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Spatio-temporal habitat assessment of the Gangetic floodplain in the Hastinapur wildlife sanctuary

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A R T I C L E I N F O

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A B S T R A C T

Remote sensing provides multi-dimensional and multi-temporal information about habitat, insights into the significant drivers of change, and the key factors affecting landscape dynamics. Such information is crucial to provide perspective and a more profound understanding of ecological surveys. This study utilizes Google Earth Engine's capability to assess a riverine wetland grassland floodplain in Hastinapur Wildlife Sanctuary (HWS) along the Ganga River, which is a critical habitat for wintering migratory birds, the critically endangered gharial, turtles, aquatic mammals such as otters and dolphins, and cervid species such as swamp deer. We have developed a framework for regular monitoring through rapid habitat assessment, which visualizes the spatio-temporal change in land cover, the seasonal dynamics in water and vegetation, changes due to anthropogenic influences on the landscape, and finally, how these factors affect the habitat availability of species of concern in the HWS. The results show a dynamic river system with high seasonal variations. The vegetation trend shows increasing greenness, indicative of the conversion of grassland, scrubland, and herbaceous cover to more permanent vegetation, which will adversely affect the riparian habitat structure. A habitat suitability index generated through geospatial analysis using the weighted overlay method suggests that 40.07% of the HWS, nearly 767.12 km^2, comprising mainly the riverscape, wetland, and riparian grasslands, is suitable habitat for aquatic and semi-aquatic species. However, only 9.93% of the sanctuary comprising 197.27 km^2, is available as a core habitat. Further, the area is threatened by encroachment evident from the rapidly increasing land-use intensity and night light pollution, which puts the grasslands sheltered to swamp deer and other wildlife at higher risk leaving almost 27.9% of the area comprising 533.63 km^2 unsuitable for wildlife. Urban and agricultural land use has taken over 67% of the sanctuary. An increase in minimum radiance value representing ALAN, from 0.41 to 0.73 W/m^2-sr in just six years from 2015 to 2021, shows a reduction in nocturnal darkness, reducing safe niches for wildlife. The study results provide critical baseline information for ecological surveys and a rapid assessment platform for future sanctuary management. Constant monitoring of anthropogenic activities such as farming, settlements, and transport routes threatening the habitat is essential for informed conservation management decisions.

1. Introduction

Floodplains are an integral part of dynamic riverscapes that are often a mosaic of wetland, grassland, agriculture, and other vegetation type or even built-up area patches. While riparian floodplains are the most productive and diverse ecosystems (Tockner et al., 2008), freshwater ecosystems are still one of the most threatened and rapidly declining habitats worldwide, with more emergent threats deepening the conservation crisis (Reid et al., 2019). The Indo-Gangetic floodplains host the largest wetland system in India, encompassing the Himalayan Terai and Gangetic Plains (Prasad et al., 2002). The River Ganga and its floodplain support various terrestrial and aquatic life forms. Of the varied habitat types that it supports, the Hastinapur Wildlife Sanctuary (HWS) depicts a riverine floodplain mosaic of wetland and grassland.

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Lying in the alluvial plains beneath the foothills of the Himalayas, this region belongs to the Gangetic Grassland Biome (Rodgers and Panwar, 1988), consisting of wetland dominated area with grassland braiding the river channel along with the presence of dry scrublands and riparian forest. These diverse habitats are home to numerous aquatic and terrestrial mammals, reptiles, and bird species. Meanwhile, being the most fertile landscape, the Gangetic plains are one the most densely populated regions of the world. Especially in the last four decades, they have undergone reformation in the form of rural development, electrification, the benefit of irrigation infrastructure, and changes in cropping patterns (Dadhwal and Chhabra, 2002; Khan, 1988). The landscape thus faces acute pressures of urbanization and agricultural intensification (Hashmi, 2012; Singh et al., 2021), especially at the cost of grasslands, wetlands, and riverbeds. Quantifying the spatial and temporal dynamics of land use land cover changes is essential for better understanding and monitoring environmental changes in the riverine floodplain (Oyinloye et al., 2002; Ozesmi and Bauer, 2002). Wetlands are among the wealthiest and most diverse ecosystems (Sjöberg and Ericson, 1992), and India stands 9th in the global position in terms of freshwater mega biodiversity. India's wetlands occupy less than 5% of the country's geographical area but support nearly 20 % of the known biodiversity ((SAC), S. A. C, 2011). Despite this, it is alarming to note that wetlands, especially the small wetlands, are rapidly getting replaced by agriculture, urban and other land uses (Garg, 2015). Similarly, grasslands in India, majorly reported as five categories- montane, alluvial riverine, coastal, terai, and tropical savanna, occupy about a quarter of the geographical area and are home to many endangered deer species such as Hangul (*Cervus elaphus hanglu*), Sangai (*Rucervus eldii eldii*), Swamp deer (*Rucervus duvaucelii*), Hog deer (*Axis porcinus*) and bird species such as Great Indian bustard (*Ardeotis nigriceps*), Bengal florican (*Houbaropsis bengalensis*) and Himalayan quail (*Ophrysia superciliosa*) (Rawat and Adhikari, 2015). However, the current scenario of grassland loss due to habitat degradation, encroachment, and land conversion has pushed many of these grassland inhabiting species to the brink of extinction (Kishwan and Venkataraman, 2011). Hence conserving these precious ecosystems is a global priority.

Habitat conservation is the preliminary step for preserving Rare, Endangered, and Threatened (RET) species and preventing biodiversity loss. Habitat assessment, in terms of habitat quality, availability, and habitat use, is often species-specific and can be determined through field-based ecological surveys. Therefore, ecological studies are significant for making judicious conservation management decisions. However, collecting information for difficult terrains such as vast riverscapes, swampy wetlands, and tall grasslands is time-consuming, intensive, and financially demanding. In such cases, space science and application often provide an easier solution (Yu et al., 2019). Biological information derived from geographic information system (GIS) and remote sensing (RS) play a crucial role in creating a decision support system for informed decision-making (He et al., 2015; Larson and Sengupta, 2004; Sharifi, 1999; Varma et al., 2000; Zhu et al., 1998). Geospatial information such as seasonal variations in vegetation indices, land cover, altitude, distance from roads and urban regions, and information on habitat fragmentation can be utilized to predict eco-sensitive zones for the conservation of focal species (Prakash et al., 2018). RS data obtained from Earth-orbiting satellites has shown immense potential not just in mapping and continuously monitoring changes but also in estimating ecosystem services and modelling the dynamics in river basins (Aghsaei et al., 2020; Siachalou et al., 2014). Satellite availability and their upgradation have facilitated this task. In the past few decades, many studies visualizing land-use changes for riverine grassland areas using remote sensing have been conducted (Raj et al., 2010; Singh et al., 2016; S. Singh et al., 2020). However, preprocessing and processing the data is time-consuming and requires high-end computing and expertise, and still has glitches. Freely available satellites such as Landsat and sentinel produce images consistently with repetitive coverage at short intervals. Data acquisition has seen advancements in high resolution, hyperspectral satellite imagery, and other datasets such as Synthetic-aperture radar (SAR), Light Detection and Ranging (LIDAR), thermal and acoustic, etc. Concurrently, big data analytics and cloud computing have revolutionized data processing, drastically reducing the effort, time, and assets required for computation (Assunção et al., 2015). Open data and code sharing have globally promoted learning and collaborations. Data-driven technology based on algorithms has the potential to process in the cloud. In recent years, Artificial intelligence employed in server-side processors such as NASA Earth Exchange (NEX), Amazon Web Service (AWS), Intel, Azure, and Google Earth Engine (GEE) has dramatically improved Land use land cover (LULC) classification accuracy and statistical analysis (Amani et al., 2020; Ferreira et al., 2020; Lee, 2012; Nemani, 2011; Sugumaran et al., 2015).

GEE is a server-side image processing software that provides satellite images and geospatial datasets with instant access using a code editor (Gorelick et al., 2017; Navarro, 2017). GEE allows users to run their script in JavaScript/ Python for data import, load, process, analyse, visualize, generate graphs, charts, and export results (Agapiou, 2016; Gorelick et al., 2017; Schmid, 2018). Google colaboratory, also called Colab, a product of Google research, is configured with cloud-based deep learning libraries and graphical processing units (GPU) (Carneiro et al., 2018; Colaboratory: Frequently Asked Questions, 2018).

Environmental data provides a blueprint of the habitat types in the landscape and tells about the habitat quality. Since the study area lies in a riverine wetland grassland floodplain, the key players are water, sand, and vegetation. The dynamics of these parameters in the landscape create vibrant habitats. However, anthropogenic activities such as farming, settlements, and transport routes are a threat to the habitat and need to be closely monitored for conservation management.

The previous studies conducted in and around HWS and the Upper Ganga Ramsar site includes an inventory of mammals, birds, and reptiles (Bashir et al., 2012), distribution of otter (Khan et al., 2014), migratory birds (Khan et al., 2013; Riyaz, 2000), a record of aquatic insects (De et al., 2021). Shruti and Dipti Adhikari, 2019, reported that only 50–60% of riparian vegetation at Bijnor and Tigri ghat are native. Boruah et al., 2019, noted the highest species richness for amphibians and reptiles near Bijnor compared to the entire length of Ganga. Nandy et al., 2012, performed a multi-criteria analysis using AHP for habitat suitability of Jhilmil jheel upstream of HWS for swamp deer. Paul et al., (Paul et al., 2018; Paul et al., 2020; Paul et al., 2021) have studied the distribution of swamp deer amidst the changing grasslands of upper Ganga and concluded that the survival of swamp deer is at stake due to loss of natural vegetation, habitat fragmentation, and human interference. The previous studies tried to look at HWS's habitat quality with a focus on a single species or class. This study looks at the Sanctuary as a combined habitat for aquatic and semi-aquatic animals such as swamp deer, turtles, crocodiles, water birds, otters, dolphins, etc. It provides a snapshot of the current situation of the habitat, especially the riparian habitat in a single framework. This is therefore one of the first studies which has considered a multi species approach towards conservation looking at the habitat availability and utilization on spatial scale.

