Journal of Scientific & Industrial Research
Vol. 82, November 2023, pp. 1208-1219
DOI: 10.56042/jsir.v82i11.3175

Integrating NDWI, MNDWI, and Erosion Modeling to Analyze Wetland Changes and Impacts of Land Use Activities in Ropar Wetland, India

Anuvesh Pandey, Kanwarpreet Singh & Ashita Sharma*
Chandigarh University, Gharuan, Mohali, Punjab, 140 413, India

Received 24 June 2023; revised 26 July 2023; accepted 25 August 2023

The Ropar Wetland is a significant freshwater ecosystem located in Punjab, India. In the recent years, this wetland has witnessed significant changes owing to anthropogenic and natural factors. In this study, the land use and land cover changes are analyzed around the Ropar Wetland using remote sensing techniques by utilizing Landsat images and GIS software. The results showed a significant increase in agricultural land from 19% in 2000 to 37% in 2010, followed by a decrease to 28% in 2020. Barren, urban, and fallow land also showed a continuous increase from 20% in 2000 to 44% in 2020. The forest cover decreased from 47% in 2000 to 17% in 2020 and water bodies decreased slightly from 14% in 2000 to 10% in both 2010 and 2020. The pictorial representation of LULC (Land Use Land Change) changes over the years, including the area of the Ropar Wetland, provided insight into the shifting patterns of land use and cover. Results from NDWI (Normalized Difference Water Index) show a small decrease in water body area in the wetland over the years, with some fluctuations in the total area. MNDWI (Modified Normalized Difference Water Index) shows the sparse water area around the wetland. Natural processes including erosion and accretion have affected the wetland region around the river, causing a net loss of 55 hectares of land, over the past two decades. The findings of this study suggest that there is a need to implement effective management practices that recognize the complex interrelationships between land use, hydrology, and ecological processes to protect the Ropar Wetland's ecological and hydrological functions. Ongoing monitoring and assessing land use and cover changes are crucial for conserving wetland ecosystems.

Keywords: Freshwater ecosystem**,** Geo sensing, LANDSAT, LULC change, Remote sensing

Introduction

Wetlands are vital ecosystems that include marshes, fens, and peatlands, with static or flowing water, fresh or salty, up to 6m deep at low tide, and play a critical role in maintaining ecological balance.[1] They support a variety of biodiversity and provide essential ecosystem services such as water purification, carbon storage and flood control.[2] Wetlands are also crucial breeding and feeding grounds for numerous species of plants and animals, including migratory birds.[3] The Ropar Wetland, associated with the River Satluj, situated in the state of Punjab in India, is home to a diverse range of flora and fauna spread over an area of approximately 1365 hectares.[4] It is a man-made wetland that was established by constructing a head regulator on the river Satluj to store and redirect water for various uses including irrigation through canals and industrial and drinking water supply.[5] The Ropar Wetland is an important breeding ground for various migratory bird species including endangered species such as, Sarus cranes. It also supports a range of fish and aquatic plant species.[6] However, the wetland is under threat from various anthropogenic activities including pollution, agricultural runoff, and habitat destruction. As a result, the wetland is facing degradation and its ecological integrity is being compromised. It is, therefore, essential to understand the factors that are affecting the Ropar Wetland and develop effective conservation strategies to protect and restore this vital ecosystem.[7]

The forest cover around the wetland sites plays a crucial role in maintaining the ecological integrity of wetland ecosystems. Wetlands provide a range of ecosystem services, including flood control, nutrient cycling, water filtration, carbon sequestration[2] and addressing the effects of climate change.[8] Forests act as natural buffers for wetlands, protecting them from erosion, sedimentation, and pollution[9] by trapping the pollutants before they could reach the wetland. Additionally, the root systems of trees help stabilize the soil and prevent erosion, ensuring that sedimentation and other pollutants do not accumulate in wetlands.[10]

*Author for Correspondence
E-mail: ashu.asr.sharma@gmail.com

Forest cover around wetlands also provides a habitat for a wide range of plant and animal species, including migratory birds, aquatic organisms, and pollinators. These species are an essential element of the wetland ecosystem and contribute to its functioning.[11] As such, understanding the technical importance of forest cover around wetland sites is essential for developing effective conservation and implementing effective measures to ensure the long-term sustainability of these ecosystems. The relationship between water bodies, forest cover and wetlands is vital as forests regulate water flow, prevent erosion, and filter pollutants, benefiting water bodies and wetlands, which in turn provide crucial ecosystem services and social and economic value.[12, 13]

As a result, conservation and restoration of both forest cover and wetlands are critical for maintaining healthy water bodies and the ecological integrity of these interdependent habitats. Continuous assessment of LULC around wetlands is important for planning conservation strategies. Remote sensing and GIS are the tools for determining LULC changes. Remote sensing tracks changes in land usage while GIS analyzes spatial data to identify changes in forest cover and water bodies. These tools aid in identifying the areas which are at high risk of losing forest cover, for guiding conservation and management activities and for protecting wetland locations.[14,15]

This research investigates LULC change, water quality and erosion in Ropar wetland, Punjab using remote sensing and geospatial analysis techniques.

Ropar wetland holds significant importance as one of India's prominent Ramsar wetland sites which has undergone drastic land use change over past few years making it essential to study the LULC pattern of Ropar wetland. Furthermore, only a few studies have focused on long-term monitoring of LULC dynamics of this wetland. This article focuses on the decadal changes around the Ropar Wetland from 2000 to 2020. Along with this, NDWI, MNDWI and erosion modelling was also used to assess water quality and erosion potential, as the comprehensive erosion modeling specific to Ropar Wetland is lacking in most of the previous studies, hindering the assessment of erosion vulnerability and identification of erosion-prone areas.

Methodology

Study Area

The Ropar Wetland (30.96°N latitude and 76.52°E) is a significant wetland located in Rupnagar district, Punjab.[16] It is around 50 km north-east of Chandigarh and is spread over a total area of about 1365 hectares including a lake spread over 750 hectares and a catchment area with surface area measuring 615-hectare. The region has semi-arid climate with warm summers and cool winters. With a maximum summer temperature of 40°C and a low winter temperature of 5°C, the average annual temperature is roughly 24°C. Most of the yearly rainfall in the wetland occurs during the monsoon season, lasting from July to September.[17,18] The creation of a barrage in 1952 to divert Sutlej River water for drinking and irrigation needs in parts of Punjab led to the construction of the artificial wetland at Ropar.[19]

The Ropar Wetland is home to a wide variety of aquatic and terrestrial plants. Reed beds, floating and submerged macrophytes and phytoplankton make up the aquatic vegetation. The most common types of aquatic plants include duckweed, water lilies and water hyacinths. The Ropar wetland is home to a wide range of fauna including birds, fish, amphibians, reptiles, and mammals. The wetland is an important wintering ground for several migratory bird species including the endangered Siberian crane *Grus leucogeranus*.[20]

The study area for this research had a stretch of 2730 hectares around the Ropar wetland spread over both the sides of the Sutlej River. The study was conducted to analyze LULC, erosion, NDWI and MNDWI on both banks of the river as the river supports a significant amount of flora and fauna on both the sides. The study area for this research includes some area upstream in the vicinity of Sutlej River and the wetland area. Moreover, for accurate erosion calculation, it is necessary to analyze along the strip of the river, as it allows for continuous monitoring of changes in water content over time. This part of the river plays a crucial role in maintaining the hydrological and ecological balance of the wetland ecosystem. The study area has been depicted in Fig. 1.

