This manuscript is submitted for publication in *Land Degradation and Development*

Land system transformations govern trophic status of urban wetland ecosystem: Perspectives from remote sensing and water quality analysis

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Running title: Land use and water quality changes in Khushalsar wetland

Acknowledgements

The first author acknowledges the Junior Research Fellowship award by University Grants Commission-Maulana Azad National Fellowship for Minorities (UGC-MANF) during the study period. The authors express gratefulness to the United States Geological Survey (USGS) for satellite data available as Open source which was used in the present study.

Abstract

Globally, urban wetlands are facing immense pressure of land use land cover changes (LULCCs) and associated water quality degradation that is severely affecting the trophic status of these pristine ecosystems. This study analyzed water quality degradation resulting due to the land system changes in the vicinity of Khushalsar, an urban wetland, in Srinagar city from 1980-2017. The analysis of satellite data indicated that the wetland has lost ~18.1 ha from 1980-2017. During the same period the urban area within the wetland increased from 0.2% to 16.5%. The land cover changes assessed in the immediate vicinity of wetland indicated an increase of 119% in built-up and 62.8% in roads. The analysis of surface water quality of the wetland showed much greater degradation of Khushalsar wetland. The Trophic State Index (TSI) ranged from 73.4-84.6 thereby indicating the hyper-eutrophic nature of the wetland. A snapshot of comparative water quality data from 2002-2018 revealed that the mean concentration of NO_3^--N increased from 219-433 µg L^{-1} and total phosphorus (TP) increased from 135.4-1236 µg L^{-1} indicative of continuous nutrient enrichment. Hierarchical cluster analysis (HCA) clustered 8 sampling sites into 4 groups based on likeness of water quality characteristics. Similarly, discriminant analysis (DA) showed the formation of similar patterns of clusters, authenticating the outcomes of HCA. Wilk's λ quotient dispersion highlighted the role of nutrients and ions in the development of clusters. Principal component analysis (PCA) formed three principal components (PC's) accounting for a cumulative variance of 90.61%.

Keywords: Land system changes; Water quality; Remote sensing; Khushalsar wetland; Kashmir Himalaya

1. Introduction

Wetlands are highly dynamic, most productive and biologically diverse ecosystems on earth (Maynard et al. 2014; Hu et al. 2018). Wetlands, also referred to as 'kidneys of nature', purify water (Barber et al. 2001; Guo et al. 2017). Globally, wetland ecosystems extend over an area of 12.1×10^6 km^2 with an estimated economic value approximated about US$15 trillion a year besides providing other ecosystem services (Reiss et al. 2014; Penatti et al. 2015; Davidson et al. 2018). Despite the economic and ecological services that wetlands provide, the loss of wetlands and their degradation continues worldwide (Junk et al. 2013). However, as anthropogenic activities constantly increased over past few decades, most of wetlands have been lost while the remaining strongly modified (Mitsch and Gosselink 2000; Bouahim et al. 2015). Wetlands continue to be the most heavily relied upon and deeply exploited systems (Ngoye and Machiwa 2004; Fraser and Keddy 2005). During 21st century, due to increased urbanization and economic development, worldwide the extent of wetlands declined by 64-71% (Li et al. 2010; Tana et al. 2013; Davidson 2014). Human population growth coupled with unsustainable exploitation of natural resources and land conversion trigger the loss of wetlands (Lin and Yu 2018). Land reclamation, encroachment, water pollution, water extraction, water diversions and excessive sediment loads from deforestation are becoming serious issues, especially for urban wetlands (Rashid and Naseem 2008; Junk et al. 2013; Hu et al. 2018; Rashid and Aneaus 2019; Dar et al. 2020a). Wetland ecosystems undergo changes due to interactions of various exogenous and endogenous processes (Lagos et al. 2008). While endogenous factors are related to decomposition of organic matter, exogenous factors are related to environmental fluctuations such as rainfall, temperature and groundwater inputs (van Bodegom et al. 2004; Erwin 2009), anthropogenic influences are related to land use land cover (LULCC) and pollution (Euliss et al. 2004; Rashid et al. 2017). LULCCs cause habitat fragmentation that leads to increased stress on wetland health resulting into decreased resilience to environmental changes (Torbick et al. 2006; Zhao et al. 2006). With the fast pace of development of urban centers, wetlands are deteriorating at a never before pace and progressively waning in function. These alterations affect the local populations given their fact socio-cultural and economic dependence on wetlands (Wondie 2018). The urbanization of wetland catchments impairs the wetland health by affecting the hydrological flows (Boyer and Polasky 2004; Bassi et al. 2014). In this backdrop, regular monitoring of urban wetlands through water quality and land cover is crucial for understanding the dynamics of these ecosystems to transient changes in their catchments (Zhou et al. 2010; Mamoun et al. 2013; Mui et al. 2015; Schilling and Dinsmore 2018).

