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An Investigation of Urban Expansion and Environmental Impacts in a Class I City of Eastern India: A Geospatial Perspective

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ABSTRACT

Unplanned urbanization is a severe challenge for Class I cities in eastern India where ecologically fragile lands and fast-growing populations converge. Without proper regulatory planning, settlement diffusion has grown more and more random, especially on the urban periphery in a rapidly growing Class I city of West Bengal. The core of the city remains densely crowded, while the population mean centre lies in the middle, showing intense population pressure. This external expansion pattern has caused intensive changes in land use and land covers (LULCs), characterized by the persistent decrease of vegetation cover, wetlands and water bodies with an accelerating increase of built-up and agricultural land. These spatial transformations, detected through systematic multispectral imageries and demographic analysis, expose the ecological implications of uncontrolled urban expansion. These involve loss of habitat, enhanced surface runoff, reduced groundwater recharge and stress on civic infrastructures. The absence of strategic urban administration further aggravates these concerns, exposing the long-term socio-environmental degradation. This study highlights ongoing expansion risks undermining the environmental resilience and general liveability of fast-expanding cities in the region without structured approaches. It underscores the critical need for comprehensive urban planning strategies that address both population dynamics and ecological sustainability.

Keywords: Environmental Degradation, Land Use and Land Cover, Mean Centre of Population, Optimum Development, Urban Sprawling.

Introduction:

Urban expansion and land consumption studies require spatio-temporal data to evaluate land use and land cover (LULC) dynamics over the period of time where natural landscape area around the cities transformed into housing estate, industrial parks, and other kinds of facilities designed to serve the community (Kumar et al., 2012). Sprawl spreads in out skirts of the city's rural or undeveloped areas involves commercial or residential areas and the residents are engaged in jobs in the city, to come at the city centre they use to walk or use bicycles and other vehicles that mostly causes air pollution and has other negative consequences on environment (Dubey and Kumar, 2013). Unplanned expansion of urban areas and acquisition of land for building construction absorbs solar radiation in the afternoon which also emits heat radiation further increases the climatic pressure and dust can provoke the condensation of water vapour into rain droplets and often receives more rain (Rai, 2017). Uncontrolled and haphazard urban growth may raise serious problems related to environment where LULC map, numbers of satellite imageries are useful for understanding and detecting the various spatio-temporal impacts of human activity (Dutta et al., 2017). The concentration of human in sprawls not only decreases the amount of forest area, farmland, woodland and open space but also creates disturbances in ecosystems and fragment habitats for species, altering movement and disrupts ecological succession (Tiwari and Goel, 2017). Against the problems of environmental degradation and to meet the challenges of sustainable development, use of remote sensing and GIS conjunction with geospatial data is suggested where priorities should be given to the issues related to planned development of the city, reduction in atmospheric pollution and traffic congestion (Rahman et al., 2010). Urban sprawl is mostly suspected to an increase of cost for transport and requires more energy, metal, concrete and has negative impact on air quality, create public health issues for inner-city residents due to high emission levels causing asthma, heart and lung diseases (Brunner, 2012). Population growth for countries like India and Brazil increases carbon emission and energy consumption for economic growth and urbanisation which is being studied in the theoretical framework of the EKC (Environmental Kuznets Curve) hypothesis and U-shaped relationship exists while studying co-efficient between environmental degradation and income level for some specific countries and also found example of Sri Lanka Government who is being successful in providing necessities even in rural areas and resulting in a less urbanised population that indicates lower environmental stress (Gasimli et al., 2019). Urban land cover information is an essential data required by urban planners for detecting human encroachment on natural resource, urban infrastructure facilities planning, and preparation for master plan and detailed developmental plan by using high spatial and spectral resolution where Sentinel-2 has all the potential for various related application in land cover map preparation and Google satellite images to perform change detection analysis to understand city growth and impact on the environment (Vigneshwaran and Kumar, 2018). NIR images are widely used for city surveying and mapping due to the difficulties in acquiring satellite images all seasons with lower cloud cover, a common characteristic of an object-based change detection is accurately extracting individual objects and ignore the spectral similarity between the pairs of images from where the object is extracted, therefore it is desirable to gain access to the technology of detecting vegetation changes (Zhou et al., 2014). Spatial pattern of urban sprawl over different time period must be systematically mapped monitored and accurately assessed from

