



Mapping and Monitoring the Selected Wetlands of Punjab, India, Using Geospatial Techniques

Gaurav Kumar¹ · Kiran Kumari Singh¹ 

Received: 11 July 2019 / Accepted: 16 January 2020 / Published online: 4 February 2020
© Indian Society of Remote Sensing 2020

Abstract

Wetland inventories especially on their spatial extent are a prerequisite for management and conservation of any wetland. The advancement in geospatial techniques has offered a wide range of methodological applications to prepare the inventories and to understand the dynamics of wetlands. The freely available Landsat imagery has been widely used in extracting spatial and temporal information about wetlands. The literature suggests that wetland has declined all over the globe over the past few decades. This study aims to prepare land use/land cover information of three wetlands of Punjab (Harike, Ropar, and Nangal) through direct on screen digitization and through digital processing using automatic digital indices as well. Evaluation of the performance of two band indices, normalized difference water index (NDWI) and modified normalized difference water index (MNDWI) is also taken up in the present study. Landsat data of two periods-1990/91 and of 2018 are used for the study to perform two band indices. The result indicates that the NDWI and MNDWI are less time consuming and serve the purpose of mapping and monitoring wetlands with higher accuracy.

Keywords Wetland mapping · LULC · NDWI · MNDWI · Landsat images · Water dynamics · Harike

Introduction

According to the Millennium Ecosystem Assessment report (2005), the global extent of wetlands is estimated to be on around 1280 million hectares (ha) and these wetlands are under severe threats of degradation due to various reasons. The wetlands comprise of the marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m (Ramsar Convention 2010). The loss of wetland is, in fact, faster than any other ecosystem all over the globe. These changes are reflected in areal shrinkages, growth of aquatic vegetation or weeds and water pollution or change in water properties. Considering the immense role of wetlands in ecosystem

protection and livelihood of people, it is imperative to generate information for their protection and management. Long-term change provides a better understanding of trends and dynamics of wetlands which enables the management agencies to prepare restoration or conservation programs. The strategic goal 2 of the Ramsar Convention's fourth Strategic Plan (2016–2024) emphasizes effective conservation and integrated management of Ramsar sites. Its mission advocates wise use of wetland by all the stakeholders to achieve sustainable development goals (SDGs) (Ramsar Handbook 2016). The critical role of wetlands in achieving SDGs cannot be ignored due to multiple benefits and services associated with it for people as well as for nature. Wetlands support biodiversity, provide water supply, support agricultural activities, regulate climate, recharge groundwater, provide flood and coasted protection, offer opportunities of recreation, tourism and livelihood (Bassi et al. 2014).

In India, inventories on wetland have been generated in different years. The first wetland inventory for India was prepared by Space Application Centre on 1:250,000 scale using Indian Remote Sensing satellite (IRS) data in 1992–93. The inventory reported the wetland extent at 8.26

✉ Gaurav Kumar
bansalgari001@gmail.com

✉ Kiran Kumari Singh
kiran.singhgeo@gmail.com; kiran.singh@cup.edu.in

¹ Department of Geography, School of Environment and Earth Sciences, Central University of Punjab, Bathinda, India

million ha of land. This inventory was updated in 2004–05 (SAC 2011; Panigrahi et al. 2012). The National Wetland Atlas prepared by Space Application Centre (SAC) in 2011 reported on the extent of wetlands at 15.26 million ha, which was 4.64% of the total geographical area of the country. The Atlas followed a three-tiered classification, and a total of 19 classes of wetlands were identified (SAC 2011). The land use/land cover categories reported by the Atlas was waterbody and vegetation. Another feature of the Atlas was its pre- and post-monsoon analysis. Seenivasan (2013) emphasized the need to undertake a study of past and present status of wetlands in order to bring out status change in their areal extent.

This study has attempted to find out the long-term change in the selected wetland of Punjab using satellite images. The present study, therefore, seeks: (1) to prepare land use/land cover inventory of three wetlands (Harike, Nangal, and Roper) in Punjab by delineating maps and provide the estimates of different classes; (2) to document surface water dynamics of three wetlands from 1990/1991 to 2018 through manual digitization; and (3) to evaluate the performance of two band indices (NDWI and MNDWI) in mapping and monitoring waterbodies and assess the accuracy.

Remote Sensing and Wetland Mapping

In order to protect wetland from degradation, there is a compelling need to monitor the status of wetlands and generate accurate inventories on the spatial extent and monitor the temporal changes. According to Gallant (2015), monitoring of wetland in situ is very expensive especially when the study intends to capture information on regional, national and global scale. Hence, remote sensing technology can provide opportunities to map wetland at different scales (Prigent et al. 2001; Ozesmi and Bauer 2002). A review paper published by Guo et al. (2017) provides an overview of wetland remote sensing research conducted between 1964 and 2017 and highlights different data and methods used in wetland research. Their study proposed the uses of remote sensing in future wetland research with consideration of scale effects.

Remote sensing is inexpensive and can provide cost-effective information on a broader scale at an economic rate and its archival data offers scope for temporal change detection of wetland (Adam et al. 2010). However, mapping and monitoring wetland using remote sensing create difficulties due to the various characteristic of wetlands (Fig. 1). Many wetlands are seasonal and mapping requires selection of data on the basis of seasons. Wetland may cover open water and aquatic vegetation which affect the reflectance properties. Studies also highlight that the land use/cover and management practices affect the quality

of water and types of aquatic vegetation in the wetland. Remote sensing data with different spatial resolutions have been used for mapping and monitoring wetland. Various studies have used MODIS (moderate resolution imaging spectroradiometers) data for mapping of the waterbody inundation (Mizuochi et al. 2014; O'Grady et al. 2014) and wetland area monitoring (Petus et al. 2013; Chen et al. 2014). Landsat data has been widely used in wetland mapping (Mertes et al. 1993; Son et al. 2015). SAR (synthetic aperture radar) data has also been used, in a combination with Landsat data, to track seasonal changes in wetland vegetation and surface water spread (Gallant 2014). Studies are also available on land cover types and water quality to determine how land cover changes affect the environment (Choi and Han 2013). Mapping and monitoring the wetland and its associated land uses are crucial to understand its dynamics and prepare conservational plans. Remote sensing data provides accurate information on encroachment of wetland areas by other activities and advances our understanding of reasons for loss of wetland.

Study Area

A study carried out by Ladhar (2002) had reported 12 natural wetlands (8.39 km² in area) and 9 human-made wetlands (147.39 km² in area) in Punjab. The National Wetland Atlas (2011) mapped 1381 wetlands in Punjab which covered 86,283 ha (including 5049 small wetlands) which accounted for 1.71% of the total geographical area of the state (SAC 2011). The major category occupying 69% of the wetland is rivers and streams, 14% is occupied by reservoir and barrages while remaining 17% are in the forms of tank/pond, waterlogged, lake and riverine wetland. Punjab is an important food grain producing state of India and the role of wetlands as sources of irrigation, hydropower generation and as shelters for varieties of birds cannot be ignored. Due to their immense role in biodiversity protection, three wetlands (Harike, Roper, and Kanjli) are included in the Ramsar list and many more are declared wetlands of national importance. Figure 2 shows location of Punjab in India and the distribution of different wetlands in the state.

