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Environmental Protection Measures for Unplanned Land Use and Land Cover Changes in a Subbasin of the Ganga River System

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ABSTRACT

In the Ganga river system, unplanned land use land cover (LULC) changes have serious threat to the environment. Protective measures are essential at local, regional, and global scales to save human life and the environment. In the present work, the land use and land cover (LULC) changes have been studied from 2002 to 2021 in a basin area between river Gandak and river Burhi Gandak in India. For the analysis, Landsat 5, 7, and 8 satellite data have been used to analyze the changes in vegetation, urban land, open land, water body, and wet soil in the last two decades. The result shows that from 2002 to 2021 the agricultural area and open land have decreased by 16.12% (158,676 ha) and 11.85% (116794.8 ha), respectively. The urban and the waterlogged area have increased by 24.32% (240,070 ha) and 4.75% (46937.3 ha), respectively. The environmental protection measures, namely conjunctive use, multiple cropping practices, land reclamation, and decentralized urban development to reduce floating population, have been studied and recommended in the study region for better land use/land cover.

INTRODUCTION

Using satellite remote sensed data provides excellent results over the land surface in temporal and spatial domains (Jovanović et al. 2015). It is cost-effective to map LULC and detect changes using remote sensing and GIS tools. Different satellite data are being used for different purposes based on spatial resolution, electromagnetic spectrum, energy source, imaging medium, and several bands. The high-resolution satellite data will attain a better degree of classification accuracy. In the past, numerous LULC estimation methods have been used to assess the shifting cultivation, landscape changes, and benefit from change detection (Anitha 2021, Jamali et al. 2015, Lu et al. 2004, Usman et al. 2015, Gaurav & Singh 2022, Jensen 1996, Bajirao et al. 2018, Mas 1999, Olokeoguna et al. 2014). Land use is influenced by environmental factors like soil characteristics, climate, topography, and vegetation (Baboo & Devi 2010).

Urbanization, industrialization, the influx of point and non-point source pollution, and the floating population are the main causes of LULC changes. Scientists and researchers have used different methods to assess the causes of changes in LULC and the repercussions of those changes owing to human activity (Cardille & Foley 2003). In water resource engineering, land use classification is crucial in determining a catchment area's runoff response (Ara 2021). Using remote sensing and geographic information systems, the ecological system uses and land cover changes have reached their optimum limits (Sultana et al. 2023).

The floating population in urban areas is very high due to the influx of people from nearby areas, villages, or towns. This creates environmental pollution regarding water pollution, sewage, and wastewater. Moreover, some environmental protection measures are essential for effective water resource management. In the present work, all such important aspects have been discussed.

MATERIALS AND METHODS

Study Area

The study area is in between Gandak to Burhi Gandak rivers system, and the total area is 9859.25 km^2 (Fig. 1). The Gandak river originates at an altitude of 7620 m above MSL in the north of Dhaulagiri in Tibet near the Nepal border at Latitude 29°18' N and Longitude 83°58' E. It flows through west Champaran, East Champaran, Muzaffarpur, Gopalganj, Siwan, Saren, and Vaishali districts of Bihar and joins Ganga at Hazipur. Burhi Gandak River is one of the tributaries of the Ganga River, which originates from Chautarwa Chaur near Bisambharpur in the district of West Champaran in Bihar at 84°12' E longitudes and 27°05' N latitude and is

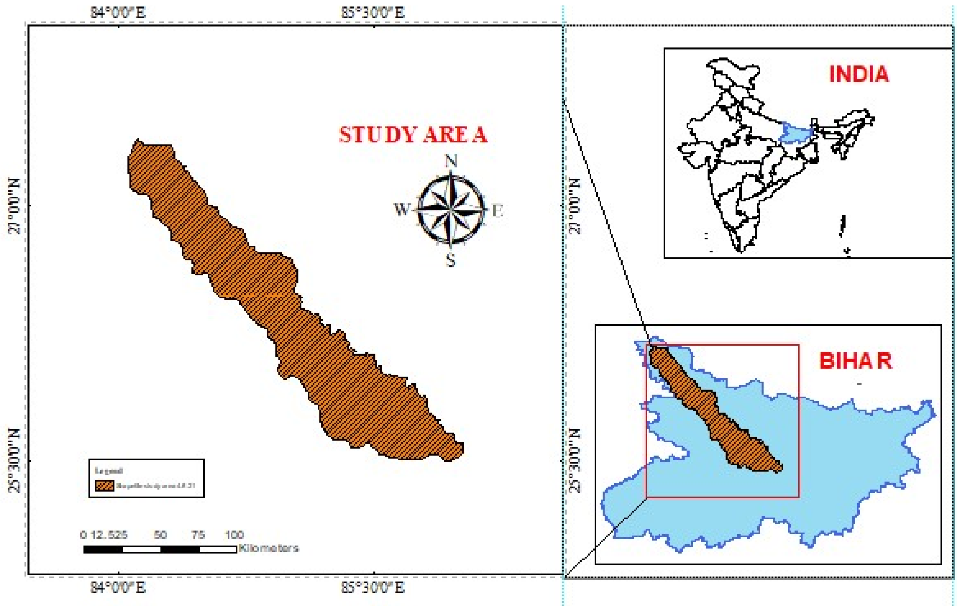

Fig. 1: Location map of the study area.

known as the Sikrahana in its upper reaches (Zakwan et al. 2018, Zakwan & Ahmad 2021). The study area is bounded by latitude 25°29ʹ0" to 27°22ʹ0" ʻ and longitude 84°13ʹ0" to 86°0ʹ0". Fig 1 provides a location map of the study area.

In the study area, there are canals that are the tail end of the Tirhut canal or Eastern Gandak canal, and important canals are Tirhut main canal (TMC), Jaitpur branch canal, Mallikpur branch canal, Vaishali branch canal (VBC), Birpur distributary, Pipara distributary, and Hajipur distributary, etc.