satellite images along with conventional ground data in which historical growth pattern of the feature spread by using urban growth models like cellular automata and artificial neural network or spatial statistics (Ibrahim and Sarvestani, 2009). Green urban areas, sports and leisure facilities areas were assigned with normalized difference vegetation index (NDVI) value in urban areas and visual interpretation and normalized difference water (NDWI) is used to classify water and non-water areas in study area in with an object-based classification processes where appropriate parameters and function selection is a significant task using multi-temporal and high-resolution satellite images that would be used satisfactorily (Akay and Sertel, 2016). Recent technological advances made in domain of spatial data with varied geographic pattern, cultural activities and the purpose of using GIS is that maps provide an added dimension to data analysis which brings one step closer to visualise the spatial pattern (Andarge, 2015). In satellite images, normalized difference built-up index (NDBI) is prepared to the urban built-up areas with automated technique and identified with the arithmetic manipulation of recorded NDVI and NDBI images (Ghosh and Siddique, 2018). NDBI image will lead to only built-up and barren pixels having positive values while all other covers have a value of 0 or -254, thus allowing built-up areas to be mapped automatically and NDBI method is superior to supervised classification with an accuracy level of 92.60% which can serve as a worthwhile alternative for quickly mapping urban land (Zha et al. 2001). In response to these concerns, a geospatial study was undertaken on a Class I city in West Bengal to assess urban expansion and its ecological implications.

Methodology:

Study Area:

Nabadwip Municipality, a class I city, was selected as the study area which is located on the western bank of the river Bhagirathi in the district of Nadia, West Bengal. This city has humid tropical climatic traits having pre-monsoonal hot summer, post-monsoonal cold winter and monsoonal rainy season. It has latitudinal and longitudinal extension from 23º23'N to 23º26'N and 88º21'E to 88º23'E. This municipality is divided into 24 wards and this area comes under the Nabadwip Community Development Block which is characterized as class I U.A. by the census of India, 2011. It is one hundred fifty years old urban city structure as the municipality was established in the year of 1869 and then at the time of partition in 1947 huge number of immigrants came from the neighboring area (Nadia District Gazetteer, 2012). Studies have shown Nabadwip with its 150 years of urban outgrowth which has grown in an unplanned manner especially during and after the partition of Bengal in 1947 A.D. According to the Census of India (2011), 125543 persons live in the Nabadwip municipality area. Among them 65415 are males and 60128 are female here. Sex ratio is 919 and number of children in the age group from 0-6 are 8790. Here the population density is 10767 persons/ sq.km. This city has experienced many geomorphological as well as structural changes whenever there were several changes occurred in the Bhagirathi. It is located on the lower Ganga basin which has surface physiographic unit is comprising Chhota Nagpur plateau and Raajmahal hills lowland where the original basement is Complex of Achaean formation. Surface alluvium cover became thin from Holocene to Cretaceous and Tertiary (Sengupta, S. 1969). The fluviatile sediment consists of clay, silt, grey colored sand with fine to coarse grained, and gravels of quartz, rock fragments and laterites (Central Ground Water Board of India, 2016). This physical and demographic complexity underscores the urgent need to assess the environmental consequences of its unregulated urban expansion.