The largest human-made wetland of northern India, the Harike wetland, came into existence in 1952 after the construction of reservoirs at the confluence point of River Sutlej and Beas and lies at 31° 05' 15" North to 31° 14' 15" North and 74° 55' 30" East to 75° 07' 30" East longitude (Chopra et al. 2001). The Harike wetland covers an area of 7406 ha (SAC 2011). In 1981, it was declared a wildlife sanctuary by the state government (Ladhar 2002; Tiwana et al. 2008). The Roper wetland is located in the eastern part of Punjab at 30° 57' North to 31° 06' 30" North

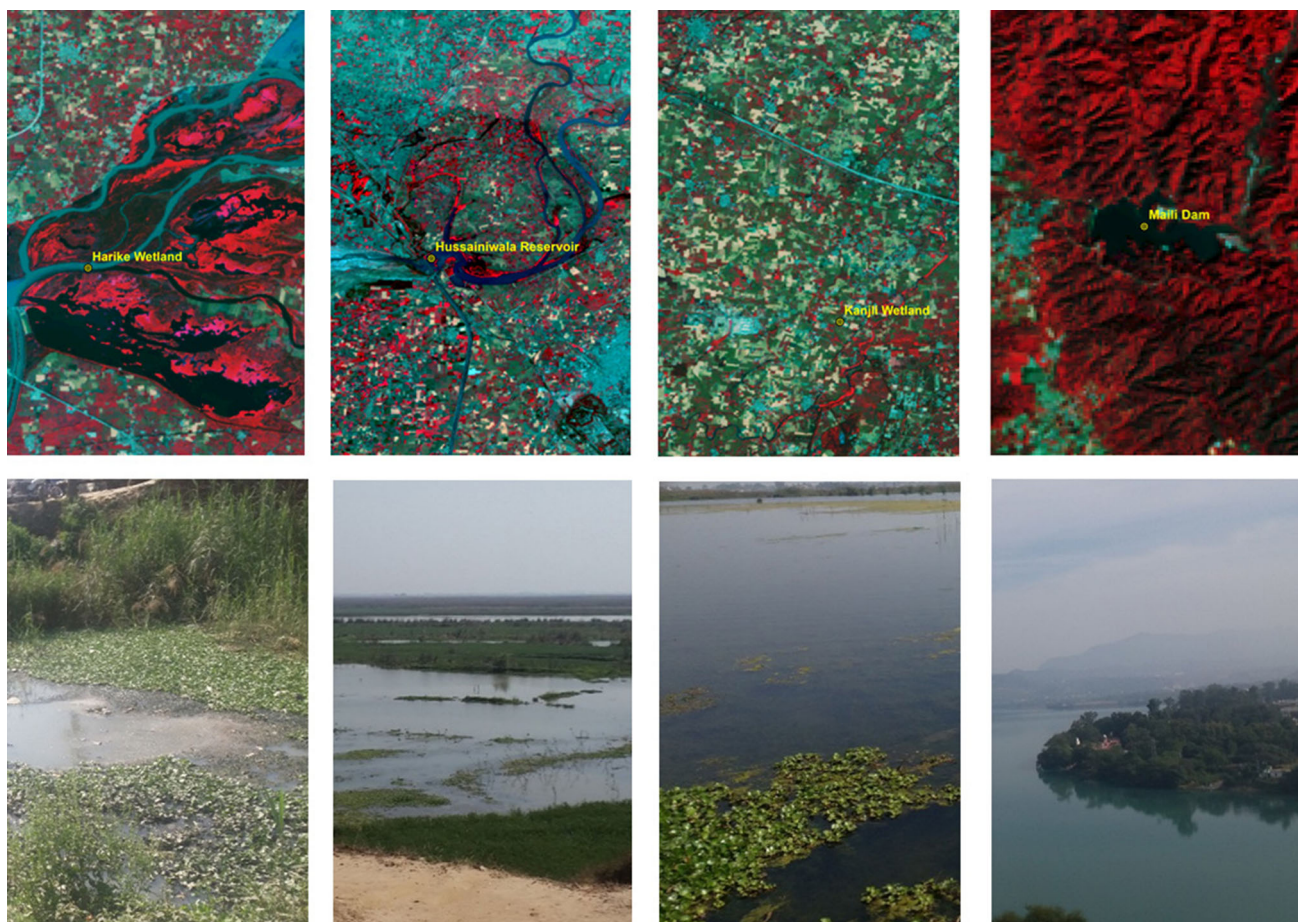


Fig. 1 Selected wetlands of Punjab are located on Landsat 8 image of 2018 (upper section). Mapping of surface waterbody is easy through remote sensing data; however, the presence of vegetation with water and marsh creates difficulty in mapping (field photo, 2018)

latitude and $76^{\circ} 25' 30''$ East to $76^{\circ} 36'$ East longitudes and is situated at an elevation of 275 m above the mean sea level (Verma et al. 1998). It covers an area of 1365 ha including 800 ha under water (ENVIS 2015). The Nangal wetland came into existence on the Sutlej River in 1961. As for its geographical location, the wetland is situated between $31^{\circ} 22'$ North to $31^{\circ} 37'$ North latitudes and $76^{\circ} 23'$ East to $76^{\circ} 38'$ East longitudes. The water from Nangal wetland is used for power generation and irrigation purposes. As per the notification of Department of Forest and Wildlife Preservation, the Nangal wetland is expanded over 715.83 acres (289.53 ha) of area (Government of Punjab 2009). All the three wetlands are important sources of fresh water, and serve as habitats to a number of migratory birds and are sites for recreational activities.

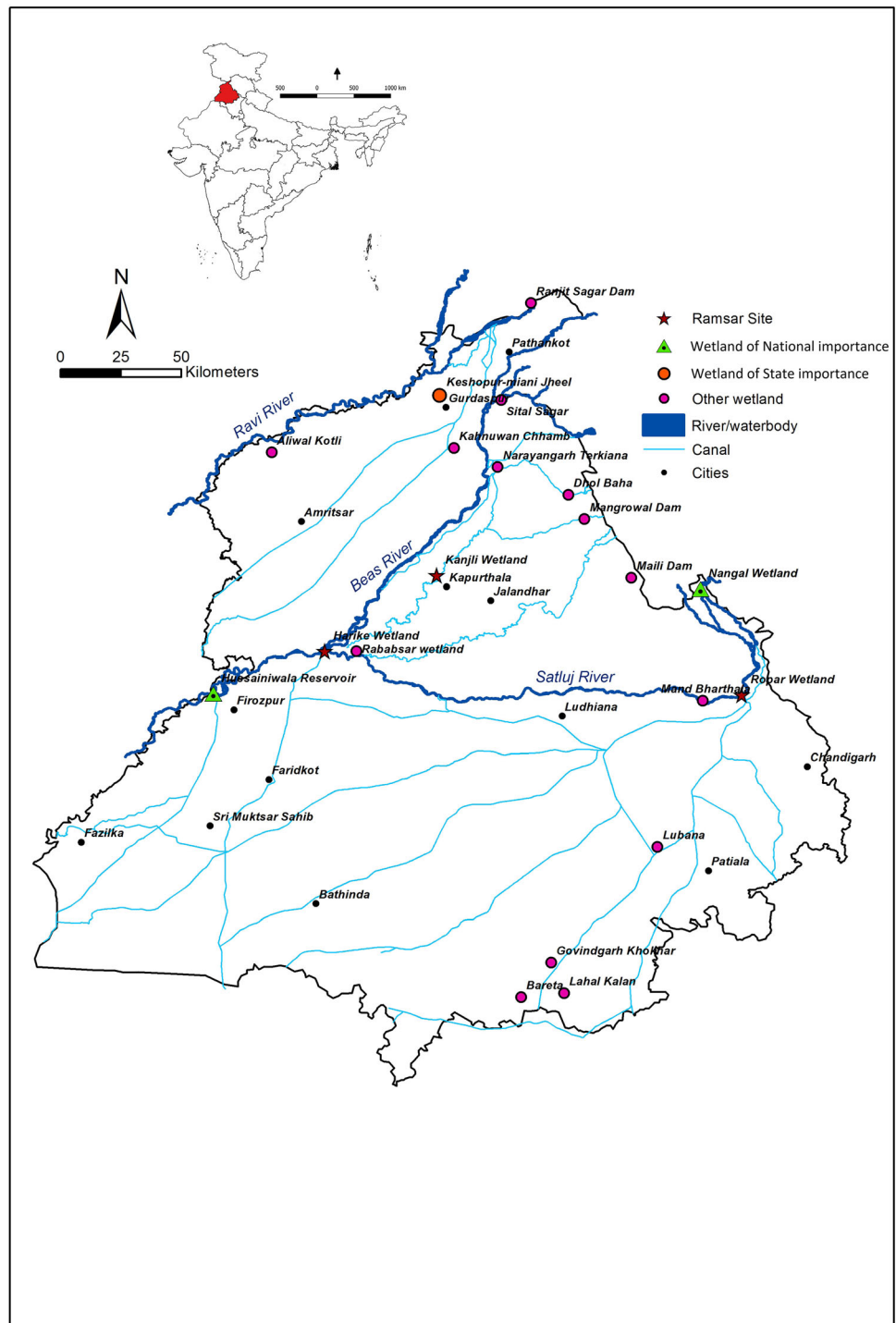
Several studies have reported the degrading conditions of the wetlands of Punjab and other states of India. Hariko, a wetland of international importance, is found to face problems of siltation, decreasing trend of flow, weed infestation (Ladhar 2002; Jain et al. 2008; Jain et al. 2008; Tiwana et al. 2008; Kumar and Kaur 2018) pollution,

