Prediction modelling of riverine landscape dynamics in the context of sustainable management of floodplain: a Geospatial approach

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**ABSTRACT**

Presently, sustainability of floodplain, a diverse element of the riverine landscape, provides an ideal research setting for investigating complex interaction between anthropogenic disturbance and eco-environmental degradation. Nowadays, these floodplains are continually degraded and fragmented on account of unsustainable land use. To analyse the spatial and temporal changes of landuse/landcover, a supervised classification (maximum likelihood algorithm) method has been made for the period 1998 to 2018. Present research simulates and predicts landuse/landcover dynamics of lower stretch of the Ganges river up to 2038 to analyse future riverine landscape dynamics stressed by various natural and socio-economic factors based on Cellular Automata-Artificial Neuron Network (CA-ANN) model clubbed with Modules for Land Use Change Evaluation (MOLUSCE) plugin of QGIS software. Outcome of research reveals that the trend of agriculture land, sand, and inland waterbody areas is reduced by 15.75, 5.71, and 1.95%, whereas, for orchard, agricultural fallow and bare land areas increased by 7.94, 7.92, and 5.69% for the period from 1998 to 2018. The simulation model predicted a continuation of the similar trend till 2038. The significant reduction of agricultural land and sand areas is largely an attribute to floodplain degradation in an altered hydrological regime. Ultimately, hydro-morphological changes, increasing population pressure, and agriculture intensification in floodplain landscape were identified as main driving forces in temporal landuse/landcover changes. The prediction of future forecast indicates that if the present rate of landuse/landcover trend persists in the study stretch of Ganges river without appropriate sustainable development practice, severe floodplain degradation will ensue. This study provides a holistic measure for understanding long-term environmental degradation related to anthropogenic activities and impact of climate changes in floodplain landscape at local and regional scale.

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1. Introduction

Riverine landscape is spatially dynamic and heterogeneous in space which consists of hydro-ecological networks within a natural environment (Robinson, Tockner, and Ward 2002). In natural state, the riverine landscape is characterized by diverse landscape elements such as extensive floodplains, surface water bodies, riparian system (alluvial forests, swamp, meadow), complex mosaic of high habitat heterogeneity and geomorphic features (channel networks, bars and islands, terraces, levees, deltas) (Church 2002; Güneralp and Rhoads 2011; Varga, Dévai, and Tóthmérész 2013; Colloff et al. 2017; Ricasurte et al. 2019). These landscape elements provide important feedback for human influence on ecosystem structure and function at the global, regional and catchment scale (Tockner et al. 2010; Poff 2018). The riverine landscape is highly sensitive to remote environmental changes occurring within the basins due to various natural and anthropogenic influences (Camporeale et al. 2013; McCluney et al. 2014). The ever expansion human-induced developmental factors including channel modification, hydraulic construction structure, land use practices, catchment urbanization have disturbed the nature of riverine landscape diversity (Twille et al. 2016; Ge, Zhang, and Yang 2019).

Floodplains are the key element of riverine landscapes that provide a broad variety of ecosystem services (Parsons and Thoms 2013; Schindler et al. 2014). In a worldwide context, the large river systems and their floodplain contain a significant proportion of key sinks for sediments, nutrients, organs, and environmental pollutants (Varga, Dévai, and Tóthmérész 2013; Lewin, Ashworth, and Strick 2017). However, it is fragmented and isolated by modification and alteration of the
natural river regime associated with damming and extensive agricultural practices (Draut, Logan, and Mastin 2011; East et al. 2015; Schober, Hauer, and Habersack 2015; Roccati et al. 2019). In the last 100 years, the extent of floodplain has tremendously reduced globally and the loss continues due to rapid land use changes and unsustainable development practices. For example, in the Danube river basin, more than 68% of the active floodplain has been reduced compared to their pre-regulation period (Hein et al. 2016). The immense loss of floodplain ecosystems threatens the agroecosystem services, conservation of key species and habitats, and water and nutrient recycling (González et al. 2010; Felipe-Lucía, Comín, and Bennett 2014).

These environmental degradations are particularly acute in the case of the lower Gangetic plain regions (Mishra et al. 2013). The impact of climate change and rapid development of economy and society have greatly affected the river Ganga and the surrounding landscapes. In the historical period, the river Ganga and its tributaries have been subjected to massive human interventions causing significant changes in the hydromorphology of the natural river-floodplain system. With a length of approximately 2601 km, the mainstream of river Ganga is impounded by five dams or barrages including Farakka. Therefore, it has been observed that about 45% of environmental flow has been reduced in Farakka during last three decades (IRF 2018). These hydromorphological changes are causing uninterrupted land cover change dynamics in lower Gangetic plain regions due to agricultural land reclamation and human migration (Thakur, Laha, and Aggarwal 2012). Therefore, monitoring and assessment of land cover dynamics due to natural and anthropogenic influence are an essential need for natural resource conservation, land management, and maintaining the integrity of riverine eco-environment to implement sustainable development in near future.

