Evaluation Wetlands Ecosystem Health using Geospatial Technology: Evidence from Lower Gangetic Flood Plain in India

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Abstract

The lower Gangetic flood plain of West Bengal occupies diversified riverine and floodplain wetlands. These wetlands played a significant role maintain ecosystem health and supports for human wellbeing. This paper presents the health of wetland ecosystem by comprising the wetland ecosystem health index (WEHI) in 2011 and 2018 at block level of Malda district, as a part of lower Gangetioc flood plain using pressure – state – response model (PSR model) and AHP method. A total number of six Landsat satellite images and statistical census data were used to determine the wetland. Wetlands are classified as very healthy, healthy, sub-healthy, unhealthy and sick category on the basis of wetland ecosystem health index score. Results showed the health of wetland ecosystem has slightly decreased from 2011 to 2018. 13.33% of blocks are fall under sick category in 2011. 26.67% block are comes under very healthy category in 2011 but it decrease to 20% in 2018. The heath of wetland ecosystem in Harischandrapur – II, Ratua-II, Maldah (Old), English Bazar, Bamongola, Habibpur, Chanchal-I and Kaliachak – II blocks are degrading from 2011 to 2018. This may be attributed to the increasing urbanization rate and associated growth of infrastructure. Developing local level institutions is useful measures to manage wetland resource; and protect biodiversity should be guided by the Government organization and NGOs for its mitigation measure.

Highlights

- Landsat ETM and OLI satellite images, census data and Google Earth data were accumulated to explore the wetland ecosystem health using open source software.
- Block wise wetland ecosystem health status of lower Gangetic flood plain region were assess in the year 2011 and 2018.
- The present study shows that, average wetland ecosystem health (WEH) score was decline from 2011 to 2018.

Introduction

The River Ganga (The Ganges) basin, which covers 26.2 percent of India's total geographical space, has been designated as the country's largest river basin. The Government of India declared it a National River on November 4, 2008, in recognition of its immense significance to the people's economic, spiritual, and cultural lives (Mukherjee et al., 1993; Mukherjee 2020). It has a complex wetland ecosystem, ranging from high-altitude oligotrophic lakes in the Himalayas, Terai region's marshes and swamps, floodplain and riverine wetlands in the Gangetic and Brahmaputra alluvial plains, and coastal wetlands in the deltaic tracts. The Gangetic Plains are a vast swath of highly fertile alluvium that serves as the Ganga Basin’s agricultural backbone. The Ganga River and its tributaries' flood pulses are intricately related to riverine and floodplain wetlands. Here, significant exchange of water, sediments, nutrients, and species occur between river channel and linking wetlands. Thus, the process and interconnected system related with biodiversity and ecosystem services. Nonetheless, natural flow regimes are being disrupted, agriculture and settlements are expanding and intensifying, deforestation, uncontrolled tourism, and invasive species are all putting pressure on the wetland landscape.

Globally, there are over 1,275 m ha wetland habitats (Finlayson and Spiers 1999) with an annual economic value of about USD15 trillion a year (MEA 2005). The population growth has continued to be a cause of wetland depletion and degradation across the globe, placing tremendous strain on water supplies and undeveloped land settlements, increased agricultural and industrial development and expansion of infrastructure (IUCN, 1990). The inefficient use of wetland services can be called a mixture of deficiencies of intelligence, business and policy deficiencies or action failures and other social and financial factors. The factors are overfishing, irrigation, erosion, invasive plants, climate change, depletion of water, land invasion and urbanization. Rapport et al. (1985) promoted the concept of 'ecosystem health' to describe the type of natural framework reliability and viability to keep up its hierarchical structure, normal controlling and recovery limit after versatility.

India is a gifted with a various dynamics of wetland landscape, covering nearly 18.4% of the land surface (MoEF, 1990) and they provide useful natural assets services to human. As per ISRO (2011), India has 69.23% of the area under inland wetland and 30.77% of the region are has a place with coastal wetland. We lose 2–3 percent of the wetlands each year. The numerous wetlands environmental system has seen a quick derogation, including reducing area, fading in water quality, and loss of biodiversity (Foote et al. 1996). But the sustainable and stable system wetlands ecosystems are essential in India for supply food to humans and consumable water accessibility for people and domesticated animals. The researchers (Das et al., 2017) tried to determine the loss of wetland area and resultant consequences. These studies (Das et al. 2015) also address that how the wetlands were benefits to households. But, the researchers of India as well as the world were mainly concern about the wetland biological system wellbeing and notoriety. Traditionally, the researchers (Dixon et al., 2019; Bornette et al., 1998) utilized field perception information and models to evaluating the wetland ecology. Water, soil, vegetation and other related indicators were commonly used by the researchers (Wu et al., 2017; Shil et al., 2019; Albert et al., 2004) for analyzing the status of wetland function and health. Albert et al (2004) demonstrated that plants as territorial pointers of Lake Ecosystem health. Shil and Singh (2019) and Kangabam et al. (2017) used the water quality parameters for assessing health conditions of wetland environment. But, the field perceptions information can't follow out the spatial and temporal situation of the health status of wetland environment. The space borne satellite images provides us the high productive information about wetland area and depth (Paul and Pal, 2020; Alanna et al., 2017). With the help of these data, we can analyse wetland ecosystem health at different spatio –temporal scale. Most the studies in China (Sun et al., 2017; Jia et al., 2015) have targeted the wetlands located the river basin or coastal region and they used remote sensing data. But the studies related to health conditions in inland wetlands were disregarded day by day.

In this specific context, there is a need to examine precise evaluations of the health status in the Gangetic flood plain of West Bengal. This study focus on Malda district as an evidence of wetland ecosystem health by comprise wetland ecosystem health index (WEHI) in 2011 and 2018 at block level of Malda district, using pressure – state – response (PSR) model. The PSR model was very common to analysed health risk of wetland ecosystem (Das et al., 2020; Mai et al., 2005; Sun et al., 2017). Based on wetland ecosystem health index (WEHI) score, we categorized the health level and differentiate the blocks where the health condition is decreasing or increasing from 2011 to 2018. The findings from this paper could helpful for the establishment and evaluation of ecological restoration policies and environmental management techniques in Malda district.

Materials And Methods

2.1. Study Area

The current study was carried out in lower Gangetic flood plain of West Bengal using geospatial technology, where wetland ecosystem is vulnerable. We selected Malda district is also a part of Diara region, where the wetlands play a vital role for maintaining landscape stability. Geomorphologically, the study area belongs to the active floodplain as it occupies more than half of the region's area occupies marsh, inactive floodplain, and levee and river islands. The Malda district lies between 24° 40′ 20″ N to 25° 30′08″ N and 87° 45′ 50″ E to 88° 28′10″ E (**Figure 1**). It includes 15 blocks and 2 sub-divisions, such as Chanchal and Malda Sadar. The total geographical area of Malda district is nearly 3652.75 km^2. The total population of the district is 3699312 with a population density of 1013 persons per sq kilometer in 2011. The major rivers in the district are Ganga, Punarbhaba, Mahananda, Pagla, Kalindri, Tangon, Fulahar etc. The river Ganga has enough evidence of lateral migration (Mukherjee and Pal, 2017). With the shifting of river course, it creates numerous ox-bow lake, cut-off channels, beels, etc. which are no longer direct link with parent river (Singh et al., 2019). Such water bodies have evolved into riparian wetlands that are vital to the floodplain ecosystem as well as the human wellbeing. Such dynamics physical and socio-economic aspects were the main attraction of researchers and that's why we selected Malda district as our study area.

2.2. Data and Methods

2.2.1 Data resources and processing procedures

Systematic procedures were done to demonstrate the health conditions of wetland ecosystem in Malda district. The systematic procedures involve- preparation of block level vector map of Malda district and tabulation of the health indicator data. The block level administrative map of Malda district was prepared by using the administrative atlas of West Bengal; the statistical data incorporates population density, percentage of cultivation area, urbanization rate is gathered from the Census of India 2001 and 2011. The road network map was prepared from the Survey of India topographical sheet and same has to be updated with the satellite data. Finally, the digital database of road network is used for the calculation of road density. The patch richness (PR), patch density (PD), largest patch index (LPI), landscape diversity index (LDI), wetland degradation rate was calculated by using a total number of six Landsat satellite images in the year 2001, 2011 and 2018. The Landsat pace borne satellite images were downloaded via the web site https://earthexplorer.usgs.gov/. The description of satellite data has been given in Table 1. The ecosystem function value index was used for the economic valuation of ecosystem services provided by the wetlands (Zhang et al., 2015).

2.2.2 Wetlands ecosystems health assessment system

The PSR model was common and popular method along the numerous research studies (Mi et al., 2005; Sun et al., 2016, 2017). The PSR model supported the cause-effects relationship, which can assess the human pressures and exercises cause to deterioration to ecological environment. The PSR model differentiates the indicators into three shorts of categories- (1) The ‘pressure’ factors are the negative factor influences to the deterioration of wetland health; (2) The ‘state’ factors demonstrate the structural integrity and functions status of the wetlands; (3) The ‘response’ indicators are quantifies its vigour, versatility and environmental services. Based on the availability and flexibility of data source, we selected ten indicators for the development of wetland ecosystem health index (WEHI) in Malda district. The analytical hierarchy processes (AHP) techniques have been employed for assessing the weights of the indicator. Detailed methodology is given below with a flow chart (Fig. 2).