Our primary objective was to delineate water bodies, sand bars, and grasslands and detect spatio-temporal changes in land cover and land use. This paper discusses how such information can understand the habitat availability and, therefore, help in surveying animals, especially crocodiles and deer, in a dynamic riverine wetland grassland landscape. At present, there is no easy-to-use, up-to-date monitoring platform accessible to park managers. Such platform based analysis can be applied to other areas of interest for rapid habitat assessment based on multi-temporal seasonal scales.

2. Material and methods

2.1. Study area

Hastinapur Wildlife Sanctuary belongs to the Upper Gangetic Plain

(7A) biogeographic zone (Rodgers and Panwar, 1988). It occupies 2073 km^2 on both sides of the Ganga River between 28° 46′–29° 35′ N and 77° 30′–78° 30′ E in Uttar Pradesh, India (Fig. 1), with an elevation gradient of 130–150 m above sea level. It is the largest Wildlife Sanctuary of the State and along the Ganga, spreading over Bijnor, Muzaffarnagar, Meerut, Amroha, and Hapur districts of Uttar Pradesh, giving protection to approx. 110 km of River Ganga. It was established in 1986 as part of the "Asia Flyway" Project to protect the State bird and animal Saras Crane (*Antigone antigone*) and Swamp Deer or Barahsingha (*Rucervus duvaucelii duvaucelii*). Other mammals include Hog deer (*Axis porcinus*), Spotted deer (*Axis axis*), Sambar deer (*Rusa unicolor*), Blackbuck (*Antilope cervicapra*), Nilgai (*Boselaphus tragocamelus*), wild boar (*Suss crofa*), Golden jackal (*Canis aureus*), Jungle cat (*Felis chaus*), Fishing cat (*Prionailurus viverrinus*) and Smooth-coater otter (*Lutrogale perspicillata*) have also reported (Paul et al., 2018; Singh and Chaturvedi, 2017). With over 200 species of birds, a large flock of migratory water birds also visits this area giving it the status of IBA, Important Bird Area (Arya et al., 2020). As per grasslands classification (Dabadghao and Shankarnarayan, 1973), western Uttar Pradesh is dominated by the sub-tropical grasslands *Dichanthium-CenchrusLasiurus* in the dry regions, while the wet and

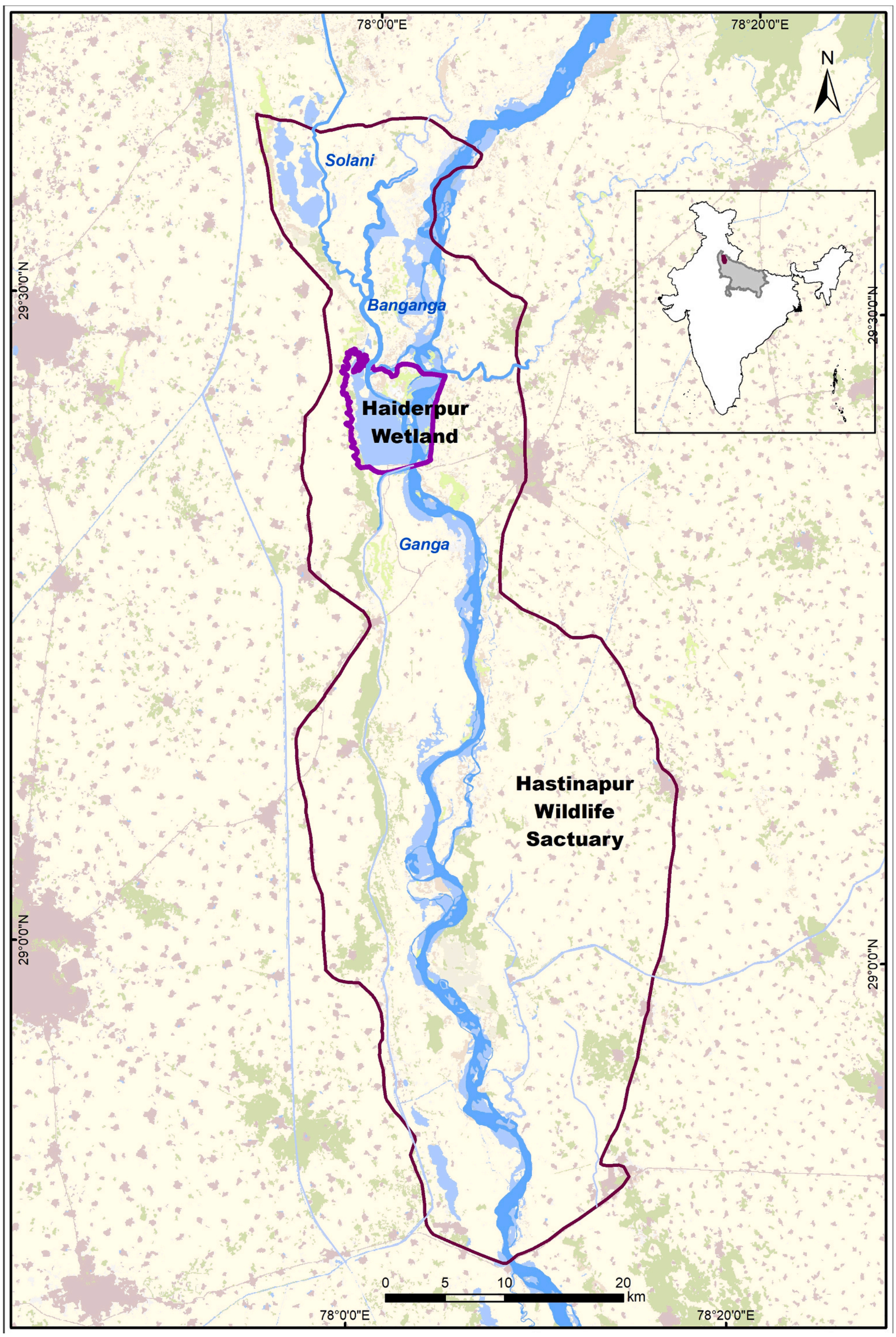

Fig. 1. Study area map of HWS.

moist habitats of riverine plains are dominated by Phragmites (*Saccharum-Imperata*). The vegetation of the sanctuary can be classified into tall wet grasslands, short dry grasslands, scrub, and plantations, and the dominant natural vegetation comprises grasslands dominated by Phragmites, Typha, Saccharum, etc. (Khan et al., 2003; Singh and Chaturvedi, 2017). It provides shelter to many wildlife species, helps in flood control, and supports livelihoods, among several ecosystem services. It was identified as a Key Biodiversity Area in 2004 and fell within the Upper Ganga Ramsar site. HWS also contains a manmade wetland known as Haiderpur wetland, formed as a result of the backwaters of the Ganga River after the construction of the Bijnor Barrage in 1985. In 2021, recognizing its significance, it has also been added to the Ramsar list.

2.2. Tools and technique

GEE offers a script library with many pre-written codes and examples of using various functions. It also possesses a substantial well-organized dataset collection of preprocessed and processed satellite images and data products. This study utilizes the GEE library and Google Colab notebook to derive insights into the desired study area. ArcGIS 10.6 software was used for geospatial analysis.

The current study looks at the study area based on different datasets to choose sites that could yield the best results while sampling. Initially, the topographic data was loaded from the ee.ImageCollection ("JAXA/ALOS/AW3D30/V3_2") in the GEE library. It provides the digital elevation model at 30 m resolution and the slope data at the same resolution that helps to understand the terrain. The data was visualized and clipped to the study area extent. For current habitat information and estimation of anthropogenic influences, Land Use Land Cover at 10 m ground resolution for the year 2020 from Copernicus-Sentinel based ESRI dataset was used. ISRO-NRSC LULC product at 1:250000 scale prepared from Advanced wide field sensor (AWiFS) data of ~54 m resolution was used to track the decadal change between 2005 and 2015. Seasonal spatio-temporal variation in water within the study area was visualized using Sentinel 1 SAR data, as shown in the Table 1. Landsat 5 imagery of 30 m resolution belonging to over three decades was utilized to observe the long-term changes in the water channel (Orengo and Petrie, 2017). Variation in vegetation was observed using Landsat Enhanced Vegetation Index 8-day composite product. The VIIRS nightlight data of stray light corrected monthly average radiance composite was used to understand the stray light pollution within the study area and the impact of urban lighting. The transportation routes, and railway and road network were visualized through Open Street Map dataset. The land surface temperature (LST) data obtained from MODIS was used to understand the urban heat island effect. Species presence information obtained from published secondary data sources were incorporated as biodiversity hotspots. Habitat classes were identified from The Copernicus-Sentinel-based ESRI Land Use Land Cover 2020 classified dataset.