Among these impacts, landuse/landcover (LULC) change has been recognized as one of the most important indicators for global and regional eco-environmental changes (Li et al. 2006; Zhang, Zhengjun, and Xiaoxia 2009). Remote Sensing (RS) and GIS techniques incorporated with multispectral satellite data have been commonly used for the acquisition of LULC information (Singh 2016; Rahman et al. 2017; Perović et al. 2018). In a river-scape context, a number of studies have identified the importance of LULC change detection. For example, Debnath et al. (2017) used RS and GIS to assess the impact of LULC changes on floodplain landscape. In another study, Milani et al. (2018) quantified riverine land cover dynamics for assessing the impacts of hydrological controls on river ecosystem. Santos et al. (2018) had documented the effects of riverine landscape changes on riparian vegetation. Therefore, LULC information provided by RS and GIS can be applied to quantify and examine the past and current trends of LULC change as well as to forecast future trends efficiently (Kamusoko et al. 2009). In recent years, several spatio-temporal prediction models have been developed, such as Markov chain (MC) model, Cellular Automata (CA) model, conversion of land use and its effects (CLUE) model to forecast the LULC and their change detections (Mas et al. 2014; Mishra and Rai 2016). MOLUSCE (Modules of Land Use Change Evaluation), the recently developed plugin of QGIS which can predict future LULC changes along with transition probability matrix (NextGIS 2017; Banket et al. 2019). This plugin incorporates four different well-known algorithm models such as Artificial Neural Networks (ANN), Logistic Regression (LR), Multi-criteria evaluation (MCE), and Weights of Evidence (WoE). Among the several spatio-temporal dynamic modelling approaches, the CA model has been widely used for land use change analysis. The CA model has an open structure and can be clubbed with another model to predict and simulate spatial patterns of land use. Due to its simplicity, flexibility, and intuitiveness to integrate the spatio-temporal dimensions of the processes, the model has widespread application in recent years. However, the CA model has some limitations in the quantitative aspect, such as the inability to include driving forces in the simulation process, which may be minimized by incorporating with other potential quantitative models (Santé et al. 2010; Aburas et al. 2016). A CA-ANN model is a robust approach for forecasting potential future LULC and plays a powerful role effectively in land use planning and management (Li and Li 2015).

The present study focuses on the lower stretch of river Ganga since this area is environmentally fragile and vulnerable to natural disasters. Unplanned anthropological interventions with climate-induced natural disasters have a great impact on the riverine landscape of these regions. Therefore, the objective of this study is to analysis the future riverine landscape dynamics in an anthropogenically modified river flow regime and associated floodplain with the help of CA-ANN modelling in a GIS environment.

2. Study area
The study area consists of 178 km stretch of the riparian land (along the centerline and has been altering over a period of time) along the river Ganga from Rajmahal in Jharkhand state to Jalangi in West Bengal state in
eastern India suffering chronology of fluvial events (figure 1). The study area is a section of the active lower Gangetic floodplain located in latitude 25°19′26″N-24°6′10″N and longitudes 88°45′09″E-87°39′07″E with a variable elevation ranging from 176 m to 27 m (MSL) based on Aster DEM, 2011. The study reach, within the younger deltaic plain, is covered by Quaternary alluvium deposited by the trans-boundary river Ganga. The lithological setting of the study area is quite distinctive. The north-western part is confined by the Rajmahal Hills, part of the Rajmahal Trap, composed of lower cretaceous trap basalts. The eastern side is of mostly old alluvium part of the Pleistocene Barind Tract. The remaining part is along the river Ganga composed of Holocene recent alluvium deposit (an alternate sequence of sand, fine silt, and sandy clay). The aerial coverage of the study zone is roughly 3130 km² and has a population of approximately 5.1 million with a density of approximately 1592 persons/km² (Census data 2011). The region falls within a tropical wet-dry climatic zone. The mean annual temperature varies 40°–10 °C receiving average precipitation in the proximity of 1400 mm and 70% of the annual precipitation occurs during the monsoonal period (July–September months). The unique geographical features along with plentiful hydraulic resources play an important role in the riparian peoples’ lives. Besides providing highly fertile alluvium and flood irrigation, the river-induced perennial disasters have become the natural curse for significant number of people in the region. For the last few decades, particularly after the construction and operation of Farakka Barrage across the Ganges river this region is being highlighted as the experimental site in hydrological and environmental perspective (Samanta et al. 2015). The course of river Ganga has experienced a substantial amount of
hydrological, morphological and sedimentological changes influenced by anthropogenic disturbances (e.g. stream hydrologic alteration, land-uses changes, and artificial-channelization). Almost the entire region has community importance for agri-settlement purposes and more than 70% of people depend on agrarian activities for their livelihood. Due to fragile land mass, instability of settlements and migration from interstate and Bangladesh, the area has become a conflict zone for political, environmental and economic issues.