Various sites of Ropar wetland as categorized into different classes are illustrated in Fig. 2.

Image Acquisition

The present study focuses on LULC classification, erosion estimation, NDWI, MNDWI calculation on the Ropar Wetland area. The analysis utilized satellite imagery from Landsat 7 and Landsat 8. Landsat 7 images were taken during December for the years 2000 and 2010. Landsat 8 images for December and

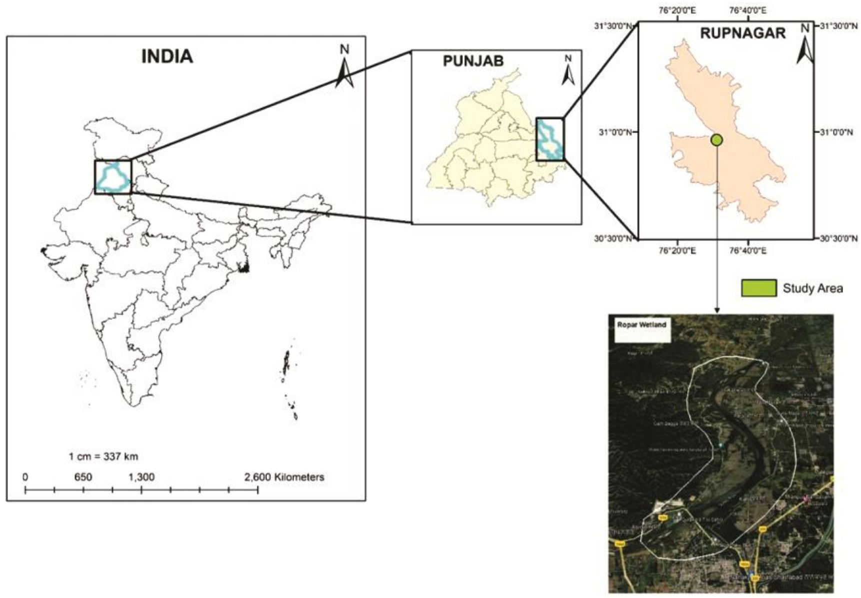

Fig. 1 — The figure depicts the study area in and around Ropar Wetland

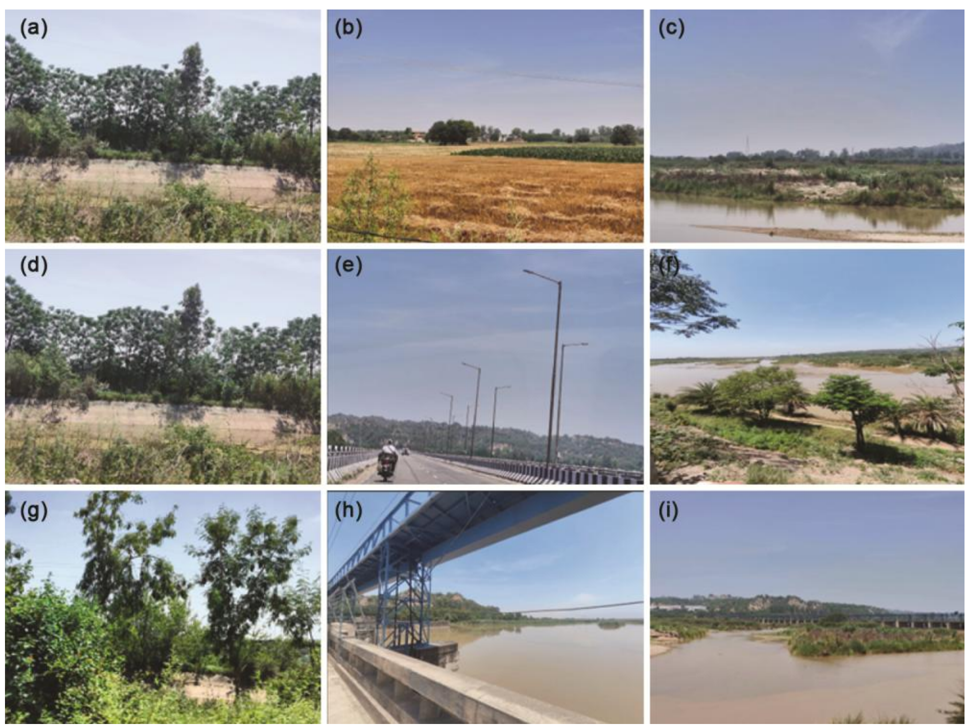

Fig. 2 — **(a)** Shrubs and sparse forest around wetland **(b)** Agricultural land with fallow land **(c)** wetland area with barren land in between (d) Canal passing through River **(e)** National highway around Wetland **(f)** Eco- Park on the bank of the river **(g)** Forest cover **(h)** Dam on the Sutlej River **(i)** Ropar Wetland

January 2020 were used for the same analysis in the same area. The spatial resolution of the Landsat 7 images is 30 meters for bands 1–5 and 7 and 15 meters for band 8, while the Landsat 8 images have a spatial resolution of 30 meters for bands 1–7 and 15 meters for band 8.[(21,22)] The study employed ARCGIS 10.4 software to analyze remote sensing and geospatial data. This software offers a wide range of tools for mapping, geocoding, routing, and spatial analysis, empowering users to make well-informed decisions using geographical insights.[23]

Methods

Land Cover Land Use Change Analysis using ArcGIS

ArcGIS 10.4 and the Landsat 7 and Landsat 8 satellite data (from December) available on the USGS website were used to examine the patterns of land cover and land use in the wetlands of Ropar. Applying supervised classification, the following methodology was used to examine the patterns of land use and land cover in and around wetlands. The flow diagram of satellite image preprocessing steps and methods used for the study of land cover land use changes around the wetland is shown in Fig. 3.

Normalized Difference Water Index (NDWI)

NDWI is used to measure the dimension and quantity of water bodies in satellite data. The water content of a pixel is determined by NDWI using the satellite utilized near-infrared and short-wave infrared bands for data capture. The NDWI approach has been used in ArcGIS10.4 to examine the water content and area of wetlands and decadal change from 2000 to 2020.

NDWI can be calculated as follows:

$$\mathrm{NDWI} = \frac{(\mathrm{GREEN} - \mathrm{NIR})}{(\mathrm{GREEN} + \mathrm{NIR})} \quad \text{... (1)}$$

Here, "Green" represents the reflectance value of the green band, while "NIR" denotes the reflectance value of the near-infrared band.[24]

In the Landsat 7 and Landsat 8 satellite images, Band 3 corresponds to the green band, and Band 5 to the near-infrared band. The range of NDWI readings is -1 to 1, with higher values indicating higher water content and vice versa.

Modified Normalized Difference Water Index (MNDWI)

This remote sensing index is employed to detect surface water in areas significantly influenced by vegetation and soil moisture. It utilizes the Green and Short-wave Infrared (SWIR) bands from a multispectral satellite image, usually from a Landsat satellite.