2.3. Methodology

Our primary objective was to understand the seasonal dynamics in the riverscape of water and sand bars and the natural vegetation such as scrubs and grasslands, the significant habitats. Decadal change in land cover was assessed using a change detection tool. Apart from this, habitat classes - river, sand bars, grassland, scrubland, and plantations were delineated. Plantations, agroforestry, or sugarcane fields often offer an excellent hide-out shelter for small mammals and birds and hence be considered habitats. This study used the following datasets: Landsat, Sentinel, Moderate Resolution Imaging Spectro Radiometer (MODIS), and Visible Infrared Imaging Radiometer Suite (VIIRS) satellite imagery in the GEE library and utilized the GEE and Colab platform for analysis.

Table 1
Dataset used for the study.

Category type	Title 2	Period
Land cover classification	ESRI Land cover 2020 ESA Sentinel-2 imagery at 10 m resolution projects/sat-io/open-datasets/landcover/ESRI_Global-LULC_10m (ESRI, 2021)	2020-01-01–2020-12-31
Habitat association	Sentinel-2 MSI: Multispectral Instrument (ID: COPERNICUS/S2; COPERNICUS/S2_SR) (Sentinel, 2C.E.)	
Water Dynamics Seasonal	Sentinel-1 SAR GRD: C-band (ID: COPERNICUS/S1_GRD) (Sentinel, 2C.E.)	2016-01-01–2020-12-31
Water Dynamics long term	Landsat 5 TM 8-Day EVI Composite SMTVI (Seasonal Multi Temporal Vegetation Index) (ID: LANDSAT/LT5_L1T_8DAY_EVI) (Orengo and Petrie, 2017)	1984-01-01 - 2012-05-05
Vegetation dynamics Seasonal dynamics	Landsat 8 Collection 1 Tier 1 8-Day EVI Composite The Enhanced Vegetation Index (EVI) Near-IR, Red and Blue bands of each scene, and ranges in value from −1.0 to 1.0 (ID: LANDSAT/LC8_L1T_8DAY_EVI	2013-04-07 - 2022-01-01
Vegetation dynamics long term variation	SAR Bands comprises of VV and VH of annually for last 10 years COPERNICUS/S1_GRD	2014-10-03 – current
Anthropogenic influences Change in temperature	1) MOD11A1.006 Terra Land Surface Temperature and Emissivity Daily Global 1 km (ID: MODIS/006/MOD11A1) 2) MCD12Q1.006 MODIS Land Cover Type Yearly Global 500 m(ID: MODIS/006/MCD12Q1)	1. 2000-03-05- 2021-12-07 2. 2001-01-01 - 2019-01-01
Anthropogenic influences Change in urban land use	Rail and Road network- Open Street Map	
Anthropogenic influences Change in nightlight	VIIRS Stray Light Corrected Nighttime Day/Night Band Composites Version 1 (463.83 m (ID: NOAA/VIIRS/DNB/MONTHLY_V1/VCMSLCFG)	

The seasonal and annual variation in the water dynamics for the period from 2016 to 2021, was visualized by filtering and grouping Sentinel-1 SAR data into three seasonal sets- monsoon, post, and pre-monsoon and visualizing them with RGB bands. This gave a composite image where each of the RGB bands depicted a season, and overall highlighted changes between the seasons. A similar visualization was done with Sentinel multispectral imagery to derive the seasonal Modified Normalised Differential Water Index (Xu, 2006). However, compared to Sentinel multispectral data, Sentinel SAR data accurately identified water and gave better results from multispectral image analysis. The grouping of months to represent season was done per climate in the Gangetic Plain; months from July to September were treated as monsoonal months, March to June as Pre-monsoon and October to February as Post-monsoon months.

The seasonal and annual variation in the vegetation dynamics were visualized by filtering and grouping Landsat EVI (Enhanced vegetation index) 8-day composite data from 2013 to 2020 into two seasonal sets, monsoon and post monsoon. A conceptual framework for the methodology workflow diagram is shown in (Fig. 2).

The anthropogenic influences were estimated from agricultural land use, land surface temperature variations and the presence of night light and built-up. Finally, to understand the habitat availability and quantify the habitat suitability for aquatic, semi-aquatic, and water-dependent species, a Weighted Overlay analysis was performed using the Spatial Analyst tool in ArcGIS 10.6 (ESRI). Land Use Land Cover 2020 was reclassified as per habitat preference. Water, flooded vegetation, scrub

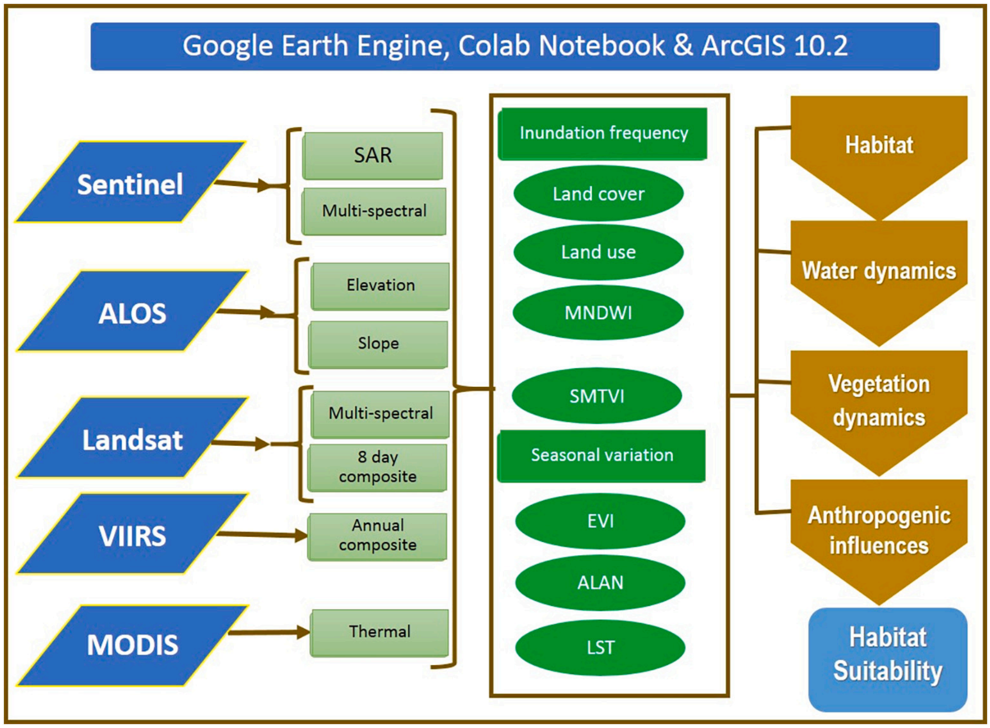

Fig. 2. Methodology workflow diagram.

and grassland classes were given high scores, followed by bare ground (which primarily included river sand) and trees. The former form the critical habitat areas while the latter provide basking sites for gharial and roosting sites for birds, respectively. Agriculture was given a low score, while the built-up area was given a negative score, as these two are the major threats that negatively influence the habitat. Distance to streams and distance to transportation routes (railway and roads) obtained through buffer analysis were given maximum positive and negative scores, respectively, as per their influence on the habitat. Nightlight was used as a proxy for anthropogenic disturbance, and the dark sky was given a high positive score while the urban sky was given a negative score. Biodiversity hotspot information obtained from previous studies was incorporated with a maximum positive score LULC was given a weight of 2, and the other four layers were given a weight of 1.

3. Results

3.1. Land cover classification

The AWiFS land use land cover data at a 1:2,50,000 scale by the National Remote Sensing Centre, ISRO, for the period of 2005–06 and 2015–16 was compared to observe the decadal changes in the study area. As per this data, the built-up area has undergone a 0.28% increase from 2005 to 2015. The intensity of agriculture has increased, showing an overall growth of about 17% and a 30% increase in the area particularly under double and triple cropping. This could be accounted to improvement in the irrigation infrastructure. The area under barren or fallow land was reduced by 16.26%. While there was a minor increase in plantation and degraded scrubland, there was a minor decrease in grassland and deciduous forest. The difference in the area classified as waterbodies min and waterbodies max as per this classification indicates that during the monsoons, the river swells up to 10 times its area. Also, as compared to the 2005–06 period, the minimum area occupied by water bodies in summer had reduced by 0.85%, indicating more shrinkage of water bodies in summer from the last decade. Since the previous data was available at a crude resolution of ~54 m, the Copernicus Sentinel land use land cover product developed by ESRI at 10 m resolution for 2020 was examined. According to this data, as shown in (Fig. 3), agriculture was the major land use occupying 59.19% of the study area, followed by 7.9% area occupied by built-up. Land cover is predominantly tree cover stretching over 22.8%, mostly in the riparian belt along Budhi Ganga and the plantations and orchards around towns such as Bijnor, Mandawar, Chandpur and Bachhraon. The riverscape comprises of 3.65% (72.55 km^2) water, 1.74% sand (34.58 km^2), 1.05% grass (20.82 km^2), 0.21% flooded vegetation (4.18 km^2) and 3.28% scrubland (65.14 km^2). This 197.27 km^2 area surrounding the riverscape could account for the core habitat area for aquatic and semi-aquatic animals. It is alarming to note that 67% of the geographical area of HWS is covered by agriculture and built-up. The area is, therefore, heavily under anthropogenic influence.