2.2.3. Wetland extraction and classification

We have used six Landsat satellite data for the extraction of wetlands on 2001, 2011 and 2018. After the essential image corrections guided by the standard procedures, we calculated Normalized Difference vegetation index (NDVI), Modified Normalized Difference Water index (MNDWI), Normalized Difference Pond index (NDPI) using the Arc GIs 10.3.1 software.

Normalized Difference vegetation index (NDVI) has been calculated based on the Eq. 1

NDVI = (NIR – RED) / (NIR + RED) ……………..*EQ.1*

NDVI is commonly used for determining different aspects of plant characteristics. The NDVI is first defined by Rouse in 1973 (Rouse et al., 1974). In this study, we have found that the NDVI value ranges between – 0.674 to 0.658. Basically, the positive value of NDVI represents green vegetation and the negative value formed from clouds, water and snow.

Modified Normalized Difference Water index (MNDWI) has been calculated based on the Eq.2

MNDWI = (GREEN – NIR) / (GREEN + NIR) *(2)*

The MNDWI has been used where the water bodies are mixed with built-up area (Xu, 2006). In this study, we have found that the MNDWI value ranges between – 0.566 to 0.893. The positive values of MNDWI denote water features and the negative values indicated the non-water feature.

Normalized Difference Pond index (NDPI) has been calculated based on the *Eq.3*

NDPI = (MIR – GREEN) / (MIR + GREEN) *(3)*

Lacaux (2006) first described Normalized Difference Pond index (NDPI) for the identification of ponds. In this study, we have found that the NDPI value ranges between – 0.986 to 0.566.

After the calculation of above indices, MNDWI is greater than zero from this maximum water features. Next, we have combined NDVI value of greater than zero and NDPI value of less than zero. This condition can separate water features from vegetation. The hybrid image provides better result.

Based on the extracted surface waterbodies, the wetlands are classified as natural lakes, natural ponds, ox-bow type or cut-off meander, natural waterlogged, natural riverine and man-made ponds. The classification scheme was considered based on the Indian Space Research Organization (ISRO) National Wetland Atlas report in the year 2011.

2.2.4 Indicator system establishment

The systematic studies involve selection of the indicator and standardize them for the computation of a score which is described the actual continuity of the study area on a specific topic. Development of wetland ecosystem health index of Malda district, we select ten health indicators, where four pressure, four state and two response indicators. Table 2 shows the detailed list of indicators. Max – min normalization method has been followed to unify the indicators. The scale of the data ranges between 0 to 1.

The ecosystem health pressure factors describe the intensity of human activities due to extensive conversion of wetlands to usable land within a time span. Based on literature study, we have selected population density, percentage of cultivated land, urbanization rate and road density for assessing wetland ecosystem health in Malda district. The population density is calculated as the persons per square kilometer of area in the year 2001, 2011 and 2018. The road density is calculated per square kilometer. The urbanization rate is calculated by subtracting percentage of urban population from succeeding year. The percentage of cultivated area is calculated as the ratio between cultivated area and total geographical area of each block.

The state factors are considered as wetland under the human pressure. Based on the previous studies (Sun et al., 2017; Jia et al., 2015; Sun et al., 2016), various indices have been employed to define the spatial information about the wetland landscape. Patch richness (PR) is important components of the landscape structure considering the way that the landscape components present in a landscape can impact an assortment of natural processes. Patch density (PD) decrease when the wetland fragmentation occurs frequently. The higher value of Largest patch index (LPI) denotes greater impact for maintain environmental process. Shannon diversity index (SHDI) helped to understand the wetland diversity in a specific area. SHDI value of ‘0’ indicates that in the study area, only one patch class exists and has no decent variety. The above indices were calculated by using Arc GIS 10.3.1.

Apart from the state indicator, we have selected two response indicators i.e., wetland degradation rate (WDR) and ecosystem service value (ESV). WDR is determined how much wetlands area has decreased within a particular period of time. Based on the previous research paper (Xie et al. 2001) we calculated ESV of the wetland classes in the study area.

2.2.5. Calculation of indicator weights and assessment methods

Saaty's AHP technique is used for the determination of weight of the indicators (Saaty, 2008). The AHP priority was calculated via the website (https://bpmsg.com), which is freely accessible. Table 3 shows the correlation matrix and weight of each indicator used in AHP technique. For the construction of WEHI, the weight of the indicators is multiplied by respective standardized value of the indicators.

$$WEHI = \sum_{i=1}^{n} w_i \times c_i \qquad (4)$$

where, WEHI is the wetland ecosystem health index, W_i is the weight of the i^{th} indicator, and C_i is the standardized value of the i^{th} indicator.

Results

3.1. Wetlands ecosystem pressure

The ecosystem pressure factors have gradually brought down the forward succession processes of the wetland ecological system. Therefore, it is difficult to implement effective management policies to sustain the natural system in wetland ecosystem. But the pressure indicators can alarm us to rethink the about wetlands deterioration process.

Malda district had a population density of 881 persons per sq. kilometers and 1069 persons per sq. kilometers area in 2001 and 2011 respectively. The population increasing rate is calculated as 21.22 % from 2001 to 2011 and the district is residing in 1st position with compare to other districts of West Bengal. Based on the population density at block level, spatial distribution map is prepared (**Figure 3**), results showed at Habibpur, Gazole and Bamangola block had the low population density in all the census year and Kaliachak –I and Kaliachak –III block had high population density. Conversions of wetland and cultivated land to built-up area were the main reason for the increasing population density.

The wetlands contribute in diverse ways to the livelihoods of millions of people. The researchers (Mccartney et al., 2011) observed that increasing population and needs of protein enhancing continuous pressure to expand agriculture within wetlands. Figure 3 show that Harischandrapur – I, Chanchal – II, Ratua – II, Gazole, Habibpur and Bamangola block had above 80 percent cultivated area in 2011. But English Bazar and Kaliachak – II block had less than 60 percent cultivated area. In 2018, Harischandrapur – I, Chanchal – II, Ratua – II and Bamangola block had more than 80 percent cultivated area and Kaliyachak-II and Kaliyachak-I block had below 50 percent cultivated area.

Urbanization is an inescapable pattern of human culture and fundamental advance of a nation's modernization; simultaneously it affects on wetland ecological system and health. The researchers (Zheng et al., 2008) determined that the effects of urbanization can change the wetland ecosystem in three aspects- hydrological change, water quality change and climate change. Results of our analysis showed that the English Bazar and Old Maldah Municipality has most urbanized where 6.825 percent and 8.57 percent population are residing in 2001 and 2011 respectively. Figure 4 shows that urbanization rate from 2011 and 2018 is high in Kaliyachak- I block, followed by English Bazar and Maldah (Old) block.

The researchers (Findlay and Bourdages, 2001; Wang et al., 2003) observed that road construction can degraded wetland ecosystem in many ways like- pollutants the environment, fragments the wetland, shrinking the area and significant loss in bio-diversity etc. The paper shows that road density is high in Kaliyachak- I, English Bazar and Maldah (Old) block in 2001 and 2011. But the road connectivity is poor in Habibpur and Manikchak blocks (**Figure 4**).

3.2. Wetlands ecosystem health state

Present study showed four state indicator of wetland ecosystem to explore the health status. The indicators have direct influences to sustain the wetland structure and help to maintain ecosystem function and services.

The patch density is an important indicator because greater patch density has greater significance of ecosystem health. Our results showed that English Bazar block has highest patch density followed by Kaliachak-III and Harishchandrapur-II block in 2011 and 2018 and the patch density is low in Bamangola, Gazole and Malda (Old) block (**Figure 7**).

The large wetlands have greater significance for maintaining ecological sustainability in Malda district. Jatradanga beel, Chakla beel, Chatra Beel, Baripur, Barabanga Dighi and Golbaka Haripur are the important large wetlands (**Figure 6**).

Patch richness in the study area has decreased from 2001 to 2018. In 2011 and 2018, the patch richness is high in English Bazar and Harishchandrapur-II block and low in the block Kaliachak-III and Bamangola (**Figure 6**).

The diversity of wetland landscape is highlighted by Shannon diversity index. If the types of wetland class increase then the Shannon diversity index (SDI) may increase. The highest value of SDI means the landscape has diversified wetlands and SDI value decreases if wetland diversity decreases. The highest SDI value is observed in English Bazar, Ratua II and Ratua-I block.

3.3. Wetlands ecosystem health response

The condition of wetland ecosystem has changed and become more complex due to combined effects of natural and human factor. This process in response to wetland degradation. The table 4 shows progressive changes of wetland area from 2.91% to 1.11% in 2001 to 2018. With the continuous population growth and infrastructure development are the main reason for wetland degradation except English Bazar and Maldah (Old) block, where urbanization is the main controlling factor. The paper determined that highest wetland degradation rate has found in Ratua-I, Chachal-II and Bamangola block from 2001 to 2011 and Gazole and Maldah (Old) block from 2011 to 2018 (**Figure 5**).

