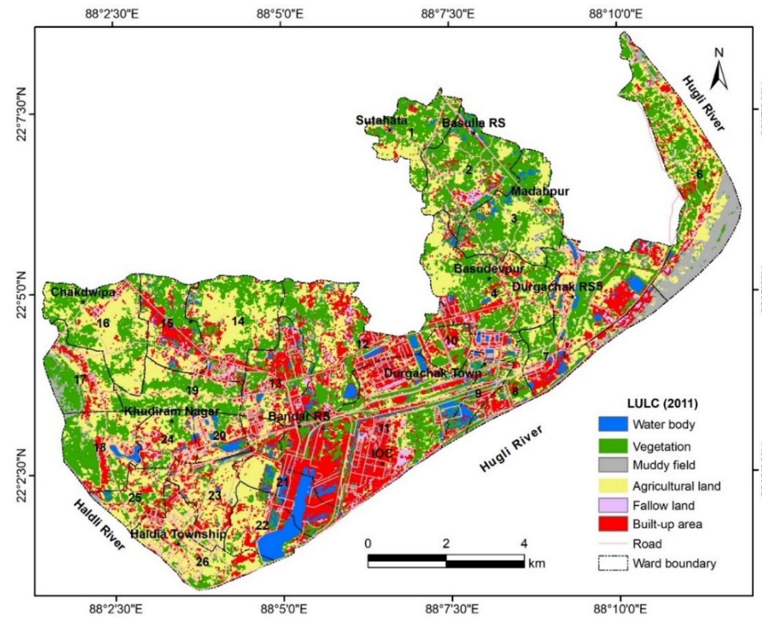

Fig. 4: Land use and land cover types of Haldia municipality area (2011)

decreased (8.04 km²), although there has been almost the same situation in the tidedominated muddy field areas of Hugli riverbank in both LULC maps of 1991 and 2001 (Fig. 2, 3). The areas of vegetation cover have increased during 2001 as a result of social forestry and environmental awareness campaigning. However, the agricultural land area is decreased (Table 2) in the same period.

During 2011, the compactness of the built-up area (22.71 km²) in the form of linear and scattered settlement is observed (Fig. 4). The linear settlement was observed along the major roads, mainly on the western side of the municipal area. Finally, in 2018 the exponential growth of built-up area (29.36 km²) has been observed in the central part and the bank margin areas of Hugli and Haldi rivers (Fig. 5). From the overall analysis of the four different periodic LULC classifications, it is observed that the new land area emerged with a significant level of vegetation in the western part of the municipality area of the Haldi river margin (Fig. 2–5).

4.2. LULC conversion

The LULC conversion during 1991 – 2018 shows that the six different LULC types are converted into other different kinds of land uses (Table 3). The agricultural

Table 2: Changing pattern of different LULC types at Haldia municipality area during 1991 – 2018.

LULC	Year-wise area (km²)			
	1991	2001	2011	2018
Vegetation cover	22.56	31.47	31.03	29.81
Agricultural land	43.83	36.00	31.35	20.70
Fallow land	3.39	3.93	2.13	14.39
Muddy field	20.78	8.04	8.33	1.63
Water body	4.68	7.27	4.43	4.08
Built-up area	4.72	13.25	22.71	29.36