3.2. Water dynamics

3.2.1. Seasonal variation

The major rivers flowing through Hastinapur are Ganga, Solani, Banganga, BudhiGanga, Malini and Chhoeya. Apart from this, the Madhya Ganga Canal, being unlined also serves the function of river augmenting soil moisture and ground water recharge due to seepage. During non- monsoon period, the canal has little standing water and it is invested by grasses providing perfect spawning and breeding ground for small fishes, mollusks, amphibians and water birds. The year-wise Sentinel SAR image composites grouped for pre, post, and monsoon, period stacked, and visualized in different bands, indicate the seasonal and year wise changes in the water level. In (Fig. 4. (a)), the red color indicates the bankful width in the monsoon, and post-monsoon period, while blue indicates the water level in summers. As revealed by the images in (Fig. 4(a)), many active channels of 2016 have thinned out by 2019, and there are changes in the river course and morphometric characters such as braids and meanders. These changes can also affect the habitat availability of shore dwellers and nesting sites for breeding birds and reptiles. In (Fig. 4(c)) seasonal water change chart is shown. In general, the high water levels last from July to September and low water level from April to June.

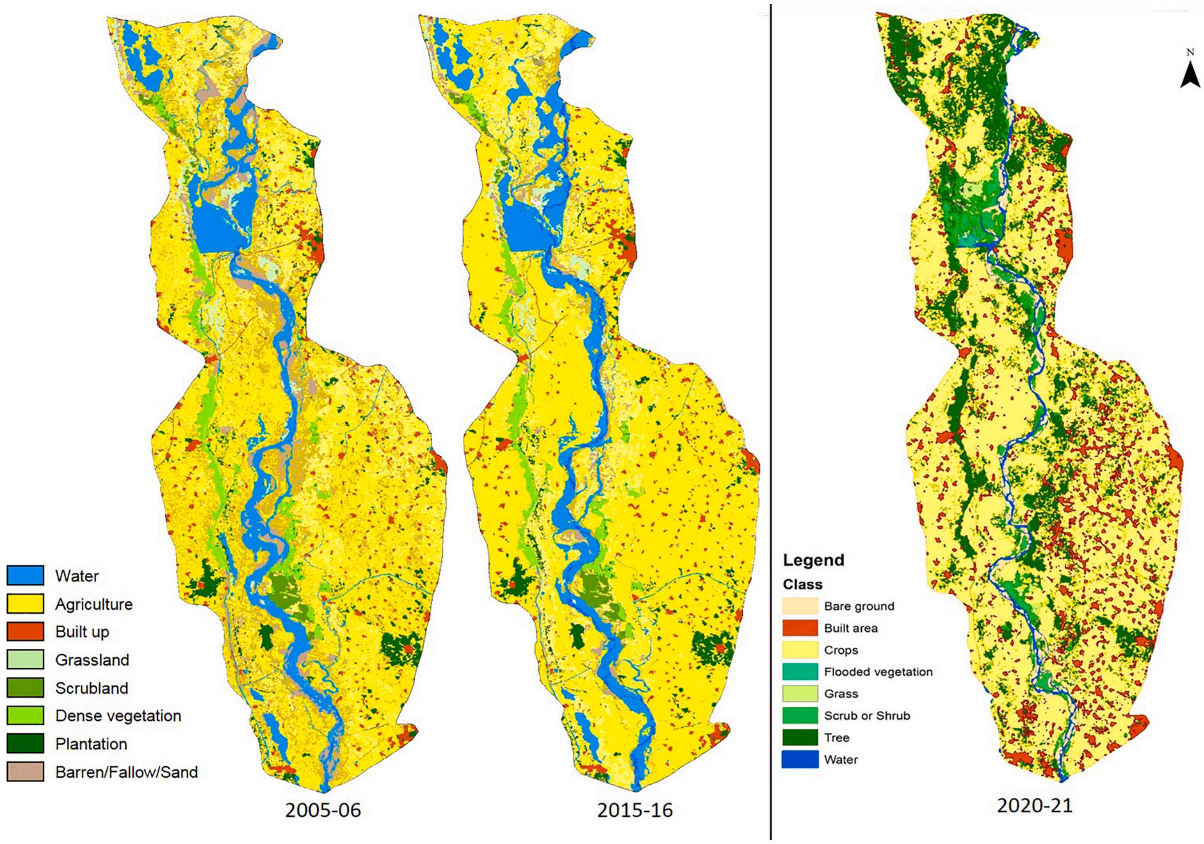

Fig. 3. LULC map for the year 2005–06 and 2015–2016 taken from NRSC and year 2020-21from ESRI.

3.2.2. *Long term variation*

The map in (Fig. 4(b)), show the inundated pixels along the river based on SAR imagery. The maximum water levels were noted in August. The chart (Fig. 4(c)) shows the month-wise dynamics in water levels from 2015 to 2021. Images of monsoonal period also help identify inundation zones as shown in (Fig. 4(b)) in the year 2017 and 2018. This can help identify alternate channels, oxbow lakes and other wetlands in the flood plains; and study lateral connectivity and strategize flood mitigation. The (Fig. 4(d)) shows SMTVI (Seasonal Multi-Temporal Vegetation Index) that helps identify paleo channels. This index uses season wise stacks of Vegetation Index over a long period to visualize long-term seasonal changes in vegetation structure. Since, the vegetation, especially of dry and monsoonal months is highly correlated to the presence of waterbodies, the SMTVI is a good indicator of perennial and seasonal water bodies that are generally undetected in the regular water indices. The image (Fig. 4(d)) comprises a composite of Landsat 5 data of 30 years and a stack of seasonal EVI. While the black regions indicate perennial water bodies, the green color represents seasonal water, and the blue color indicates paleo channels. Paleo channels are river channels that run dry due to channel migration or reduced flow, but still possess sub surface flow. The Ganga River has shifted its course almost up to 3 km to the east in the middle region of the HWS. The old channel locally known as Budhi Ganga has been reduced to a thin seasonal stream and the old riverbed has been brought under cultivation. The SMTVI is an excellent index capable of detecting seasonal streams that are otherwise difficult to delineate.

3.3. *Vegetation dynamics*

3.3.1. *Seasonal variation*

Enhanced Vegetation Index is an optimised vegetation index, using near infrared, red and blue bands, with improved high biomass sensitivity and atmospheric noise and background canopy corrections. The following images in (Fig. 5). show seasonal Landsat 8 Collection 1 Tier 1 composite EVI (Chander et al., 2009) was prepared from 2013 to 2020 for pre monsoon (dry) and monsoon period (wet). There is a stark contrast between the dry and wet periods in the landscape. While only the plantations, grasslands of Haiderpur wetland, and vegetation adjoining the streams and canals seem to sustain even during the dry seasons, the fields remain fallow, and riparian grassland vegetation can be demarcated. During the wet season, the farms are converted to green. The dark green patches seen in the fields could be sugarcane patches. A few such points were verified during a ground truth field visit in September 2021. Permanent vegetation include plantation by forest department or orchards around towns.

3.3.2. *Long term variation*

Comparison of EVI from 2013 and 2020 shows an increase in permanent vegetation from 2013 (Fig. 5). This could be due to plantation activities undertaken as part of management practice. In addition, in the wet season, the dark green patches seem to be increasing, which could indicate the increase in sugarcane farming in the area. The vegetation shows an increasing trend from 2013 to 2020 as evident from the various classes based on EVI value depicted in (Fig. 5). Though it might look like a positive change, it could indicate the replacement of the natural grassland ecosystem with perennial vegetation or crops. Field visit for ground truth revealed that many of the grasslands were converted to agricultural fields predominantly to sugarcane. A very small area of the sanctuary has forest or natural vegetation. The entire sanctuary is a sugarcane belt intermittent with poplar and other agroforestry crops. Even river banks and river islands were utilized for cultivation of summer crops such as musk melon, watermelon, cucumber, summer squash, various gourds, corn, pumpkin, tomato, and beans. As a measure to control encroachment by farmers, the forest department undertook