Moreover, large wetland has provides more ecosystem service to the society. This paper shows that English Bazar and Kaliachak-III block provides highest ecosystem service and Habibpur block has lowest ecosystem service in 2011 (**Figure 10**). In 2018, English Bazar and Bamangola block has highest ecosystem service and Kaliachak-II, Maldah (Old) and Bamangola block has lowest ecosystem service (**Figure 7**).

3.4. Spatial - temporal variations and levels in the health status of wetland ecosystem

After the computation of WEHI, we have categorized the WEHI score into five classes- very healthy, healthy, sub-healthy, unhealthy and sick based on the previous research study (Sun et al., 2016, 2017; Jia et al., 2015). The description of the classes has been given in table 5, where higher value describes wetland landscape has stable and healthy ecosystem status and lower value denotes relatively unstable and poor ecosystem health status. In Malda district, the ecosystem health status has continuously changing with the increase of population pressure. Rapid urbanization and population density are the major factor that degraded the ecosystem health status. The wetland ecosystem health status of Malda district shows 13.33% of blocks fall under sick category in 2011 as well as 2018Table 6). It is also noticed that 26.67% block are residing under very healthy category in 2011 but it decreases to 20% in 2018. Figure 9 shows that English Bazar, and Kaliachak-I blocks are the identified as sick category where wetland ecosystem conditions have very risk zone in 2011 and 2018. Manikchak, Gazole and Bamangola blocks have stable ecosystem with less human pressure in 2011 and 2018.

Our results showed that the average WEHI has been slightly decreased from 0.703 to 0.699 in 2011 and 2018 respectively. It is also noticed that the cultivation area of each block decreased from 2011 to 2018. This observation indicated that conversion of cultivated land to built-up area can regularly occur and has less pressure on wetlands in Malda district. Our results also stated that Harischandrapur – II, Ratua-II, Maldah (Old), English Bazar, Bamongola, Habibpur, Chanchal-I and Kaliachak – II blocks are degraded in terms of ecosystem health from 2011 to 2018. Urbanization rate has significant impact for the degradation of wetland ecosystem in case on English Bazar and Maldah (Old) block. Other blocks are influenced by increase population density and road density.

Moreover, irrigation, high dependency in wetlands by household's use, canalization for conveying water to agricultural lands and continuous shifting of river channels have wrecked wetland landscape. This has driven to decrease in wetland area, decreasing in water holding capacity and change in water quality makes an unfortunate and wiped out situation for widely varied flora and fauna. The habitats – food, shelter and protection of the living organisms are exceptionally influenced. Therefore, the carrying capacity of the wetlands by supporting the human society of Malda district is making it significantly more vulnerable. Therefore, the useful wetlands protection policies and restoration strategies should emphasize and implemented in these regions by the Government or NGOs.

Discussion

Wetland biological systems are viewed as the most ecological diverse and the characteristics of the ecosystems are exceptionally unique and complex. The evaluation of wetland environment wellbeing is fulfilled on the grounds that the effects of controlling components are fluctuated from spatio-temporal scale. The present research work showed that the status of wetland ecosystem health in Malda district is slightly decreased from 2011 to 2018. Natural as well as the anthropogenic factors were the main thrusts which are responsible to deteriorate wetlands ecosystem health in Malda district. The paper also reveals that change in population, growth in transport network, urbanization and sub-urbanization related infrastructure development is the major influencing factor for changing wetland ecosystem (**Figure 10**). Sun et al., (2017) confirmed that urbanization rate is an important controlling factor resulting to deterioration of wetland ecosystem health. The researchers (Jia et al., 2015; Jiang et al., 2005) recognize that higher population density having greater negative effect on the status of wetland ecosystem. With the increase of population density and economic developments were responsible for the conversion of wetlands to cultivated lands (Guo et al., 2010). The researchers (Cue et al., 2002; Ghosh and Das, 2019) evaluated that urbanization rate influence the environmental quality by the reduction of wetland area. Sharma et al., (2012) and Mistry et al., (2015) established that development in transport network had a direct impact. Transport network influenced the wetlands and increased in number of vehicles in National Highway – 34 (N.H. 34) is responsible for decreasing of birds gathering in and around the wetlands.

There are couples of limitations in the study. This study do not consider the water quality parameters, species abundance, soil erosion and terrain slope for identifying the wetland ecosystem health. Previous studies (Horwitz et al., 2012; Das et al., 2017) also determined that biological and chemical characteristics and socio-economic conditions were linked with the wetland ecosystem health. Dechsa et al. (2019) observed that the households are directly and indirectly used the wetlands for their daily need. Das et al., (2015) stated that demographic factors and their living conditions are forces to greater use of wetlands and leads to decrease in health status of the wetlands. The proposed assessment system depends on author’s assessment with the guidance of a group of field experts and earlier research observations. Thus, future research study and analysis is necessary to validate and progress of the study.

Conclusion

Exploration of wetland ecosystem health index using geospatial technology in Malda district was carried out after the consideration of ten measurable indicators. The block wise variations map was prepared to establish the result. Both the spatial and non-spatial data were accumulated for the development of wetland ecosystem health index. The result of this paper determined that wetland ecosystem health has slightly increasing from 2011 to 2018. The percentage of blocks placed in sick category is 13.33 in 2011 as well as 2018, while the percentage of blocks in very healthy category has decreased from 26.67 to 20.00 from 2011 to 2018.

The wetlands make the environment healthy by maintaining ecological system and making liveable for living organisms. The majority of the people situated nearing wetlands dependent on wetlands by using water resource. Describing the block wise variations of WEHI is taken as subject matter in order. Developing local level institutions is useful measures to manage wetland resource and protect biodiversity should guided by the Government organization and NGOs. The emphasis should go to degraded blocks to protect wetlands environment it for the life and livelihood of a large community.

Declarations

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Contributions

P.K.Shit - conceptualized and planned the study and reviewed and edited the manuscript. S. Das - conducted the survey, analyzed the data, prepared the maps and interpreted the results. G.S.Bhuni - reviewed and edited the manuscript. B.Bera - supervised the study and reviewed and edited the manuscript. All authors have read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

References

1. Alanna, J.R., Paul, S., Karen, J.E., Patrick, M., 2017. Detecting, mapping and classifying wetland fragments at a landscape scale. Remote Sensing Applications: Society and Environment. 8, 212 – 223.
2. Albert, D.A., Minc, L.D., 2004. Plants as regional indicators of Great Lakes coastal wetland health. Aquat. Ecosyst Health Manag. 7, 233–247.
3. Bornette, G., Amoros, C., Piegay, H., Tachet, J., Hein, T., 1998. Ecological complexity of wetlands within a river landscape. Biological Conservation. 85, 35–45.
4. Chen, Z., Shang, H., Yao, B., 2009. Methods of wetlands health assessment in USA. Acta Ecol. Sin. 29 (9), 5015–5022.
5. Das, S., Behera, B., Mishra, A., 2015. Determinants of household use of wetlands resources in West Bengal, India. Wetlands Ecol Manage. DOI 10.1007/s11273-015-9420-8.
6. Das, S., Pradhan, B., Shit, K.P., Almari, M.A., 2020. Assessment ofWetland Ecosystem Health Using the Pressure–State–Response (PSR) Model: A Case Study of Mursidabad District ofWest Bengal (India). Sustainability. 12, 5932, 1 – 18.
7. Das, T.R., Pal, S., 2017. Exploring geospatial changes of wetland in different hydrological paradigms using water presence frequency approach in Barind Tract of West Bengal. Spat. Inf. Res. DOI 10.1007/s41324-017-0114-6.
8. Das, T.R., Pal, S., 2017. Investigation of the principal vectors of wetland loss in Barind tract of West Bengal. Geo Journal. DOI 10.1007/s10708-017-9821-8.
9. Datta, T., 2011. Human interference and avifaunal diversity of two wetlands of Jalpaiguri, West Bengal, India. Journal of Threatened Taxa. 3(12), 2253–2262.
10. Dechasa, F., Senbeta, F., Dirba, D., 2019. Determinants of household wetland resources use and management behaviour in the Central Rift Valley of Ethiopia. Environmental sustainability. DOI 10.1007/s42398-019-00075-z.
11. Dixon, H., Das, L., Allan, R., Kangabam, R., 2019. Ecosystem service assessment of selected wetlands of Kolkata and the Indian Gangetic Delta: multi-beneficial systems under differentiated management stress. Wetlands ecology and management. DOI: 10.1007/s11273-019-09668-1.
12. Findlay, S.C., Bourdages, J., 2001. Response Time of Wetland Biodiversity to Road Construction on Adjacent Lands. Conservation Biology. 14(1), 86 – 94.
13. Finlayson, C.M., Spiers, A.G., 1999. Global Review of Wetland Resources and Priorities for Wetland Inventory. Supervising Scientist, Canberra, Australia.
14. Foote, L.A.;, Pandey, S., Krogman, T.N., 1996. Processes of wetland in India. Environmental conservation. 23 (1), 45 – 54.