MNDWI is calculated as the ratio of subtraction and summation, respectively, of reflectance value in green spectral band (GREEN) and the reflectance value in the Short-Wave infrared spectral band (SWIR):

$$\mathrm{MNDWI} = \frac{(\mathrm{GREEN} - \mathrm{SWIR})}{(\mathrm{GREEN} + \mathrm{SWIR})} \quad \text{... (2)}$$

Where, Green is the reflectance value in the green spectral band and SWIR is the reflectance value in the

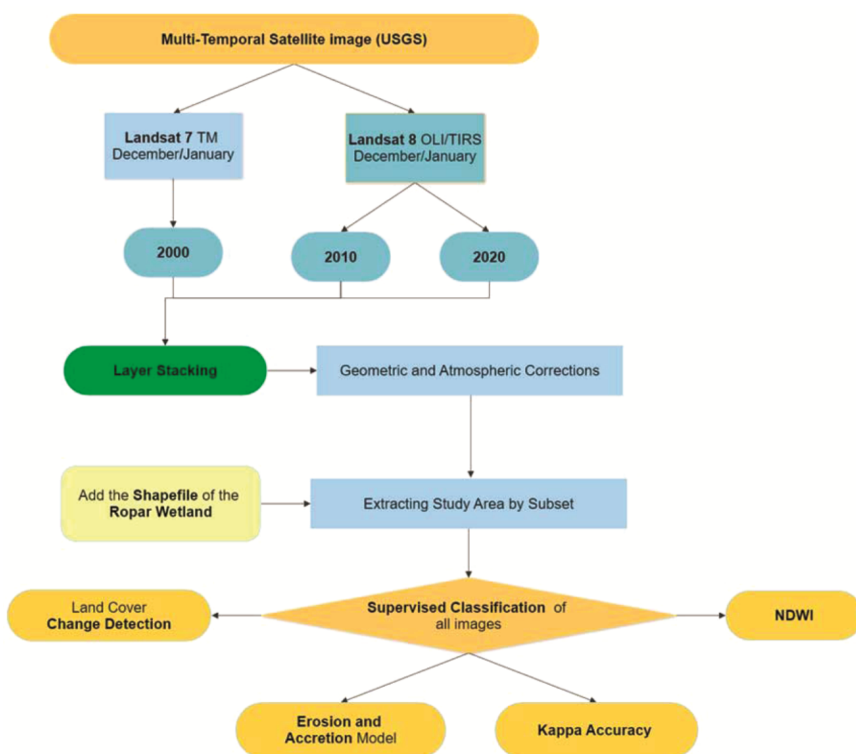

Fig. 3 — Methodology followed in the present study

Table 1 — Area of different land cover types of Ropar wetland in the year 2000, 2010 and 2020

Land Use	2000 Area (ha)	%	2010 Area (ha)	%	2020 Area (ha)	%
Agricultural land	509.63	19%	1015.12	37%	760.15	28%
Barren, Urban, Fallow	558.49	20%	653.22	24%	1213.63	44%
Forest cover	1284.53	47%	779.72	29%	474.61	17%
Water body	378.13	14%	283.48	10%	283.34	10%
Grand Total	2730.77	100%	2731.54	100%	2731.72	100%

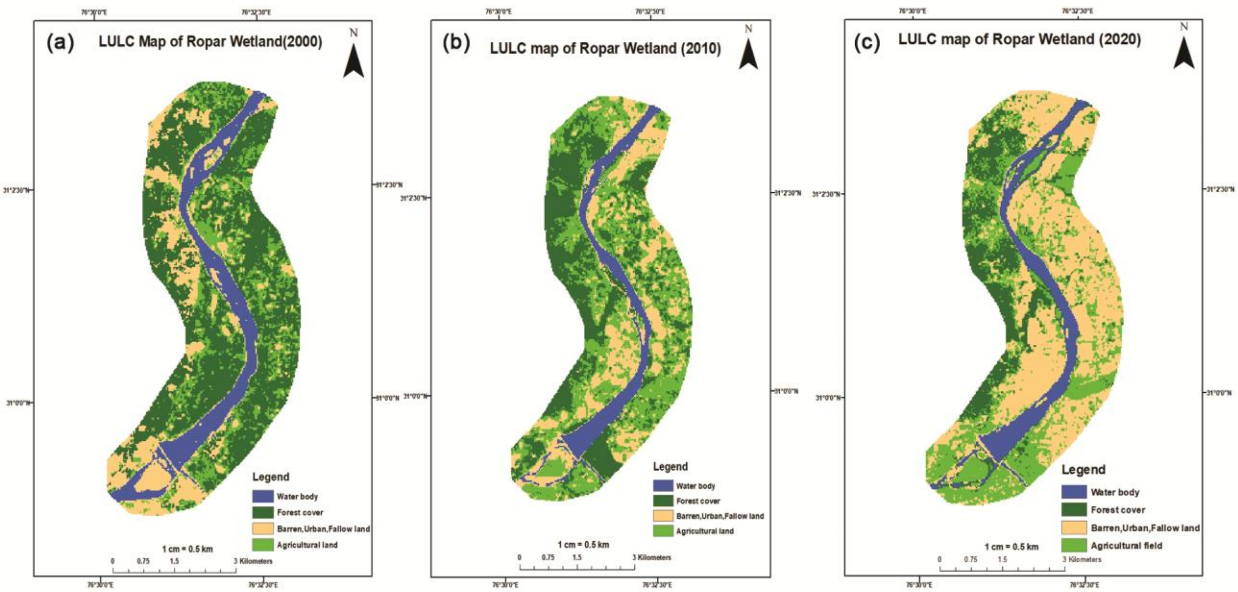

Fig. 4 (a) — LULC change in Ropar Wetland in year 2000; (b) LULC change in Ropar Wetland in year 2010; (c) LULC change in Ropar Wetland in year 2020

Short-Wave infrared spectral band. MNDWI values range from −1 to 1. Positive values indicate the presence of water, while negative values, such as land or vegetation, signify the absence of water.[25] The likelihood that a pixel includes water increases with the MNDWI score.

Erosion and Accretion Calculation

The erosion and accretion areas can be calculated using the unchanged area and changed area values. Erosion and accretion areas along riverbanks can be calculated as follows:

- Unchanged Area:

$$\text{Unchaged Area (Hectare)} = \text{Total River Area (Year n} - 10) - \text{Changed area (year n)} \quad \dots (3)$$

- Erosion and Accretion Area:

$$\text{Erosion Area (Hectare)} = \text{Area (Year n} - 10) - \text{Unchanged Area (year n)} \quad \dots (4)$$

$$\text{Accretion Area (Hectare)} = \text{Area (Year n} + 10) - \text{Unchanged Area (Year n)} \quad \dots (5)$$

Kappa Accuracy

To evaluate the accuracy of the land cover land use classification, the statistical measure of kappa accuracy was employed. It measures the agreement between the observed classifications and the expected classifications, taking into account the possibility of agreements occurring by chance.

Results and Discussion

Land Use Land Cover Pattern (LULC)

The land use data for three different years: 2000, 2010, and 2020 is depicted in Table 1.

In this study, land use is classified into four classes; Agricultural Land, Other Land (Barren, Urban, and Fallow land), Forest Cover, and Water Body. The changes in LULC over the years 2000, 2010, and 2020 in the study area are depicted in Fig. 4 (a, b, c).

The changes in LULC that have occurred over the years are depicted in Fig. 5, which provides an insight into the shifting patterns of land use and cover, including the impact on the Ropar Wetland in the studied region.