Currently, Srinagar district in Kashmir Valley is bestowed with 21 water bodies that include rivers, lakes and wetlands (Panigrahy et al. 2010) that provide overwintering habitats/sheltering needs to migratory birds from Europe and Central Asia (Habib 2014). Besides providing refuge from floods by absorbing large volumes of flood waters (Romshoo et al. 2017), they play an important role in enhancing the socio-economic status of local populations (Badar et al. 2013a). However, with urban expansion and development of the city, area of wetlands has declined rapidly (Kuchay and Bhat 2014). Wetland functions progressively impaired while pollution increased substantially. While quantifying the land system changes in the wetland catchments it also becomes essential to enumerate the associated driving factors forcing such changes in order to better understand linkages between anthropogenic activities and wetland ecosystem dynamics. Additionally, the political instability in a region like Kashmir hinders environmental conservation in general and wetland protection in particular.

In this context, Khushalsar wetland in the heart of Srinagar city, India was chosen to assess spatio-temporal patterns of urban wetland losses through land transformation and associated ecological degradation between 1980 and 2017. Given the scenario that more than 50% wetlands in and around the Srinagar city have vanished over the last century (Rashid and Naseem 2008), this paper is an attempt to describe LULCCs using high resolution satellite imageries for Khushalsar wetland from 1980-2017. Additionally, physio-chemical characteristics of water quality were assessed and related to land system changes.

2. Materials and methods

2.1. Study area

Khushalsar is a typical urban wetland located towards the north-west of Srinagar city (Fig. 1). The wetland covers an area of 109.8 ha, and lies between geographical coordinates 34°06' - 34°07' N to 74°47' - 74°48' E at an elevation of 1579 m asl. During the 19th century this wetland formed one continuous body 'Khushalsar' but the 20th century saw a narrow path built over the wetland that finally turned into road and fragmented the wetland into two parts - upper Gilsar and lower Khushalsar (Abubakr and Kundangar 2008). The road was constructed along east-west axis by land-filling large area of the wetland. The basin width decreased and at present water moves from Gilsar to Khushalsar through a 12 feet narrow passage below a bridge, locally called *Gil Kadal.* Traditionally, the wetland had two inlets, one on northern side (Nallabal Nowshera) and the other on southern side (Narwara Eidgah). On the Northern side it still receives the water from Dal Lake via Nigeen basin through Nallah Amir Khan (Nissa and Bhat 2016). On the southern side, the wetland used to receive water from Brari Nambal wetland through Mar canal. The canal was land-filled in 20th century and converted into road that blocked the inlet stream and thus choked the wetland (Rashid and Naseem 2008). The wetland drains on its western side into the Anchar Lake via Saidpora bridge through a stream, locally called *Achan Nallah*. Marshy areas along the wetland peripheries are continuously filled and encroached upon to construct houses whose wastes and untreated sewage directly find their way into the wetland mostly along eastern and western sides. There are washing ghats along the banks of wetland whose waste goes directly into the wetland. As per 2011 census, the wetland catchment has a population of 66339 persons. The wetland has a great socio-economic influence as a large chunk of population around the wetland relies on the vegetable gardens, especially lotus stem and fodder from the wetland. The wetland is ecologically important as it provides an indispensable refuge and breeding ground for large number of migratory ducks, waterfowls and other bird species, besides acting as storage basin by absorbing large volume of flood waters during extreme floods and storm water events.

2.2. Satellite Data acquisition and image processing

In order to detect LULCCs, high spatial resolution satellite imageries, CORONA and Basemap Imagery of ESRI ArcMap 10.1 (Table 1) were used. The wetland boundaries were delineated from satellite images using on-screen digitization method at 1:3000 scale. To quantify the changes in the immediate catchment of Khushalsar wetland, a buffer of 1000 m was created around the wetland boundary in ArcMap10.1 and areas which were not the inflow contributing sources to wetland were excluded utilizing information from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM). The land use land cover (LULC) classes were delineated following National Natural Resources Management System (NNRMS) standards laid down by Indian Space Research Organisation (ISRO) (2005) and local studies (Mushtaq and Pandey 2014; Rashid et al. 2017). Reference data for validating 2017 lab-delineated land cover data was 232 ground-truth samples collected using stratified random sampling approach (Rashid et al. 2013a).