3. Materials and methods

1.1. Data used

Remotely sensed multispectral imageries were used to measure and map LULC change and to identify future erosion-deposition risk zone in the selected study reach. In this study, Landsat images of winter seasons (December to January), collected from USGS Earth Explorer (https://earthexplorer.usgs.gov/) consisting of 1998 Landsat 5 TM data, 2008 Landsat 7 ETM+ data and 2018 Landsat 8 OLI data were used with a pixel size of 30 metres. The atmospheric correction was applied to the images using the FLAASH tool in ENVI software. Elevation map has been generated from the ASTER Global Digital Elevation Model (ortho-rectified-30 m resolution) dated 17 October 2011. Projected climate data RCP (Representative Concentration Pathway), of Norwegian Earth System Model (NorESM1-M) was acquired from IPCC assigned Coupled Model Intercomparison Project, Phase 5 (CMIP5) database (http://gismap.cgiar.org/MarksimGCM/) for 20 years’ time span (2020–2040). Statistical boundaries of build-up and road buffer parameters were prepared by the digitization process in ESRI ArcGIS version 10.6 using Google Earth Images. Population data of year 1991, 2001, and 2011 were obtained from the Census of India web portal (http://censusindia.gov.in/). Primary information or qualitative data were collected from riparian respondent living along the river banks across randomly selected 10 different locations using a participatory research tool with a structured questionnaire.

1.2. Methodology

The workflow of the methodology is represented in (figure 2).

1.2.1. Land use/land cover (LULC) mapping

To prepare landuse/landcover map in the selected study stretch, a maximum likelihood algorithm (MLC) of supervised order classifier was applied in ERDAS Imagine V. 2015 software (figure 3). In this study, a total number

![Figure 2. Flowchart of the methodology.](image-url)
of nine key landuse/landcover classes (table 1) were identified on the basis of field knowledge and visual observation of Google earth. For acquiring better classification accuracy, over 200 numbers of signatures have been taken for each of the LULC classes. Among these classification methods, the misclassified/doubtful area were corrected by using recode tools in ERDAS Imagine software based on the ground verification based on 256 GCPs (Ground Control Points).

1.2.2. Population projection
Population projection is a widely used important tool for planning and policy analysis. It is a simple mathematical extrapolation technique of future assumption based on current trends.

It can be calculated using the following steps (De Andreis and Ricci 2005).

\[ P_t = P_0 e^{rt} \]  \hspace{1cm} (1)

and

\[ r = \frac{1}{t} \ln \left( \frac{P_t}{P_0} \right) \]  \hspace{1cm} (2)

In the above equations, \( P_t \) is population at year \( t \), \( P_0 \) is population of the base year, \( r \) is exponential growth rate, \( t \) is the time gap.
Table 1. Description of Landuse/Landcover classes

| LULC Classes     | Description                                                                 |
|------------------|----------------------------------------------------------------------------|
| Inland waterbody | Reservoirs, lakes, ponds, ox-bow lake, marshes or stagnant pools, ash pond of thermal power plant. |
| River water      | Lotic water (e.g., natural river, artificial channel).                      |
| Natural vegetation | Moist deciduous forest; dominant species of Sal (Shorea robusta); natural regularly flooded vegetation into the riverbed. |
| Agricultural land | Land covered by farmlands under cultivated or harvested.                   |
| Agricultural fallow | Land covered by cultivated land with seasonal fallow.                    |
| Bare land        | Land covered by sparse vegetation, rocky surfaces, poor drainage, high alkalinity, and low organic materials soil. |
| Orchard          | Mixed vegetation with rural settlement, economic plantation (mainly Litchi chinensis and Mangifera indica). |
| Build-up area    | Land used for urban, settlement in villages, industries, transportation services. |
| Sand area        | Fine sand deposited into the riverbed.                                     |

1.2.3. Riverbank line shifting and erosion-deposition phenomena

For estimating the river bank shift associated with the erosional and depositional activity, most widely used approach of comparing remotely sensed satellite imagery of different time periods in GIS environment was adopted for this study. Preliminary, onscreen manual digitization of channel shorelines or bank lines and its emergent interior as well as vegetated islands from satellite images of different time periods (say 1998, 2008 and 2018) were carefully delineated using ArcGIS software version 10.6 at a scale of 1:50,000 with assigned projection Universal Transverse Mercator (UTM) WGS 1984 with zone 45. The total erosional and depositional activity between two time periods was calculated by superimposition using spatial overlaying techniques. To quantify the temporal river shifting during the given study period, a total number of 96 cross-sections at 2 km. intervals based on river channel centerline along the 140 km selected study reach of the river Ganga/Padma were prepared by using the River Bathymetry toolkits in ArcGIS through geomorphic variables high resolution ALOS PALSAR DEM. The River Bathymetry toolkit is a freeware GIS toolkit developed by ArcGIS. Within the toolkit, the frameworks used are: firstly, to compute centerline for active channel based on Thiessen polygonization; secondly, to generate user-defined cross-sections through the high-resolution DEM for removed longitudinal valley slope, and thirdly, to calculate bankfull-width in each cross-section. The cross-section was extended in east-west direction as the river is gradually shifting in this direction. The temporal bankline shifting had been analysed in the delineated vector layer for two time periods 1998–2008 and 2008–2018 whereas the year 1998 was used as the baseline of the measurement. The channel migration rate was calculated from the temporal linear change of the position between reference centerline and bank line intersection point on both banks along each cross-section. In this method, a negative value is interpreted as bank erosion, while a positive value as deposition and a minimal or zero value is considered as stable areas. In the processing of river shifting zonation map inverse distance weights (IDW) interpolation method was used.