Data Acquisition

The Survey of India Topographical map on the 1: 100,000 scale for 2002 was used for the study. To identify the areas of vegetation, open land, barren land, water body, and changes in the wet soil using the satellite data of Landsat 5, 7, and 8 of path/row 140/42, 141/41, 141/42 and 142/41 for 20 years (between 2002 to 2021) of post-monsoon (October to December) were selected for downloading from https://earthexplorer.usgs.gov (Table 1). Four spectral bands, which

Table 1: Satellite data used in the present work.

Satellite/Sensor	Bands used	Wavelength ranges (μm)				Acquisition date	Path/Row no
		Green	Red	NIR	MIR/SWIR-1		
Landsat-5 TM	2,3,4,5	0.52-0.60	0.63-0.69	0.77-0.90	1.55-1.75	2009/12/02	140/42
						2009/11/07	141/41
						2009/10/22	141/42
						2009/10/29	142/41
Landsat-7 ETM+	2,3,4,5	0.52-0.60	0.63-0.69	0.77-0.90	1.55-1.75	2002/12/07	140/42
						2009/11/28	141/41
						2009/10/27	141/42
						2009/11/03	142/41
Landsat-8 OLI	2,3,4,5,6	0.53-0.59	0.64-0.67	0.85-0.88	1.57-1.65	2016/11/03, 2021/11/01	140/42
						2016/11/10, 2021/11/10	141/41
						2016/10/10, 2021/11/08	141/42
						2016/11/01, 2021/10/14	142/41

correspond to the green (G), red (R), near-infrared (NIR), and short-wave infrared (SWIR) bands, were taken from Landsat data. The cloud-free data that could be downloaded was chosen with care.

Methodology

Land Use and Land Cover (LULC) Mapping

To prepare the LULC map, a layer stack of 2, 3, 4, and 5 bands and mosaic the images. After mosaicking all the layers, the study area shape file was prepared using the software ERDAS. The Supervised image classification "Maximum Likely hood" technique was used to classify land use maps (Patel et al. 2019). The current study primarily examines five types of land use: vegetation, urban land, open land water body, and wet soil. Here is a methodology flow chart cover. A flow chart of the methodology used is given in Fig 2.

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI)

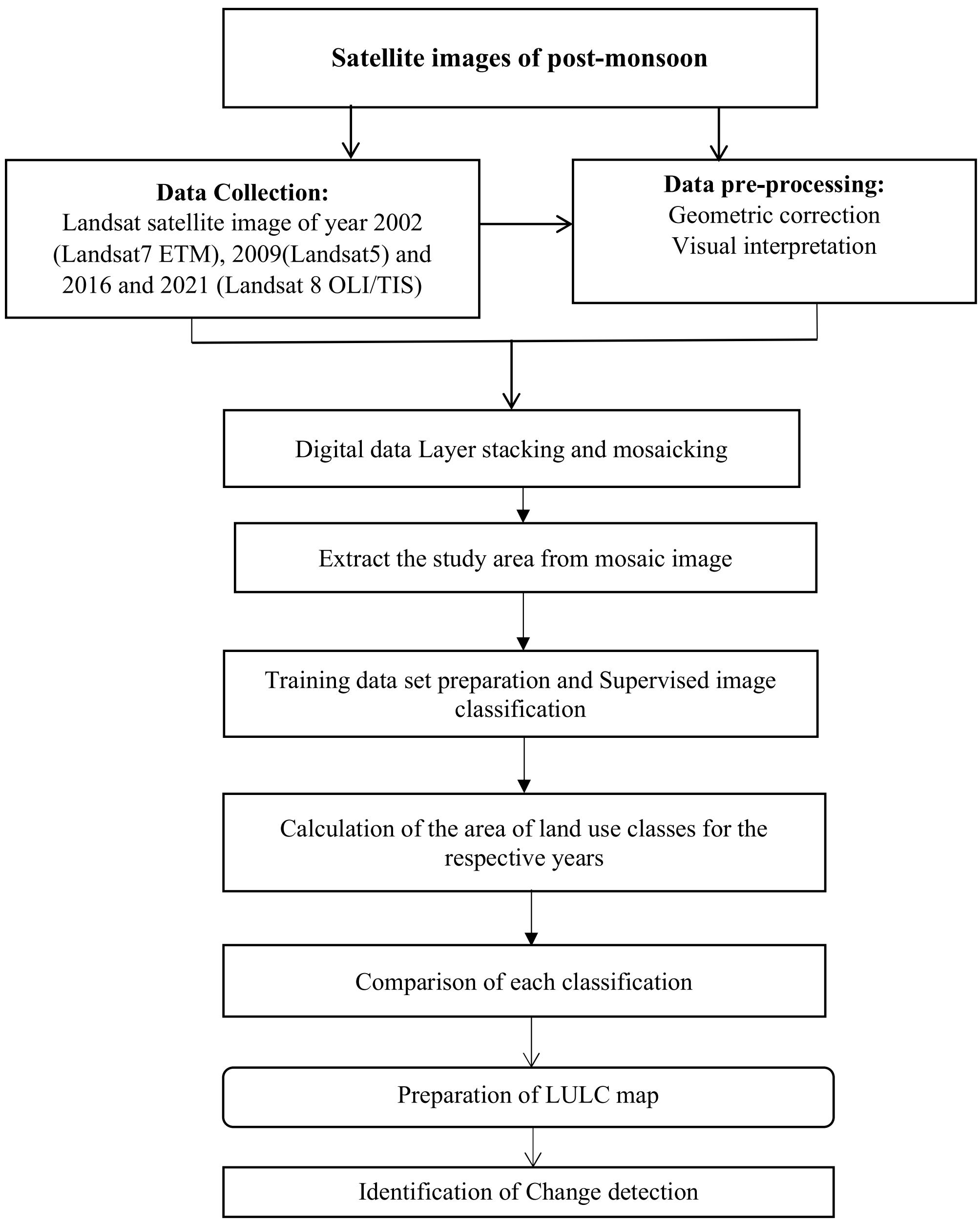

Fig. 2: Land-use/Land-cover mapping flow chart.