2.3. Accuracy assessment

Assessment of accuracy of the LULC maps derived from remote sensing techniques is essential not only for checking the quality of the maps but also for understanding the errors and their likely implications (Foody 2002; Hu et al. 2018). In this study Kappa coefficient, utilizing information from error matrix (Rashid et al. 2017), and Overall accuracy (Rashid et al. 2013a, b) were generated for accuracy assessment. Kappa coefficient, a discrete multivariate technique and a measure of accuracy (Jensen 1996), is computed as:

$$k = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} \left(X_{i+} . X_{+i} \right)}{N^2 - \sum_{i=1}^{r} \left(X_{i+} . X_{+i} \right)} \qquad \textbf{(1)}$$

Where *'k'* is the Kappa statistic; *'r'* is the number of rows in confusion matrix; 'X_{ii}' is the number of observations in row *i* and column *i*; 'X_{i+}' is the total of observations in row *i*; 'X_{+i}' is the total of observations in column *i*; and *'N'* is the total number of observations included in the matrix.

2.4. Water quality data collection

The water quality sampling sites were selected by creating a sampling grid of 350x350m in ArcMap10.1 software (Fig. 1). To characterize surface water quality status, water samples were collected during four seasons - spring, summer, autumn and winter in 2018. On spot measurements of water quality parameters including Water temperature (WT), pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity (Sal) were recorded using a portable multi-parameter probe (PCS Testr 35), Depth (D) was measured by a graduated rod and Secchi Disc Transparency (SDT) was measured using Secchi disc. A total of 24 physico-chemical parameters of water quality were assessed following standard protocols of American Public Health Association (APHA, 2017) (Table 2).

The average water quality data of four seasons during 2018 assessed at each site was interpolated using Inverse Distance Weighted (IDW) algorithm (Setianto and Triandini 2013) in ArcMap 10.1. IDW interpolation makes the supposition that the value of points that lie closer to each other are more similar than those points which are away from one another. To predict the value of an unsampled point, IDW presumes that every calculated point has a neighboring influence on the unmeasured points that diminish with distance from the measured points.

$$Z_0 = \frac{\sum_{i=1}^{N} . d_i^{-n}}{\sum_{i=1}^{N} d_i} \quad \textbf{(2)}$$

2.5. TROPHIC STATE INDEX (TSI)

TSI determines the degree of productivity and nutrient enrichment of aquatic ecosystems (Xu et al. 2001). Based on the value of TSI, different aquatic ecosystems are classified into various trophic categories (Carlson 1977) reflected in (Table 3). Carlson TSI of the Khushalsar wetland was calculated using information of data sets of SDT, chlorophyll-a (Chl_a) and the concentration of TP.

The TSI was calculated using the equations below:

$$TSI_{SDT} = 60 - 14.41(\ln SDT) \quad \textbf{(3)}$$

$$TSI_{TP} = 14.42(\ln TP) + 4.15 \quad \textbf{(4)}$$

$$TSI_{Chla} = 9.81(\ln Chla) + 30.6 \quad \textbf{(5)}$$

$$TOT_{TSI} = \frac{(TSI_{SDT} + TSI_{TP} + TSI_{Chla})}{3} \quad \textbf{(6)}$$

2.6. Environmetric statistical treatment

HCA

Cluster analysis, a protrusive multivariate technique, assembles parameters into clusters based on their individual characteristics. Ward's method was employed for performing HCA on 22 water quality parameters from 8 sampling sites (Ward 1963). The HCA extracts a dendrogram which delivers a graphic summary of clustering procedure (Hamid et al. 2016), displaying a picture of clusters and their juxtaposition with a dramaturgical decrease in dimensionality of the original data.

DA

DA was employed to validate the correctness of clusters described by HCA. The investigation displays to what degree the surfaces isolating the clusters can be differentiated using an extrapolative model for group relationship. The model is designed of a discriminant function based on linear amalgamation of the prognosticator parameters which are the superlative discriminants among the clusters.