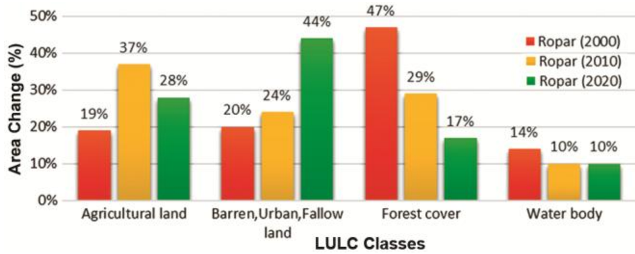

Fig. 5 — Percentage change in the Land Use Land Cover pattern of Ropar Wetland

A sharp rise in the area of agricultural land surrounding the Ropar wetland from 19% of the area in 2000 to 37% in 2010 can be clearly seen in Fig. 5. There is a decrease in the area of agricultural land in the following years, by 9 percent points, falling down to 28% in 2020. Similarly, a continuous increase in barren, urban and fallow land from 20% in 2000 to 44% in 2020 around Ropar wetlands has been observed. The forest cover decreased from 47% in 2000 to 17% in 2020 and water bodies from 14% to 10%. Similar trends in the land use and land cover changes were observed in various studies conducted on Daihai Lake, Mongolia (wetland area decreased by 84.47 km^2 from 1976 to 2015)[(26)], Deepor Beel, Assam (decrease in wetland area by 9.8 km^2 from 2001 to 2011)[(27)], Pong Dam wetland[27] and Kapkatet Wetland, Kenya (wetland decreased by 24.77% from 1986 to 2019).[(28)] Numerous causes including population growth, urbanization and the need for increased food production to satisfy the growing demand, can be related to the development of agricultural land near wetland habitats.[29]

Punjab contributes significantly to the rice and wheat procurement, which has played a vital part in its agricultural success. Ninety-five percent of the rice and sixty-five percent of the wheat in the state, produced locally, were acquired by government agencies in Punjab in 2016–17.[(30)] Since rice cultivation requires more water, agricultural areas in Punjab have shifted more towards the rivers. The major reason for the conversion of land around the wetlands into agricultural land is the enrichment of soil around wetlands due to nutrient deposition.[31] Also, few farmers may have shifted near wetlands due to other economic reasons such as, easy availability of water for irrigation.[32] Unfortunately, this has caused a lot of natural wetlands areas to decline, which also affects the water bodies present near them.[33] The boost in government policies in recent decades that support growth in the agricultural sector may also be a reason for the expansion in agricultural land area near water bodies and in general. The Punjab State Agricultural Policy (2013) aims to make agriculture sustainable, profitable, and productive and to ensure food security for the state. It provides various incentives and support to farmers for adopting modern farming techniques and practices. These projects may encourage farmers in the region to boost their agricultural productivity, which could have led to the increase of agricultural land near the wetland locations of Ropar. Similar trends have been seen in a study by Mabwoga and Thukral[34] on the Harike wetlands of Punjab.

There may be several reasons for the increase in barren, urban and fallow land. Firstly, the growth in population and urbanization is a major factor. India's overall population expanded from 0.4 billion to 1.2 billion between 1951 and 2011, at a decadal growth rate of roughly 22% on average. Urban centers doubled in size during this period, while urban population expanded eightfold. As the population grew, need for land, food and housing grew leading to the conversion of agricultural and natural land to urban areas, putting pressure on wetlands and flood plains to meet the increased demand for resources.[35] The development of infrastructure such as, highways and roads can lead to the acquisition of land, resulting in the conversion of agricultural or natural land into barren or urban land.[36,37] Construction and infrastructure projects near a wetland site cause physical and chemical alterations that can extend for miles and persist for years and these modifications induce a predictable set of biological effects.[38] Although building a highway has economic benefits, it can have a negative impact on wetlands. The construction process and increased traffic can lead to pollution, fragmentation and destruction of the ecosystem. Moreover, highways require a lot of land which often leads to displacement or damage of wetlands.[39] The National Highway 21 and the Beas-Sutlej Link Project have been built near Ropar between 2000-2020 and both the projects have contributed to an increase in urban and arid areas in the vicinity of wetlands. This increase in barren, urban and fallow land may have social and economic impacts as well. Along with the aforementioned, extensive deforestation, conversion of forest land to farmland and development of tourism sector also influences the land use change significantly.[40] Urbanization and development activities including construction, infrastructure development, and land-use change are the main change in LULC. Paddy fields, water bodies and wetlands have all significantly decreased as a result of these operations. Areas used for paddy farming have decreased by 83%, while settlements have developed and expanded by 112%.[41] Furthermore, increase in commercial activities such as, saltpan activities around the wetland can lead to decrease in forest cover and fallow ground in wetlands.[42] Further, a large eco-park was established near the Ropar wetlands which can have adverse effects on the wetland ecosystem due to human activities like tourism and pollution. A similar impact was seen in protected areas of Kenya.[43]

Forest cover around the Ropar wetland decreased from 47% in 2000 to 17% in 2020 and the possible reason could be urbanization around wetlands leading to clearing up the forest cover. The Ropar wetland habitats may suffer serious long-term effects if the forest cover continues to alter. Loss of forest cover may cause water quality to deteriorate which may affect the aquatic and avian species that depend on wetlands for habitat and food. Wetlands play an important role for many migratory bird populations. When wetlands are degraded, bird species can suffer decreases in both numbers and distribution.[44] Studies have found that resource scarcity due to degradation of wetlands, especially during the winter months, is a big problem. It is suspected that nearly half of all bird species worldwide are suffering population decreases.[45] Recent research shows that habitat distribution and hunting account for much of the avian diversity loss in wetlands.[46]

If, the area around wetlands gets converted into barren land or brought under cultivation may contribute to water pollution and cause siltation leading to loss of water bodies.[47] Replacement of deep-rooted wetland vegetation with shallow-rooted crops results in increased siltation.[34] During the harvest season, there is a release of excess nutrients into the water bodies, leading to chemical imbalances due to altered nutrient composition of water. Additionally, there may be surface runoff caused by obstructions in river channels. These factors can contribute to a decline in the water quality of the wetland and disrupt its ecosystem.[48] Apart from this, encroachment, fishing, boating operations and the disposal of plastic waste will lead to deterioration of wetland's Water Quality Index (WQI) leading to water pollution.[49,50]

NDWI (Normalized Difference Water Index) and MNDWI (Modified Normalized Difference Water Index)

NDWI results suggest that the percentage of the area under the water body in Ropar wetland decreased slightly from 14% in 2000 to 10% in both 2010 and 2020. The minimum and maximum values of NDWI (−0.2 and 0.1) (Fig. 6) are typical thresholds used to distinguish water bodies from other land cover types in remote sensing analysis. The total area for water bodies in 2000 was 375 hectares, which decreased to 289 hectares in 2010. In 2020, the total area of water bodies increased to 306 hectares.

MNDWI map of the study area is displayed in Fig. 7, with blue colors indicating areas with positive values which are interpreted as water bodies. Each pixel on the map represents a unique value that is computed using the previously given method. MNDWI values range from positive to negative. The MNDWI map in this study demonstrates that regions with strong green band reflectance, mostly close to zero MNDWI values, are vegetation regions with less water, whereas regions with negative MNDWI values are associated with bare land or non-water characteristics.