measures the greenness of the vegetation and helps determine vegetation density and evaluate changes in plant health. The Normalized Difference Vegetation Index is useful for interpreting land resources (Gandhi et al. 2015). The normalized difference vegetation index between the red and near-infrared bands from an image is used to calculate NDVI on a per-pixel basis. (Equation 1)

$$NDVI = \frac{NIR - R}{NIR + R}. \qquad ...(1)$$

The range of the NDVI is from -1 to 1. Higher NDVI values indicate high Near Infrared (NIR) reflection, which indicates heavy greenery. In general, NDVI values between -1 and 0 reflect water bodies, between -0.1 and 0.1 indicate barren rocks, sand, or snow, 0.2 and 0.5 indicate shrubs and grasslands, and 0.6 and 1.0 indicate thick vegetation or tropical rainforest.

Normalized Difference Water Index

Normalize Difference Water Index (NDWI) is used for water bodies exploration. The index makes use of remote-sensing images of green and near-infrared wavelengths**.** NDWI can be calculated using Equation 2.

$$NDWI = \frac{Green - NIR}{Green + NIR} \qquad ...(2)$$

The values of NDWI range between 0 and ± 1, and vegetation is represented by negative values or values near 0. In contrast, positive values or values close to 1 represent surface and deep water bodies.

Conjunctive Use

Combining surface and groundwater resources is called conjunctive use. It also discusses the hydrological cycle, water balance components, interactions between surface water and groundwater, and groundwater recharge. In general, the conjunctive is a function of (a) rainfall characteristics, (b) types of soil and soil moisture, (c) types of crop, (d) crop water requirement, and (e) groundwater table being used in the study area (equation 3).

$$C_u = (a*C_{WR} + b*G_{WT} + c*S_{MC} + d*R_I + e*C_T) \qquad ...(3)$$

Where C_u = Conjunctive Use, C_{WR} = Crop water requirement, G_{WT} = Ground Water Table, S_{MC} = Soil Moisture Content, R_I = Rainfall intensity, C_T = Types of Crop, and a, b, c, and d = Constant

Multiple Cropping Practices

Two or more crops are typically grown in the same field yearly. Cropping is intensified in both the temporal and spatial dimensions during multiple cropping. With the minimal deterioration of soil health, multiple cropping aims to produce the most crops per unit of land area. Multiple cropping can improve agricultural efficiency and reduce crop production's sometimes negative environmental impact.

Land Reclamation Using "Cut and Fill" Approach

In the study area, extensive waterlogging was observed. For the land use/land cover analysis, it is essential to adopt the 'cut-fill' analysis and 'raised bed' concept to develop the agriculture area and reduce the waterlogging area, as shown in Fig 3.

Decentralization of Urban Area Development

The land uses Land cover analysis shows that urban areas like west Champaran, East Champaran, Muzaffarpur, Gopalganj, and Hajipur Vaishali have centralized development, and it causes significant water scarcity and water pollution. Decentralized development is the need of the day for

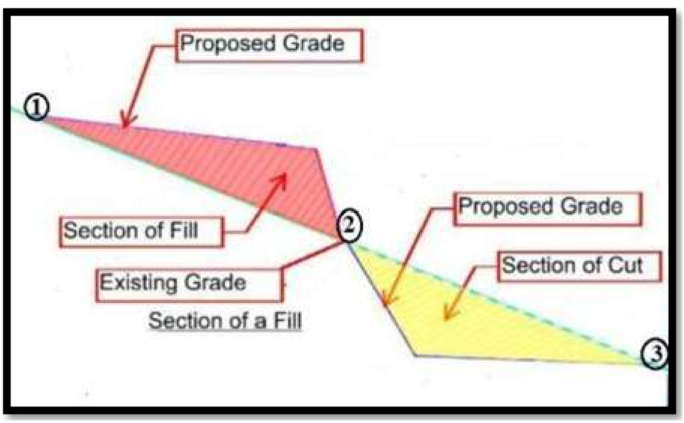

Fig. 3: Method for raised bed and cut-fill analysis.

environmental protection work in the urban and peri-urban areas of the study region.

The floating population in urban areas is very high due to the influx of people from nearby areas, villages, or towns for work and various activities. This creates environmental pollution in terms of water pollution, sewage, and wastewater generation after consuming good food and freshwater.

RESULTS AND DISCUSSION

Land Use and Land Cover (LULC) Mapping

The LULC maps were prepared for the years 2002 to 2021. Fig 4 shows the results of LULC classification for 2002, 2009, 2016, and 2021 as representative results. All these images were classified using the maximum likelihood