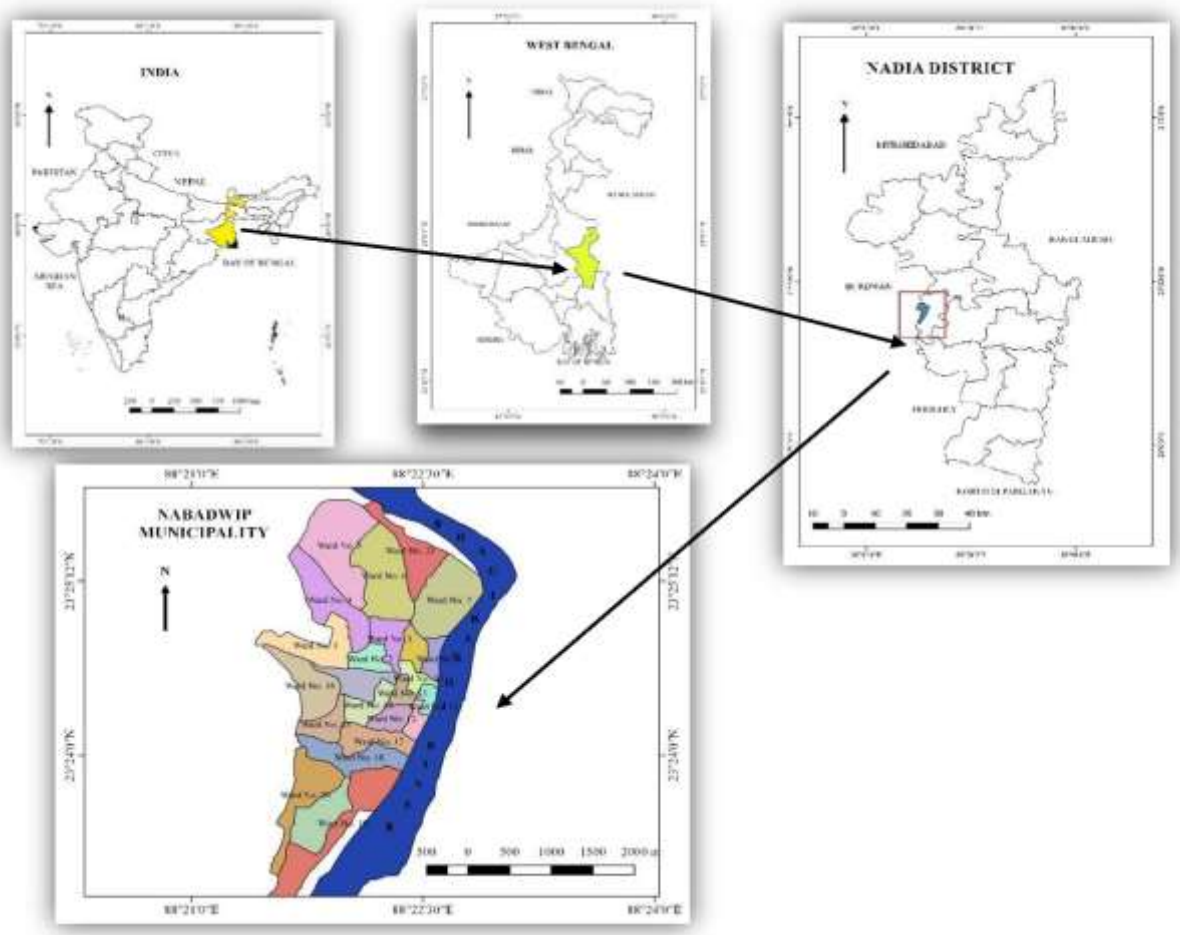

Figure 1: Location map of the study area showing the selected class I city

Database of the Study:

Source of the Population Data

The analyses have been done on the basis of secondary data source. The statistical data of population are either collected from Census of India (2011) or from Nabadwip Municipality by visiting their official websites.

Source of the Data for Image Based Analysis

Google Earth Pro® which gives a 3D pictorial view of the earth surface (Mercator projection system, modified spherical datum of WGS 84) provides free of cost access for public. Images are collected from its option of historical imagery which have been used by time slider to move between the acquisition dates. Next to analyse the changes in Land Use and Land Cover, expanded built-up and their probable effects on the environment satellite data of different years in used here.

Satellite Data Acquisition

United States Geological Survey (USGS) website is accessed here to download satellite Images of 9th May 1991 and 7th November 2005. Images of these two mentioned years are actually Landsat 4-5 satellite images operated by NASA / NOAA with Thematic Mapper sensor and temporal resolution of 16 days repeatability launched in 16th July 1982 and 1st March 1984. The recent year satellite images are downloaded from the website of USGS. But it belongs to Sentinel-2 (constellation with twin satellites Sentinel-2A and Sentinel-2B) satellite image operated by European Space Agency (ESA) which carries Multi Spectral Instrument (MSI) launched in 23rd June 2015 and 7th March 2017 with their specific bands and spatial resolution.

Methods of Analysing Census Data:

Ward Wise Population density

Population Density of a Ward = $\frac{Population\ of\ the\ Ward}{Area\ of\ the\ Ward}$

Mean Centre of Population of the Municipality

Mean Centre of Population on Longitude (X) = $\frac{Population\ of\ the\ Ward \times Longitude\ of\ the\ Centre\ of\ the\ Ward}{Total\ Population\ of\ the\ Municipality\ Area}$

Mean Centre of Population on Latitude (Y) = $\frac{Population\ of\ the\ Ward \times Longitude\ of\ the\ Centre\ of\ the\ Ward}{Total\ Population\ of\ the\ Municipality\ Area}$

Methods of Analysing Satellite Data:

Normalised Difference Built-Up Index:

This index is used for monitoring urban expansion using reflectance in the shortwave infrared region (SWIR) and compared with near infrared region (NIR). The value ranges between -1 to +1 and it helps to identify the expansion from a lower level to a greater extent.

NDBI = $\frac{SWIR\ Band - NIR\ Band}{SWIR\ Band + NIR\ Band}$

Normalised Difference Vegetation Index:

This index is used for measuring the availability of green plants based on the absorb radiation in the visible region of the spectrum where NIR (Near Infrared) band and compared with the Red Band. The value ranges between -1 to +1 to represent an area with lower to higher vegetation coverage.