1.2.4. Change detection and future prediction of LULC dynamics

After preparation of LULC maps over 10 years’ interval (1998 to 2018), prediction was done based on CA-ANN (Cellular Automata and Artificial Neural Network) model using the MOLUSCE (Modules for Land Use Change Simulation) plugin in QGIS Desktop V. 2.18.16 software. The simulation model based on CA-ANN is a convenient and suitable method for predicting and analysis of LULC, especially dynamic riparian landscape. This proposed model includes three major processes such as Artificial Neuron Network, Cellular Automata, and validation. The prediction of LULC change using a CA-ANN model occurred in three major steps: firstly, applying the ANN quantitative analysis to the classified LULC maps for compute transition probabilities; secondly, computation of transition potential maps, and thirdly, application of the CA spatial filter to the transition probabilities and the transition potential maps to simulate the future LULC. According to Santé et al. (2010), CA is a discrete dynamic system consists of a grid of cell space, in which states characterize every cell. The basic principle of CA is that the state of each cell is determined on its previous state and the state of its neighbourhood properties defined a set of transition rules, as time moves forward. To prepare predicted LULC map in the CA-ANN simulation tab based on Monte Carlo Algorithm by using the two classified images (2008 and 2018) four defined predictors such as topographic variable (altitude), proximity to the road (road buffer), human interface (population density), and economic variables (build-up) were used as land use dynamic factors (figure 3). A set of static or dynamic variables that potentially influence the land cover changes are identified by previous studies and field examinations. The static variables are site variables that are unchanged over the prediction period. The dynamic variables are considered as time-dependent that change over time and recalculated at specific intervals (Mishra and Rai 2016). Eastman (2006) reported that one of basic variables that can influence the land cover dynamics is proximity, including proximity to road and proximity to development. Within this module, the transition probabilities/transition potential matrix and area changes were computed using the Markovian approach. In this
CA-ANN model, 1000 number of iteration were demarcated to simulate the LULC mapping. Finally, the model has been validated by comparing the predicted (2018) and observed map (2018) using kappa index statistics.

1.2.5. Primary data collection

In order to assess the impact of LULC dynamics on riparian people livelihood, a participatory research tool (PRA technique) namely focused group discussion (FGD) were conducted with a structured interview/discussion schedule during August–September of 2018. A total of ten FGDs were held with the help of trained interviewers. In each of the FGDs, nine to ten elder and experienced respondents (average age in the range of 35–50 years) were selected based on their livelihood activity involvement (which includes agricultural farmer, fisherman, agricultural labour, boatman, environmentally challenged displaced peoples) living along the river bank.

2. Results and discussion

2.1. Landuse/landcover transformational analysis

The spatio-temporal distribution of the large alluvial floodplain landscape is classified and quantified into nine classes during three observation years of 1998, 2008 and 2018. Out of the total study area (approximately 3125 km$^2$ in 1998), classification of satellite imagery reveals that agricultural land (1278.30 km$^2$) and orchard (448.37 km$^2$) areas are the dominant LULC classes. In the lower stretch of Ganges river, specifically the main channels and its tributaries are used by agricultural activities. The transformation of LULC changes in the floodplain of river Ganga during the two periods (1998–2008 and 2008–2018) is shown in the following table as follows (table 2).

During the 1998 to 2008 period, remarkable LULC changes are observed in the study reach. A significant increase have been observed in seasonal agricultural fallow by 275.85 km$^2$ (8.83%) and bare lands areas by 114.14 km$^2$ (3.65%), whereas a considerable decline is observed in agricultural land by 215.62 km$^2$ (6.90%) and sand areas 158.02 km$^2$ (5.05%). The area of build-up land increased by 27.78 km$^2$ (0.88%) but the rate of transformation is the least among all land use types.

The LULC change during the period 2008 to 2018 was lower than the previous period (1998–2008) by 21.70%. During this period, the remarkable changes observed in orchard class expanded by 219.08 km$^2$ (7.01%), whereas agricultural land continued to shrink by 276.47 km$^2$ (8.85%) with greater amplitude.

Over the total study period of 1998 to 2018 the major LULC changes, categorized in four dominant classes i.e. agricultural land, seasonal agricultural fallow, orchard and bareland areas along the river Ganga floodplain were represented in (table 3). Quantitatively agricultural land and orchard areas have significantly decreased and increased from 1278.30 km$^2$ to 786.21 km$^2$ (15.75%) and 488.37 km$^2$ to 736.30 km$^2$ (7.94%) respectively, during entire span of 1998 to 2018. Whereas, agricultural land with seasonal fallow areas at first increases 316.92 km$^2$ to 592.77 km$^2$ (8.83%) during 1998 to 2008 thereafter slightly decreased from 592.77 km$^2$ to 564.50 km$^2$ (0.90%). Generally, the spatial extension of bareland areas increased 208.38 km$^2$ to 386.29 km$^2$ (5.69%) over the study period. Similarly, the coverage of inland waterbody and sand areas had continued to shrink but the build-up area continued to expand with little amplitude. This may be probably due to the greater impact of