declining water quality due to industrial waste, presence of heavy metals (Kumar et al. 2016; Braich and Jangu 2016; Mabwoga et al. 2010) and encroachment due to agricultural activities (Chopra et al. 2001). Due to dependency over wetland for agricultural activities and requirement of land for many developmental activities, the wetlands are highly vulnerable to change in land use and conversion (Chitra 2016). The threats identified for Ropar wetland are industrial expansion, indiscriminate use of agricultural land, human interferences and recreational activities (Verma et al. 1998). Nangal wetland is facing the problem of siltation, weed infestation and agricultural runoff.

Materials and Methods

The data used in the study are Landsat 5, Landsat 7, Landsat 8 of 30 m spatial resolution and IRS LISS IV data of 5.8 m spatial resolution. All the Landsat data with a span of 28 years from 1990/1991 to 2018 are downloaded from the website of the US Geological Survey (USGS-<http://>

Fig. 2 Distribution of important human-made and natural wetland in Punjab (Map prepared using Google Earth)



www.usgs.gov). The IRS LISS IV data were procured from the National Remote Sensing Centre, Hyderabad. Table 1 shows the details of the satellite data used for the study.

The most common method used in the extraction of the water surface is two band indices (Ryu, Won and Min 2002). Many studies have shown that variables such as the normalized difference vegetation index (NDVI), normalized difference water index (NDWI), and normalized

difference built-up index (NDBI) are useful for wetland classification (Rouse Jr. et al. 1974; Allen 2012; McFeeters 1996; Xu 2006; Rokni et al. 2014; Zha et al. 2003; Chen et al. 2006). Studies have also used the method of density slicing of mid-infrared band (Johnston and Barson 1993), land surface water index (LSWI) (Dong et al. 2014), maximum likelihood supervised classification (Zhang et al. 2011), object-oriented classification method (Jia

Table 1 Satellite images used in this study

S. no.	Sensor	Acquisition date	Spatial resolution (m)
1	Landsat 8 OLI	30 March 2018	30
2	Landsat 8 OLI	06 March 2018	30
3	Landsat 7 ETM	10 February 2003	30
4	Landsat 5 TM	03 April 1990	30
5	Landsat 5 TM	17 February 1991	30
6	Landsat 5 TM	09 March 1990	30
7	IRS P6 LISS IV	03 March 2005	5.8
8	IRS R2 LISS IV	10 February 2015	5.8

et al. 2013, 2014), visual interpretation method (Xue et al. 2018) and Tasseled-cap Wetness index (TWI) (Ndayisaba et al. 2017) to monitor wetland. The normalized difference water index (NDWI) is a widely used method to delineate open water features because waterbodies appear very distinct in visible and infrared wavelength due to their strong absorbability (Ashtekar et al. 2019; Yan et al. 2017; Bahera et al. 2012). The NDWI makes use of visible green light and reflected near-infrared radiation (NIR) to enhance the presence of waterbody. The method of NDWI ($\text{Green} - \text{NIR} / \text{Green} + \text{NIR}$) was designed by McFeeters in 1996 to detect surface waters in wetland environments and to allow for the measurement of surface water extent. He classified the positive value above zero as waterbody and all the negative values as non-water. Another index used is MNDWI (modified normalized difference water index) which uses green and short wave infrared (SWIR) bands for extraction of water features ($\text{MNDWI} = \text{Green} - \text{SWIR} / \text{Green} + \text{SWIR}$). Studies have shown that the built-up features also produce positive values in NDWI and the water features are mixed up with built-up noise and affect the accuracy of the result. The MNDWI enhances the water feature results especially of open water features and the built-up land, soil and vegetation come up with negative values and are nearly suppressed or even removed (Xu 2006). Several studies have reported that long-term change detection can enable researchers to better understand the trends and dynamics of wetlands and can assist in preparing protection strategies (Guo et al. 2017). The present study has generated NDWI of three wetlands of Punjab for three different years 1990/1991, 2005 and 2018 and MNDWI for 1990/1991 and 2018. These two methods are compared for two different periods: 1990/1991 and 2018. Another widely adopted method to quantify wetland change is land use/land cover classification and change detection (Chopra et al. 2001; Douglas et al. 2018; Widney et al. 2018). Visual interpretation of land use features focussing water feature is performed for 1990, 2005 and 2018 for Harike wetland. The land use/land cover maps for

Ropar and Nangal wetlands and their surroundings are created through visual interpretation for the year 2018. Thus, water features are extracted using three different methods: visual interpretation, NDWI, and MNDWI. The results obtained through the two band indices are compared and evaluated with pixel-by-pixel comparison using the reference images and accuracy is assessed.

It should be noted as limitation of the study that the atmospheric correction of images has not been done and the minimum, maximum and optimum threshold values may differ from the corrected images. The spatial resolution of the Landsat data used in the study is 30 m and the result at edge pixels can cause underestimation of the result for the waterbody. In order to perform the indices, a large section covering wetlands are subset from the image. The purpose of performing two band indices is to assess the accuracy of the result generated by these two. The larger area represents the wetland and their surrounding and therefore, the area of waterbody generated through two band indices is likely to vary from the total area of the wetland boundaries.