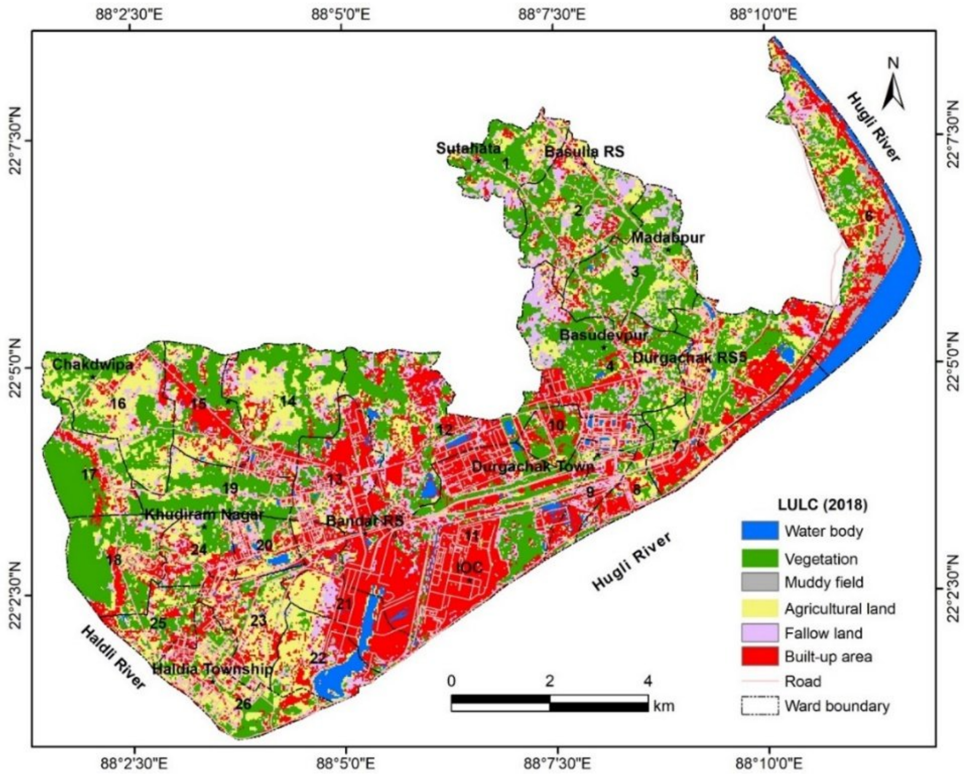

Fig. 5: Land use and land cover types of Haldia municipality area (2018).

land has been mostly converted into the built-up area (12.58 km²), fallow land (8.20 km²) and vegetation cover (9.07 km²). The fallow land converted into the built-up area (1.51 km²), agricultural land (0.83 km²), and vegetation cover (0.46 km²). Most of the areas of the inland muddy field have been modified as built-up areas (6.29 km²), agricultural land (3.02 km²), fallow land (3.19 km²), and vegetation cover (5.81 km²). The muddy field of the bank margin areas of the river Hugli remained in the same condition, but some part of this muddy field was converted into water bodies (1.55 km²) (Table 3) during the high tide condition. Some areas of water bodies converted into built-up areas (1.11 km²) and other types of LULC. Therefore, it is clear that the urban area is now expanding over the agricultural land, fallow land, low-lying muddy fields, vegetation cover areas, and water bodies after land-filling.

The year-wise LULC conversion (Table 4) showing that the area of vegetation cover, built-up, water body and fallow land increased with an areal coverage of 8.91 km², 8.53 km², 2.59 km² and 0.55 km², respectively during the period from 1991 to 2001. With such increases, the area of agricultural land and muddy field decreased respectively as 7.84 km² and 12.74 km². During 2001–2011, the built-up area has significantly increased (9.46 km²) with an accountable increase of a muddy field (0.29 km²), and the reduction of vegetation cover (0.45 km²), agricultural land (4.65 km²), fallow land (1.80 km²), and water bodies (2.85 km²). Similarly, during 2011–2018, the fallow land (12.26 km²) and built-up area (6.65 km²) are increased by the detriment of vegetation (1.22 km²), agricultural land (10.65 km²), muddy field (6.70 km²) and water bodies (0.35 km²). The overall (1991–2018) scenario of LULC change

Table 3: LULC conversion types during 1991-2018 in Haldia municipality area

Previous land use type	Converted land use type	Area (km²)
Agricultural land	Agricultural land	13.11
	Built-up area	12.58
	Fallow land	8.20
	Muddy field	0.46
	Vegetation cover	9.07
	Water body	0.40
Built-up area	Built-up area	4.72
Fallow land	Agricultural land	0.83
	Built-up area	1.51
	Fallow land	0.45
	Muddy field	0.13
	Vegetation cover	0.46
	Water body	0.02
Muddy field	Agricultural land	3.02
	Built-up area	6.29
	Fallow land	3.19
	Muddy field	0.93
	Vegetation cover	5.81
	Water body	1.55
Vegetation cover	Agricultural land	3.18
	Built-up area	3.14
	Fallow land	2.38
	Muddy field	0.09
	Vegetation cover	13.62
	Water body	0.15
Water body	Agricultural land	0.56
	Built-up area	1.11
	Fallow land	0.18
	Muddy field	0.02
	Vegetation cover	0.85
	Water body	1.96
Total		99.97

reveals the reduced areas of agricultural land (23.14 km²), muddy field (19.15 km²) and water bodies (0.61 km²) converted into vegetation cover (7.25 km²), fallow land (11.00 km²) and built-up (24.64 km²). The nature of land conversion and changing pattern of LULC indicates that since 1991, a continuous reduction of agricultural land, and an inverse situation is observed in the case of built-up areas (Fig. 6; Table 4). It is also observed that the accelerated rate of the built-up area increases with due effects of the conversion of agricultural land, fallow land, muddy field and interior water bodies. Although the vegetation cover increased in the Haldi river margin areas of wards number 17 and 18 (Fig. 5), the area of vegetation cover has decreased due to a dramatic expansion of the built-up areas in the central part and levee areas of river Hugli and Haldi. The area of fallow land has dramatically increased with due effects from waste deposition in wetland areas. However, a few years later, this waste dumping area is to be further converted into the built-up area. Similarly, the area of inland water bodies and wetlands is shrinking by land filling which is also further converted into built-up areas in the following stage of land conversion.