| Table 2. Proportion of Landuse/Landcover categories |
|-----------------------------------------------|
| **Years** | **1998** | **2008** | **2018** |
| **LULC types** | **Area (km$^2$)** | **Area in %** | **Area (km$^2$)** | **Area in %** | **Area (km$^2$)** | **Area in %** |
| Inland waterbody | 104.08 | 3.33 | 67.42 | 2.16 | 43.27 | 1.39 |
| River water | 296.25 | 9.48 | 261.88 | 8.38 | 300.27 | 9.61 |
| Natural vegetation | 109.52 | 3.51 | 107.57 | 3.44 | 107.00 | 3.43 |
| Agricultural land | 1278.30 | 40.92 | 1062.68 | 34.02 | 786.21 | 25.17 |
| Agricultural fallow | 316.92 | 10.14 | 592.77 | 18.97 | 564.50 | 18.07 |
| Bareland | 208.38 | 6.67 | 322.52 | 10.32 | 386.29 | 12.37 |
| Orchard | 488.37 | 15.63 | 517.22 | 16.56 | 736.30 | 23.57 |
| Build-up area | 72.94 | 2.34 | 100.72 | 3.22 | 129.19 | 4.14 |
| Sand area | 249.32 | 7.98 | 91.30 | 2.92 | 71.05 | 2.27 |
| Total | 3124.08 | 100 | 3124.08 | 100 | 3124.08 | 100 |

| Table 3. Changes in Landuse/Landcover from 1998–2018 |
|-----------------------------------------------|
| **Years** | **1998–2008** | **2008–2018** | **1998–2018** |
| **LULC types** | **Area (km$^2$)** | **Δ %** | **Area (km$^2$)** | **Δ %** | **Area (km$^2$)** | **Δ %** |
| Inland waterbody | −36.66 | −1.17 | −24.15 | −0.77 | −60.81 | −1.95 |
| River water | −34.37 | −1.10 | 38.39 | 1.23 | 4.02 | 0.13 |
| Natural vegetation | −1.95 | −0.06 | −0.57 | −0.02 | −2.52 | −0.08 |
| Agricultural land | −215.85 | −6.90 | −276.47 | −8.85 | −492.09 | −15.75 |
| Agricultural fallow | 275.85 | 8.83 | −28.27 | 0.90 | 247.58 | 7.92 |
| Bareland | 114.14 | 3.65 | 63.77 | 2.04 | 177.91 | 5.69 |
| Orchard | 28.85 | 0.92 | 219.08 | 7.01 | 247.93 | 7.94 |
| Build-up area | 27.78 | 0.89 | 28.47 | 0.91 | 56.25 | 1.80 |
| Sand area | −158.02 | −5.06 | −20.25 | −0.65 | −178.27 | −5.71 |
Farakka dam construction, altering hydrologic regime thereby causing significant ecological consequence including the geomorphological evolution, groundwater depletion, increase of salinity, leading to substantial effects on agricultural land use (Mirza, 1998). The floodplain regions were degraded by large amount of resettlement of environmental migrants during this period and thereby exploited under cultivation of water-intensive crops. Therefore, considerable sand areas were reclaimed for intensified agricultural land use to access irrigation water from the river. Over the last decades, the trend of orchard land increased remarkably due to the afforestation of economic plantation (mainly

| LULC types         | Year     | Inland waterbody | River water | Natural vegetation | Agriculture land | Agriculture fallow | Bareland | Orchard | Build-up | Sand |
|-------------------|----------|------------------|-------------|--------------------|-----------------|-------------------|----------|---------|----------|------|
| Inland waterbody  | 1998–2008| 0.237            | 0.058       | 0.002              | 0.277           | 0.122             | 0.027    | 0.200   | 0.064    | 0.013|
|                   | 2008–2018| 0.279            | 0.268       | 0.003              | 0.123           | 0.091             | 0.027    | 0.156   | 0.019    | 0.031|
| River water       | 1998–2008| 0.047            | 0.424       | 0.000              | 0.067           | 0.297             | 0.009    | 0.023   | 0.014    | 0.120|
|                   | 2008–2018| 0.019            | 0.516       | 0.004              | 0.153           | 0.164             | 0.016    | 0.027   | 0.010    | 0.089|
| Natural vegetation| 1998–2008| 0.004            | 0.001       | 0.705              | 0.095           | 0.017             | 0.120    | 0.056   | 0.003    | 0.000|
|                   | 2008–2018| 0.001            | 0.002       | 0.732              | 0.053           | 0.043             | 0.075    | 0.093   | 0.002    | 0.000|
| Agriculture land  | 1998–2008| 0.010            | 0.020       | 0.009              | 0.488           | 0.152             | 0.117    | 0.163   | 0.038    | 0.004|
|                   | 2008–2018| 0.005            | 0.022       | 0.011              | 0.365           | 0.186             | 0.091    | 0.264   | 0.049    | 0.007|
| Agriculture fallow| 1998–2008| 0.006            | 0.050       | 0.001              | 0.458           | 0.268             | 0.095    | 0.079   | 0.032    | 0.012|
|                   | 2008–2018| 0.005            | 0.122       | 0.007              | 0.265           | 0.320             | 0.065    | 0.114   | 0.034    | 0.037|
| Bareland          | 1998–2008| 0.007            | 0.047       | 0.004              | 0.181           | 0.287             | 0.407    | 0.030   | 0.013    | 0.023|
|                   | 2008–2018| 0.001            | 0.018       | 0.055              | 0.124           | 0.099             | 0.579    | 0.100   | 0.018    | 0.008|
| Orchard           | 1998–2008| 0.013            | 0.009       | 0.003              | 0.317           | 0.077             | 0.059    | 0.474   | 0.046    | 0.001|
|                   | 2008–2018| 0.012            | 0.015       | 0.015              | 0.141           | 0.092             | 0.081    | 0.540   | 0.102    | 0.002|
| Build-up          | 1998–2008| 0.021            | 0.054       | 0.001              | 0.249           | 0.172             | 0.032    | 0.176   | 0.283    | 0.013|
|                   | 2008–2018| 0.034            | 0.052       | 0.006              | 0.213           | 0.108             | 0.070    | 0.264   | 0.244    | 0.010|
| Sand              | 1998–2008| 0.019            | 0.259       | 0.001              | 0.117           | 0.404             | 0.032    | 0.018   | 0.010    | 0.128|
|                   | 2008–2018| 0.005            | 0.349       | 0.002              | 0.250           | 0.218             | 0.016    | 0.019   | 0.012    | 0.128|