Wilk's λ quotient

Once the clusters are authenticated, Wilk's λ distribution was employed to determine the impact of each water quality parameter in the creation of a cluster (Wilks 1932). From every sampling site, the Wilk's λ quotient for every water quality parameter was assigned by the following equation

$$\lambda = \frac{\sum_i \sum_j \left(x_{ij} - \bar{x}_i\right)^2}{\sum_i \sum_j \left(x_{ij} - \bar{x}\right)^2} \qquad \textbf{(7)}$$

PCA

PCA is an important stochastic method used to decrease the dimensionality of a huge figure of interrelated variables of a dataset by converting unique, interrelated parameters into few orthogonal (uncorrelated) parameters known as principal components (PCs). The method actually works with a correlation matrix and thus reflects the stochastic interdependencies. The input (physicochemical WQ parameters) of PCA are correlated whereas the hypothetical parameters (PCs) are uncorrelated and are obtained as a linear combination of the observable WQ parameters (Hatvani et al. 2014).

3. Results

3.1. LULCC within Khushalsar

Analysis of satellite data of 1980 revealed that aquatic vegetation spread over 64.3 ha was the most dominant land cover type covering 58.6% of the wetland area (Fig. 2a). This was followed by marshy lands (38.2 ha, 34.8%), open water (7.1 ha, 6.5%) and road (0.2 ha, 0.2%). The LULC types increased from 4 in 1980 to 9 in 2017 (Fig. 2b). Although aquatic vegetation is still a dominant land cover type (39.9 ha, 36.3%), it reduced by ~37%. The area under marshy lands increased by ~18% covering an area of 45.4 ha in 2017. The area under open water spreading over 6.4 ha in 2017 decreased by ~10% during the observation period. The details of land system changes within Khushalsar wetland are provided in Table 4. This analysis indicated that the natural land cover types in Khushalsar wetland have been taken over by anthropogenically modified land use types like built-up (~8.9%), cropland (~0.3%), green space (~0.4%), open space (~1.4%), and plantation (~5.1%). Our analysis revealed that the area of wetland shrunk by ~16.5% from 109.8 ha in 1980 to 91.7 ha in 2017 since these areas were taken over by plantation, built up, cropland, etc.

3.2. LULCC in the vicinity

Major highlights of the LULCC analysis in the vicinity of the Khushalsar wetland from 1980-2017 indicate substantial shrinkage in plantation (~51%) followed by cropland (~48%), aquatic vegetation (~37%), open space (26%) and open water (16%). The highest increase was observed in built-up which expanded by ~119%. The area under roads increased by ~62% followed by green spaces (~27%). The LULC maps of the Khushalsar vicinity for 1980 and 2017 are shown in Fig. 3a, b respectively. The detailed statistics pertaining to land system changes are provided in Table 5.

The accuracy assessment of 2017 land cover data was carried to verify the quality of information derived from satellite data (Fig. 4). Overall, approximately 20.12% digitized LULC categories were validated on ground. The user's accuracies for aquatic vegetation, marsh land and open water was 100%, and lowest for open space (83.7%). The producer's accuracies were 100% for aquatic vegetation, open water and plantation and lowest for cropland (Details in Table 6). For 2017 LULC the overall accuracy was 94.3% and kappa statistic 0.9. As per Lea and Curtis (2010), measurement of accuracy assessment of classified images requires the overall accuracy above 90% and kappa statistics above 0.9 which were successfully achieved in the present study.

3.3. Water quality

The water quality characteristics of Khushalsar wetland examined at 8 sites revealed significant spatio-temporal variations. The WT of the wetland followed a seasonal trend being maximum in summer (22^{o}C) and minimum in winter (9.2^{o}C). The water of the wetland is neutral to slightly alkaline with a pH value ranging from 7-8.1. High values (pH=8.1) were found at sites 7 and 8 of the wetland during winter. EC ranged from 311µS cm^{-1} in summer at site 8 to 957µS cm^{-1} in winter at site 2. TDS ranged from 220 ppm at site 8 during summer to maximum of 680 ppm at site 2 during winter. Salinity ranged from 145 ppm at site 8 during summer to 435 ppm at site 2 during winter. A gradual increase in transparency was observed from south towards the northern side of wetland. The transparency showed a seasonal pattern of being maximum in spring followed by summer, autumn and winter. SDT ranged from 15 cm at site 1 during winter to 99 cm at site 7 during spring. Depth ranged from 76 cm at site 2 during winter to maximum 366 cm at site 7 during spring. Anoxic conditions were observed wherein DO was found altogether absent at site 1 during summer, autumn and winter and reached to a maximum of 4 mg L^{-1} at site 7 and 8 during winter. The interpolated mean values of WT, pH, EC, TDS, Sal, SDT, D, and DO are shown in Fig. 5.