Table 4: Temporal conversion types of LULC of Haldia municipality area.

LULC	Year-wise land use conversion area (km²)			
	1991–2001	2001–2011	2011–2018	1991–2018
Vegetation cover	8.91	-0.45	-1.22	7.25
Agricultural land	-7.84	-4.65	-10.65	-23.14
Fallow land	0.55	-1.80	12.26	11.00
Muddy field	-12.74	0.29	-6.70	-19.15
Water body	2.59	-2.85	-0.35	-0.61
Built-up area	8.53	9.46	6.65	24.64

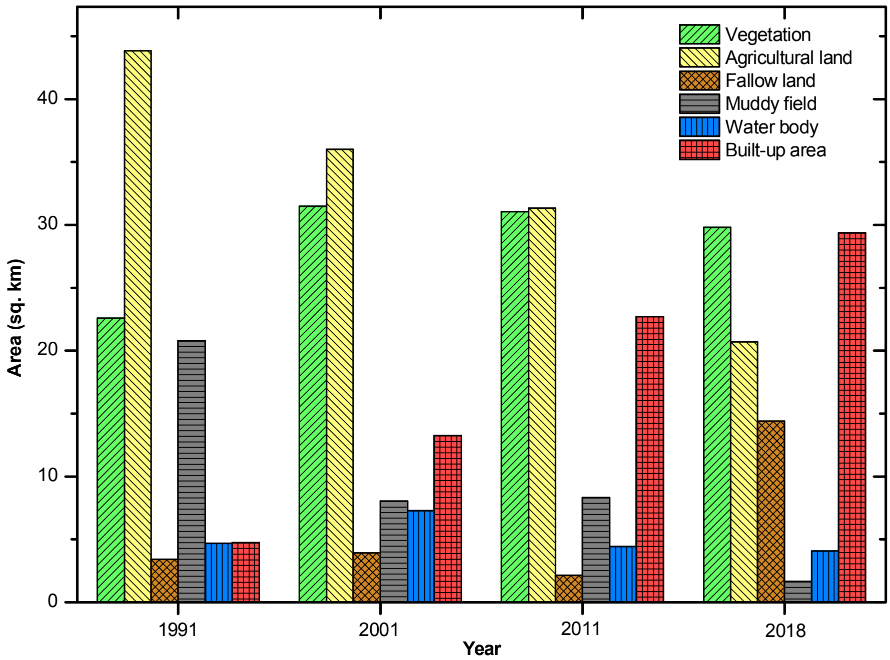

Fig. 6: Changing pattern of land use and land cover types of Haldia (1991–2018) urban centre.

4.3. Urban sprawling

The most dramatic change in the LULC pattern and the built-up area took place in the Haldia municipality centre during the years 1991 to 2018. The Haldia town was initiated as a port-industry based economic activity. Afterwards, such economic activities enforcing the urban infrastructures developed coupling with residential and market complexes. In 1991, the urban built-up areas were found in some scattered form mainly in the three sites (IOC, Durgachak, and Township areas) around the port (Fig. 7). After the 2000s, the built-up areas significantly increased in the central part, western and eastern levee side areas. The brick-field or brick kiln areas have remained in the eastern levee (Hugli riverside), which are extracted as the built-up areas (Fig. 7). The settlements and some industries developed in the roadside areas on the north-western side of the study area. After 2010, the settlements are mostly constructed in the low-lying areas in the central part through land-filling. Among the three sites, the highest percentage (29.37%) of total land remains under the built-up area. Since 1991, the area under the built-up of the total municipal area is dramatically increased by 4.72% (1991), 13.25% (2001), 22.71% (2011), and 29.37% (2018) (Table 5). Such kind of urban expansion over the most risk-prone areas of the river banks, low-lying areas and wetlands after degrading the natural landscape, vegetation covers and agricultural land will create miseries to the urban dwellers in the future.