Figure 4. River shifting zones map for the duration of 1998-2008 and 2008-2018 and shifting rate of right and left bank of the selected stretch of river Ganga (1998-2008 and 2008-2018).
mango plantation) to meet an ever-increasing demand from the international market.

3. Probability matrix

The trend of LULC change for the 1998 to 2008 and 2008 to 2018 period can be understood from the transition probability matrix calculated by the Markovian approach in MOLUSCE plugin (table 4). The transition probability diagonal indicates that the value of natural vegetation class remains most stable during the study period, whereas the transition probability of sand areas is less persistence that undergoes a change from one class to another. Over the study period, the expansion of orchard and build-up areas is being resulted from extensive use of agricultural land areas. In addition, expansion of agricultural land with seasonal fallow areas is converted from reclamation of large amount of riverine sand areas.

3.1. Detection of shifting of river course at the selected stretches of river Ganga during 1998-2018

It has been observed in the satellite imagery that river Ganga has changed its course drastically all along its channel width with the passage of time. Superimposition of river course map during 1998, 2008 and 2018 indicate that considerable shifting at different places due to morphological adjustments in river driven by erosion-deposition phenomena. The river course in the study reach has shifted off both left and right bank more in east-west direction over the span of 20 years. The dynamics of banklines for different cross-sections in the study reach during the period 1998 to 2008 and 2008 to 2018 are presented in (figure 4). During the first evaluation period 1998 to 2008, the higher rate of temporal bankline shift is found at the left bank (44.37 m/year), mostly shifting towards an eastward direction whereas, the migration rate of right bank (36.61 m/year) is low. In the upstream of the Farakka Barrage, the highest temporal shift is observed at right bank (about 2814 m, section 24) due to the rise of depositional activities whereas the left bank has shifted 1403 m (section 4) from its earlier position due to erosional activities of the river. In downstream side of the Barrage most significant shifting of 2698 m is noted at the right bank of at cross-section 79 due to erosional activities. In the second evaluation period i.e. 2008–2018, the significant temporal migration rate is noticed at the left bank (53.14 m/year) of the river in comparison to the right bank (35.63 m/year). The maximum shifting of right and left bank migration is found as 1465 m (section 30) and 2013 m (section 5) respectively, in the upper reach of Farakka Barrage. During the entire time frame of 20 years, shifting tendencies of the river are mostly found towards left bank (eastward direction) because of the presence of unconsolidated deposits like sand, silt in comparison to the right bank due to the presence of hard lateritic soil of Rajmahal traps. Evidence suggests that the release of water from the Farakka Barrage periodically leads to higher deposition of sediments into the riverbed in both up and downstream of the Barrage and the erosion-deposition phenomena is also very prevailing in these regions due to alteration of river morphology (Rudra 2010).

4. Impact of temporal shifting of river course in the LULC changes

Water flowing over the land surface is the leading agent of landscape alteration. The river channel dynamics in these regions is highly controlled by high water level during monsoon flooding and sudden and frequent excess discharge from Farakka Barrage Project (FBP). This phenomenon affects riverine landscape and floodplain uses significantly. The north-eastern edges (Barind tract) of the investigation area along the river course experienced high mean erosion rates which results in significant conversion of agricultural land to a waterbody, bareland and seasonal agricultural land areas resulting rise in socio-economic vulnerability of the riparian people. Furthermore, a noticeable LULC dynamics in the riverine island was observed to meet the demand for agrarian development. The gradual temporal shifting of the river course in this region significantly influences the land use character changes, and worsens eco-environment with great intensity of the floodplain degradation. Whereas, the north-western edges part of the Rajmahal Trap has gained a large amount of deposited landmass within the river reach under the influence of active accretion of river Ganga. The deposited landmass often creates opportunities for riparian peoples to pursue agrarian activities. Most of the lands are waterlogged and swampy areas used for seasonal agricultural activities because they will be inundated by typical flood water. River channel dynamics have also affected inland water bodies, which has declined by more than 50% from 1998. The riparian people incline to convert inland water bodies into cultivated land and build-up as per their requirement. The modification of land use pattern in the Ganges floodplain is derived in a distinctive cycling process. Agricultural land and settlement have been washed away in erosional activities and emerged into depositional land which was again used for both agricultural and settlement purposes.
4.1. Future prediction of LULC changes