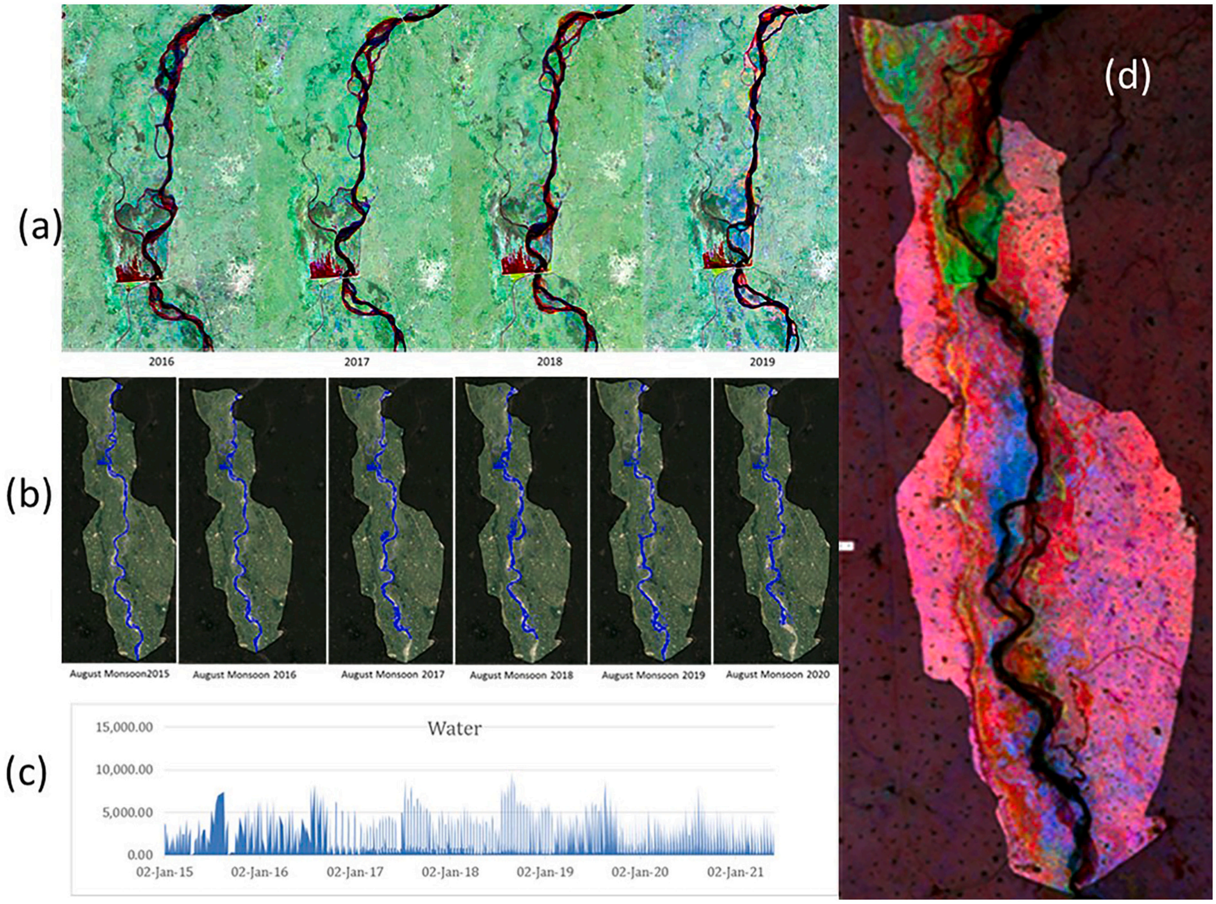

Fig. 4. Image depicting (a) Seasonal change Sentinel SAR Image for HWS for the year 2016, 17, 18, 19 and 20. (b) Monsoonal inundation for the year 2015–20 (c) Seasonal.

plantation activities, replacing the grasslands. Grasslands are rapidly depleting and even the remaining patches face heavy disturbance from people and cattle.

3.4. *Anthropogenic influences*

3.4.1. *Change in nightlight*

Artificial lighting at night (ALAN) indicates the human presence and a measure of infrastructural encroachment and development (Elvidge et al., 2017). Analysis of VIIRS nighttime data reveals an increase in the presence of light within the HWS. The minimum radiance value within the study area increased from 0.41 W/m^2-sr in 2015 to 0.70 W/m^2-sr in 2018 and 0.73 W/m^2-sr in 2021. This indicates a reduction in the natural nocturnal darkness in the region. Nocturnal darkness is important for maintenance of circadian rhythm, metabolism and stress levels. The mean value of nighttime radiance shows a similar rising trend with 0.72, 0.91, and 1 [W/m^2-sr] for 2015, 2018, and 2021 respectively. The map shown in (Fig. 6(a-c)) portrays the rising illumination within the HWS and its surrounding areas in the last five years. More striking is the rise in illumination around the HWS, especially in the large PA cities, Delhi, Meerut, Muzaffarnagar, Bijnor, Chandpur, Hastinapur, Amroha, Gajraula, and the transport routes between them. In a recent study, (Bedi et al., 2021) classified night sky based on light pollution. Similar classification for the study area revealed prominent results. Based on VIIRS data, as is apparent in (Fig. 6(d)), the area under Urban and Semi-Urban sky doubled, and the area under Rural sky tripled. Dimly lit sky increased by over five times while the area under Dark sky reduced from 92% to 67%. It is evident that the sanctuary has been filled with artificial lights over the years, and the riverscape habitat is being encroached on peripherally.

3.4.2. *Change in temperature*

The land surface temperature (LST) provides an approximation of heat emitted by a unit surface. (Fig. 7 (a)) shows the variation in LST within HWS. The first image shows the annual composite of 2020, while the second and third images depict the LST during summer (max up to 41 °C) and winter months (min up to 15 °C). The red hotspots in the annual composite are urban heat islands (UHI) over major urban built-up areas. Comparison of MODIS LST of last five years for rural spot and the nearest urban spot of Bijnor show a clear difference in the temperature of both the settlements. There is a temperature difference of 2° to 5° between rural and urban temperatures, as shown in (Fig. 7 (b)). This means that the urban presence has the potential to increase land temperatures.

3.4.3. *Habitat suitability*

The Habitat Suitability map in (Fig. 8). highlights in dark blue, the regions that are the most suitable habitats with minimum threats. The areas in light blue also offer habitat and can act as buffers. These suitable regions include sandbars, grasslands, riparian scrublands, water, wetlands, and biodiversity hotspots from previous known studies. The areas highlighted in yellow and light green show less suitable areas dominated by agriculture. At the same time, the regions in orange and red have high threat levels due to transportation routes and high human densities. While 767.12 km^2 covering 40.07% area of the sanctuary was predicted to be suitable, 32.13% (613.24 km^2) scored low in the habitat suitability index, and 27.8% of the area (533.63 km^2) was found to be unsuitable. The suitable areas were surveyed and verified for animal presence

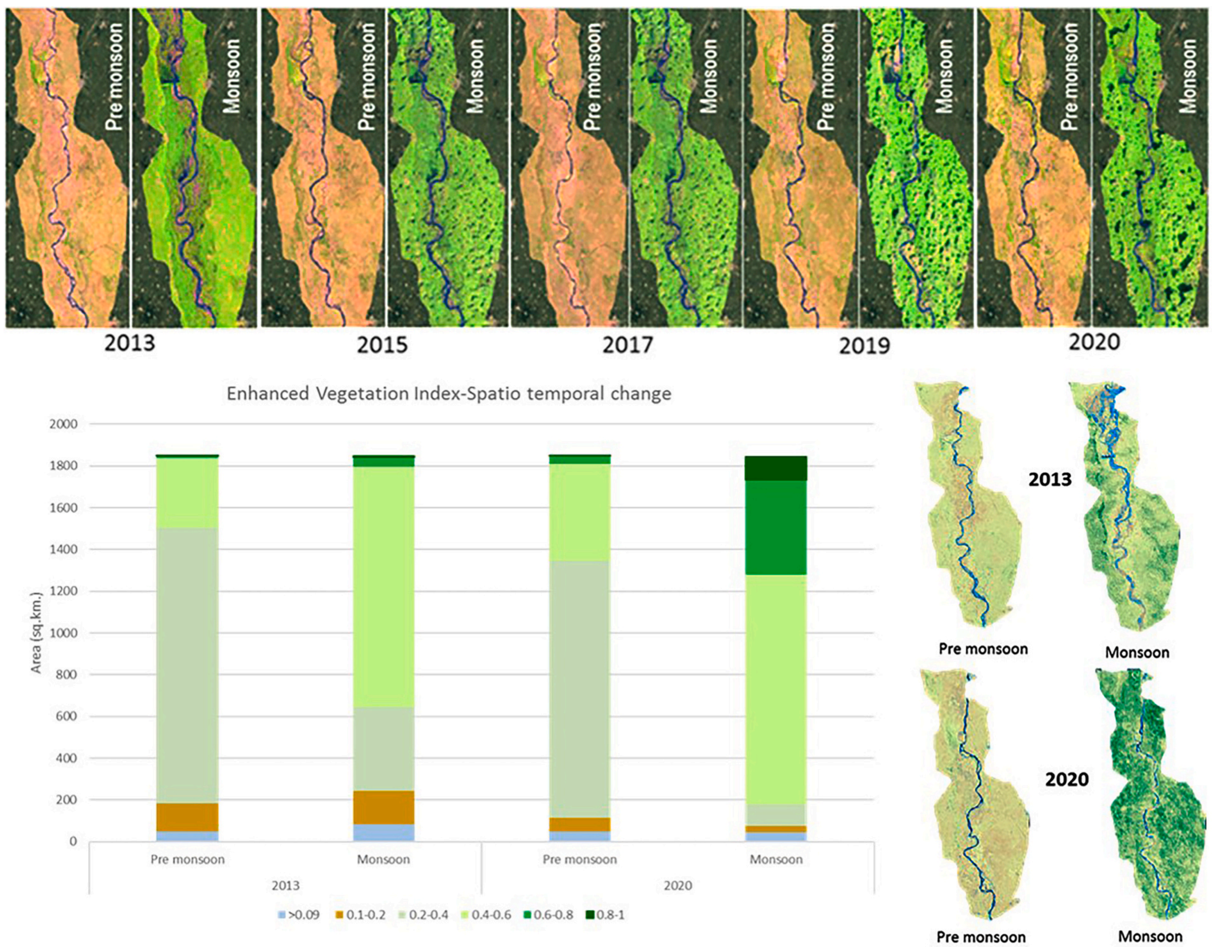

Fig. 5. Seasonal composite Landsat based Enhanced Vegetation Index from 2013 to 2020 for pre monsoon (dry) and monsoon period (wet) and graphical chart showing the.

(Supporting file Table 1).