15. Ghosh, S., Das, A., 2019. Urban expansion induced vulnerability assessment of East Kolkata Wetland using Fuzzy MCDM method. Remote Sensing Applications: Society and Environment. 13, 191 – 203.
16. Guo, B., Jiang, C.B., Yang, C., 2010. Health assessment of Yellow River Delta wetland. Journal of Yangtze River Science Research Institute. 27, 44–8.
17. Gurung, H., Thapa, I., 2013. Important Bird Areas in Nepal deliver vital ecosystem services to people. Journal of Himalayan Ornithology. 2, 1 – 183.
18. Horwitz, P., Finlayson, C.M., Weinstein, P., 2012. Healthy wetlands, healthy people - A review of wetlands and human health interactions. Ramsar Convention on Wetlands/ World Health Organisation, Report No. 6.
19. IUCN., 1990. Directory of Wetlands of International Importance. Ramsar Convention Bureau, Gland, Switzerland: 796 pp.
20. Jia, H., Pan, D., Zhang, W., 2015. Health assessment of wetlands ecosystems in the Heilongjiang river basin, China. Wetlands. 35, 1185 – 1200.
21. Jiang, W.G., Li, J., Li, J.H., 2005. Assessment of wetland ecosystem health in the Liaohe River Delta. Acta Ecologica Sinica. 25(3), 408 – 414.
22. Mai, S.Z., Xu, S.J., Pan, Y.J., 2005. Application of the PSR model to the evaluation of wetland ecosystem health. Trop. Geogr. 25 (4), 317–321.
23. Mccartney, M., Rebelo, M. L., Sellamuttu, S. S., Silva, D. S., 2011. Wetlands, Agriculture and Poverty Reduction. IWMI Research Report, 137. P O Box 2075, Colombo, Sri Lanka.
24. Millennium Ecosystem Assessment (MEA)., 2005. Ecosystems and Human Well-being: Wetlands and Water Synthesis World Resources Institute, Washington, DC.
25. Ministry of Environment and Forests (MoEF)., 1990. Wetlands of India: A Directory MoEF, Government of India, New Delhi.
26. Ministry of Environmental Forests (MoEF)., 2011. National wetland Atlas: As a part of the project on National Wetland Inventory and Assessment (NWIA). Indian Space Research Organisation (ISRO), Ahmedabad.
27. Mistry, J., Mukharjee, S., 2015. Status and threats of water birds in ahiran lake, Mursidabad, West Bengal, India. International Journal of Plant, Animal and Environment Sciences. 5(2), 59 – 64.
28. Morgan, L., Finnegan, P., 2007. Benefits and Drawbacks of Open Source Software: An Exploratory Study of Secondary Software Firms. International federation For Information Processing. 234, 307 – 312.
29. Mukherjee, D., Chattopadhyay, M., Lahiri, S.C., 1993. Water quality of the River Ganga (The Ganges) and some of its physico-chemical properties. Environmentalist. 13 (3), 199–210.
30. Mukherjee, K., 2020. Wetland habitat stability assessment in hydro-geomorphological (HGM) and surface water availability (SWA) conditions in a lower Gangetic floodplain region of Eastern India. Ecological Indicators. 119, 106842.

31. Mukherjee, K., Pal, S., 2017. Channel migration zone mapping of the River Ganga in the Diara surrounding region of Eastern India. Environ. Dev. Sustain. 20 (5), 2181–2203. https://doi.org/10.1007/s10668-017-9984-y.
32. Paul, S., Pal, S., 2020. Predicting wetland area and water depth of Ganges moribund deltaic parts of India. Remote Sensing Applications: Society and Environment. 19, 1 – 11.
33. Rapport, D.J., Regier, H.A., Thorpe, C., 1985. Ecosystem behaviour under stress. The American Naturalist. 125, 617 – 640.
34. Rouse, J.W., Jr, H., Schell, H.R., Deering, D.W., 1974. Monitoring vegetation system in the Great Plains with Erts. NASA special publication, 351.
35. Saaty, T.L., 2008. Decision making with analytic hierarchy process. International journal of Services Sciences. 1(1), 83–98.
36. Sharma, S., 2012. Trend of urbanisation in berhampore municipality: a Geographical analysis. Geo-Analyst. 2(2), 49 – 56.
37. Shil, S., Singh, K., 2019. Health risk assessment and spatial variations of dissolved heavy metal and metalloids in a tropical river basin system. Ecological Indicators. 106, 1 – 12.
38. Space Applications Centre (SAC)., 2011. National Wetland Atlas. SAC, Indian Space Research Organisation, Ahmedabad.
39. Sun, R., Yao, P., Wang, W., Yue, B., Liu, G., 2017. Assessment of wetland ecosystem health in the Yangtze and Amazon River Basins. International journal of Geo-Information. 6, 81, 1 – 14.
40. Sun, T., Lin, W., Chen, G., Guo, P., Zeng, Y., 2016. Wetland ecosystem health assessment through integrating remote sensing and inventory data with an assessment model for Hangzhou bay, China. Science of the total environment. 556 – 567, 627 – 640.
41. Wang, Z.H., Wang, K.L., Xu L.F., 2003. The assessment indicators of wetland ecosystem health. Territory Natural Resource Study. 4, 63–80.
42. Wu, C., Chen, W., Cao, C., Tian, R., Liu, D., Bao, D., 2017. Diagnosis of wetland ecosystem health in the Zoige wetland Sichuan of China. Wetlands Journal. DOI. https://doi.org/10.1007/s13157-018-0992-y.
43. Xie, G., Lu, C., Cheng, S., 2001. Progress in evaluating the global ecosystem services. Resour. Sci. 11, 5–9.
44. Xu, H., 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing. 27(14), 3025 – 3033.
45. Zhang, P., He, L., Fan, X., Huo, P., Liu, Y., Zhang, T., Pan, Y., Yu, Z., 2015. Ecosystem Service value assessment and contribution factor analysis of land use change in Miyun in County, China. Sustainability. 7, 7333 – 7356.
46. Zheng, K.X., Chunhui, L., Huang, H.G., Yang, F.Z., 2008. Research process in effects of urbanization on wetland ecosystem in watershed. Wetland Science. 6(1), 87 – 96.

Tables

Table 1
Description of satellite images in the study area.

Satellite	Details					
	Sensor	**Path / Row**	**Date**	**% of Cloud**	**Resolution (m)**	**Wave length (μm)**
Landsat – 7	ETM				30	Band 1: 0.45–0.515
		139/42	27-01-2001	0.00		Band 2: 0.525–0.605
		139/43	28-01-2001	2.00		Band 3: 0.63–0.69
		139/42	25-12-2011	0.00		Band 4: 0.75–0.90
		139/43	25-12-2011	0.00		Band 5: 1.55–1.75
						Band 7: 2.09–2.35
Landsat – 8	OLI	139/42	19-02-2018	7.30	30	Band 1: 0.435–0.451
						Band 2: 0.452–0.512
						Band 3: 0.533–0.590
						Band 4: 0.636–0.673
		139/43	19-02-2018	14.30		Band 5: 0.851–0.879
						Band 6: 1.566–1.651
						Band 7: 2.107–2.294
						Band 9: 1.363–1.384

Table 2
Selected indicators of wetlands ecosystem health index in Malda district.

Criteria	Indicator	Formula
Pressure	Population density	Population / Block area
	Percentage of cultivated area	(Cultivated area / Block area)* 100
	Road density	Road length / Block area
	Urbanization rate	Present year urbanization rate - current year urbanization rate
State	Patch richness	Number of patches
	Patch density	Wetland area / block area
	Largest patch index	Largest wetland area / Block area
	Landscape diversity index	Number of patch type / Number of patch type in the landscape
Response	Wetland degradation rate	Difference between previous year and current year wetland area / Previous year wetland area
	Ecosystem service value	Economic value in rupees

Table 3
The correlation matrix and weights of the indicators using analytic hierarchy process (AHP) method.

Higher Level Indicator	Lower Level Indicator	AHP Matrix				Priority	Weight
		A	B	C	D		
Wetland ecosystem health	A. Pressure	1	1/3	3		0.258	
	B. State	3	1	5		0.637	
	C. Response	1/3	1/5	1		0.105	
Pressure	A. Population density	1	3	5	3	0.505	0.183
	B. Road density	1/3	1	5	3	0.288	0.142
	C. Percentage of cultivated area	1/5	1/5	1	1/3	0.064	0.026
	D. Urbanization rate	1/3	1/3	3	1	0.143	0.071
State	A. Largest patch index	1	1/3	2	5	0.239	0.127
	B. Patch density	3	1	5	7	0.574	0.244
	C. Patch richness	1/2	1/5	1	3	0.131	0.072
	D. Shannon diversity index	1/5	1/7	1/3	1	0.056	0.026
Response	A. Wetland degradation rate	1	5			0.833	0.091
	B. Ecosystem service value	1/5	1			0.167	0.018

Table 4
Wetland area and percentage of wetland area at Malda district.

Year	**2001**	**2011**	**2018**
Wetland area (ha)	10634.37	5041.87	4056.95
Percentage of wetland area	2.91	1.38	1.11

Table 5
Levels of wetland ecosystem health in Malda district.