NDVI = $\frac{NIR\ Band - Red\ Band}{NIR\ Band + Red\ Band}$

Normalised Difference Water Index:

This index is used for measuring water availability that would help to understand the instability of water content in this area. To estimate this index, the green band is compared with NIR (Near Infrared) band and the value ranges from -1 to +1 which signifies lower to higher availability of water.

NDWI= $\frac{Green\ Band - NIR\ Band}{Green\ Band + NIR\ Band}$

Objectives:

1. To assess the demographic profile of Nabadwip Municipality.
2. To evaluate the dynamicity of land use and land cover of Nabadwip Municipality.
3. To highlight the environmental impact due to unplanned growth of this Municipality Region.

Results:

Demographic Profile of Nabadwip Municipality:

The city had vast demographic transitions throughout its history. According to the census of India (2011), The city reached total population of 125528 in which 65,415 were identified as males and 60,128 as females. The literatures underscored the growth of population in a rising trend and the most rapid growth is found in the year of 1981 (Nadia District Gazetteer, 2012). It might be due to the partition period when immigrants came from adjoining areas. The total area of this municipality was around 11 sq. km in which the river Bhagirathi have impacted a greater influence over this area as the river causes for annual floods and became devastating and hazardous for the people when inundation takes place all over the area. On the other hand, this river helps to get more fertility to the land through pouring the soil with required minerals. This city is divided into 24 wards with more than one lakh population residing in this municipality area. All wards are not having equal areas where the following trends show that size of the wards increase as go far from the centre of the city. Wards at the middle of the city are smaller in size having approximately 2900 to 4000 population as it goes far from the central part of the city and getting relatively loaded with approximately 4000 to 7000 population. The northern and southern edges of the city are having the biggest wards with highest population viz. ward no. 5 in northern edge and ward no. 18, 19 and 24 in the southern edge of the city where the population is ranging between 6963 to 7970 people.

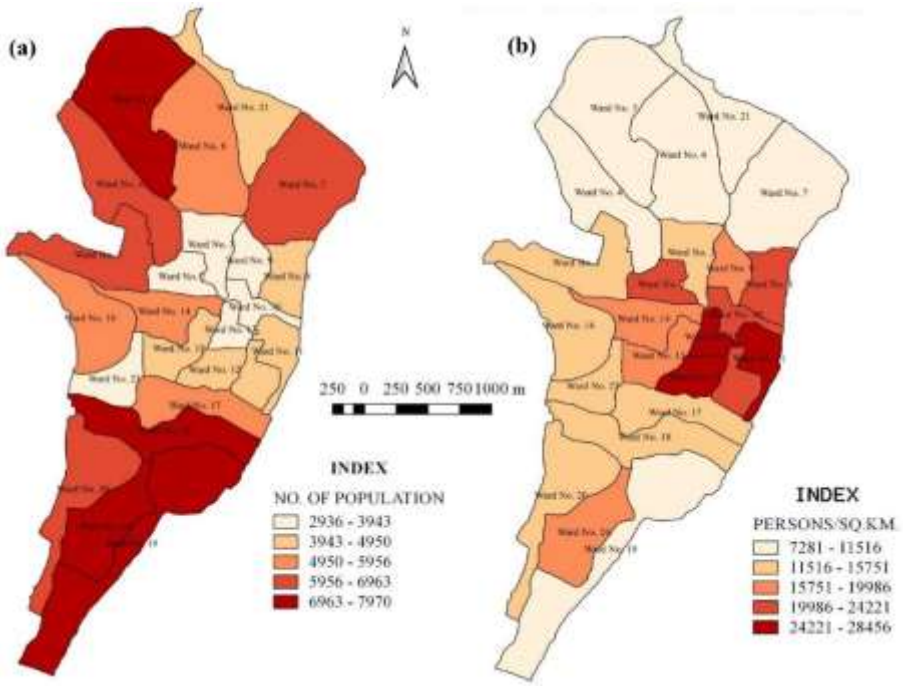

Figure 2: Population dynamics showing (a) number of populations residing and (b) population density in each ward of Nabadwip Municipality

Very High Population Density Zone: The middle of the city is more congested than the outer parts where population density is also high. In the Middle Eastern edge ward no. 11, 12, 13 are highly congested with 24221 to 28456 population per square kilometre. This is the area where the larger markets are actively passing the major business economy of the town.

High Population Density Zone: There are population density of 19986 to 24221 population per square kilometre in ward no. 2, 8 and 10 which are situating around the very high population density wards. This area has the most famous tourist spots for which Nabadwip is famous as the place for pilgrims.