3.5. Haiderpur wetland

The Haiderpur Wetland shown in (Fig. 9(a-d)) is an important habitat patch within the HWS, key habitat for swamp deer species and migratory birds. Dynamically changing with the water level of the River Ganga, the landscape has floating and aquatic vegetation, wetland grassland, dry grassland, and river scrub in sand bars. The seasonal changes in water are reflected in (Fig. 9) (Supporting file Table 2). (Fig. 9) depicts (a) Google map of wetland delineating water and vegetation area (b). Modified normalised difference water index of sentinel data map highlighting water in the wetland (c). Normalised difference vegetation index of wetland (d). SMTVI showing variation in water and vegetation within Haiderpur Wetland. Monitoring the habitat can understand the natural dynamics, which can provide insights into conservation management decisions such as regulating water level at the barrage, which affects the flooding in the wetland.

4. Discussion

Globally, wetland and grassland land cover followed by forested land and water witnessed the maximum negative change, during the last two decades from 1995 to 2015 (Sannigrahi et al., 2018). Riparian grasslands and wetlands play a crucial role as habitats in the aquatic-terrestrial zone. They are home to a multitude of mammals, amphibians and reptiles. Ecological surveys determine the status of biodiversity and the habitat health. One of the primary decisions in ecological surveys that can profoundly affect the results of the study is sampling site selection. This often requires prior knowledge of the study site, the dynamic nature of the landscape, the ecological niche of the target species, and animal behavior. RS can provide thematic data on multiple parameters such as climate, vegetation, and topography. It can also provide historic data giving a glimpse of changing trend. However, processing such large datasets is a time-intensive, heavy computing effort, often challenging to incorporate before fieldwork. Google Earth Engine is a platform capable of heavy computing with a massive collection of satellite data from various sources that supports online server-side image processing. It provides freely, an array of preprocessed data sets from multiple sources, and prewritten codes for various indices, visualizations and spatial analysis. Organisations such Space Application Centre, Ahmedabad release detailed inventory and reports of wetlands in India but often the time between data updation is more than 5 years, during which a lot of small wetlands can get lost. It is important to track development closely and perform rapid assessments. Platforms such as GEE can be utilized to create such apps that can help administrators ‘watch’ their natural resources. GEE has been previously used to monitor wetlands (Amani et al., 2019; Fekri et al., 2021; Hird et al., 2017) but very few studies further dwell into the habitat assessment and habitat suitability. While previous studies focused on mapping wetlands and time-series analysis (Chen et al., 2014; Mahdianpari et al., 2020) the recent studies are focused on LIDAR based water- dynamic modelling (Zhang et al., 2022), exploring wetland modifications and predicting water spread area and depth using ANN based cellular

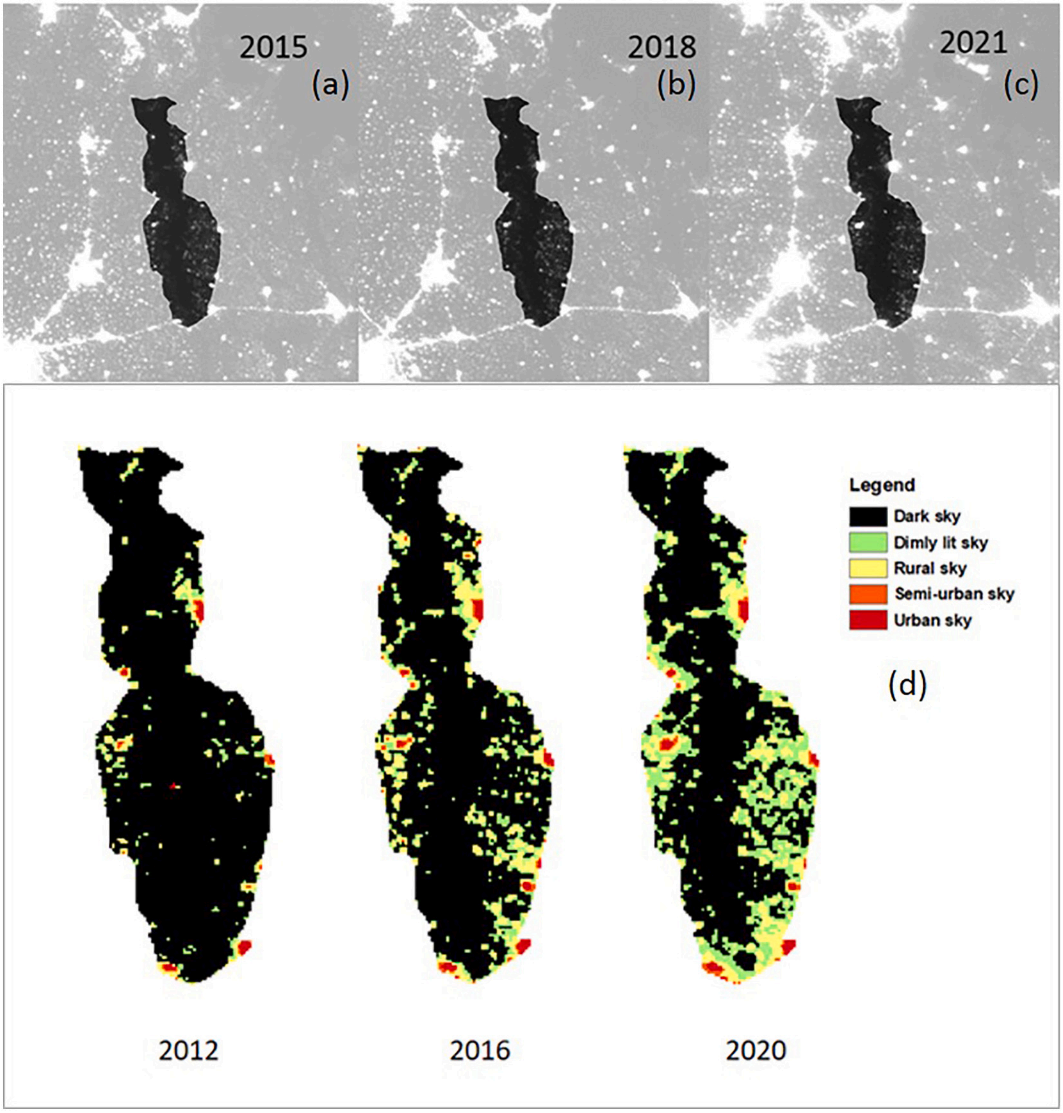

Fig. 6. Image depicting VIIRS nightlight map for the years (a). 2015 (b). 2018 (c). 2021 for study area and surroundings (d) Image.

automata (Pal et al., 2022; Saha et al., 2021), predicting wetland intergrity and security etc. (Pal and Debanshi, 2021).

4.1. Habitat association

Adequate information on species presence and habitat parameters such as elevation, slope, and vegetation type can strengthen conservation management decisions (Kushwaha and Roy, 2002; Panwar, 1991). Based on the literature, we can draw habitat associations and preferences of various species and groups occupying the ecosystem. Cervid species, for e.g., prefer wetland - grassland away from human interference while also navigate large distances through the riverscape (Tewari and Rawat, 2013). Migratory ducks prefer the dammed water, whereas wader birds prefer shallow water banks. Dolphins prefer deep waters and show affinity towards, meanders and confluences, while turtles and gharial look out for sand bars to bask on and nest (WII-NMCG, 2019). A study on the Indus river evaluated the habitat of smooth-coated otter based on affinity to mudflats and riverine vegetation (Ali et al., 2010). Gharial prefers the sandy part of the riverbank over rocky or clayey surfaces and shallow water of around 4 m depth (Hussain, 2009). With this assumption, keeping these aquatic, semi-aquatic animals in mind, the preferred habitat can be classified into habitat types such as rivers, shallow banks, sand bars, riparian grasslands, and wetlands. Studies on the diet of swamp deer indicate their preferences for grasses in all seasons, sedges in winter, and aquatic flora and herbs in summer (Tewari and Rawat, 2013). Distribution modelling predicted a high correlation of vegetation (NDVI) in May and low nighttime light to swamp deer presence up to 7 km from the river (Paul et al., 2018). Hence, distance from human disturbance, proximity to river, ALAN, vegetation of dry months and vegetation type influence habitat selection by deer in the landscape.

4.2. Habitat dynamics

The study area seems to exhibit contrasting variations in wet and dry seasons. The river channel in this region is very dynamic, with changing braids and meanders. Seasonal variation in vegetation in the landscape too are dramatic.