Results

Land Use/Cover Dynamics in Wetlands

Figure 3 shows the land use/cover categories of Harike wetland in three different years. The wetland has experienced significant changes due to influences of human activities inside the sanctuary area during the past 28 years (Table 2). The dominant category was waterbody in 1990 while the cultivated land covered 2% of the total area. Over 28 years, the area under cultivated land has increased while the area under waterbody (stagnant water in the form of the lake) has significantly decreased within the sanctuary area from 3114.60 ha in 1990 to 1330.41 ha in 2018. Area under shrub and marshy land has also decreased (see Table 2 for change in different years). The decrease is very conspicuous in southern and central parts where open waterbody is covered by aquatic plants like hyacinth (Fig. 3). The entire wetland is very fertile and expansion of cultivated land can be seen in the northern part and along river Sutlej in the southern part. Encroachment inside sanctuary area for cultivation and grazing activities are considered major obstacles in management of the wetland. Land use/cover maps for Ropar and Nangal wetlands are prepared for the year 2018. The land use has been categorized into seven classes for Ropar wetland and four classes for Nangal wetland (Fig. 4). The area under each class is given in Tables 3 and 4. The major portion of these two wetlands is covered by water, and therefore, the land use/cover was prepared in and around the wetlands. This is

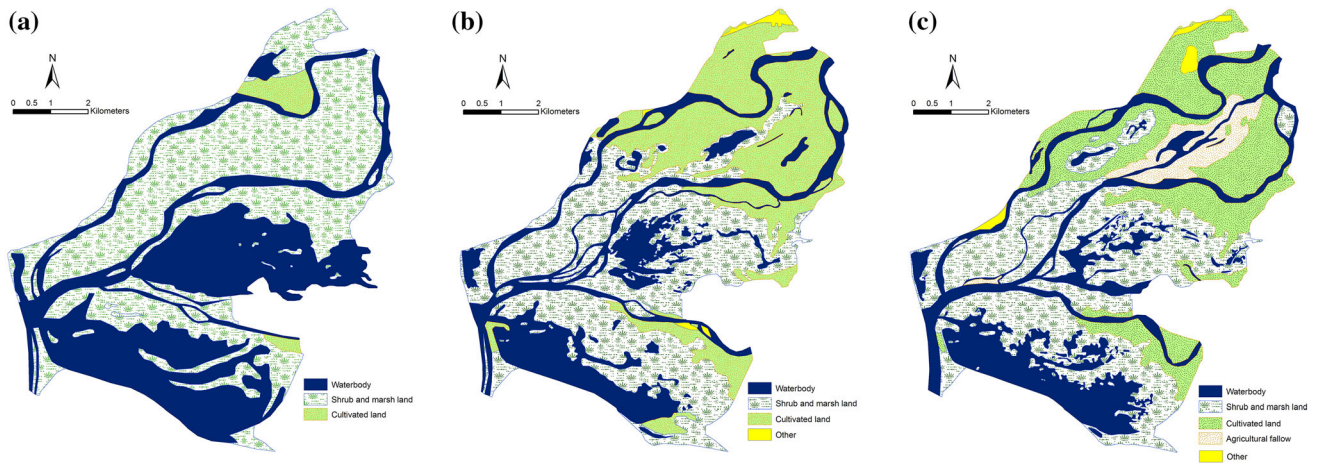


Fig. 3 Land use/cover change inside the Harike sanctuary area. March, 1990 (a), March 2005 (b), March 2018 (c)

Table 2 Aerial estimates of land use/cover classes in Harike Wetland (Areas in hectare)

Sr. No.	Category name	1990		2005		2018		Net change (1990 to 2018)	% Change (1990 to 2018)
		Area	%	Area	%	Area	%		
1	Cultivated Land	166.30	02.25	1821.40	24.61	1268.90	17.15	1102.60	663.01 increase
2	Waterbody	3114.60	42.09	1758.20	23.76	1330.41	17.98	- 1784.20	- 57.28 decrease
3	Shrubs and Marshy Land	4120.00	55.68	3088.30	41.73	4054.30	54.79	- 65.70	- 1.59 decrease
4	Other	0.00	0.00	732.10	09.89	750.0	10.14	750.00	-

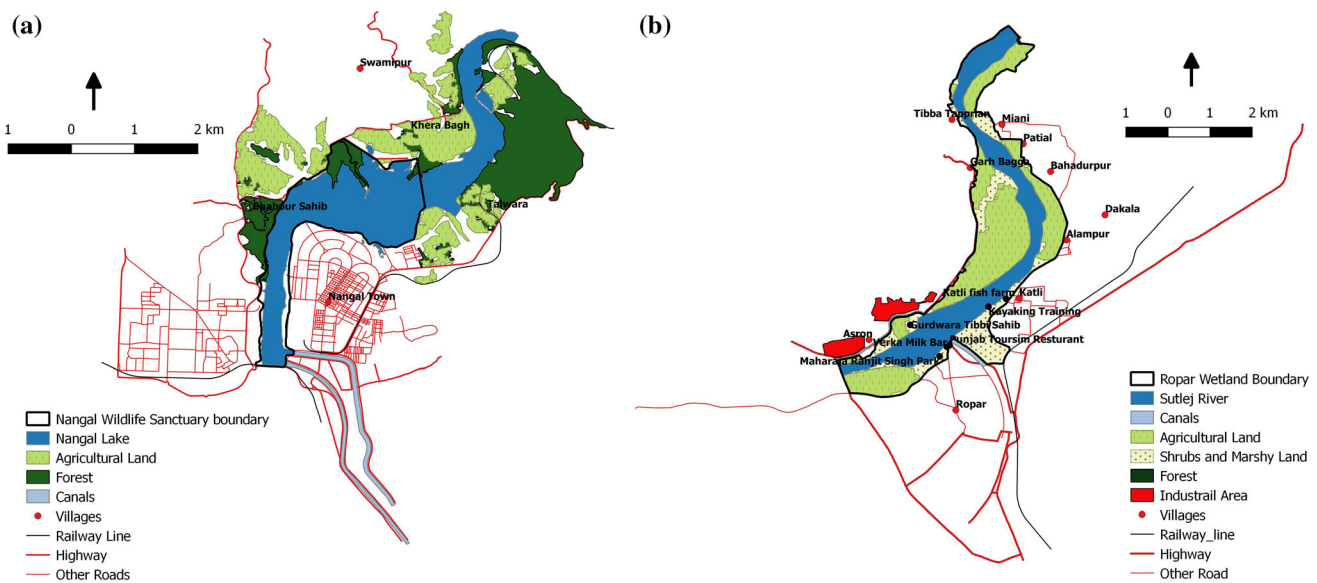


Fig. 4 Land use/cover around Nangal Wetland, 2018 (a) and Ropar Wetland, 2018 (b)

done because the land use practices in surrounding environment can affect the quality of wetlands. The land use/cover categories for all the three wetlands vary due to different activities observed in and around of the wetlands.

For example, agricultural land is a common land use category in all the three wetlands while industrial activities are observed only around Ropar wetland. Much changes are not reported in land use/cover categories of the

Table 3 Aerial estimates of land use/cover classes in Ropar wetland and surrounding (2018)

Sr. no.	Category	Areas in hectare
1	Agriculture land	520.48
2	Commercial plantation	18.42
3	Waterbody (inside Ropar wetland)	426.40
4	Canals	16.61
5	Forest	128.85
6	Industrial area	77.31
7	Marshy and Shrubs	185.44

Table 4 Aerial estimates of land use/cover classes in Nangal wetland and surrounding (2018)

Sr. no.	Category	Areas in hectare
1	Agriculture land	303.9
2	Waterbody (inside Nangal wetland)	234.9
3	Forests	314.72
4	Settlements	21.7

wetlands, and therefore, the change detection was not performed.