The MNWDI values for the years 2000, 2010, and 2020 hectare are 396, 342, and 345, respectively. The primary distinction between NDWI and MNDWI is that the NDWI is more sensitive to open water bodies while the MNDWI may identify smaller or shallower water bodies that may be spread by nearby vegetation. The change in MNDWI area through different decade is shown in Fig. 8

The difference in the area covered by water bodies in these years could be due to a variety of factors, including changes in precipitation patterns, changes in land use and land cover and anthropogenic activities such as dam construction or floodgate opening.[51] For example, the increased area noticed in 2020 could be the consequence of excessive rainfall or the opening of floodgates, resulting in a higher flow of water in the region.[41] Similar trends were observed in Renuka wetland, Sirmaur District, Uttarakhand,[52] Atikhisar Dam Lake, Çanakkale City, Turkey and Babina Islet in the northern Danube Delta.[53]

The NDWI and MNDWI studies (Figs. 5 & 6) on the Ropar wetland sites found plenty of negative NDWI values, indicating a drop in water content. Drought, human activities such as damming and

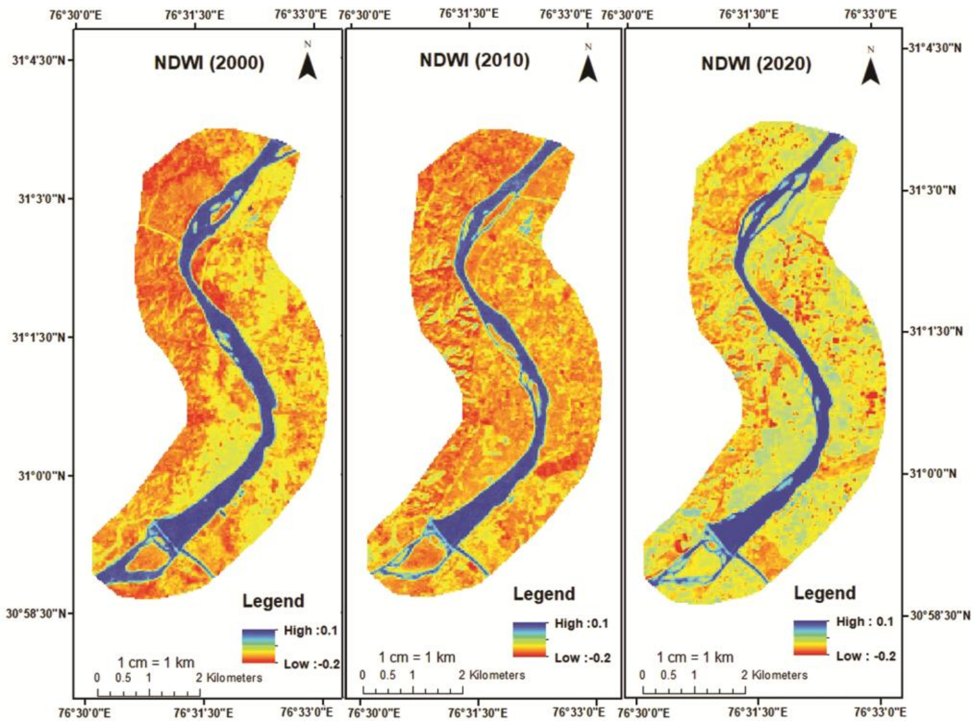

Fig. 6 — NDWI for the Ropar wetland for the years 2000, 2010, 2020

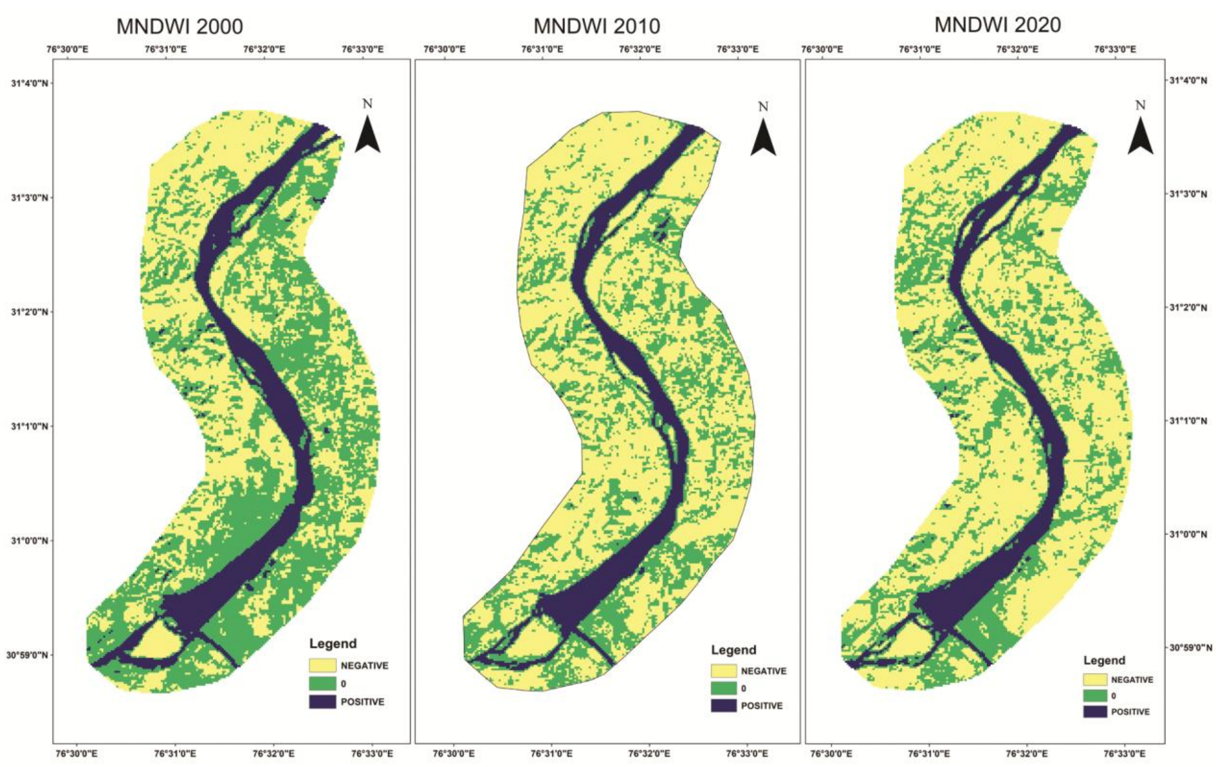

Fig. 7 — MNDWI for the Ropar wetland for the years 2000, 2010 and 2020

groundwater pumping, land-use change, natural processes such as evapotranspiration, and climate change may all be responsible for the decline in water content. These factors can harm wetland ecosystems, resulting in habitat loss for plant and animal species, decreased water quality, and increased wildfire risk.

The primary distinction between NDWI and MNDWI is that the NDWI is more sensitive to open water bodies while the MNDWI may identify smaller or shallower water bodies that may be covered by nearby vegetation.

Erosion and Accretion Calculation

The changes in the Ropar wetland's land area in hectares over three different periods: 2000–2010, 2010–2020, and 2000–2020 is shown in Table 2.