Previous studies have found high correlation of vegetation index of May month towards predicting swamp deer presence (Paul et al., 2020). This means that especially during summers, when the deer congregate, dense vegetation offers safe haven to deer populations. This area falls in the Khadar and is prone to inundation with the rising water level in the river. Sugarcane is the safest option for being a flood tolerant cash crop and hence the most common crop. As per previous estimates within HWS, only 17% of the Sanctuary area was covered with vegetation,

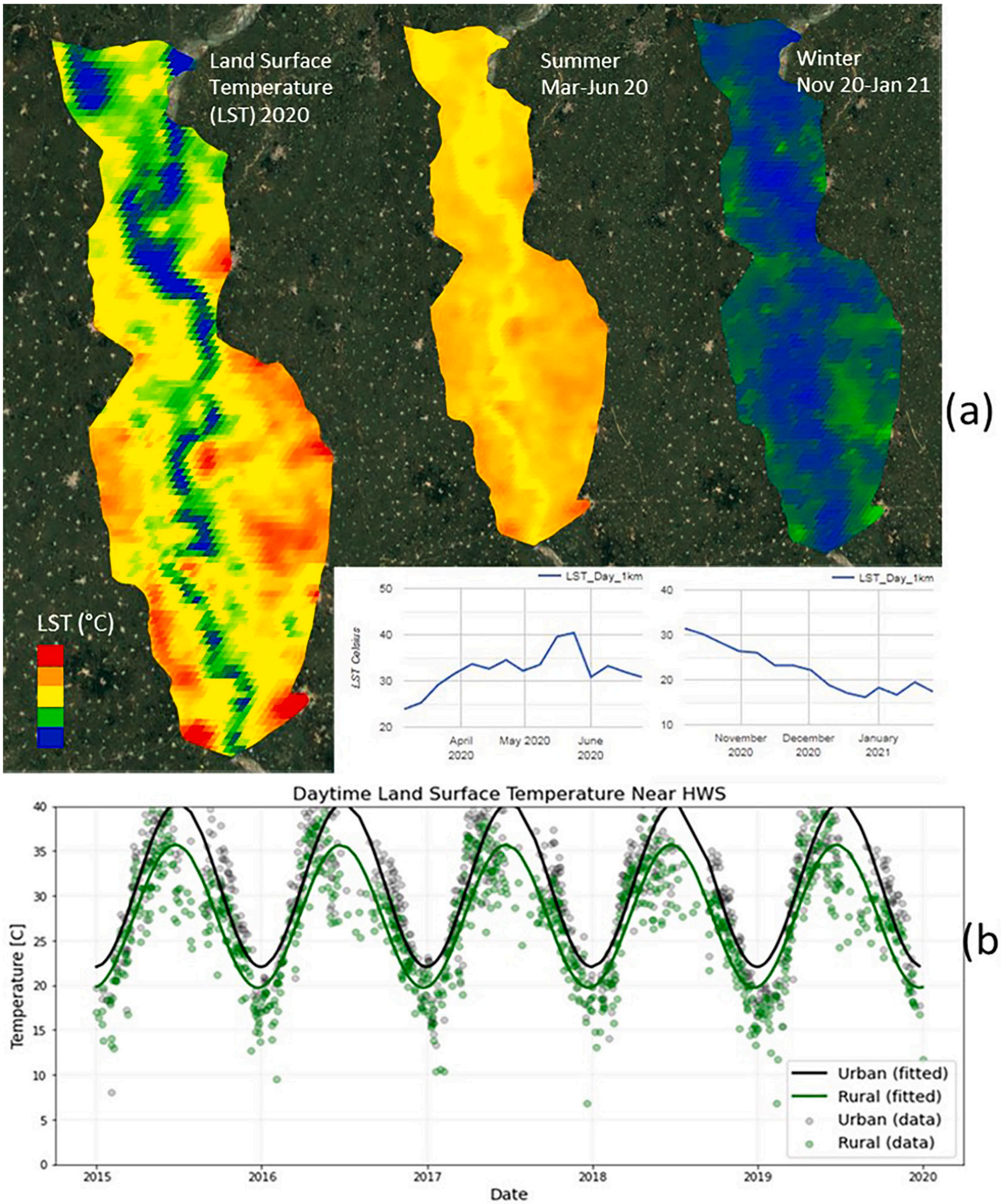

Fig. 7. Land surface temperature for the year 2015 to 2020.

comprising of tall wet grasslands, short wet grasslands, dry scrub grasslands and plantations constituting 35.3%, 23.5%, 29.4% and 11.8% respectively (Khan et al., 2003). A township and cultivation occupied the remaining 83% of the Sanctuary area resulting in considerable human disturbance (Agarwal, 2009; Khan, 2010; Khan et al., 2003). However, these studies were not performed using geospatial tools that accurately estimate the spatial extent of various land cover and land use classes.

Our study based on decadal change in LULC found a rising trend in agriculture and built-up area. 1980–2010 saw rapid rise in urbanization across India but more evidently in the Gangetic Plains. 14.8 million hectare of grasslands in India, mostly in the Gangetic plains were converted to cropland (Tian et al., 2014). With reference to the Upper Ganga River, previous results based on RS showcase significant changes in the composition of the LULC from 1993 to 2017, with approximately 12 times increase in the agricultural extent and five times increase in built-up, and a decrease of vegetation from 43.9% to 10.94%. (Prasad et al., 2021).

Nocturnal darkness is important for maintenance of circadian rhythm, metabolism and stress levels in animals. The presence of light pollution or stray light and human-induced illumination over regions of natural nocturnal darkness is found to disturb the life cycle of insects, birds, fishes, and aquatic mammals (Hölker et al., 2010; LaRoe et al., 2022). Unnatural illumination can increase the risk of being seen by predators, reduce the safety of eggs in nests (Horváth et al., 2009; Silva et al., 2017). ALAN has been studied and noted to negatively affect the phenology of grasslands, community structure of freshwater producers and invertebrate assemblages (Davies and Smyth, 2018). Guetté et al.

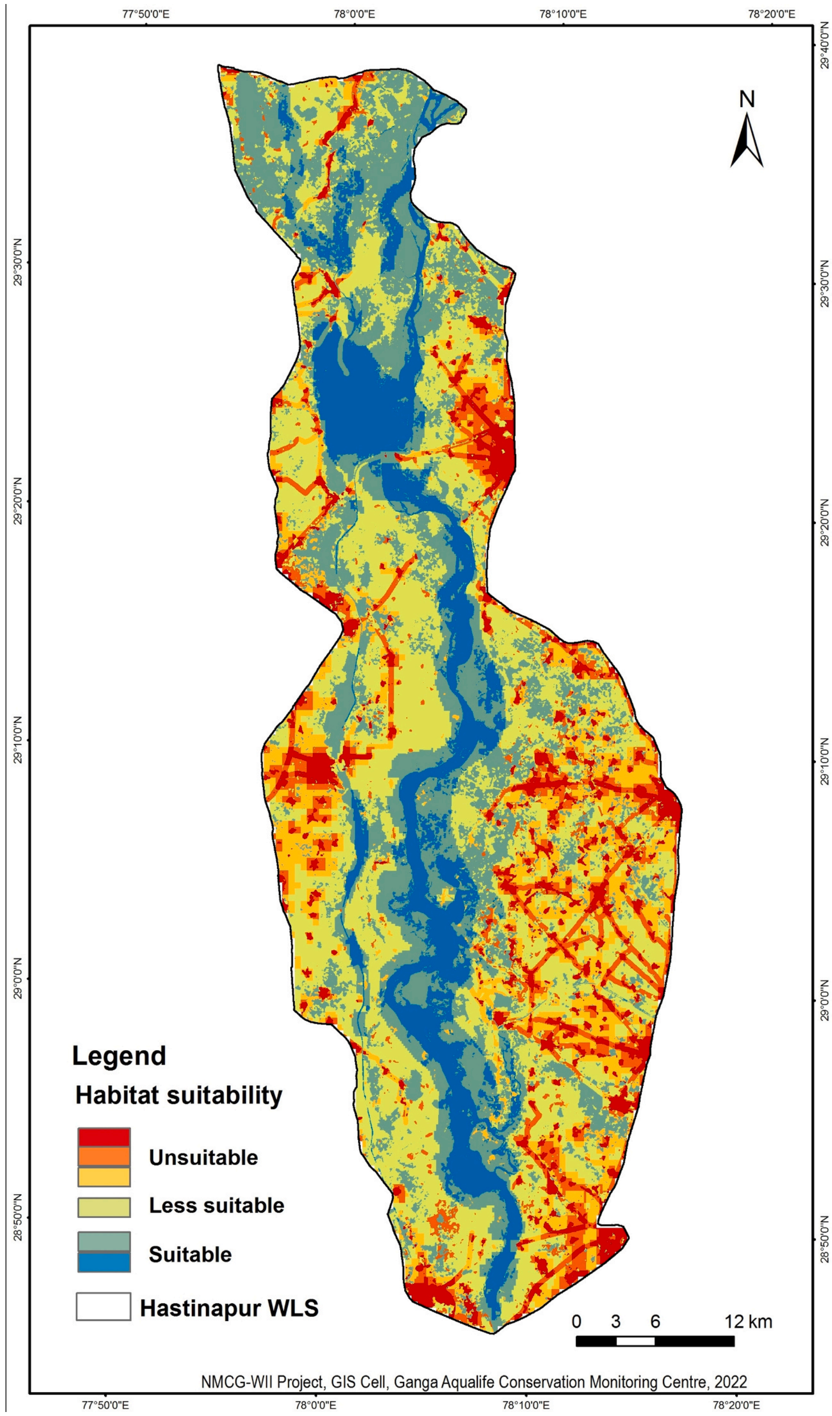

Fig. 8. Habitat suitability map depicting unsuitable, less suitable and suitable habitat in HWS.

(2018) and Jiang et al. (2022) advocated the integration of ALAN into conservation policies, reporting increase in ALAN within PAs and Biodiversity Hotspots and their resultant isolation by concentric human encroachment. Kumar et al. (2019) reported a high increase in the intensity of light pollution in Uttar Pradesh in the last two decades and identified urban expansion, industrial development, and resultant air pollution as the main drivers for increasing light pollution. There should be a mechanism to restrict and put a permissible limit to ALAN especially within protected areas to cause minimum disturbance to wildlife.