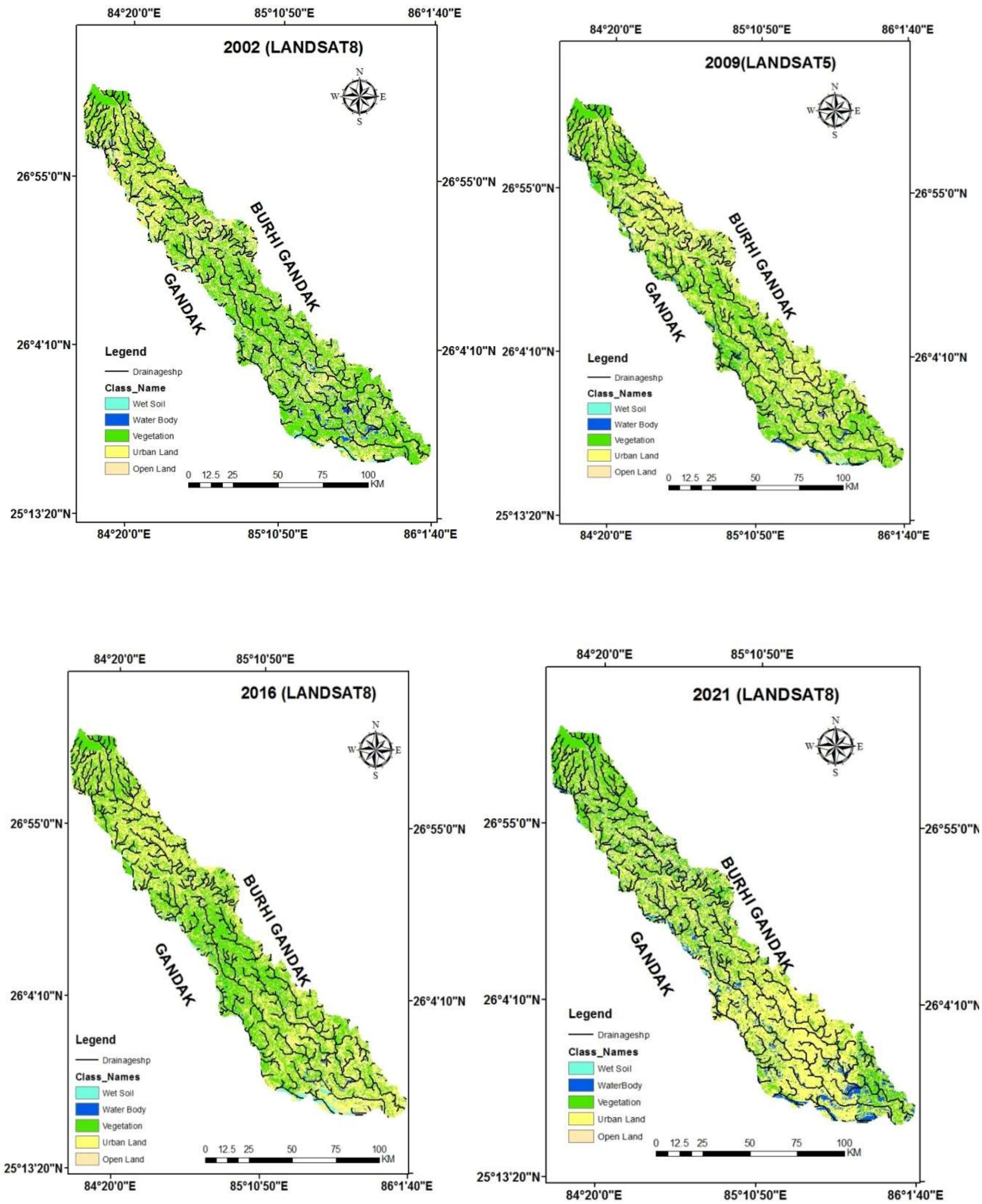

Fig. 4: Land use changes in the years 2002, 2009, 2016, and 2021 (post-monsoon).

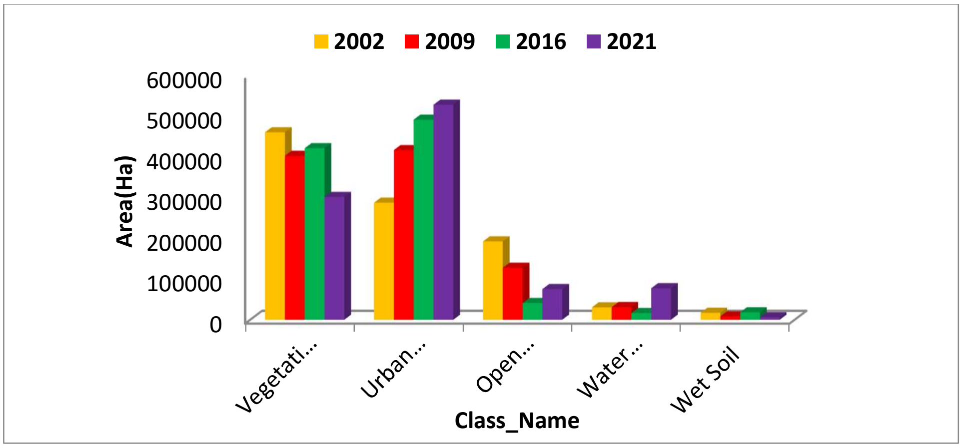

Fig. 5: Bar chart of LULC change from 2002 to 20021.

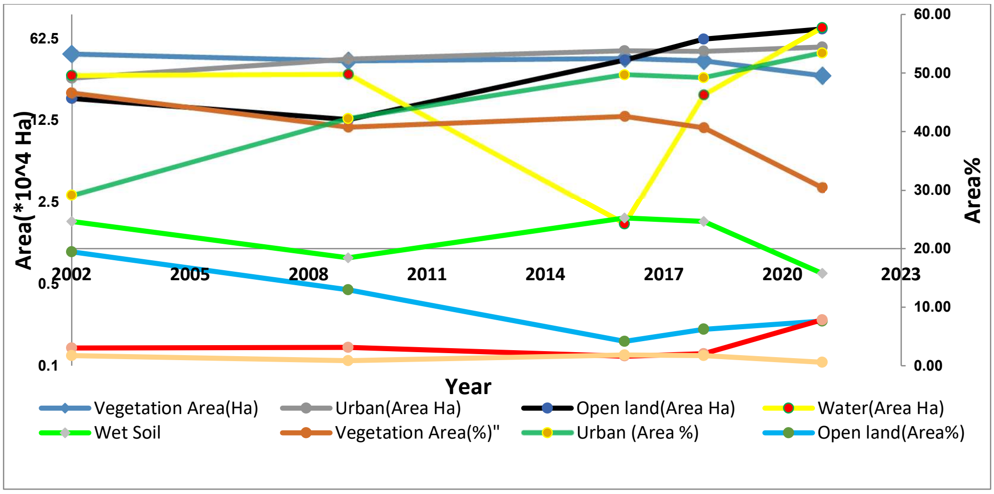

Fig. 6: Post-monsoon Land use/Land cover change from 2002 to 20021.