CA-ANN model is used to simulate future LULC maps for the year 2028 and 2038 using the 2008 and 2018 LULC maps (figure 5) as input. Model outcomes predict a drastic decrease of agricultural land area from 25.17 to 20.31% and increase of orchard area (from 23.57% to 27.35%) in the study stretch during the period of 2018 to 2038 (table 5). Model also predicts marginal increase of bareland (12.36 to 12.71%) and build-up areas (4.14 to 4.94%). The other land cover classes (inland water body, natural vegetation, and sand areas) will experience decreasing trend in their spatial extent within the next 20 year period (table 6). The continuing upward trend in build-up area and downward trend in natural resource is attributed to the adverse impact of population growth in the investigation area. Nonetheless, degradation of agriculture land indicates decrease in soil fertility and flood-plain deterioration. Increasing trend in bareland areas and the continue decreasing trend of agriculture land areas, implies severe land degradation in the near future which also will give rise to potential threat on riparian people livelihood in these study regions. Furthermore, the climate change has a significant influence on the

Figure 5. Predicted landuse/landcover classification map for the year’s 2028 and 2038 and percentage change of area between different time periods.
Table 5. Proportion of predicted Landuse/Landcover categories

| Years   | 2018     | 2028     | 2038     |
|---------|----------|----------|----------|
| LULC    | Area (km²) | Area % | Area (km²) | Area % | Area (km²) | Area % |
| Inland waterbody | 43.27 | 3.39 | 34.73 | 1.11 | 30.35 | 0.97 |
| River water | 300.27 | 9.61 | 314.85 | 10.08 | 315.43 | 10.10 |
| Natural vegetation | 107.00 | 3.43 | 102.70 | 3.29 | 98.06 | 3.14 |
| Agricultural land | 786.21 | 25.17 | 676.61 | 21.66 | 634.48 | 20.31 |
| Agricultural fallow | 564.50 | 18.07 | 576.22 | 18.44 | 587.45 | 18.80 |
| Bareland | 386.29 | 12.36 | 395.54 | 12.66 | 397.18 | 12.71 |
| Orchard | 736.30 | 23.57 | 828.06 | 26.51 | 854.42 | 27.35 |
| Build-up area | 129.19 | 4.14 | 137.79 | 4.41 | 154.32 | 4.94 |
| Sand area | 71.05 | 2.27 | 57.58 | 1.84 | 52.39 | 1.68 |
| Total | 3124.08 | 100 | 3124.08 | 100 | 3124.08 | 100 |

the selected stretch of river Ganga in near future. Prediction reveals that the study stretch of river Ganga will experience depositional activities to a greater extent during the period 2018–2028 and 2028–2038, in lieu of significant reduction of erosional activities (table 7). During 2018–2028 time period prediction model showed that the probability of deposition zone will increase by 0.10% (3.12 km²) whereas, erosion zone will decline by 0.22% (6.91 km²). Likewise, during the period 2028–2038, deposition zone will increase by 0.8% (2.39 km²) whereas, erosion zone will decline by 0.13% (4.19 km²). The analysis also shows that a large amount of landmass will be deposited in the study stretch of river Ganga, which will have a significant impact on the inter-fluvial plains. After initiation of the Farakka Barrage project in 1975 the intensity of stream energy becomes reduced and each year Ganga carries millions of tons of sediment load and deposits them in the plain areas. Reduction of stream energy and carrying capacity of sediment load is one of the major reasons behind increasing trend of deposition in these regions. Similarly, riverine islands will continue to expand over time. The newly deposited landmass expectedly would be natural resource hunting area of the riparian people.

4.3. Model validation

For a specific project, prediction of potential LULC is considered reliable by validating the result with the existing datasets. Therefore, we compared the simulated LULC maps for 2018 generated from the year 1998 and 2008, with the actual Landsat satellite-derived LULC maps of 2018 based on the comparative analytical process of Kappa validation. The overall simulation success of CA-ANN model is 67% and current kappa value is 0.62, which is considered favourable as per Perović et al., 2018. However, for validating the simulated LULC 2018 with ground reality, total number of 256 survey points are randomly selected (figure 7). The selected points are then overlaid on the simulated map for cross-checking. Based on the ground verification, some classes like inland waterbody, natural vegetation, bareland are
relatively close to the corresponding classes in the simulated LULC map for 2018, while agricultural land with seasonal fallow class is moderately simulated. This is probably due to seasonal variation in standing crop and floodwater extension. The tested result of built-up class is poorly simulated because of employing the spatial contiguity rule of CA-ANN model. Most of the neighbouring pixels belong to the orchard class, which is the most dominant class in the studied area. Therefore, an effective model validation, the CA-ANN model has been further used for prediction of potential LULC spatial distribution for 2028 and 2038, respectively.