The data on erosion and accretion in the Table 2 shows changes in the land area brought on by natural processes like erosion, 'the loss of land as a result of water or wind movement', and accretion, 'the gain of land as a result of sediment deposition'. A section of the Sutlej River that forms the Ropar wetland is depicted in Fig. 9.

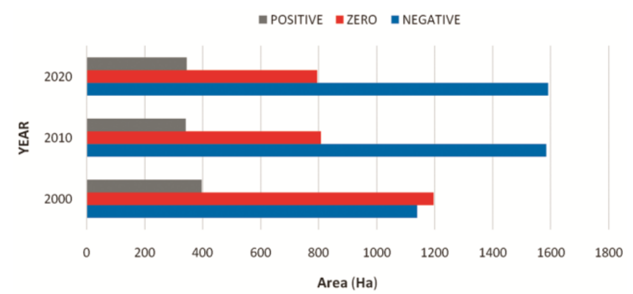

Fig. 8 — Area changes in percentage for different decades using MNDWI

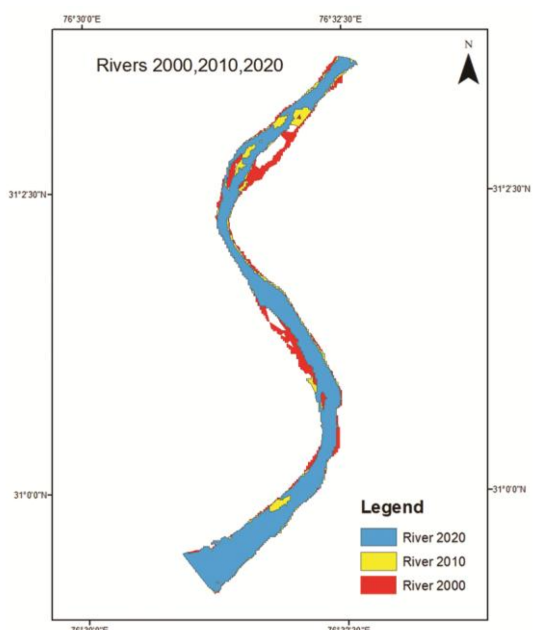

Fig. 9 — Part of Sutlej River that forms the Ropar wetland

The river surrounding the Ropar Wetland in 2000, 2010 and 2020 and the decadal changes that have occurred in terms of erosion and accretion are illustrated in the Fig. 10.

2000 – 2010: During this period, the wetland area declines by 75 Ha due to erosion, while gains 12 hectares through accretion. This means that there was a net loss of 63 hectares of land over the decade. The unchanged land area was 251 hectares.

2010 – 2020: In the following decade, from 2010 to 2020, the wetland area declined by 6 Ha due to erosion and gained 26 hectares through accretion. This represents a net gain of 20 hectares of land over the decade. The unchanged land area was 257 hectares.

2000 – 2020: For an entire 20-year period from 2000 to 2020, the data show that the wetland lost a total of 69 hectares of land due to erosion while it gained 14 hectares through accretion. This means that there was a net loss of 55 hectares of land over the two decades. The unchanged land area was 326 hectares.

Overall, these results imply that the wetland had significant erosion during the two decades, which was not entirely compensated by gains through accretion.

The main cause for the erosion around wetland sites is a change in land use patterns and hydrological alternations during this period. The wetland is suffering these disruptions due boost in urban development as well as an increase in the agricultural land around the wetlands. Furthermore, the construction of large reservoirs and dam hinders the natural flow of the river ultimately resulting in sedimentation. Sedimentation and erosion are interrelated processes. When sedimentation occurs, a large chunk of sediments builds up at the bottom of the river or water body which can be dislodged by the strong flow of the river causing erosion. During erosion, strong force of water move sediments from the bottom and changes the shape and depth of the water body and possibly damages the ecosystem. The

Table 2 — The area around Ropar wetland with data of Unchanged area, Erosion and Accretion area (Ha)

Year	Previous 10 Years	Next 10 Years	Unchanged Area	Erosion	Accretion	Net Gain/Loss
2000–2010	326	263	251	75	12	−63
2010–2020	263	257	232	6	26	+20
2000–2020	326	257	243	69	14	−55

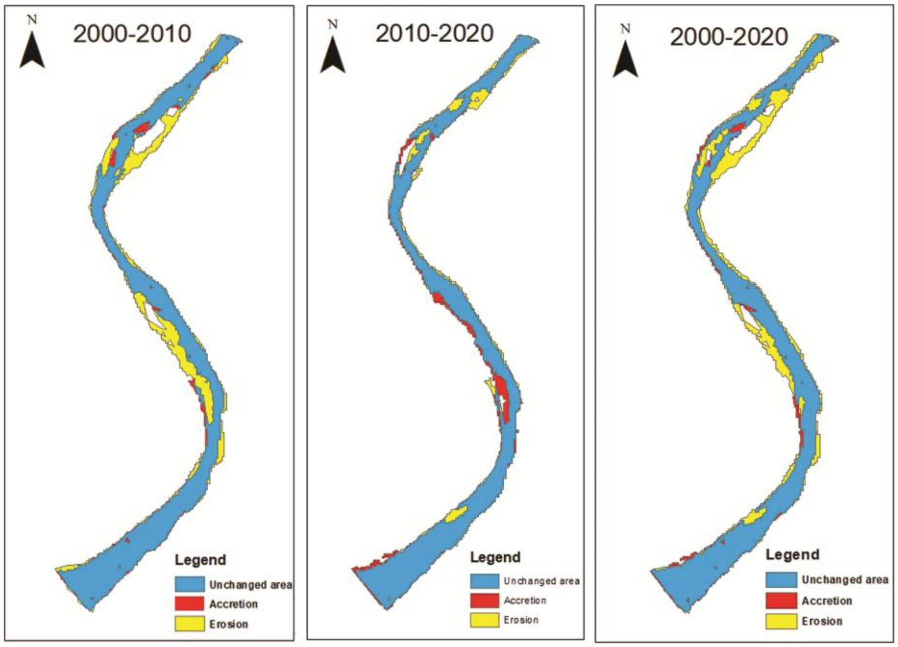

Fig.10 — River around Ropar wetland during the years 2000, 2010 and 2020 and decadal change representing Erosion and Accretion

Table 3 — Kappa accuracy for years 2000, 2010, 2020

Land Cover Type	User Accuracy (2000)	Producer Accuracy (2000)	User Accuracy (2010)	Producer Accuracy (2010)	User Accuracy (2020)	Producer Accuracy (2020)
Water Body	100%	80%	100%	100%	100%	100%
Barren/Fallow/Urban	87.5%	77.78%	100%	88.89%	87.5%	100%
Forest cover	87.5%	87.5%	100%	100%	100%	88.89%
Agricultural land	75%	85.72%	87.5%	100%	87.5%	87.5%
Overall Accuracy	87.5%	—	96.87%	—	93.75%	—
Kappa Coefficient	0.8334 (83.34%)	—	0.9583 (95.83%)	—	0.91 (91.67%)	—

building of the Bhakra Dam on the Sutlej River in the 1960s caused greater sedimentation in the Ropar wetlands downstream which may affect the reservoir's capacity significantly. Sand and gravel mining in the Ropar Wetland's catchment area, which receives water from the Sutlej River caused sediment to accumulate in the wetland. Mining activities involved removing rocks and mud, which increased the river's silt load and led to settling. As can be seen in Fig.10, sedimentation in Ropar wetland during the period of 2000–2020 can be attributed to a combination of factors, including land use changes, agricultural runoff, water infrastructure, climate change, and natural erosion. Addressing these factors is critical for the protection and preservation of wetlands and their ecosystem services.