Total Alkalinity (TA) ranged from 52 mg L^{-1} at site 8 during winter to 336 mg L^{-1} at site 1 during summer. Free carbon dioxide (F-CO_2) concentration recorded in the wetland ranged between 1.76 mg L^{-1} during winter to 17.6 mg L^{-1} during autumn. Higher concentrations were recorded in southern portion and lowest in northern portion of the wetland. The total ionic composition of wetland indicates that the waters of the wetland are of medium-hard water type. TA (HCO_3^-, CO_3^{2-}) was highest followed by calcium (Ca). The order of equivalency of cations and anions is (HCO^{3-}, CO_3^{2-}) > Ca^{2+} > Mg^{2+} > Cl^-. The concentration of both cations and anions were higher in southern portion and lower in northern portion. The interpolated mean values of TA, F-$CO_{2,}$ T hard, Ca hard, Mg hard, Ca, Mg and Cl are shown in Fig. 6.

Ammoniacal nitrogen (NH_3-N) ranged from a minimum of 117.9 µg L^{-1} at site 8 to a maximum of 1334.4 µg L^{-1} at site 1 during summer. Nitrite nitrogen (NO_2^--N) ranged from 20.2 µg L^{-1} at site 2 during spring to 241.4 µg L^{-1} at site 8 during winter. Nitrate nitrogen (NO_3^--N) values range from 210.2 µg L^{-1} at site 2 during summer to maximum of 679.6 µg L^{-1} at site 5 in winter. Total kjeldhal nitrogen (TKN) ranged from 0.6 mg L^{-1} during spring to a maximum of 4.5 mg L^{-1}

at site 7 during autumn. Total nitrogen (TN) ranged from a minimum of 1 mg L^{-1} at site 8 to a maximum of 5.1 mg L^{-1} at site 7 during autumn. Orthophosphorus (Ortho-P) ranged from a minimum of 263.3 µg L^{-1} at site 8 during spring to a maximum of 956.4 µg L^{-1} at site 1 during summer. TP ranged from a minimum of 725.2 µg L^{-1} at site 8 during spring to a maximum of 2113.2 µg L^{-1} at site 1 during autumn. Chl_a ranged from a minimum of 7.4 mg m^{-3} at site 4 during spring to a maximum of 46.9 mg m^{-3} at site 1 during summer. The interpolated mean values of NH_3-N, NO_2^--N, NO_3^--N, TKN, TN, Ortho-P, TP, and Chl_a are shown in Fig. 7.

TSI

The spatial and temporal variation in TSI_{SDT} values during the four seasons is shown in (Fig. 8). During all the four seasons, the northern portion of the wetland remained eutrophic and the southern portion hyper-eutrophic. The average TSI_{SDT} values of the four seasons range from 60.7-78.2 (Fig. 8e) indicating eutrophic to hyper-eutrophic nature of the wetland. The spatio-seasonal and average variation in the TSI_{TP} values is shown in Fig. 9. Based on both the spatio-temporal variation during four seasons and the average values of the four seasons, the wetland falls in hyper-eutrophic category. The spatio-seasonal and average concentration of TSI_{Chla} are shown in Fig. 10 indicating that the wetland remains in a eutrophic state during all the four seasons. Based on the TOT_{TSI} values as seen from the Fig. 11, the wetland remains hyper-eutrophic during all the four seasons of the year. The average TOT_{TSI} value ranging from 73.4-84.6 are indicative of the hyper-eutrophic nature of the wetland, with highest TOT_{TSI} values along the southern portion of the wetland.

HCA

The spatio-temporal inconsistency in the water quality of the Khushalsar wetland is pertinently characterized by the cluster analysis of 8 sampling sites which recognized four distinguishing clusters each having virtually similar water quality (Fig. 12). Sites S1 and S2 from Cluster 3 which comprises high polluted sites. Sites S3 and S4 form cluster 1 and receive pollutants from non-point sources. Sites S5 and S6 form cluster 4, sites S7 and S8 form cluster 2, these sites are located towards the northern side of the wetland that receive polluted waters form the Nigeen lake.