Moderate Population Density Zone: Ward no. 19, 14, 15, 24 are characterised under moderate population density zone with 15751 to19986 no. of population per square kilometre which are almost situating around the high population density region. Fastest accessibility can be provided from these wards to reach the city centre.

Low Population Density Zone: As far from the centre of the city population density has a trend of lowering down with increasing distance. There are wards having relatively low population density with 11516 to 15751 no. of people per square kilometre such as ward no. 1, 3, 16, 17, 18, 20 and 23.

Very Low Population Density Zone: Wards lying at the edges of the city are having the lowest population density with 7281 to 11516 no. of population in the ward no. 4, 6, 7, 19, 21, 22 and 24. These are wards having the potentiality to hold more population in future and the population growth of these are indicating further rising the density of human population.

Figure 3: The mean centre of population in Nabadwip Municipality based on census data of 2011

Although, the mean centre of population provided a selection of the region where the most populous ward was congested. The calculated mean centre of the population of 2011 was found over the ward no. 14 that suggested the mean congestion of the population is located at the centre of the city (Figure 3).

Stages of Urban Sprawling of the City:

The delineated study area had identified the urban outgrowth of the city in several years (Figure 4). The clustered settlement was only found at and around the centre of the city in 2003 and its centrifugal growth was noticed in 2010 with its peripheral growth. It was further developed towards the outskirts of the municipality area which was characterised by low density population and less traffic congestion. This kind of extension encouraged the growth of the city, proliferated due to the willingness of a growing number of people to live in around the periphery where they find life calmer and more peaceful than in the middle of the city and characterised as sprawling edge city (Siddhartha, K. & Mukherjee, S., 2016).

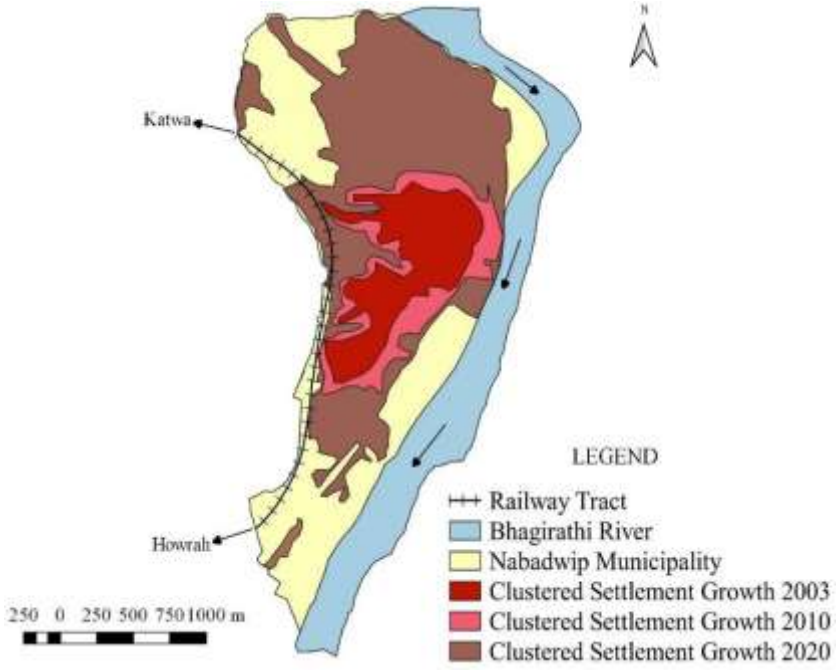

Figure 4: Stages of population growth over different years in the study area

Road Network and Density:

The centre of the city was identified as the most road connected area as this region showed the highest population density. Even, the road density was also high in this central part of the city. As far from the congested central area, the road density was getting lower and almost nil towards the outskirt of the city. Although, this whole region was characterised with mostly dense road network throughout the city and these were connected with each and every node of human settlement.

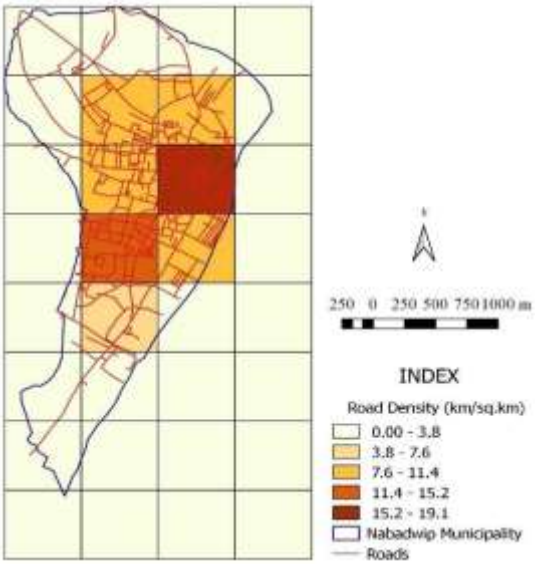

Figure 5: Road density map in a grid-based method over the study area

Analysis of Changes in the Land Use and Land Cover:

The LULC analysis of 2005 was prepared by Landsat 4-5 satellite imagery where one pixel represents 30m on ground. The study site was categorised into major six different sectors viz. water body, vegetation, settlement, agricultural land, fallow land and wet land. Most of the area was categorized under vegetation (52%) covering 6.49 sq.km. Settlement was occupied by 3.12 sq.km area (25%) and water body were lied over 0.36 sq.km area (3%) followed by fallow land with 1.08 sq.km area (9%), wet land with 0.93 sq.km (7%) and 0.47 sq.km of agricultural land (4%) sectors.

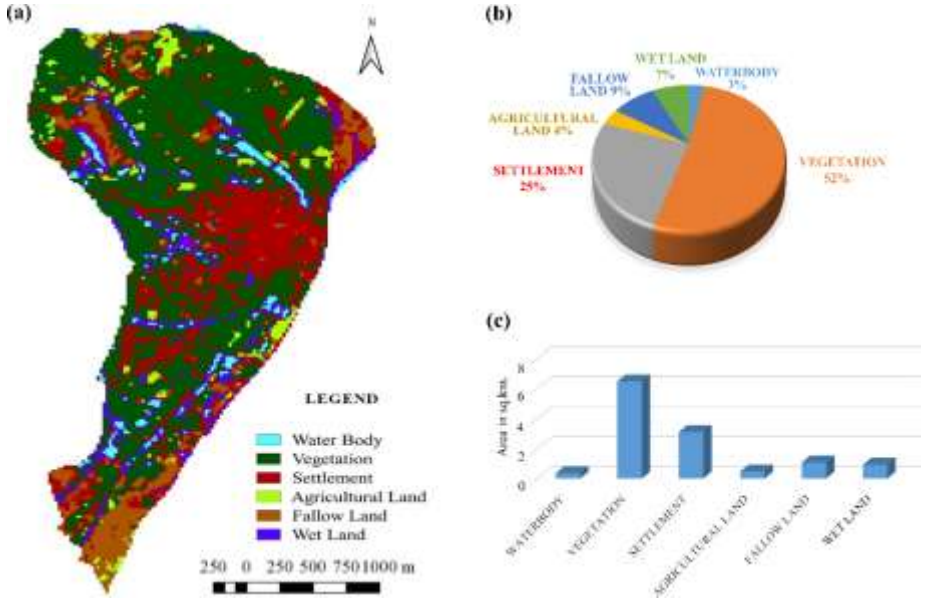

Figure 6: (a) Land use and land cover (LULC) dynamics and areal coverage of selected sectors (b) in percentage and (c) in sq.km. of 2005

Also, the LULC of 2020 was prepared by using Sentinel-2 satellite imagery where one pixel represents 10m on the ground. Here, the area was also categorised into major six different sectors as of 2005. The most of the region was again covered by vegetation (44%) covering 5.51 sq.km. that indicated decreasing trend of vegetation in upcoming years. Settlement had occupied 3.28 sq.km area (26%) and water body was denoted under 0.13 sq.km area (1%) followed by fallow land in 1.96 sq.km area (16%), wet land of 0.31 sq.km (3%) and 1.20 sq.km of agricultural land (10%) sectors.