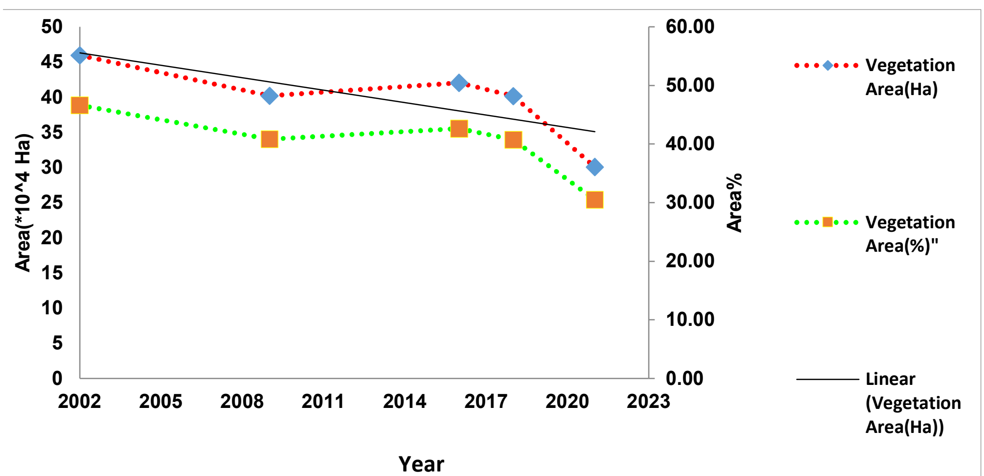

Fig. 7: Extent of vegetation during post-monsoon and the trend.

supervised classification technique using the combination of near-infrared (NIR), red (R), and green (G) bands of satellite images in ERDAS-Imagine software.

The results indicate that in the past 20 years, i.e., from 2002 until 2021, vegetation area and open land decreased to 158,676 ha (16.12%) and 116794.8 ha (11.85%), respectively. However, the urban land and waterbodies increased to 240,070 ha (24.32%) and 46937.3 ha (4.75%), respectively, during this period (Fig. 5). The vegetation values found to decrease due to centralized urbanization and migration of the population in urban fringes. LULC changes in the study area are mostly influenced by population growth. Fig 6 indicates both are area and percentage of the total area under each land use category. Fig 7 indicates the changes in vegetation using the supervised classification "maximum likely hood method."

Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI)

There has been a change in vegetation cover over the past two decades. The area covered under vegetation by NDVI is found to increase from 36.08% to 70.25% from 2002 to 2021 (Fig. 8). It was observed that NDWI values over zero are seen in water bodies. In contrast, negative values are