WEHI score	Health Level	Status of Health
0.81–1.00	Very healthy	Wetland ecosystem has sustainable and stable condition, very healthy functions with very low human pressure
0.71–0.80	Healthy	Wetland ecosystem has sustainable and stable condition, healthy functions with less human pressure
0.61–0.70	Sub-healthy	Wetland ecosystem has maintains basic system with some changes of landscape, deteriorative ecosystem functions and greater human pressure
0.51–0.60	Unhealthy	Wetland ecosystem has been degraded condition with fragmented landscape, unhealthy functions and relatively higher human pressure
0–0.50	Sick	Wetland ecosystem has been in daggered condition with entirely destroyed landscape, sick ecosystem functions and very high human pressure

Table 6
Level of wetland ecosystem health index in Malda district.

WEHI score	Health Level	2011		2018	
		No of block	%	No of block	%
0.81–1.00	Very healthy	4	26.67	3	20.00
0.71–0.80	Healthy	7	46.67	6	40.00
0.61–0.70	Sub-healthy	1	6.67	3	20.00
0.51–0.60	Unhealthy	1	6.67	1	6.67
0–0.50	Sick	2	13.33	2	13.33

Figures

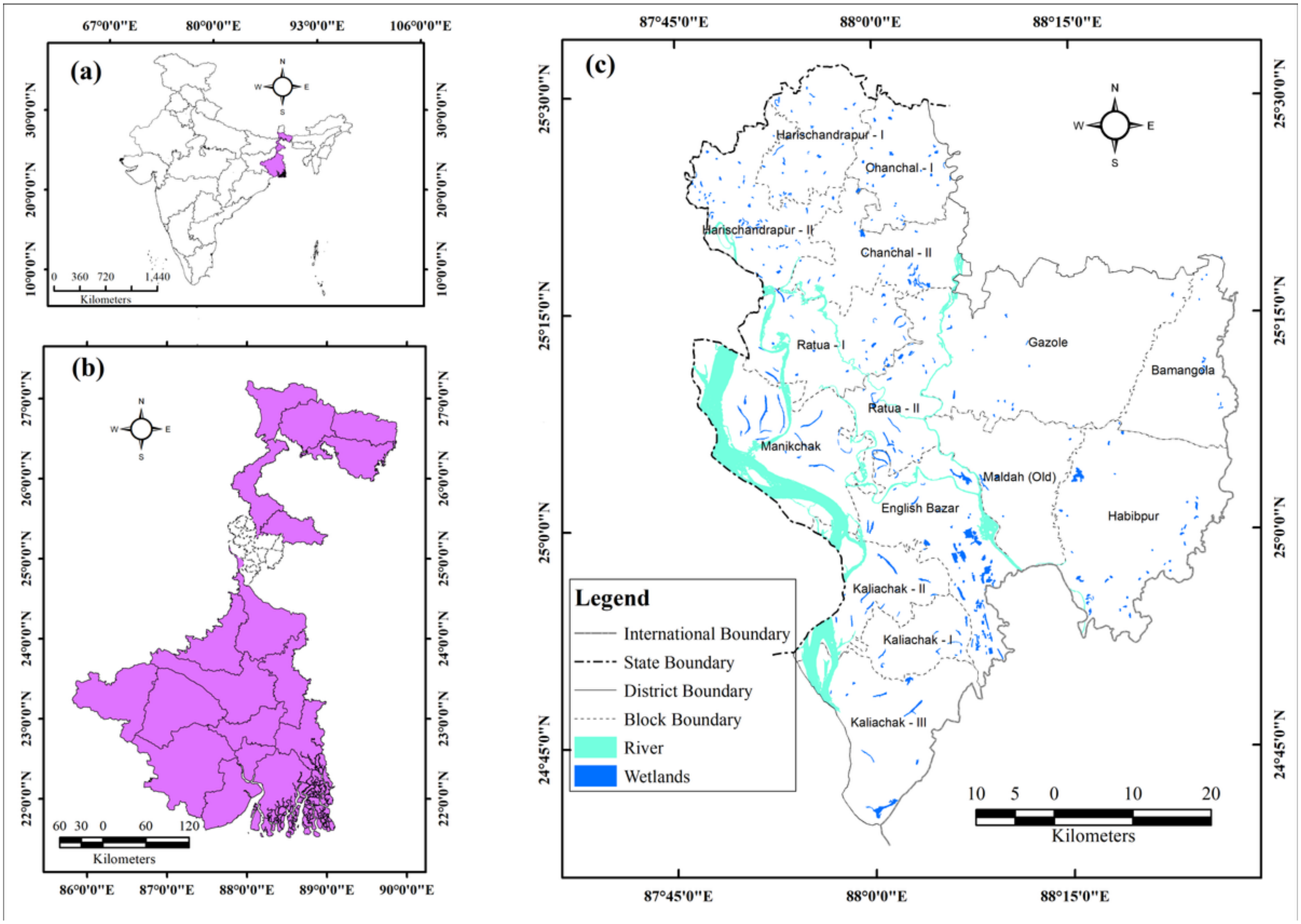

Figure 1

Location map of Mursidabad District (a) Location of West Bengal within India (b) Location of Malda district within West Bengal (c) Location of Malda district and wetlands Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

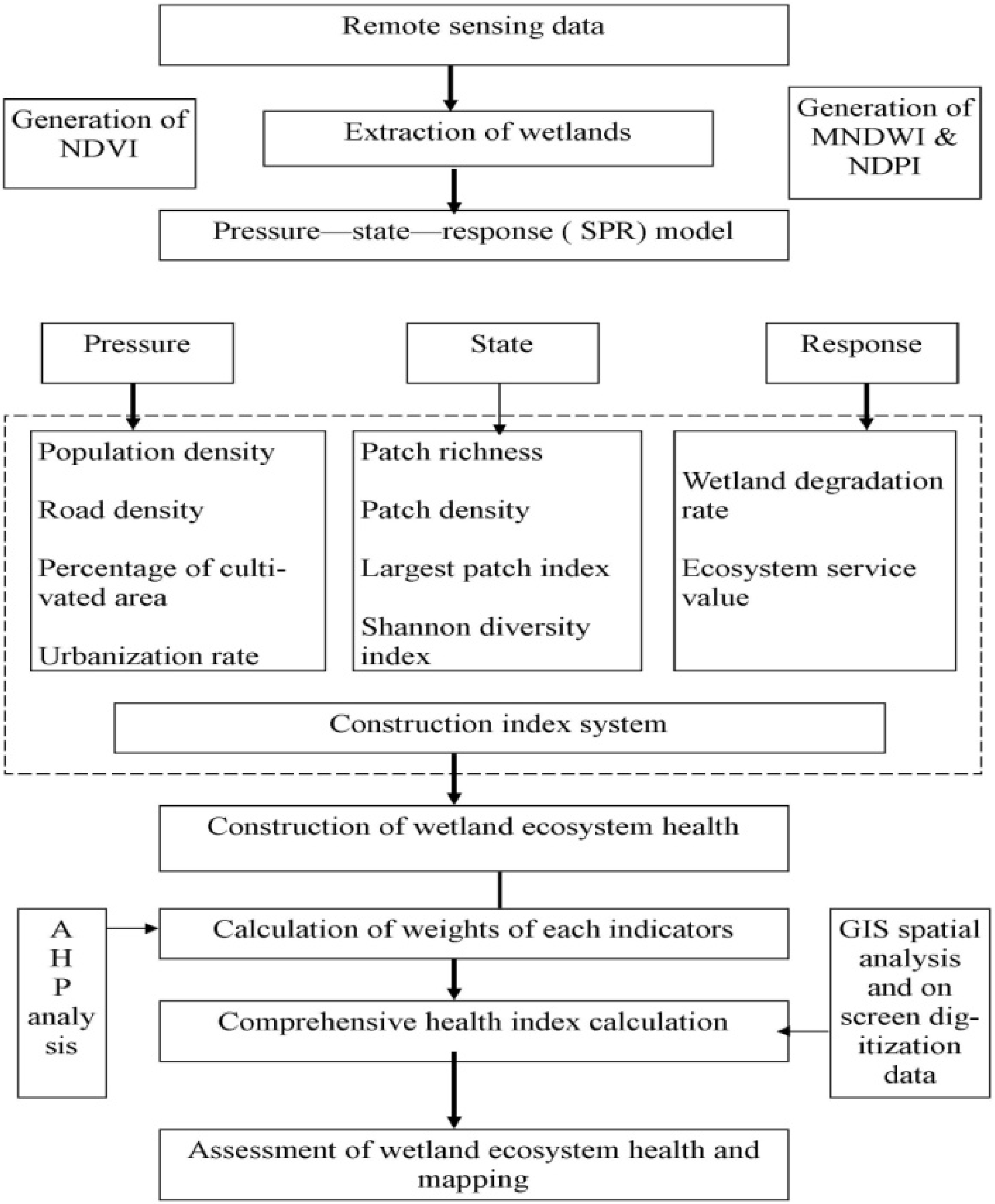

Figure 2

Flow chart of the wetland's ecosystem health assessment.