Temperature can affect freshwater biochemistry, water quality, and transport of nutrient, ion, and sediment. Temperature regimes can therefore influence growth of phytoplankton and zooplankton and geographical distribution of aquatic species (van Beek et al., 2012). Climate change can have stronger impact on river flow characteristics even greater than regulatory structures (Döll and Zhang, 2010). Climate change can impact freshwater ecosystems and their phenology. Aquatic habitat can buffer terrestrial effects such as higher temperatures as in urban heat island (UHI) by providing microclimatic conditions (Villalobos-Jiménez and Hassall, 2017). Riparian belts can therefore provide thermal refuge to animals. Xi et al. (2021) highlighted climate mitigation and minimization of human disturbance as essential for future Ramsar wetland conservation. Despite the commendable commitment by the Convention on Wetlands in judicious use globally, there is still significant scope in improving the conservation outcomes (Kingsford

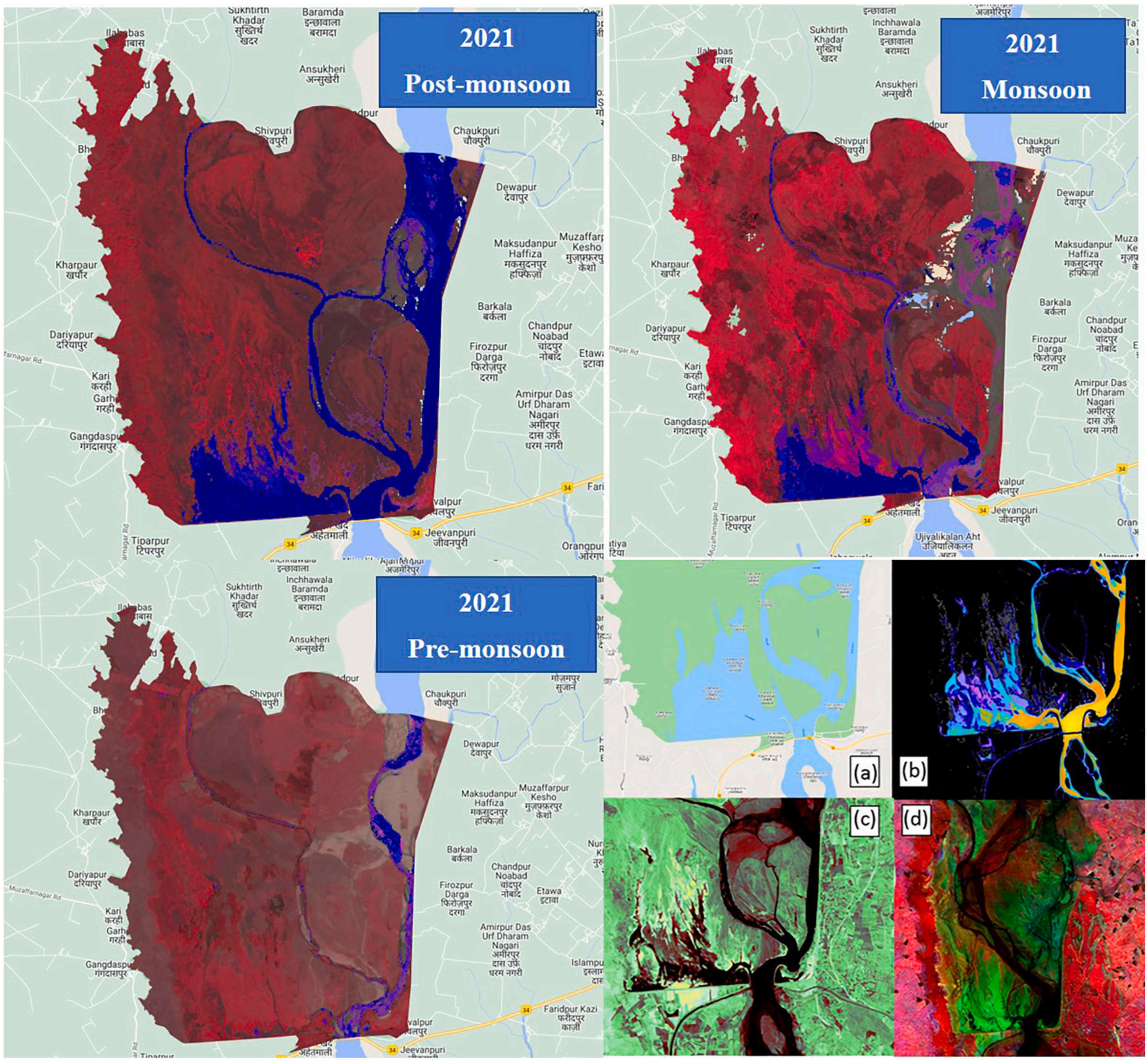

Fig. 9. Image depicting water dynamics season wise and (a). Google map (b). MNDWI (c). NDVI (d). SMTVI for Haiderpur Wetland within the study.

et al., 2021), especially in terms of regulating the high human influence (Reis et al., 2017) and evaluation tools for wetland monitoring (Munguía and Heinen, 2021). The Haiderpur wetland has now been recognized as a riverine wetland of international importance. In such scenario our results can provide spatial inputs to prepare management plans and a platform for regular close monitoring.

4.3. Threats

Population growth, economic development, and increase in human demand trigger the rapid change in land cover (Somers et al., 2013). Urbanization seem to be an inherent threat resulting in illegal activities such as sand mining. High level of sand mining activities from Ganga river were observed in and around Hastinapur. Anthropogenic pressures faced by HWS include agriculture and grazing by the locals. There is very high fragmentation in the riverine grasslands and riparian vegetation that affect the habitat integrity and expose the faunal species to anthropogenic threats. Contiguity of grasslands patches, presence of corridors of animal movement and lack of impedance in the form of linear infrastructure in the floodplain mosaic is essential for a healthy habitat. A decade old study reporting the presence of Swamp deer in the Jhilmil jheel reserve and Banganga Wetland on the banks of the Ganga River concluded that the protected area is too small to contain the population (Tewari and Rawat, 2013). Recently, another study recorded the movement patterns of swamp deer along the northern Gangetic Plain and noted that the swamp deer restricted up to 10 km on either side of the river (Paul et al., 2020). Thus, there is high pressure on the PA, both as sheltering habitats for wildlife and high-yielding croplands for locals. The sugarcane canopy offers shelter and breeding ground to leopards. Many incidents of human animal conflict arise during the harvesting season when the sugarcane are cut. This region seems to be vulnerable to climate change. As per Water Resource Information System (WRIS) (India-WRIS, 2022), the blocks downstream of Hastinapur fall under the "Critical" and "Over-exploited" category of Groundwater. The ground water table across the basin is declining (Misra, 2011). This point towards the susceptibility to water crisis and the importance of water conservation, rainwater retention, and groundwater replenishment. Activities that implement aquifer recharge, wetland rejuvenation, protection of riparian covers, and erosion control need to be carried out in this belt to overall improve the water availability The area is also susceptible to flood and in the climate change scenario, the incidents of flash floods are predicted to be more frequent. The region was till the recent years, lined with small wetland patches, and multiple braid channels that served as flood mitigation structures, which are now converted to agricultural land. A global study using LULC products based on European Space Agency's Climate Change Initiative identified forest, wetland, grassland, and water bodies as the significant contributors to ecosystem services providing key functions of climate regulation, water regulation, soil formation, biodiversity enrichment etc. These ecosystems were also identified as the highest sensitive ecoregions and most sensitive to LULC change; hence, loss of these ecosystems leads to a decline in these vital ecosystem services (Sannigrahi et al., 2018).

5. Conclusion

Management of Protected Areas require thorough understanding of the ecology and the play of biotic and abiotic factors in the landscape, as well as management of the inhabiting population and their resource utilization. This study visualized the study area based on GIS and RS tools and identified seasonal water variation, changes in temperature, and vegetation dynamics as the key drivers influencing habitat quality. The available habitat for aquatic and semi-aquatic animals was quantified. It is alarming to note that 59.31% area of the sanctuary was less suitable or completely unsuitable. This is because majority of the landscape is dominated by agriculture, except for a few patches of wilderness maintained by the forest department. The significant threats surrounding the PA include rapid development, intensifying agriculture, fragmented grasslands and increasing artificial lighting at night. The resource utilization by people is high. With the rural areas steadily converted to urban, sand mining from the River Ganga for construction is on the rise. The residents regularly cut grasses for fodder and grasslands are also heavily used as grazing ground. River bank cultivation is also common, often extending up to the water edge, compromising the nesting and shoreline basking sites for reptiles and birds. The habitat suitability index has utility for multiple stakeholders such as city planners, PA managers, ecologist, and tourism department for selecting sites for development, tourism, declaring prohibition zones and choosing biological sampling sites. Since regular patrolling of riverine landscapes might not be possible, remote sensing can provide satisfactory solution in visualizing the entire landscape at a good 10-m ground resolution. This output can be further developed into a GEE based application for decision makers that can visualize real time situation of habitat blocks and encroachments in the field. However, the results obtained from satellite data would need occasional verification through very high-resolution data such as Unmanned Aerial Vehicles. With the level of threats faced by wetlands right from climatic issues such as drought, reduced ground water table etc. from human-induced water regulations, encroachment, and rapid blinded development, conversion to fields; regular monitoring of LULC change of wetlands and PAs is imperative to track intrusion, habitat health, and human influence. With the availability of frameworks such, GEE such essential analysis can be easily performed, visualized and shared. The future work could extend this study by developing a GEE based app for administrator to visualize the current extent of wetland and grassland habitats within the HWS using latest satellite imagery from the GEE library and monitor the spatial extent and presence of encroachment with in the prime habitats. This study along with the other contemporary studies emphasizes the grim situation of swamp deer's survival in the heavily competing landscape. Immediate conservation measures such as close monitoring of population structures and protection of habitat are imperative for ensuring the survival of the species.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoinf.2022.101851.

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