Surface Water Dynamics of Wetlands

The Harike sanctuary area comprises of a section of river Beas, river Sutlej and lakes. Figure 5a shows the surface water dynamics of Harike wetland from 1990 to 2018. In a

span of 28 years, severe changes have occurred inside the sanctuary area. Fluctuations in the course of Beas and Sutlej rivers can also be seen. Shrinkage in surface water cover has occurred from 1990 to 2005 due to growth of hyacinth and other aquatic weeds in the lakes (in the south, between eastern branch of river Beas and river Sutlej and between two branches of river Beas. In 2002, a cleanliness drive was started by the state government with the help of Indian Army to remove aquatic weeds especially hyacinth (Kumar 2019). This resulted in an increase in the area under surface water after 2002. Though the area of surface waterbody has declined, the result of cleanliness drive can be seen in the south-eastern part of the sanctuary. In between 2015 and 2018, surface waterbody again increased marginally in the central lake.

Nangal and Roper wetland are located in hilly areas and are of small spatial extent. Contrary to the observation of Harike wetland, areas under surface water bodies in the Ropar and Nangal wetlands have reported marginal status change from 1990/1991 to 2018. This study reports that the water surface in Nangal wetland has declined by 13.7 ha from 248.6 ha to 234.9 ha from 1990 to 2018. From Fig. 5, it is observed that very few changes have occurred in the northeast direction of Ropar wetland and its surface waterbody extent has increased from 413.8 ha in 1990 to 426.4 ha in 2018.

Two Band Indices for Water Body Extraction: NDWI and MNDWI

The NDWI images have been generated for the Harike, Ropar and Nangal Wetlands for 1990/1991, 2005 and 2018.

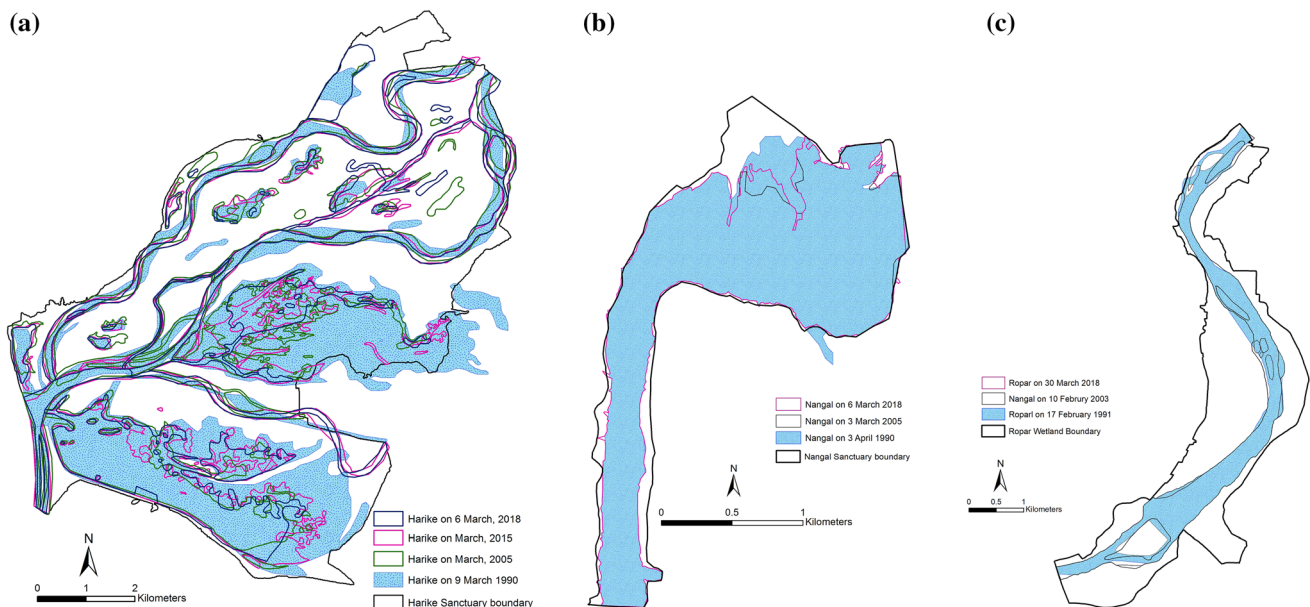


Fig. 5 Surface water dynamics of Harike wetland (a); Nangal Wetland (b); Ropar wetland (c)

The result is presented in a color-coded image with only two categories: surface water body and the other/non-waterbody. The index value of NDWI of Harike wetland ranges from -0.486 to 0.202 . The positive value above 0 shows the waterbody. The lowest value corresponds with the agricultural land. Marshy land and other non-waterbody show negative values. The MNDWI value for Harike wetland ranges from -0.266 to 0.290 , and the value above 0 shows the waterbody. The area computed for waterbody through MNDWI is found to be higher than that derived from NDWI. Waterbody covered under weeds and marshy land also showed positive value in MNDWI. The NDWI and MNDWI values for Nangal wetland range from -0.432 to 0.145 and -0.381 to 0.225 , respectively, and in both the indices the results for water body and non-waterbody are similar. The NDWI and MNDWI values for Ropar wetland range from -0.452 to 0.115 and -0.290 to 0.220 , respectively, and MNDWI gives better result than NDWI. The output of waterbody extraction from NDWI for three wetlands is presented in Fig. 6.

The NDWI and MNDWI images both, of all the three wetlands, clearly show open water features as the result of enhancement (Fig. 7). Nevertheless, the MNDWI produced

a better result as compared to NDWI. The NDWI gives inconsistent result at various places: The waterbody gives negative value and the bare soil value is found to be similar with waterbody value at many places. While these inconsistent values are quite stable in the MNDWI suggesting that the errors present in the NDWI can be removed or suppressed with the use of SWIR band (Li et al. 2013; Singh et al. 2015). In the case of Nangal and Roper wetlands and their surroundings, the MNDWI presents more contrasting result by suppressing the reflectance values of other features. However, the difference in water surface area was not significant in both the images. Table 5 shows the areal change in waterbody derived from two indices between 1990/1991 and 2018 (Fig. 8).

The validity of the result obtained through two band indices is tested through accuracy assessment. The stretched images are classified using threshold value into two categories: water and non-waterbody. Campbell (2007) has suggested using evidence to test the validity of the result. The accuracy of both the images was assessed using 60 random samples points for water/non-waterbody categories in ERDAS Imagine 2014 software. The reference data used to check accuracy for the year 2018 images is high spatial