Kappa Accuracy

The accuracy of the classification of satellite imagery in three different years was evaluated during the study. In the year 2000, the overall accuracy was found to be 87.5%, with a kappa coefficient of 83.33%, indicating moderate to strong agreement between the classified map and the reference map. In 2010, the overall accuracy was found to be 96.87%, with a kappa coefficient of 95.83%, indicating a strong agreement between the classified map and the reference map. In the year 2020, the overall accuracy was found to be 93.75%, with a kappa coefficient of 91.67%, indicating a strong agreement between the classified map and the reference map. Results of land cover classification accuracy for the Ropar wetland area in three different years: 2000, 2010, and 2020 are depicted in Table 3. For each year, the table provides user accuracy and producer accuracy values for each land cover type, as well as overall accuracy and kappa coefficient values.

Conclusions

The investigation of changes in land use and land cover in the Ropar wetland, utilizing remote sensing techniques shows that major alterations have occurred over the last 20 years. The study shows a slight reduction in the wetland's water body area and forest cover change with erosion leading to a net loss of land. Additionally, some accretion has happened in the wetland over the years. These results emphasize the need to develop better management strategies to protect and restore the wetland's ecological and hydrological functions, especially in the face of forthcoming environmental challenges. Implementing effective management practices that understand the intricate links between land use, hydrology, and ecological processes is crucial to safeguard the Ropar wetland's ecological and hydrological functions. This study contributes to understanding wetland ecosystem health and emphasizes the importance of monitoring and protecting wetlands from human activities negative impacts. Additionally, encouraging integrated evaluations that take into account issues such as land use, erosion processes, hydrology, and climate change can help develop a comprehensive strategy for managing the wetland ecosystem. The effective conservation and sustainable management of Ropar Wetland will be ensured by aligning these research objectives with the Sustainable Development Goals (SDGs) and incorporating the results into governmental policies, fostering environmental protection, socioeconomic development, and long-term ecological sustainability.

Author's Contributions

Mr. Anuvesh Pandey collected and analyzed the data. Ashita Sharma is the mentor for the conception and design of work. Dr. Kanwarpreet Singh helped in analysis of data and preparation of manuscript. All authors reviewed the manuscript.

Conflict of Interest

Authors declare that there is no conflict of interest.

Availability of Data and Materials

Not applicable

Funding

No funding was received to assist with the preparation of this manuscript.

References

1 Ramsar, About the Convention on Wetlands: Ramsar, (2014) [https://ramsar.org/about-the-convention-on-wetlands-0] Accessed on 10 April 2023
2 Silvius M J, Oneka M & Verhagen A, Wetlands: Lifeline for people at the edge, Physics and Chemistry of the Earth, Part B: Hydrology, *Oceans Atmos*, **25** (2000) 645–652. https://doi.org/10.1016/s1464—1909(00)00079—4
3 Ramachandra T V & Ahalya N, *Conservation and Management of Wetland Ecosystems in Karnataka*, (2000) PhD Thesis, Indian Institute of Science, Bangalore.
4 Akhter S & Brraich O S, Physico - Chemical analysis of fresh water of ropar wetland (Ramsar site), India, *Curr World Environ*, **15** (2020) 117–126, https://doi.org/10.12944/cwe.15.1.15
5 Ladhar S, Ropar Wetland, *Punjab State Council for Science and Technology* (2005) Chandigarh.
6 Forest Department, Punjab, *Flora & Fauna*, (2023) Retrieved on April 10, 2023, from [https://forest.punjab.gov.in/en/forest/flora/]
7 Kumar G & Singh K K, Mapping and monitoring the selected wetlands of Punjab, India, using geospatial techniques, *J Indian Soc Remote Sens*, **48** (2020) 615–625, https://doi.org/10.1007/s12524-020-01104-9
8 Lal R, Carbon sequestration, *Philos Trans R Soc B*, **363** (2007) 815–830. https://doi.org/10.1098/rstb.2007.2185
9 Philip A, Reejo R J & Jayalekshmi V K, Impact of urbanization on natural heritage with special reference to wetland depletion in Thiruvananthapuram City, Kerala, *Int J Sci Res* **9(7)** (2020) 442–446, https://doi.org/10.21275/v9i7.NOV192368
10 Xiu Y & Gang W, The strategy for conservation and sustainable utilization of biodiversity in Changbaishan Biosphere Reserve, *J For Res*, **9** (1998) 217–222, https://doi.org/10.1007/bf02910074
11 Abebe Y D & Geheb K (eds), Wetlands of Ethiopia, *Proc Seminar Resources Status Ethiopia's Wetlands*, (2003)
12 Pearce D W, The economic value of forest ecosystems, *Ecosyst Health*, **7** (2001) 284–296, https://doi.org/10.1046/j.1526-0992.2001.01037.x
13 Brogna D, Dufrêne M, Michez A, Latli A, Jacobs S, Vincke C & Dendoncker N, Forest cover correlates with good biological water quality, Insights from a regional study (Wallonia, Belgium), *J Environ Manag*, **211** (2018) 9–21, https://doi.org/10.1016/j.jenvman.2018.01.017
14 Behera D K, Saxena M R & Ravi Shankar G, Decadal landuse and landcover change dynamics in east coast of India-case study on Chilika lake, *Indian Geogr J*, **92** (2017) 73—82.
15 Kuenzer C, Bluemel A, Gebhardt S & Quoc T V, Dech S, Remote sensing of mangrove ecosystems: A review, *Remote Sens-Basel*, **3** (2011) 878–928, https://doi.org/10.3390/ rs3050878
16 Ladhar S S, *Inventory and Ecological Status of Wetlands and Lake Ecosystems of Punjab*, (1995), *PSCST Document*.
17 NRI Punjab *About District Roopnagar* (2013), [http://nripunjab.gov.in/rupnagar-about.htm] [Accessed 21 Apr. 2023].
18 Administration R, 'Demography Climate and Rainfall Roopnagar (2023) [https://rupnagar.nic.in/demography/] (Accessed: 21 April 2023).
19 Singh J, Health hazards of water pollution and its legal control with special reference to state of Punjab, *IUP J Environ Healthcar Law* **9** (2010).
20 Ropar, Retrieved from Ramsar Sites Information Service, [https://rsis.ramsar.org/ris/1161], (2002)
21 USGS USGS EROS Archive - Landsat Archives - Landsat 7 Enhanced Thematic Mapper Plus Collection 2 Level-1 Data, *US Geological Survey*, (2020) [https://www.usgs.gov/centers/eros/science/usgs-eros-archive-landsat-archives-landsat-7-enhanced-thematic-mapper-plus]