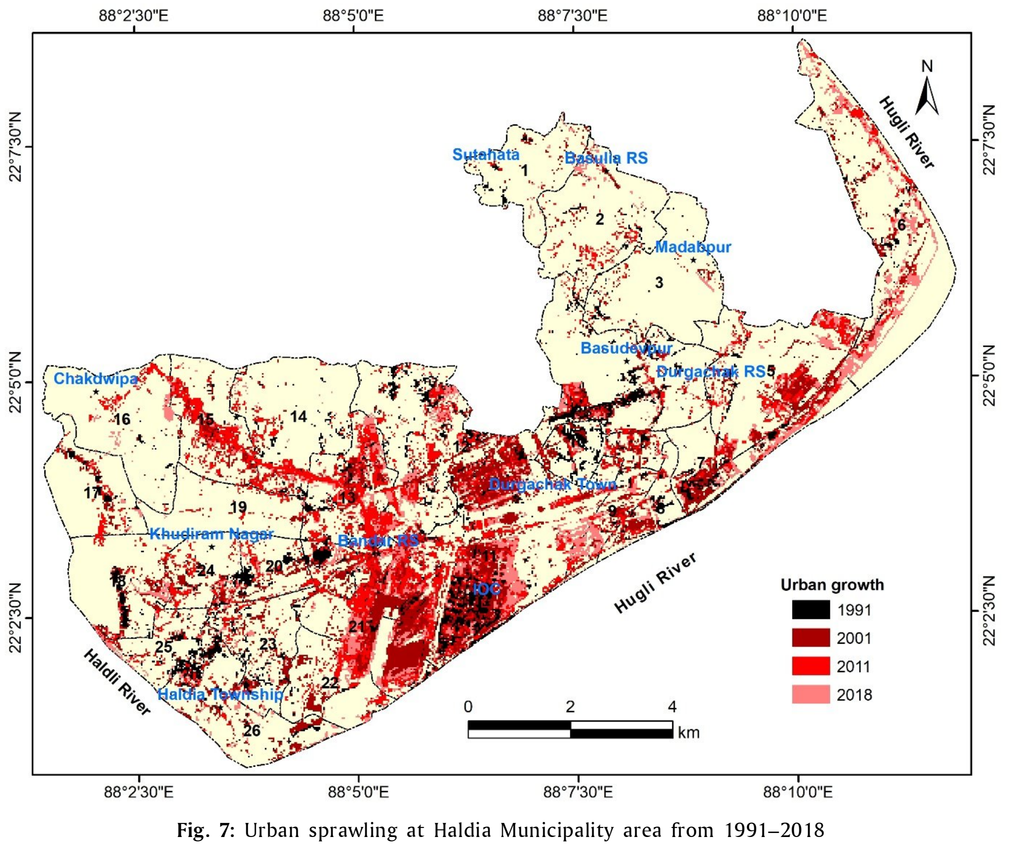

Fig. 7: Urban sprawling at Haldia Municipality area from 1991–2018

Table 5: Urban sprawling at Haldia municipality area from 1991–2018.

Year	Built-up area of total area (99.97 km²)	
	in km²	in %
1991	4.72	4.72
2001	13.25	13.25
2011	22.71	22.71
2018	29.36	29.37

5. Conclusion

The present study tried to focus on geospatial application based analysis of LULC changes and urban sprawling in the Haldia municipality area. The urban centre was initially established based on port and port-related industries mainly at the IOC, Durgachack and Township areas over the relatively elevated natural levee portion. But afterwards, complete urban infrastructural development is going on coupling with residential and market complexes and service related activities. However, the suitable elevated land areas in the existing levee portion were shrinking gradually which leads to the acquisition and conversion of the existed agricultural land, low-lying muddy fields, and water bodies. As a result, a dramatic enhancement in the built-up area took place in the Haldia municipality area during the study period which is from 4.72 km^2 (1991) to 29.36 km^2 (2018). Most of the agricultural lands and low-lying muddy fields have been converted into build-up areas. Moreover, the water bodies and fallow land areas have been drastically converted into built-up areas by constructing industries and settlements followed by waste dumping sites. The build-up area significantly increased in the central part and eastern side of the municipality. However, the central part has existed in the low-lying area among the entire municipality area. The residential complexes and some industries have been built along the roadside in the north, only residential complexes on the western side and eastern side have grown up as a service sector. However, the intensive land conversion leads to drainage problems and sewage water draining from the central parts. Also, most of the residential sectors in the low-lying areas are inundated during heavy rainfall almost every year. Therefore, there should need to restrict the haphazard land conversion without maintaining the proper drainage plan.

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