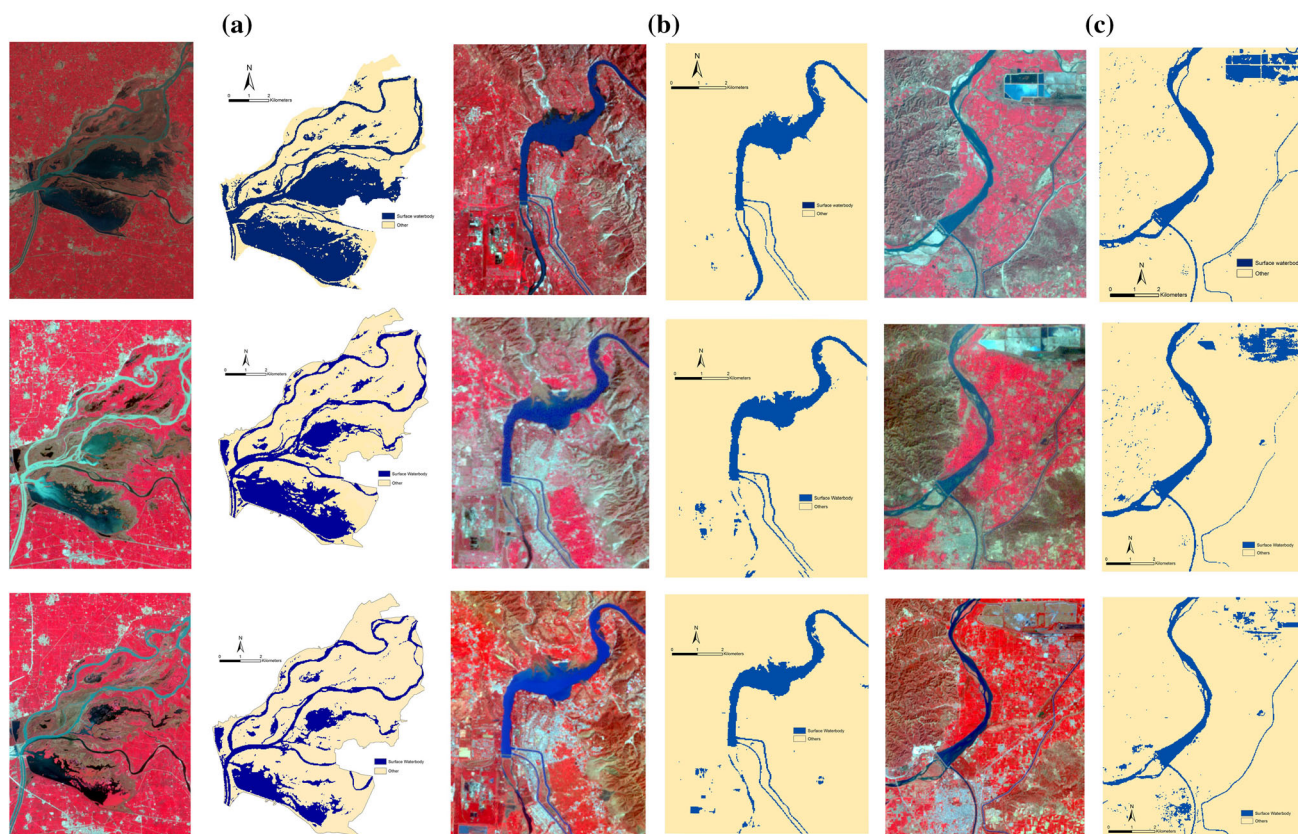


Fig. 6 **a** Landsat image of Harike wetland and color-coded NDWI image of 1990 (top), 2005 (middle), 2018 (bottom). **b** Landsat image of Nangal wetland and its surrounding and Color-coded NDWI image

of 1990 (top), 2005 (middle), 2018 (bottom). **c** Landsat image of Ropar wetland and its surrounding and color-coded NDWI image of 1991 (top), 2005

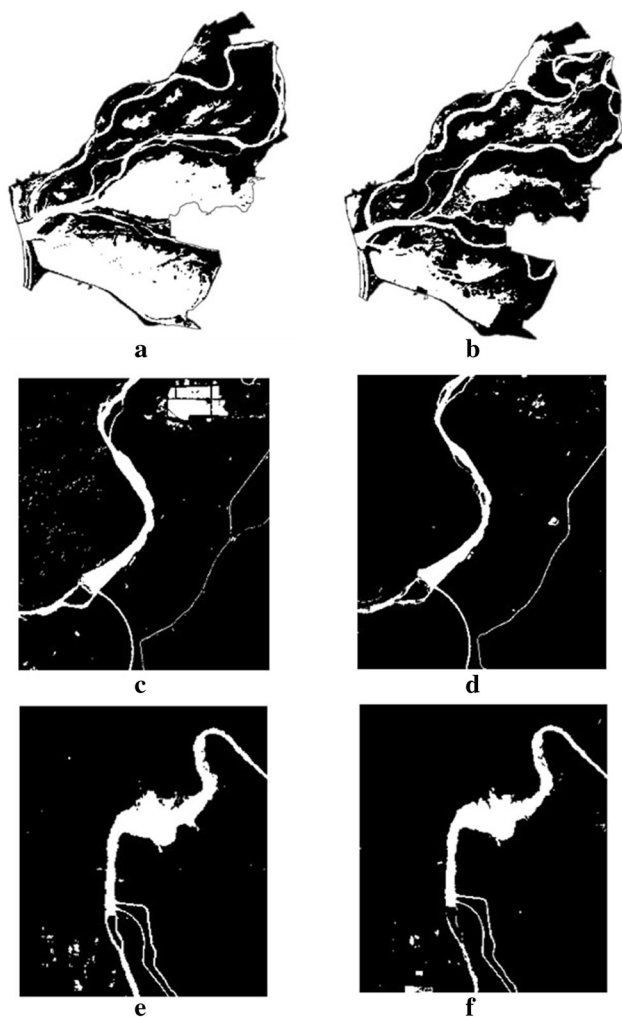


Fig. 7 Comparison of waterbody extraction from MNDWI at three wetland sites. **a** Harike wetland in 1990; **b** Harike wetland in 2018; **c** Roper wetland and its surrounding in 1991; **d** Roper wetland and its surrounding in 2018; **e** Nangal wetland and its surrounding, 1990; **f** Nangal wetland and its surrounding, 2018. The threshold value is set at 0

Table 5 Change in the area under waterbody in Harike, Ropar and Nangal wetlands based on double band indices (Areas in hectares)

Wetlands	1990/1991		2018	
	NDWI	MNDWI	NDWI	MNDWI
Harike	3153	3182	1497.46	1809.38
Ropar	790	790.60	850.00	852.89
Nangal	366.21	366.00	348.00	348.18

The total area of waterbody in case of Nangal and Ropar wetlands have varied from their reported area due to a larger section of the image taken to perform the indices

resolution Google Earth image of 2018 while multispectral images are used for the year 1990/1991 as reference data. The kappa coefficient for NDWI image is 0.8036 and

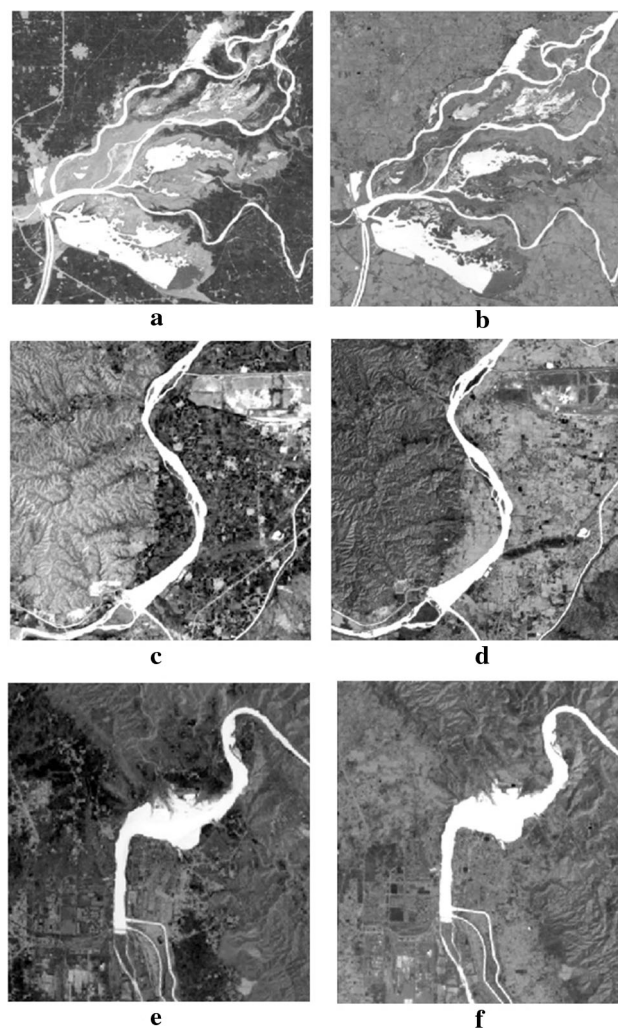


Fig. 8 Comparison of waterbody shown in NDWI and MNDWI stretched images at three wetland sites. **a** NDWI image of Harike wetland; **b** MNDWI image of Harike wetland; **c** NDWI image of Roper wetland and its surrounding; **d** MNDWI image of Roper wetland and its surrounding; **e** NDWI image of Nangal wetland and its surrounding; **f** MNDWI image of Nangal wetland and its surrounding. All the images are for year 2018

0.8567 and for MNDWI image is 0.8567 and 0.9495 for the years 1990/1991 and 2018, respectively.