4.4. Impact of LULC changes on riparian people’s livelihood

The impact of LULC change in the study area has significant effect on environmental and socio-economic factors such as livelihood vulnerability and involuntary migration. The outcome of focus group discussion reflects on the livelihood vulnerability in an agrarian economy which is the major issue of socio-economic development. In the last decade, about 40% of the respondents have shifted their occupation from agricultural farming to non-farm activities. As per their opinion,
the impacts of climate change, groundwater depletion, and scarcity of river water have serious consequences on soil fertility, crop failures, and agricultural activities, which severely affect on their quality of live and livelihood. Floodplain production systems in the study site are mainly based on cropping systems, combining paddy (deep water rice) and pulses in winter season, and fibres (jute) in monsoon season. Based on a recent report published by Bureau of Applied Economics and Statistics, average yield rate of paddy and pulses among the study sites varied from 2031 kg/ha and 1149 kg/ha in 2009–2010 to 1943 kg/ha and 992 kg/ha in 2014–2015, respectively. In case of fibres, the average yield rate varied from 16.9 bale/ha to 15.9 bale/ha (B.A.E. & S., 2016). As land degradation occurred, the agricultural inputs (such as, organic fertilizer, improved seeds, labour

Figure 7. Landuse/landcover 2018 (1a. River bank, 1b. Bare land, 2a. & 2b. Riparian settlement, 3a. Agriculture land, 3b. Agricultural fallow land, 4a. Deposited sand area, 4b. Inland waterbody). (A) Simulated versus actual landuse/landcover class in 2018.

Figure 8. Households’ response regarding migration towards riverine island.

Figure 1. Location of the study area
force) has exacerbated the challenges for cultivation practices. Therefore, farmers have made an attempt to diversify main source of income through non-crop economic activities. And to build resilience, farmers have adopted various strategies including agroforestry, riparian resource dependency, riverbank cultivation, and opt-in temporary migration. Due to the lack of appropriate infrastructure and government support, the riparian people could not manage an upgraded livelihood. For better economic opportunity, the riparian people migrate to prior existing or newly emerged sandbars within the riverine areas. This newly emerged sandbar, locally known as ‘Charland’ which is highly fertile in nature and hunting ground of environmental refuges for untitled landmass and their natural resources. Figure 8 represents the respondents’ opinion regarding their migration towards sandbar. Survey reveals that about 32% of respondent have preferred sandbars for agriculture farming whereas, 25.3% have selected due to the availability of untitled land regarding migration. Hence, the forced migration saved them from the trauma of losing livelihood but the quality of life could not be improved. After forced migration, peoples suffered from acute poverty, loss of identity and displacement resulting in the degradation of their quality of life and livelihood.

5. Conclusion

From the above study, it has been stated that by the using of satellite-derived LULC maps integration with biophysical and socioeconomic data, the CA-ANN model were simulated and predicted effectively for the LULC changes in the lower region of Ganges river. Overall, the accuracy of the simulation results (67%) is favourable for prediction. Nevertheless, the simulation results are not directly comparable because they vary on the land use pattern in each area. Accurate prediction of potential land use change in some special areas like environmentally fragile and perennial disaster-stricken areas is complex, which may be improved with additional environmental variables. The future prediction analysis indicates that the potential distribution of the LULC classes have significantly modified the floodplain landscape in the study stretch. The impact of climate change and population growth will direct influence on the LULC changes. In the entire study period from 1998 to 2018, the agricultural practices along with the bank and adjacent bars are continually expanded and this trend is likely to continue. The land cover dynamics of the river bed and human activities are directly or indirectly associated with each other. The area loss from inland waterbody and sand cover under the pressure of human activities (agriculture) amplifies this trend. The degradation and conversion of land resource, expanding riverbed cultivation practices, and unplanned human settlement indicate an alarming future scenario considering the floodplain biodiversity. However, the increasing trend of plantation areas may benefit the study stretch by minimizing erosion risk, improving livelihoods of the local people, and reducing land degradation impacts. Moreover, the anthropogenic intervention to the natural flow regime leads to the modification of the floodplain landscape. Therefore, the study demands for an interdisciplinary approach for measuring floodplain vulnerability, mapping and zoning of areas to maintain riparian buffer and developing appropriate policy guidelines for the riparian land use to facilitate sustainable development and to avoid recurring crisis. The study will help towards the better preparedness for land degradation in the future. Simultaneously, the continuous retention of river flow by construction of dams and barrages are the major reason behind the changing state of river beds. This decrease of flows creates a narrow river bed which is the key reason behind the depletion of natural value chain of a riverine ecosystem. Therefore, preparation of sustainable management practices and planning are the main important factor for this landscape.

Disclosure statement

No potential conflict of interest was reported by the authors.

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