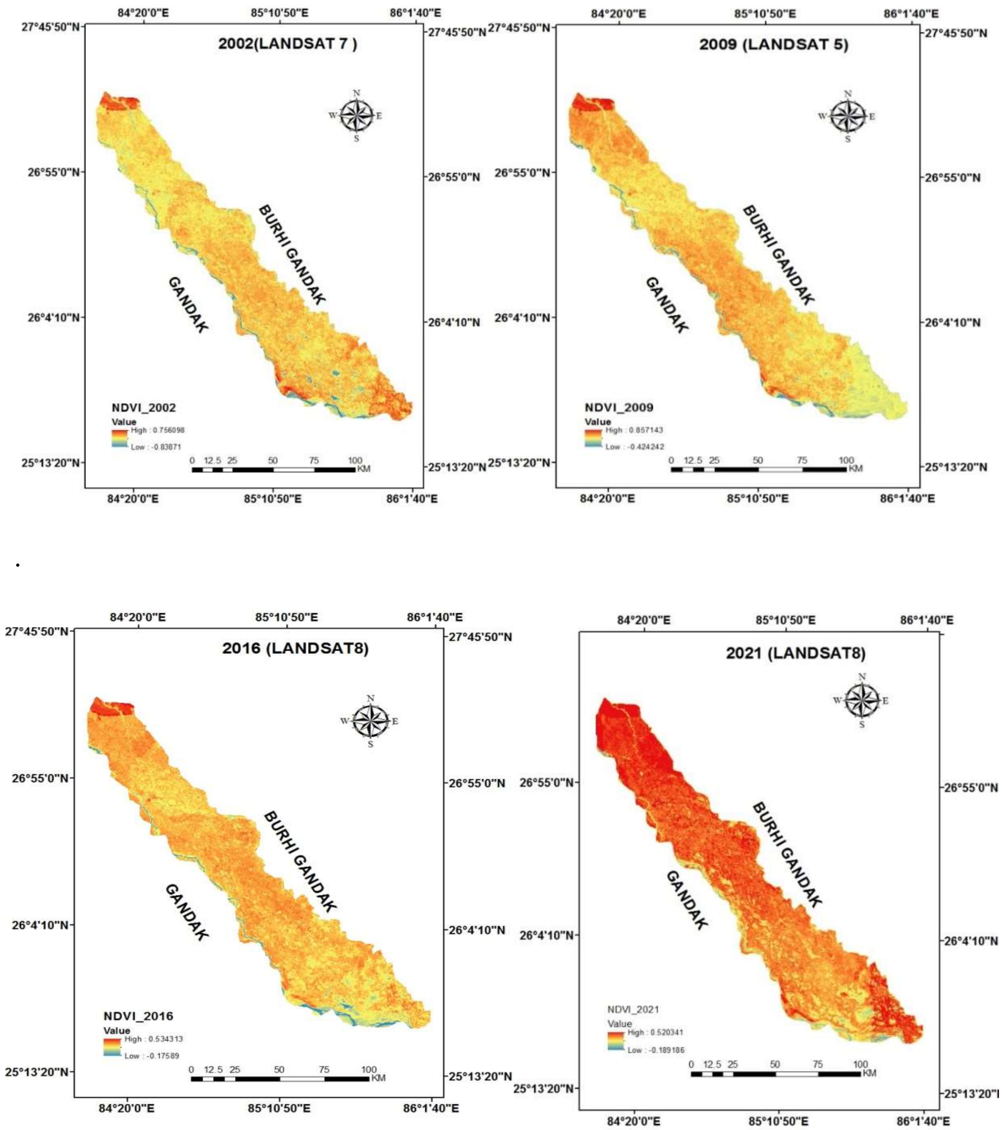

Fig. 8: Images of NDVI calculated for the years 2002, 2009, 2016 and 2021.

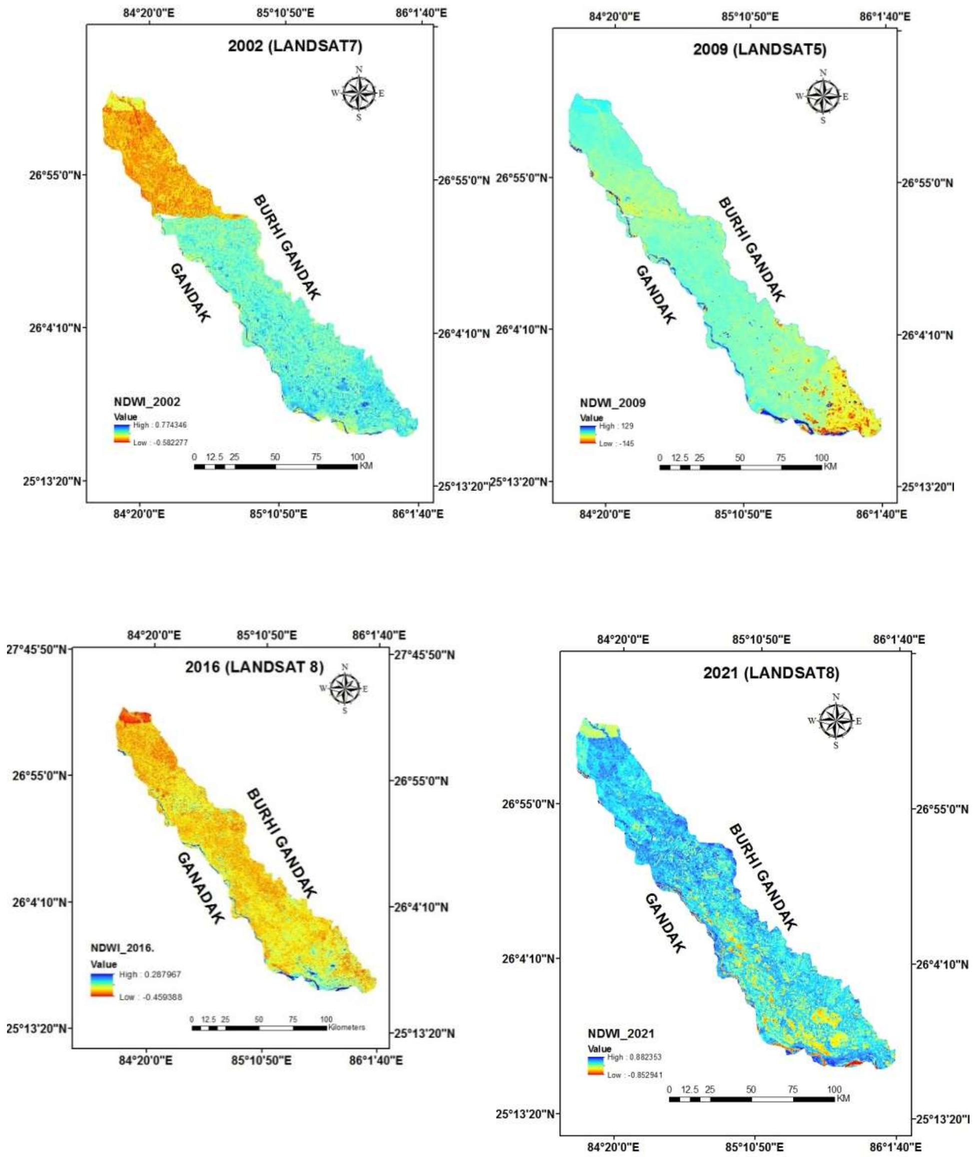

Fig. 9: Images of NDWI calculated for the years 2002, 2009, 2016 and 2021.

observed in urban areas and vegetative land. The NDWI indices are shown in Fig 9 for the study area from 2002 - 2021. A comparison of all the methods is shown in Fig 10, with the best results as supervised classification.

Conjunctive Use

Conjunctive use is a function of (a) rainfall characteristics, (b) types of soil, (c) types of crop, (d) crop water requirement, and (e) groundwater table. Based on the net irrigation requirement (NIR) and available water resources from rainfall, groundwater, and water available in the soil, the irrigation schedule is prepared for different crops in different study area locations.