Discussion

Different methods were employed to create land use/cover and to work out surface water spread in wetlands. When the area is small, the classes can be created by manual digitization through visual interpretation. Manual digitisation of smaller areas gives good results provided it is done very patiently over high resolution data; but, of course, is time consuming. Digital methods are a better alternative especially when the areas are complicated and large. The study

found that there are conspicuous changes in the land use pattern of Harike Wetland. The area under waterbody, derived through visual interpretation, has declined from 42% (3114.6 ha) in 1990 to 18% (1330.4 ha) in 2018. The extent of other land uses has increased from 5 to 82% during the same period. The decline in water level in Harike wetland is due to weed infestation and human interferences for agricultural activities. The MNDWI result suggests that the area under waterbody in Harike wetland has declined from 3182 ha in 1990 to 1809.38 ha in 2018. In addition, areas under the waterbody decreased in the southern, central and northern regions.

The NDWI and MNDWI for Ropar wetlands and its surroundings show little changes because the level of water is maintained by the construction of headworks. Similarly, very few changes occurred in the surface waterbody of Nangal wetland and its surroundings due to the nature of wetland as a result of dam construction. A fixed amount of water in Nangal wetland is released from the Bhakra Dam and a fixed amount of water is discharged into Nangal hydel and Anandpur Sahib hydel channels from Nangal wetland (Kumar 2019). The study shows that the wetland located in hilly areas for the purpose of hydel power generation has little fluctuation in water surface while the Harike wetland located in plain area has suffered major fluctuation in the extent of water spread. The MNDWI result shows that the surface waterbody of Ropar wetland and its surroundings has increased from 790.6 to 852.89 ha while it has decreased from 366 ha in 1990 to 348.18 ha in 2018 in Nangal wetland and its surroundings.

Acknowledgments The United States Geological Survey (<https://earthexplorer.usgs.gov/>) is thankfully acknowledged for providing Landsat images free of cost. The National Remote Sensing Agency, Hyderabad, is acknowledged for providing satellite images. The first author is thankful to the UGC for granting research fellowship. The authors are grateful to the Central University of Punjab for providing necessary infrastructural facilities. The constructive comments of the anonymous reviewers are gratefully acknowledged.

Author Contributions The First author mapped the land use classes of the wetlands and conducted the ground verification at various locations. The second author performed the digital classifications and wrote the manuscript. Both the authors equally participated in revision process.

References

- Adam, E., Mutanga, O., & Rugege, D. (2010). Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: A review. *Wetland Ecology and Management*, 18(3), 281–296.
- Allen, Y. C., Couvillion, B. R., & Barras, J. A. (2012). Using multi-temporal remote sensing imagery and inundation measures to improve land change estimates in coastal wetlands. *Estuaries and Coasts*, 35(1), 190–200.

- Ashtekar, A. S., Mohammed-Aslam, M. A., & Moosvi, A. R. (2019). Utility of normalized difference water index and GIS for mapping surface water dynamics in sub-upper Krishna Basin. *Journal of the Indian Society of Remote Sensing*. <https://doi.org/10.1007/s12524-019-01013-6>.
- Bassi, N., Kumar, M. D., Sharma, A., & Pardha-Saradhi, P. (2014). Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. *Journal of Hydrology*, 2, 1–19.
- Behera, M. D., Chitale, V. S., Shaw, A., Roy, P. S., & Murthy, M. S. R. (2012). Wetland monitoring, serving as an index of land use change—A study in Samaspur Wetlands, Uttar Pradesh, India. *Journal of the Indian Society of Remote Sensing*, 40(2), 287–297. <https://doi.org/10.1007/s12524-011-0139-6>.
- Braich, O. S., & Jangu, S. (2016). Comparative account of accumulation of heavy metals and structural alterations in scales of five fish species from Harike Wetland, India. *Iranian Journal of Ichthyology*, 3(4), 275–282.
- Campbell, J. B. (2007). *Introduction to remote sensing* (4th ed.). New York: The Guilford Press.
- Chen, L., Jin, Z., Michishita, R., Cai, J., Yue, T., Chen, B., et al. (2014). Dynamic monitoring of wetland cover changes using time-series remote sensing imagery. *Ecological Information*, 24, 17–26.
- Chen, X. L., Zhao, H. M., Li, P. X., & Yin, Z. Y. (2006). Remote sensing image-based analysis of the relationship between urban heat island and land use/cover changes. *Remote Sensing of Environment*, 104(2), 133–146.
- Chitra, K. P. (2016). How Kerala is destroying its Wetlands, Amendment to Kerala Conservation of Paddy Land & Wetland Act 2008. *Economic and Political Weekly*. 51(22). <https://www.epw.in/journal/2016/22/reports-states/how-kerala-destroying-its-wetlands.html>
- Choi, M., & Han, S. (2013). Remote sensing imageries for land cover and water quality dynamics on the west coast of Korea. *Environment Monitoring and Assessment*, 185(11), 9111–9124.
- Chopra, R., Verma, V. K., & Sharma, P. K. (2001). Mapping, monitoring and conservation of Harike Wetland ecosystem, Punjab, India, through remote sensing. *International Journal of Remote Sensing*, 22(1), 89–98.
- Dong, Z., Wang, Z., Liu, D., Song, K., Li, L., Jia, M., et al. (2014). Mapping wetland areas using Landsat-derived NDVI and LSWI: A case study of West Songnen Plain, Northeast China. *Journal of the Indian Society of Remote Sensing*, 42(3), 1–8. <https://doi.org/10.1007/s12524-013-0357-1>.
- Douglas, S. H., Bernier, J. C., & Smith, K. E. L. (2018). Analysis of multi-decadal wetland changes, and cumulative impact of multiple storms 1984 to 2017. *Wetlands Ecology and Management*, 26(6), 1121–1142.
- ENVIS. (2015). Wetland of Punjab, Punjab ENVIS Centre. <http://www.indiaenvironmentportal.org.in/files/Wetlands%20of%20Punjab.pdf>.
- Gallant, A. L. (2015). The challenges of remote monitoring of wetlands. *Remote Sensing*, 7(8), 10938–10950. <https://doi.org/10.3390/rs70810938>.
- Gallant, A. L., Kaya, S. G., White, L., Brisco, B., Roth, M. F., Sadinski, W., et al. (2014). Detecting emergence, growth, and senescence of wetland vegetation with polarimetric synthetic aperture radar (SAR) data. *Water*, 6(3), 694–722.
- Government of Punjab. (2009). Department of Forest and Wildlife Preservation (Forest Branch) Notification no: 34/2/2009-FT-5/7069. Dated 10.08.2009.
- Guo, Q., Pu, R., Li, J., & Cheng, J. (2017). A weighted normalized difference water index for water extraction using Landsat imagery. *International Journal of Remote Sensing*, 38(19), 5430–5445.