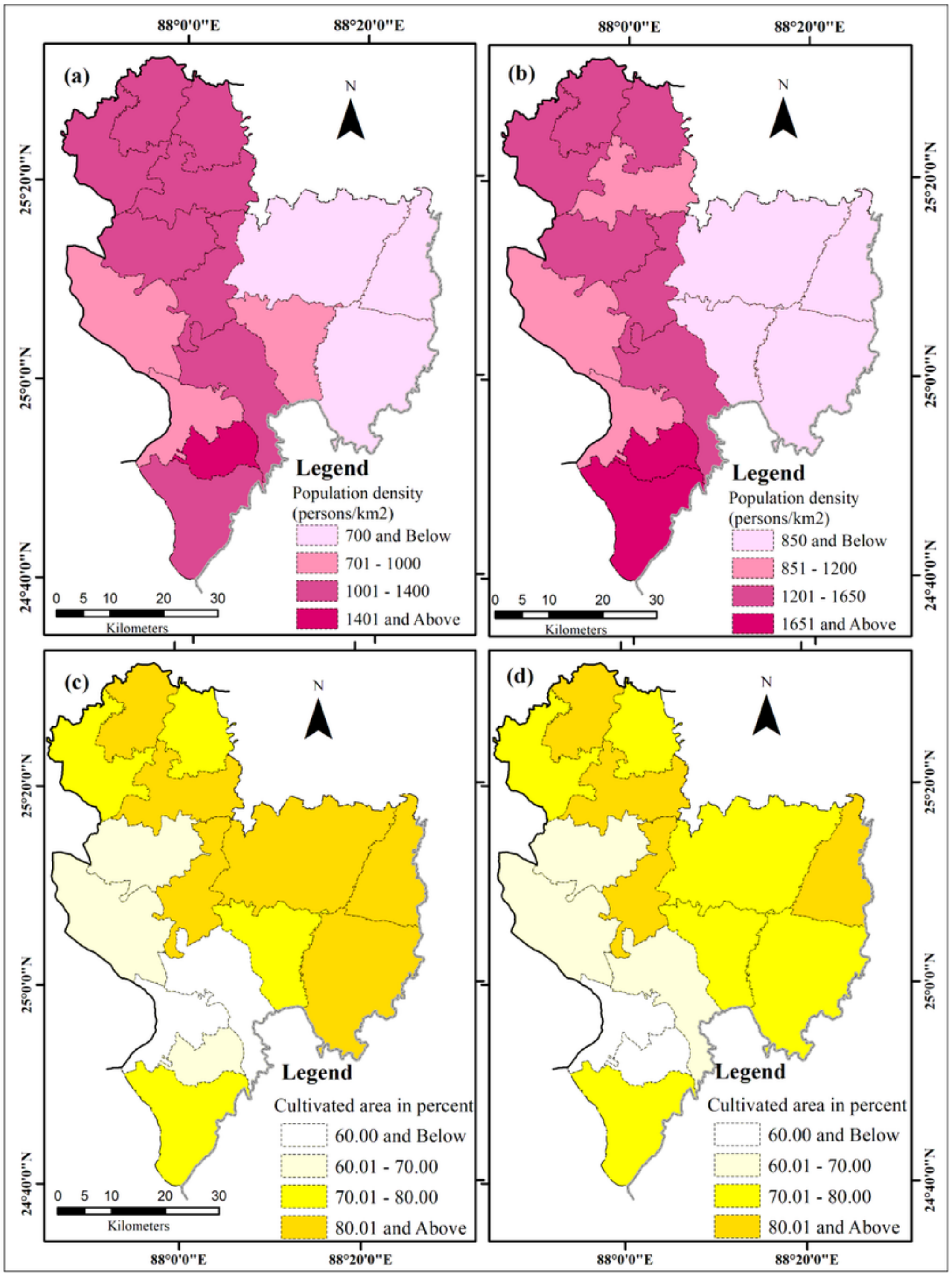

Figure 3

Distribution maps of population density in (a) 2011 and (b) 2018; and percentage of cultivated area in (c) 2011 and (d) 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

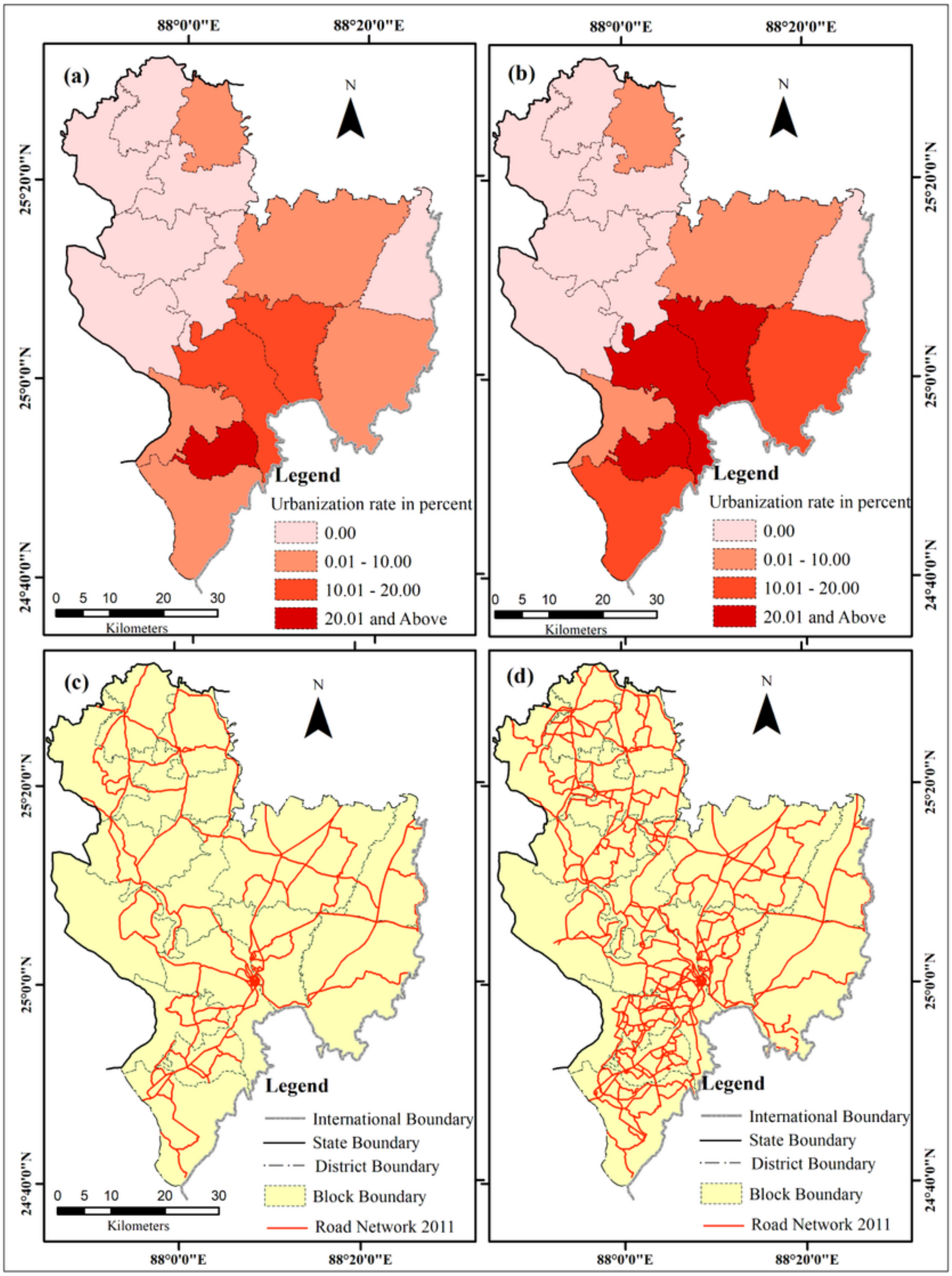

Figure 4

Distribution maps of urbanization rate in (a) 2011 and (b) 2018; and road network in (c) 2011 and (d) 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