Fig 11 indicates the rainfall map of the study area. The rainfall has been varying between 600 mm to 1200 mm, except for heavy rainfall in 2007. It is also observed that the rainfall trend is similar in all four stations, namely East Champaran, Muzaffarpur, Vaishali, and Samastipur. The rainfall trend provides a guideline for using surface water and groundwater in the study area. The Kharif crops can use the rainfall by rainwater harvesting at agricultural lands. Also, the same rainwater can be used to store water,

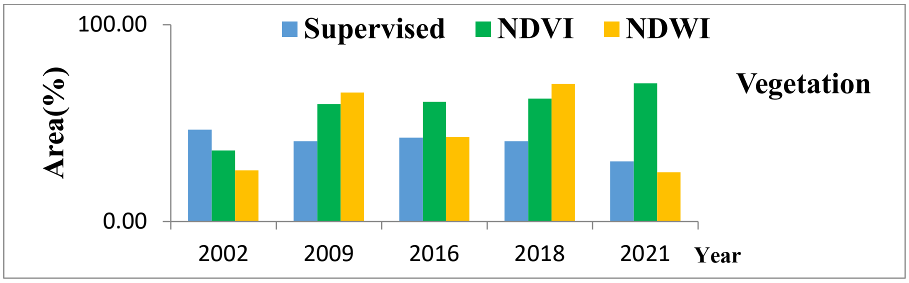

Fig. 10: Comparison of the Vegetation computed by different methods.

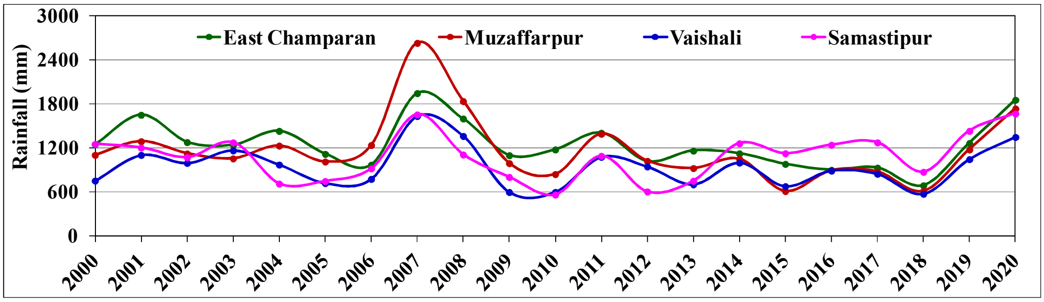

Fig. 11: Rainfall map of different rain gauge stations in the study area.

reduce waterlogging, and use it for irrigation during the Kharif period by the "Cut and Fill" approach, as discussed above.

For conjunctive use analysis, it is important to study the soil types. Different samples at 30 and 60 cm depths were collected and analyzed in the laboratory. It is found that the Clay contents are 10-15%. The top layer root zone depth up to 2 m is predominantly silt and finds sand, i. e. silt load. The percentage of sand varied between 32-45%, whereas the silt varied between 38-68% at 30 to 60 cm depths.

The cropping pattern of the study area is predominantly a paddy growing area. Maize and Wheat are other important cereal crops. Arhar, Gram, Moong, and Masoor are the principal pulses grown in the area. Rapeseed and Mustard are major oil seed crops. Sugarcane, Chilly, and Tobacco are the main cash crops.

As in most parts of North Bihar, there are three distinct crop seasons: Garam or Summer (March to June), Kharif (July to October), and Rabi (November to February). The most common Kharif crops are paddy and maize, and during Rabi, wheat, winter maize, gram, mustard, and tobacco are taken. In Garam, lands are kept, or certain summer crops like maize and vegetables are grown. In addition to these crops, perennial crops like sugarcane are also grown. Apart from these crops grown in various seasons, mixed cropping, i.e., growing more than one crop in a given crop season is also practiced.

The crop water requirement (CWR) is estimated using a particular crop's evapotranspiration (ETcrop). It depends on the crop coefficient (K_c) and is given by the equation.

$$ET_{crop} = ET_0 \times K_c \qquad \ldots(4)$$

Several factors influence the crop coefficient, including the type of crop, its rate of growth, as well as the harvesting season, and the prevailing weather conditions. The Value of Kc has been used from FAO-33. Net irrigation requirements (NIR) are the depths of irrigation required to meet evapotranspiration (ETcrop) minus the contributions from precipitation, groundwater, and stored soil water, excluding operational losses and leaching requirements. Therefore,

$$NIR = ET_0 \times K_c + \text{special need if any} - \text{effective rainfall} - \text{groundwater} - \text{stored soil water} \qquad \ldots(5)$$

Using equation (5), the NIR for each crop is estimated for each region and crop, as shown in Table 2 below.

Multiple Cropping Practices

As shown in Table 2, two or more crops are typically grown on the same field in a single year, and the cropping is intensified in both the temporal and spatial dimensions during multiple cropping. The present practices must be enhanced for three crops, oils, fruits, and vegetables, in one annual cycle with minimal deterioration of soil health to produce the most crops per unit of land area.

Table 2: NIR for different crops in different seasons.

Hot Season			Kharif Season		
S.No.	Crop	NIR (mm)	S.No.	Crop	NIR (mm)
1	Vegetables	555.00	1	Paddy	424.00
2	Maize	547.00	2	Maize	97.00
Rabi Season					
1	Wheat	523.00	4	Mustard	487.00
2	Maize	315.00	5	Tobacco	415.00
3	Potato	414.00	6	Gram	432.00

Land Reclamation Using "Cut and Fill" Approach

In the study area, extensive waterlogging was observed in the agricultural land due to the influx of rainfall, river flood water, and leakage in the Tirhut Canal. The area-elevation and elevation capacity curves were derived for all major waterlogged areas and are shown in Fig 12.

Using equations of area elevation and elevation capacity to understand their utility, a typical water body is considered for the study, and the calculation for a 5% reduction/reclamation of the areal extent is done, as shown in Fig 13.