- Jain, S. K., Sarkar, A., & Garg, V. (2008). Impact of declining trend of flow on Harike Wetland, India. *Water Resource Management*, 22(4), 409–421.
- Jia, M., Wang, Z., Li, L., Song, K., Ren, C., Liu, B., et al. (2014). Mapping China's mangroves based on an object-oriented classification of Landsat imagery. *Wetlands*, 34(2), 277–283.
- Jia, J., Yang, N., Zhang, C., Yue, A., Yang, J., & Zhu, D. (2013). Object-oriented feature selection of high spatial resolution images using an improved relief algorithm. *Mathematical and Computer Modelling*, 58(3–4), 619–626.
- Johnston, R. M., & Barson, M. M. (1993). Remote sensing of Australian Wetlands: An evaluation of Landsat TM data for inventory and classification. *Marine & Freshwater Research*, 44(2), 235–252.
- Kumar, G. (2019). Wetlands in socio-economic and geographical contexts: A study of Harike, Ropar and Nangal Wetlands. Unpublished Ph.D. dissertation, Central University of Punjab.
- Kumar, G., & Kaur, A. (2018). Status of wetlands in Punjab: A review on policy frameworks. *Asian Journal of Multidimensional Research (AJMR)*, 7(10), 169–177.
- Kumar, V., Sharma, A., Chawla, A., Bhardwaj, R., & Thukral, A. K. (2016). Water quality assessment of river beas, India, using multivariate and remote sensing techniques. *Environmental Monitoring and Assessment*, 188(3), 1–10.
- Ladhar, S. S. (2002). Status of ecological health of wetlands in Punjab, India. *Aquatic Ecosystem Health and Management*, 5(4), 457–465.
- Li, W. B., Du, Z. Q., Ling, F., Zhou, D. B., Wang, H. L., Gui, Y. M., et al. (2013). A comparison of land surface water mapping using the normalized difference water index from TM, ETM plus and ALLI. *Remote Sensing*, 5, 5530–5549.
- Mabwoga, S. O., Chawla, A., & Thukral, A. K. (2010). Assessment of water quality parameters of the Harike Wetland in India, a Ramsar Site, using IRS LISS IV satellite data. *Environmental Monitoring Assessment*, 170(1–4), 117–128. <https://doi.org/10.1007/s10661-009-1220-2>.
- McFeeters, S. K. (1996). The use of the normalized difference water index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7), 1425–1432.
- Mertes, L. A. K., Smith, M. O., & Adams, J. B. (1993). Estimating suspended sediment concentrations in surface waters of the Amazon river wetlands from Landsat images. *Remote Sensing of Environment*, 43(3), 281–301.
- Millennium Ecosystem Assessment Report. (2005). Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute, Washington, DC. <https://www.millenniumassessment.org/documents/document.358.aspx.pdf>.
- Mizuochi, H., Hiyama, T., Ohta, T., & Nasahara, K. (2014). Evaluation of the surface water distribution in north-central namibia based on MODIS and AMSR series. *Remote Sensing*, 6(8), 7660–7682.
- Ndayisaba, F., Nahayo, L., Guo, H., Bao, A., Kayiranga, A., Karamage, F., et al. (2017). Mapping and monitoring the Akagera wetland in Rwanda. *Sustainability*, 9(2), 174.
- O'Grady, D., Leblanc, M., & Bass, A. (2014). The use of radar satellite data from multiple incidence angles improves surface water mapping. *Remote Sensing of Environment*, 140, 652–664.
- Ozesmi, S. L., & Bauer, M. E. (2002). Satellite remote sensing of wetlands. *Wetland Ecology and Management*, 10(5), 381–402.
- Panigrahy, S., Murthy, T., Patel, J., & Singh, T. (2012). Wetlands of India: Inventory and assessment at 1: 50,000 scale using geospatial techniques. *Current Science*, 102(6), 852–856.
- Petus, C., Lewis, M., & White, D. (2013). Monitoring temporal dynamics of great artesian basin wetland vegetation, Australia, using MODIS NDVI. *Ecological Indicators*, 34, 41–52.
- Prigent, C., Matthews, E., Aires, F., & Rossow, W. B. (2001). Remote sensing of global wetland dynamics with multiple satellite data sets. *Geophysical Research Letters*, 28(24), 4631–4634.
- Ramsar Convention Secretariat. (2010). *Wetland inventory: A Ramsar framework for wetland inventory and ecological character description*. Gland: Ramsar Convention Secretariat.
- Ramsar Convention Secretariat. (2016). The fourth Ramsar strategic plan 2016–2024. Ramsar handbook for the wise use of wetlands, 5th edn, Vol. 2. Ramsar Convention Secretariat, Gland, Switzerland. https://www.ramsar.org/sites/default/files/hb2_Sed_strategic_plan_2016_24_e.pdf.
- Rokni, K., Ahmad, A., Selamat, A., & Hazini, S. (2014). Water feature extraction and change detection using multitemporal Landsat imagery. *Remote Sensing*, 6(5), 4173–4189.
- Rouse, J. W., Jr., Haas, R., Schell, J., & Deering, D. (1974). *Monitoring vegetation systems in the great plains with ERTS*. Washington, DC: NASA Special Publication.
- Ryu, J. H., Won, J. S., & Min, K. D. (2002). Waterline extraction from Landsat TM data in a tidal flat—A case study in Gomso Bay, Korea. *Remote Sensing of Environment*, 83(3), 442–456.
- SAC. (2011). National wetland atlas. http://saconenvis.nic.in/publication%5CNWIA_National_atlas.pdf.
- Seenivasa, R. (2013). National wetland atlas of India: A review and some inferences. *Economic & Political Weekly*, 48(18), 120–124.
- Singh, K. V., Setia, R., Sahoo, S., Prasad, A., & Pateriya, B. (2015). Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. *Geocarto International*, 30, 650–661.
- Son, N. T., Chen, C. F., Chang, N. B., & Chen, C. R. (2015). Mangrove mapping and change detection in Ca Mau Peninsula, Vietnam, using Landsat data and object-based image analysis. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 8(2), 503–510.
- Tiwana, N. S., Jerath, N., Saxena, S. K., & Vivek, S. (2008). Conservation of Ramsar Sites in Punjab. In Proceedings of Taal: The 12th World Lake conference (pp. 1463–1469).
- Verma, V. K., Chopra, R., Sharma, P. K., & Charanjit, S. (1998). Integrated resource study for conservation and management of Ropar wetland ecosystem, Punjab. *Journal of the Indian Society of Remote Sensing*, 26(4), 185–195.
- Widney, S., Klein, A. K., Hackney, C., & Craft, C. (2018). The value of wetlands for water quality improvement: An example from the St. Johns River Watershed, Florida. *Wetlands Ecology and Management*, 26, 265–276.
- Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27, 3025–3033.
- Xue, Z., Lyu, X., Chen, Z., Zhang, Z., Jiang, M., Zhang, K., et al. (2018). Spatial and temporal changes of wetlands on the qinghai-tibetan plateau from the 1970s to 2010s. *Chin. Geogr. Sci.*, 28, 935–945. <https://doi.org/10.1007/s11769-018-1003-1>.
- Yan, D., Wang, X., Zhu, X., Huang, C., & Li, W. (2017). Analysis of the Use of NDWIGreen and NDWIred for Inland Water Mapping in the Yellow RiverBasin Using Landsat-8 OLI Imagery. *Remote Sensing Letters*, 8(10), 996–1005.
- Zha, Y., Gao, J., & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing*, 24(3), 583–594.
- Zhang, Y., Lu, D., Yang, B., Sun, C. & Sun, M. (2011). Coastal wetland vegetation classification with a Landsat Thematic Mapper image. *International Journal of Remote Sensing*, 32, 545–561.