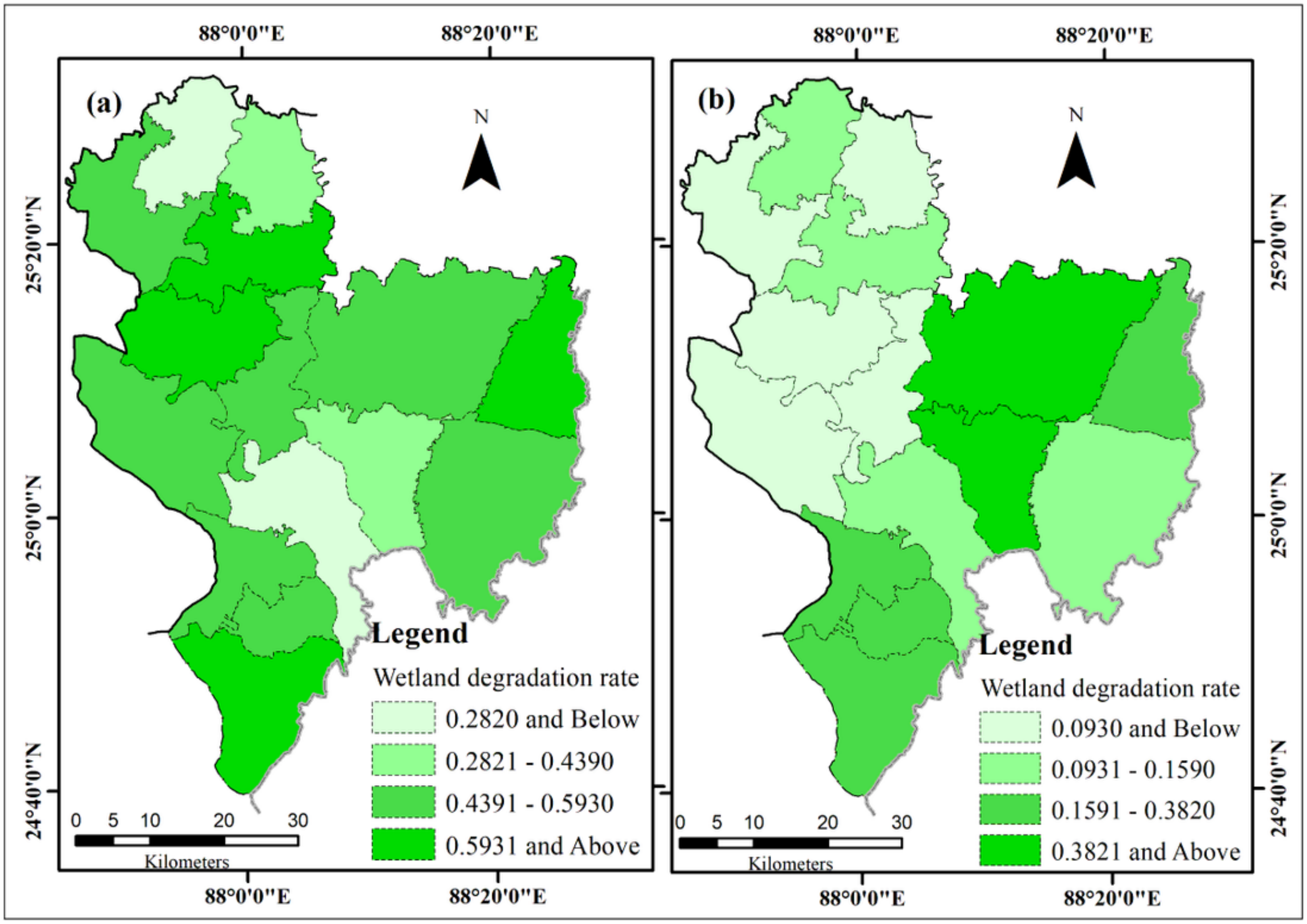

Figure 5

Distribution maps of wetland degradation rate in (a) 2011 and (b) 2018 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

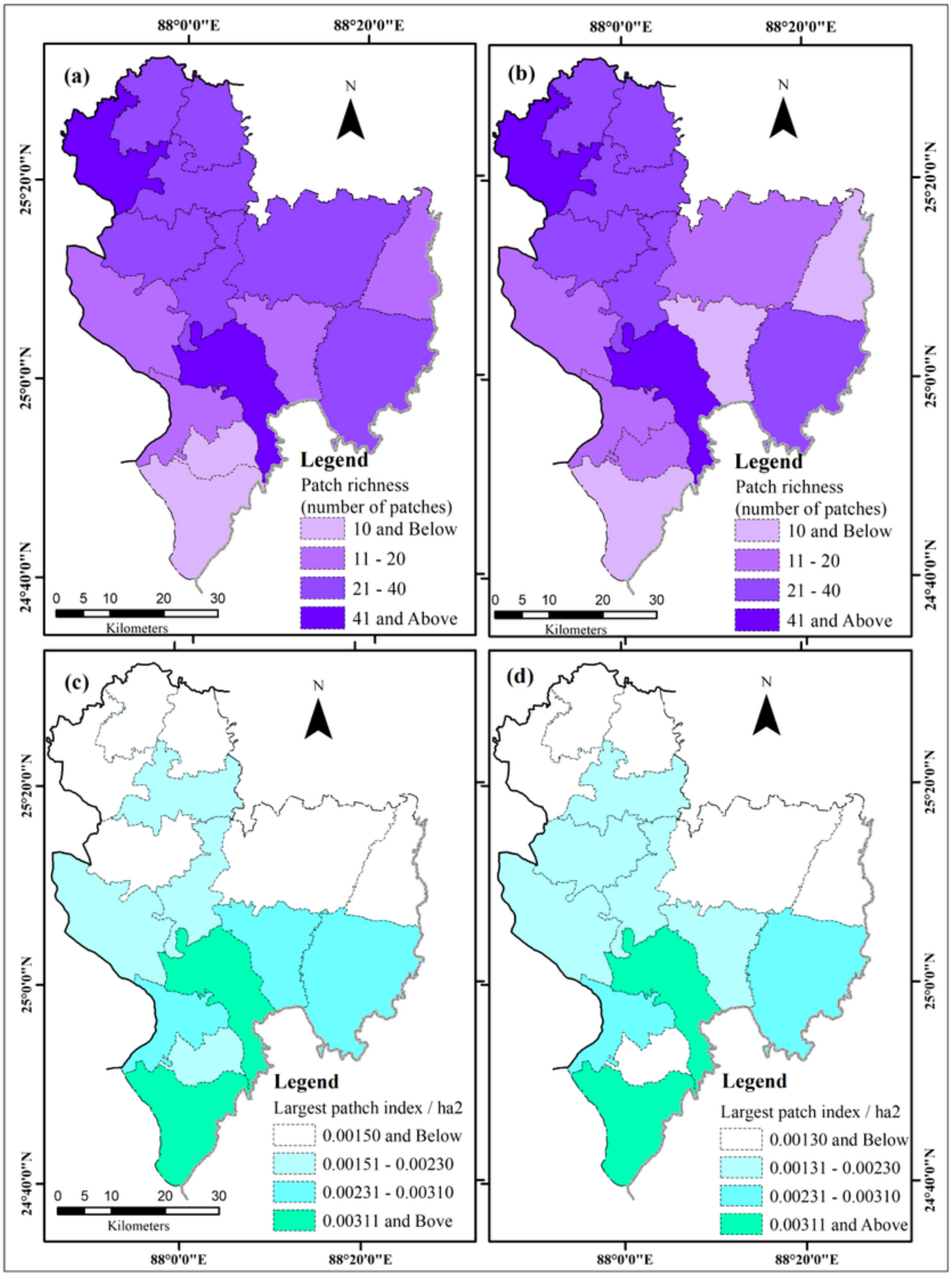

Figure 6

Distribution maps of patch richness in (a) 2011 and (b) 2018; and largest patch index in (c) 2011 and (d) 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