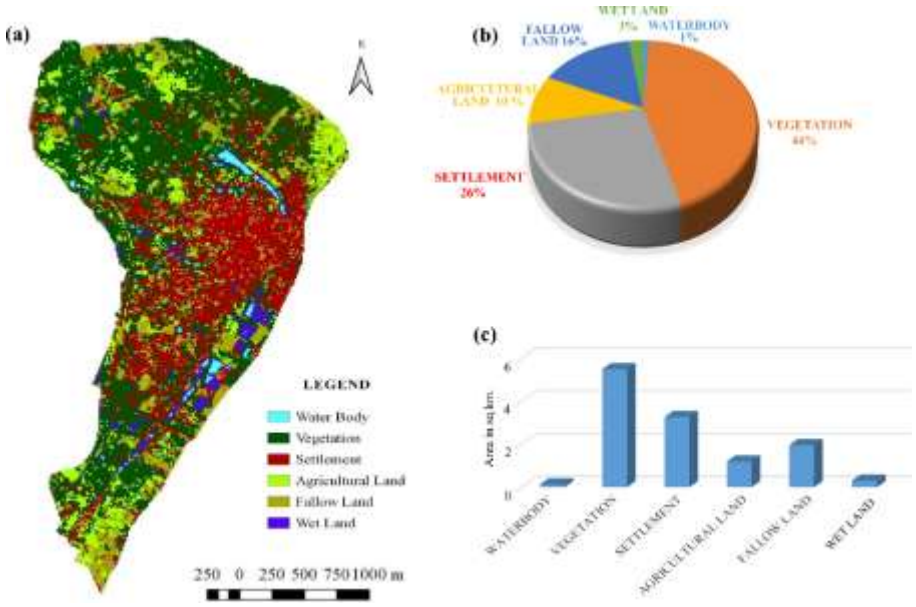

Figure 7: (a) Land use and land cover (LULC) dynamics and areal coverage of selected sectors (b) in percentage and (c) in sq.km. of 2020

It was observed that the vegetation coverage of the city was 52% in 2005 that substantially decreased up to 8% in 2020, and became 44% areal coverage within the city. Water body and wetland areas also followed a diminishing trend over the years. These two following LULC classes had become 1% and 3% from 3% and 7%, respectively, in this study site. Subsequently, settlement, agricultural land and fallow land area had expanded in this city over the years. These fluctuations across different sectors reflected significant changes in the LULC patterns. The observed growth in settlements and urban sprawl had directly contributed to alterations in the LULC, highlighting the transformative impact of unplanned urban expansion on the natural landscape. Settlement was one of the most rapidly expanding land uses, where the spread of concrete built-up areas significantly altered natural processes such as surface runoff and groundwater percolation, contributing to soil pollution. The decline of water bodies and wetlands indicated a drying landscape, leading to the disruption of ecological functions and imbalances in soil structure. Every component of the environment held intrinsic value and maintained a delicate interrelationship with others. Unregulated and unconscious urban expansion increasingly encroached upon natural areas, posing serious risks to ecological balance. Such expansion threatened biodiversity through habitat destruction, food scarcity, and potential species extinction. Ultimately, these developments led to severe and unpredictable environmental degradation.

Monitoring Environmental Impact Using Geospatial techniques:

Several indices were used to identify the direction and extent of urban expansion in the study area. The derived indices, firstly, NDBI value of 2005 ranged between -0.34 to 0.27 it ranged in between -0.38 to 0.041 in 2020 (Figure 8a and 8b). The NDBI of 2005 identified a concentrated built-up in the middle of the city, but in 2020, a centrifugally expanded built-up area from the centre of the city towards its outskirts was observed. Also, the NDVI in 2005 ranged between -0.16 to 0.60 that denoted a decent amount of vegetation cover around the city. But, the NDVI in 2020 ranged from 0.093 to 0.68 and it identified that the edges of the city became greener than the centre of the city. Therefore, an obvious diminishing rate of vegetation cover is noticed in the span of 15 years. Area around the centre of the municipality area was also impacted greatly.