22 USGS Landsat 8, *US Geological Survey*, (2023) [https://www.usgs.gov/landsat-missions/landsat-8]
23 Mann K, *ArcGIS 10.4 is here*, ESRI, (2016) [https://www.esri.com/arcgis-blog/products/3d-gis/3d-gis/arcgis-10-4-is-here/]
24 Özelkan E, Water body detection analysis using NDWI indices, derived from Landsat-8 OLI, *Pol J Environ Stud*, **29** (2020) 1759–1769, https://doi.org/10.15244/pjoes/110447
25 Du Y, Zhang Y, Ling F, Wang Q, Li W & Li X, Water bodies' mapping from sentinel-2 imagery with modified normalized difference water index at 10-m spatial resolution produced by sharpening the SWIR band, *Remote Sens-Basel*, **8** (2016) 354, https://doi.org/10.3390/rs8040354
26 Chun X, Qin F, Zhou H, Dan D, Xia Y & Ulambadrakh K, Effects of climate variability and land use/land cover change on the Daihai wetland of central Inner Mongolia over the past decades, *J Mt Sci*, **17** (2020) 3070–3084, https://doi.org/10.1007/s11629-020-6108-1
27 Mozumder C, Tripathi N K & Tipdecho T, Ecosystem evaluation (1989–2012) of Ramsar wetland Deepor Beel using satellite-derived indices, *Environ Monit Assess* **186** (2014) 7909–7927, https://doi.org/10.1007/s10661-014-3976-2
28 Kibet R, Olatubara C O, Ikporukpo C O & Jebiwott A, Land use land cover changes and encroachment issues in Kapkatet wetland, Kenya, *Open J Ecol*, **11** (2021) 493–506, https://doi.org/10.4236/oje.2021.117032
29 Koscica M, Agropolis: the role of urban agriculture in addressing food insecurity in developing cities, *J Int Aff*, **11** (2014) 177—186.
30 Gulati A, Roy R & Hussain S, Performance of agriculture in Punjab, in *Revitalizing Indian Agriculture and Boosting Farmer Incomes, India Studies in Business and Economics* edited by A Gulati, R Roy, S Saini (Springer, Singapore) 2021, 77–112, https://doi.org/10.1007/978-981-15-9335-2_4
31 Vepraskas M J & Craft C B, *Wetland Soils: Genesis, Hydrology, Landscapes, and Classification*, (CRC Press) 2016.
32 Dahl T E, Status and trends of wetlands in the conterminous United States 2004 to 2009, *US Department of the Interior*, (US Fish and Wildlife Service, Fisheries and Habitat Conservation) 2011.
33 Gandhi V P & Zhou Z, Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China, *Food Res Int*, **63** (2014) 108–124. https://doi.org/10.1016/j.foodres.2014.03.015
34 Mabwoga S O & Thukral A K, Characterization of change in the Harike wetland, a Ramsar site in India, using Landsat satellite data, *Springer Plus* **3** (2014), https://doi.org/10.1186/2193-1801-3-576
35 Bassi N, Kumar M D, Sharma A & Pardha-Saradhi P, Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies, *J Hydrol Reg Stud* **2** (2014) 1–19, https://doi.org/10.1016/j.ejrh.2014.07.001
36 Kushwaha S, Sinha D K, Yadav A & Ahmad N, Changes in land use pattern in Uttar Pradesh: A zone-wise analysis, *Int J Curr Microbiol App Sci*, **9** (2020) 1689–1699, https://doi.org/10.20546/ijcmas.2020.901.186
37 Danso G K, Takyi S A, Amponsah O, Yeboah A S & Owusu R O, Exploring the effects of rapid urbanization on wetlands: insights from the Greater Accra Metropolitan Area, Ghana, *S N Soc Sci*, **1** (2021), https://doi.org/10.1007/s43545-021-00218-2
38 Darnell R M, Impacts of construction activities in wetlands of the United States (No. 3143), *US Environmental Protection Agency, Office of Research and Development, Corvallis Environmental Research Laboratory* (1976).
39 Zhong P, Yang Z F & Cui B S, Advance on ecological effects of highway construction on wetland and its reactions, *Wetl Sci* **7(1)** (2009) 89–98.
40 Wu G, Gao Y, Wang Y, Wang Y & Xu D, Land-use/land cover changes and their driving forces around wetlands in Shangri-La County, Yunnan Province, China, *Int J Sustain Dev World Ecol*, **22** (2014) 110–116, https://doi.org/10.1080/13504509.2014.915894
41 Rostami S, He J & Hassan Q, Riverine water quality response to precipitation and its change, *Environments*, **5** (2018) 8, https://doi.org/10.3390/environments5010008
42 Vijay R, Pinto S M, Kushwaha V K, Pal S & Nandy T A, Multi-temporal analysis for change assessment and estimation of algal bloom in Sambhar Lake, Rajasthan, India, *Environ Monit Assess*, **188** (2016) https://doi.org/10.1007/s10661-016-5509-7
43 Belsoy J, Korir J & Yego J, Environmental impacts of tourism in protected areas, *J Environ Ear Sci*, **2** (2012) 64—73.
44 Chopra G, Tyor A K, Kumari S & Rai D, Status and conservation of avian fauna of Sultanpur National Park Gurgaon, Haryana (India), *J Appl Natl Sci*, **4** (2012) 207–213, https://doi.org/10.31018/jans.v4i2.251
45 Mishra H, Kumar V & Kumar A, Population structure and habitat utilization of migratory birds at bakhira bird sanctuary, Uttar Pradesh, India, *Pak J Zool*, **52** (2019) https://doi.org/10.17582/journal.pjz/2020.52.1.247.254
46 Rather H A, Shrivastava P, Gautam V, Ganie N A, Dar R A & Hurra W A, Effects of anthropogenic activities on bird diversity in an urban waterbody (Bhoj Wetland), Bhopal, Madhya Pradesh, India, *Int J Fauna Biol Stud*, **9** (2022) 21–24, https://doi.org/10.22271/23940522.2022.v9.i2a.886
47 Pattanaik C & Reddy C S, Need for the conservation of wetland ecosystems: A case study of Ansupa Lake (Orissa, India) using remote sensing-based data, *Natl Acad Sci Lett*, **30** (2007) 161.
48 Mishra S, Sharma M P & Kumar A, Assessment of water quality in Surha Lake based on physiochemical parameters, India, *J Mater Environ Sci*, **6** (2015) 2446–2452.
49 Krishnan J U, Saroja Devi S, Jithine J R, Ajesh G & Lekshmi N R, Pollution status of Ashtamudi lake, Kerala, India and its impact on some key stone mangrove species-A case study, *Int J Innov Stud Aquat Biol Fish*, **1(2)** (2015) 17—22.
50 Lekshmiprasad S & Mophin K, Water quality assessment of Ashtamudi lake using NSFWQI, *Int J Emerg Technol Adv Eng* **7(1)** (2017).
51 Liu K, Li X & Long X, Trends in groundwater changes driven by precipitation and anthropogenic activities on the southeast side of the Hu Line, *Environ Res Lett*, **16** (2021) 094032, https://doi.org/10.1088/1748-9326/ac1ed8.
52 Ashok A, Rani H P & Jayakumar K V, Monitoring of dynamic wetland changes using NDVI and NDWI based landsat imagery, *Remote Sens Appl Soc Environ*, **23** (2021) 100547, https://doi.org/10.1016/j.rsase.2021.100547
53 Alsdorf D E, Rodríguez E & Lettenmaier D P, Measuring surface water from space, *Rev Geophys* **45** (2007), https://doi.org/10.1029/2006rg000197.