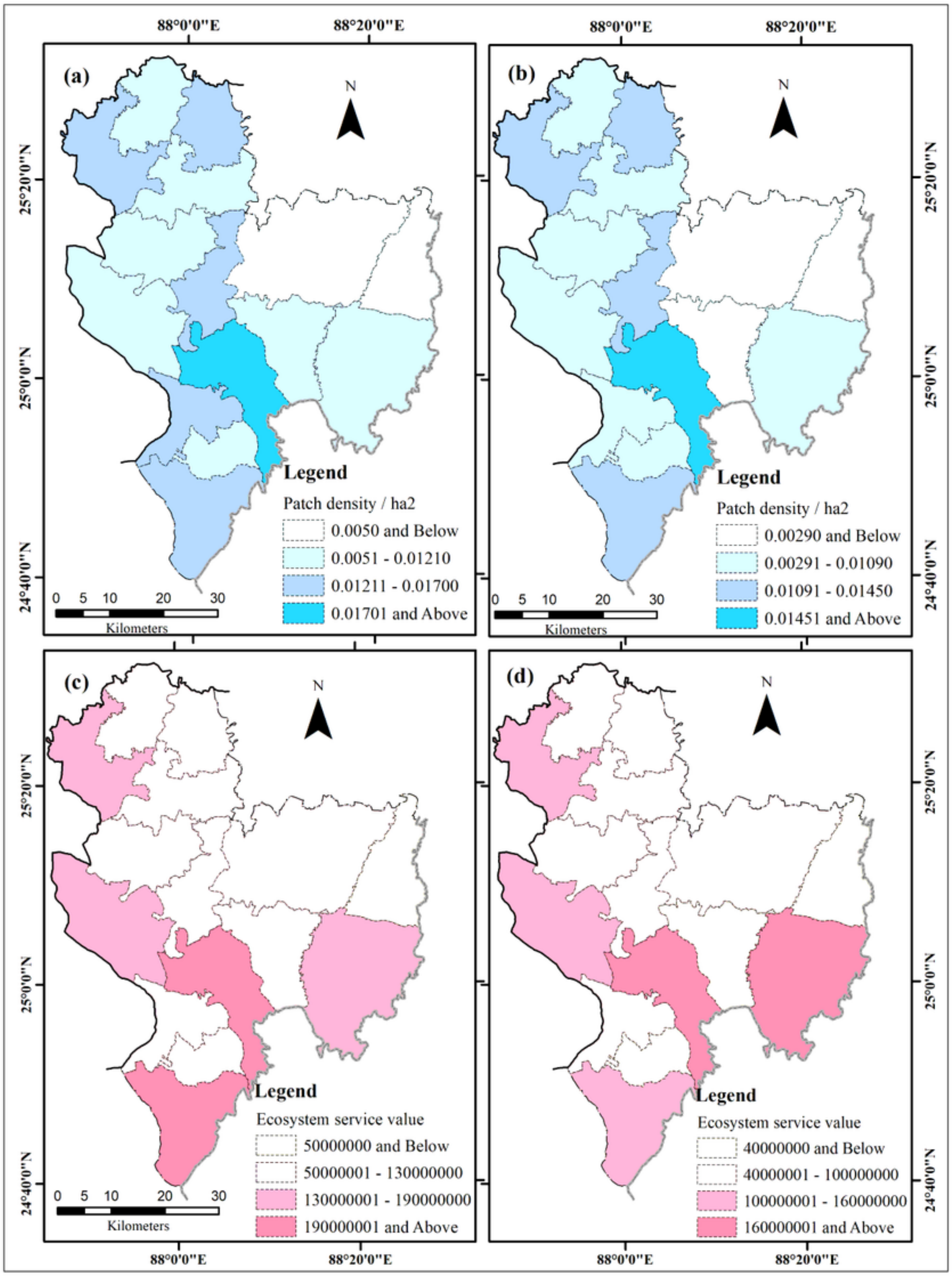

Figure 7

Distribution maps of patch density in (a) 2011 and (b) 2018; and ecosystem service value in (c) 2011 and (d) 2018. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

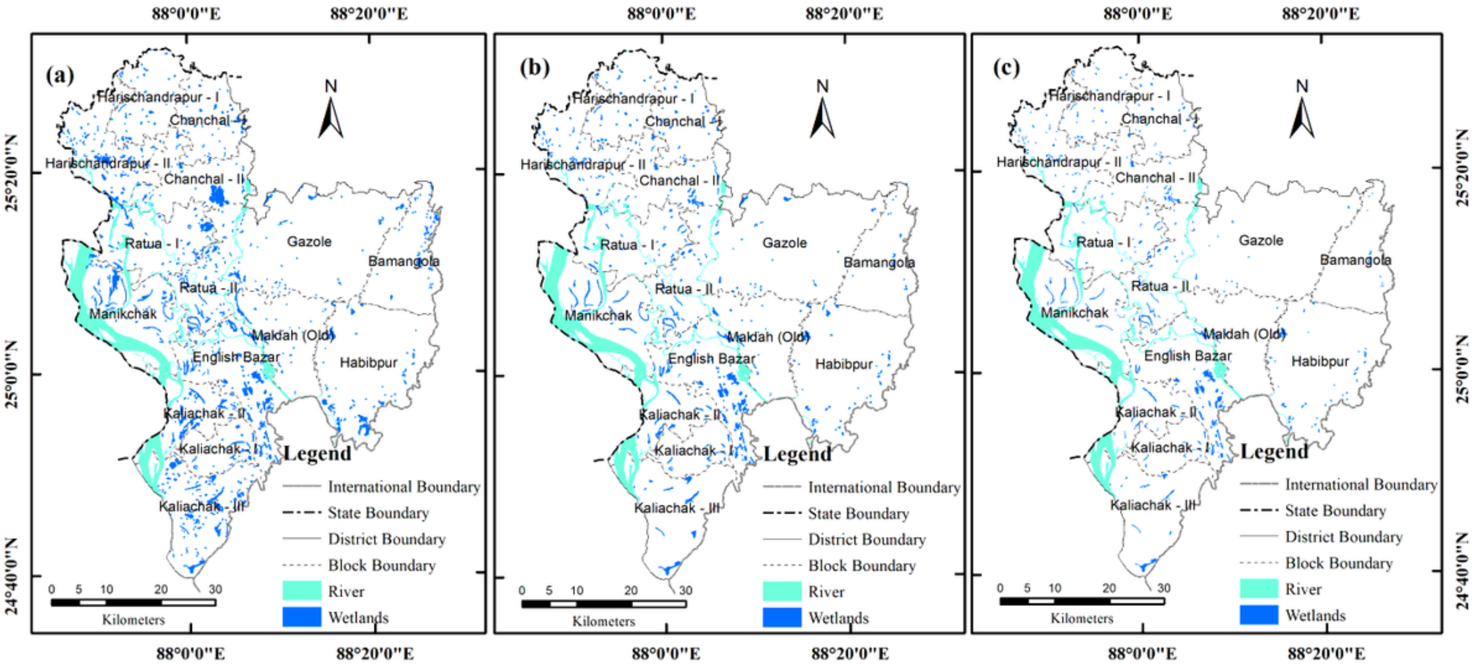

Figure 8

Distribution maps of wetlands in (a) 2001, (b) 2011 and (c) 2018 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

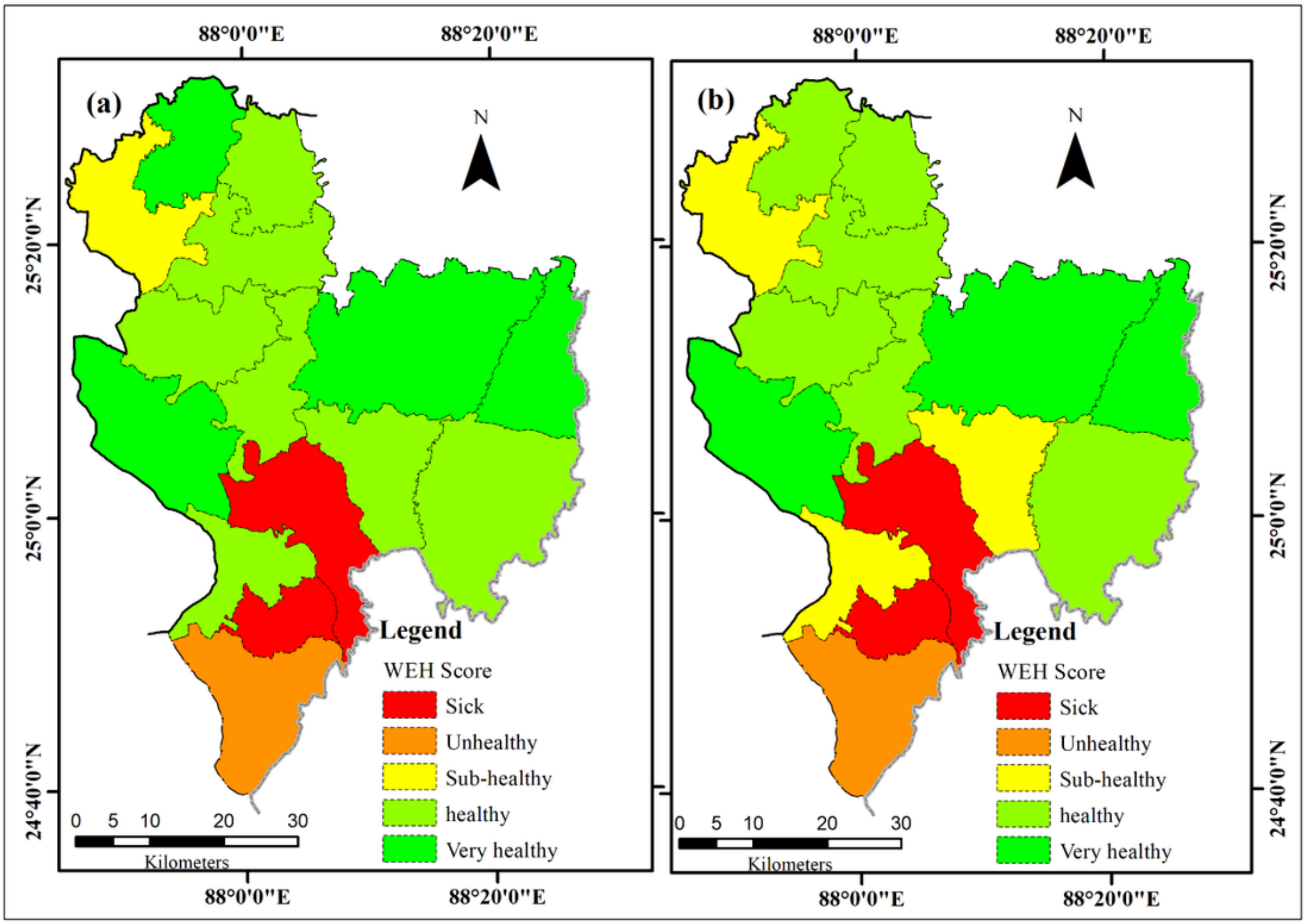

Figure 9

Distribution maps of wetlands ecosystem health index in (a) 2011and (b) 2018 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 10

Causes of wetland transformation - (a) Expansion of urbanization, (b) Expansion of settlements within wetlands, (c) Sub-urbanization related infrastructure developments within wetlands and (d) Expansion of transport network within wetlands