Decentralization of Urban Area Development

Fig 14 illustrates the urban area population growth at West Champaran, East Champaran, Muzaffarpur, Gopalganj, Hajipur, and Vaishali, causing significant water scarcity and water pollution. With the development of peri-urban areas near the above towns, a significant improvement can be observed at par with developed townships elsewhere.

Decentralized development is the need of the day for environmental protection work in the urban and peri-urban areas of the study region. The floating population in urban areas is also very high due to various offices, colleges, and

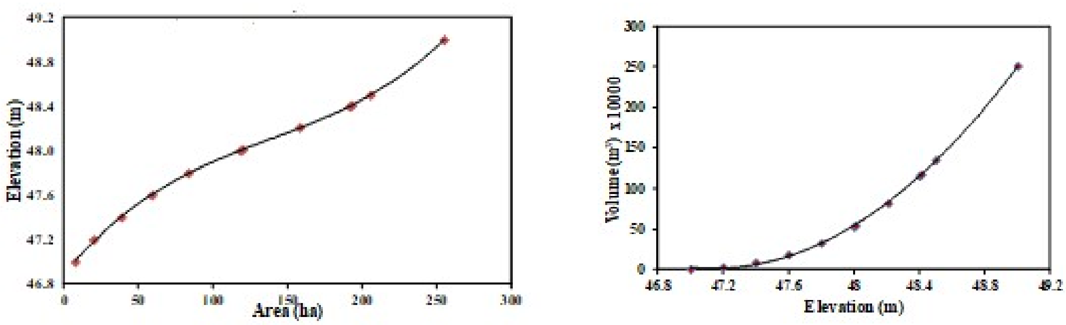

Fig. 12: Area-elevation, elevation-capacity curve.

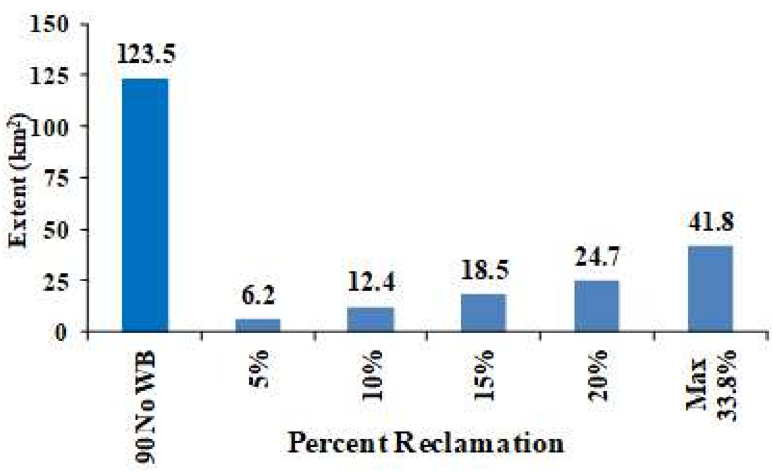

Fig. 13: Waterlogged area reclamation using the "Cut and Fill" approach.

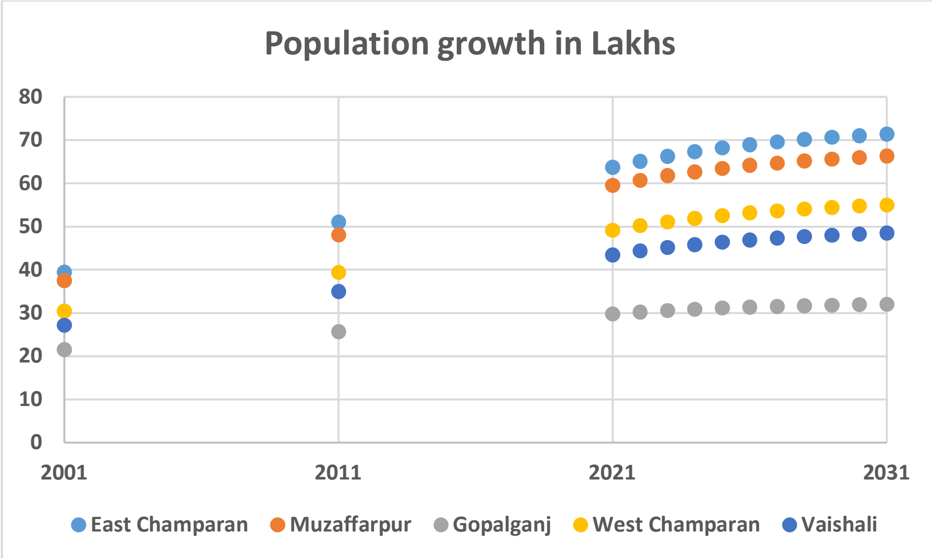

Fig. 14: Population growth in urban areas of the study region.

Institutes. This needs to be changed as it generates sewage and wastewater pollution.

CONCLUSIONS

In the present work, the LULC changes have been studied from 2002 to 2021 in a basin area between river Gandak and river Burhi Gandak in India and precisely detect changes in LULC. It has been determined that the vegetation is decreasing at the expense of the uncertain expansion settlements. The agricultural area and open land have decreased by 16.12% and 11.85% respectively whereas the urban and the waterlogged areas have increased by 24.32% and 4.75% respectively.

The conjunctive use based on net irrigation requirement (NIR), available rainfall, groundwater, river flow, and soil moisture is very useful in the study area. The cropping pattern being utilized and the use of multiple cropping would help to improve the land use of the study area.

Land reclamation using the "Cut and fill" approach is useful for increasing agricultural land and preserve for future uses. It is also important to develop peri-urban areas to protect the environment from sewage, solid waste, and wastewater.

The study is very useful for effective environmental protection and land use management in India's study area and other river systems.

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