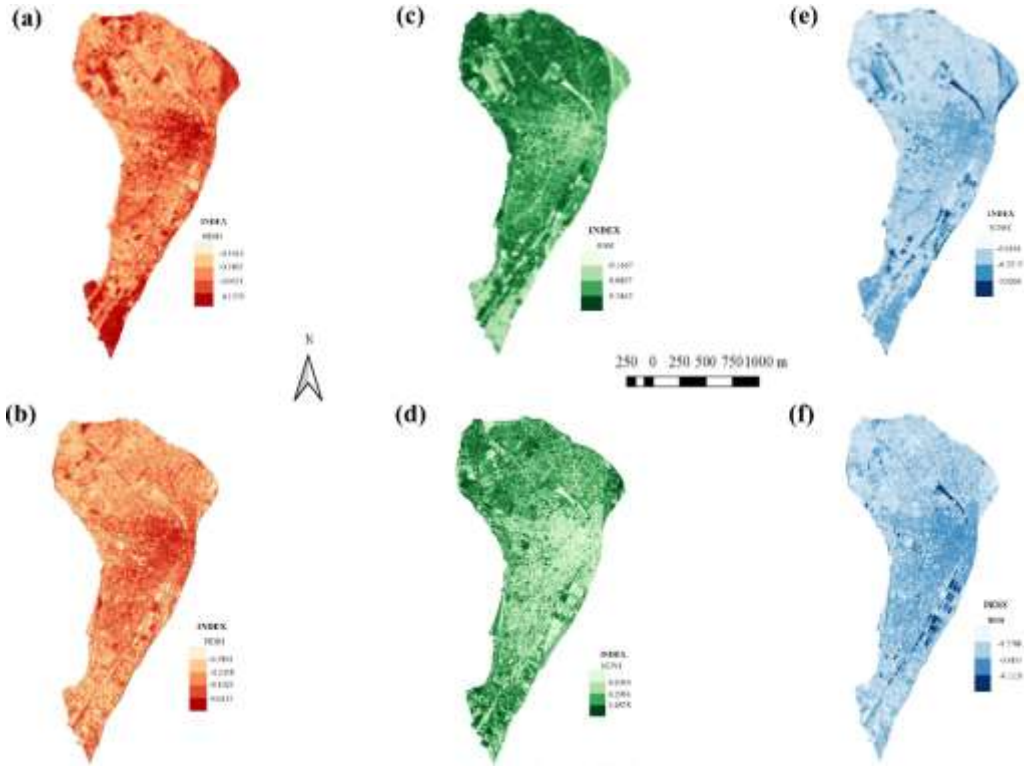

Figure 8: Environmental indicators showing (a) NDBI of 2005, (b) NDBI of 2020, (c) NDVI of 2005, (d) NDVI of 2020, (e) NDWI of 2005 and (f) NDWI of 2020 of the study area

Lastly, the calculated NDWI in 2005 ranged from -0.61 to 0.26 and it decreased substantially and came within the range of -0.57 to 0.12 in 2020. The value of NDWI had proved a declining rate of water content in this area which is not a good indicator for future development and would also hamper the environment by creating fresh water scarcity. This declining rate had occurred due to unplanned growth of the city, lack of preservation and management plan.

Environmental Impact Assessment:

• Removal of Greeneries:

Only between the gap of 15 years vegetation cover has reduced from 52% to 44% of the total area. This reduction further leads to – soil erosion, ecological hamper, habitat loss for animals and species extinction.

• Reduced Area under Water Body:

In the year of 2005, there was 0.36 sq.km area under inland water bodies throughout the city. But in the year of 2020, there is only 0.13 sq.km area under inland water bodies. This would further lead to – fresh water scarcity, destruction of swamp ecosystem and aquacultural activities' destruction.

• Conversion of Agricultural Land:

Nabadwip Municipality area is not well known for any agricultural production. In spite of that the satellite images have shown that there is an expansion of agricultural land from 3.8% of the total area in 2005 to approximately 10% of the total area under agriculture in the present year of 2020. This conversion may have economic significance but it also has probabilities to degrade the natural environment.

• Absence of Wetland:

Wetland is an important environmental component which can hold a unique ecosystem with various floral and faunal community. In the year of 2005, there was 7.5% area under wetland in this region but with the changing of time wetlands are being vanished from this city and there is only 2.9% area under wetland in this present year. It would have broader impact on the environment as follows – waterlogging may take place during monsoonal heavy rain, destruction of wetland ecosystem, absence of space for water storage etc.

• Increased Built Up Area:

Build up area has increased within last 15 years in Nabadwip Municipality area. It is expected that the areal expansion of human habitat also has influenced the environmental sustainability as it has converted area into concrete walls without having proper management plans. This expansion would further create – restriction to water infiltration, restriction of natural water flow, reduction of vegetation cover, habitat loss for other animals etc.

Conclusion:

Urban expansion at the edges of the selected class I city is taking place and its trend indicating amplification of sprawling. Population projection is also directing towards a higher growth rate in the upcoming years. So, it would need land for residential establishment, market places, educational institution etc. But there would not be any areal extension in the total area of this Municipality. If it continues without any urban plan and management then it will create a congested city and slum area settlement along the roads or railway tracts as there are more than 40 slums have been detected in this area by Nabadwip Municipality in 2011. Hence, proper planning and management is necessary to handle this urban outgrowth without any environmental hamper. Reducing area under vegetation cover, wetland and decreasing water bodies are the sign of environmental degradation because these causes will also affect the nature from so many others ways. Soil erosion, water pollution, infertility in land, air pollution, water pollution, noise pollution, ecological imbalance, habitat loss for the animals and so on. These affects also have greater effects in the environment. At last human will get affected for not having proper environment to live and survive. To eradicate the environment related problems the local government should take steps and have to make the indigenous people aware of the risks for them and for the environment. National Slum Development Programmes (NSDP), Integrated Low-Cost Sanitation Scheme (ILCS), JNNURM (Jawaharlal Nehru National Urban Renewal Mission), CBPHCS (Community Based Primary Health Care Services) are in operation for slum improvement in and around Nabadwip municipality.

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