Wilk's λ quotient

Discriminant analysis displayed that the original clusters were properly recognized in 100% of the cases (Fig. 13). Wilk's λ quotient was determined for all the WQ parameters at each sampling location to assess the influence of each parameter on the cluster pattern. The lower quotient values are depicted by SDT (0.073), EC (0.013), TDS (0.036), Sal (0.056), DO (0.020), F-CO_2 (0.044), TH (0.043), Ca-Hard (0.020), Mg-Hard (0.074), Cl (0.068), NO_2^-N (0.041), and Ortho-P (0.040) (Table 7)

PCA

PCA performed on 22 water quality parameters yielded three PCs accounting for 90.6% of the data variance (Table 8). The first PC explains 72.28% of variance, having a strong positive component loading mainly from ions, EC, TDS, Sal, F-CO_2, Alk, TH, Ca-Hard, Mg-Hard, Cl, NH3, TKN, TN, Ortho-P, TP, Chla and strong negative loadings from WT, SDT, D, pH, and DO. The second PC is responsible for 12.38% of variance with D, TKN and TN showing strong loadings. The third PC accounts for 90.61% of total variance with NO3-N showing strong positive loadings.

4 Discussion

Between 1980 and 2017, a substantial area of wetland (18.1 ha) has been lost owing to land system transformations. The aquatic vegetation decreased by 24.4 ha and open water by 0.7 ha.

These areas were taken over by marsh lands and land filling of shallower areas along the periphery of the wetland. Increase in marshy areas and land filling has been reported for other wetlands in Kashmir region (Pandit 1988; Bhat et al. 2019; Dar et al. 2020a). It is pertinent to mention that the production of lotus stem (cash crop) from the Khushalsar wetland dwindled owing to shrinkage in open water and aquatic vegetation, similar studies were reported in other lakes and wetlands of Kashmir Himalaya (Rashid et al. 2015; Nazir 2018). The wetland is practically being treated as wasteland by both the public and policy makers given the fact that a huge quantity of municipal solid wastes, agricultural waste and domestic sewage is dumped in the wetland body from the neighboring settlement areas without any prior treatment (Showqi et al. 2018). Similar pressures are being faced by other urban, semi-urban and rural wetlands across Kashmir Himalaya (Shah et al. 2015; Najar et al. 2017). These land-filled areas are used for construction of houses and result into open spaces and green spaces in the wetland. Due to siltation and soil erosion from the catchment (Alam et al. 2011; Badar et al. 2013b; Romshoo et al. 2017), decrease in stream flows (Romshoo and Rashid 2014; Showqi et al. 2014; Rashid et al. 2020) and blockage of *Mar* canal along southern portion of wetland, the depth of wetland decreased. This has altered the wetland hydrology and resulted into expansion of marshy areas that over the course of time have been transformed either into open spaces for construction of settlements or plantation. Their scenario is no different from other wetlands in Srinagar city (Rashid et al. 2017; Rashid and Aneaus 2019). The enormous anthropogenic pressures have translated into wetland loss since the neighboring settlements areas proliferated and expanded into the wetland. Although, the Government has established a full-fledged Lakes and Waterways Development Authority (LAWDA) in 1997 for lake and wetland conservation, it has miserably failed to curb the wetland degradation and encroachment of wetland areas (Bhan and Trisal 2016).

The wetland vicinity also faced a brunt of land transformation between 1980 and 2017. The area under settlements increased by 119% while road infrastructure and green spaces increased. The population of Srinagar has increased from 1.2 lacs to 12 lacs between 1901 and 2011 (Census 2011) with areas around Khushalsar being no exception. The exacerbated population growth and urbanization appear to be the prime drivers of encroachments, environmental degradation and wetland change. The area under plantation, cropland and open space shrunk during the 37 years of observation period. This decrease is attributed to rapid expansion of settlements in the area which took over these LULC types over the last four decades. Although, Srinagar Municipal Corporation (SMC) and Srinagar Development Authority (SDA) are mandated to ensure environment friendly sustainable development of the city, the agencies have been unsuccessful in putting a blanket ban on settlements around the otherwise pristine lakes and wetlands of the city. The Master Plan 2035 (accessible at: http://www.sdasrinagar.com/wp-content/uploads/2019/03/Master-Plan-2035-ReportFinal.pdf) in fact allows for infrastructure development especially in the southern part of Srinagar city which was traditionally wetland area. The proposed Land Use Plan 2021 for Srinagar Metropolitan Area (accessible at: http://www.sdasrinagar.com/wp-content/uploads/2017/03/land-use-map.jpg) has not earmarked any green spaces in the vicinity of Khushalsar wetland and suggests that the area is appropriate for construction of houses. This could not only exacerbate the wetland loss but also increase the vulnerability of people to floods and earthquakes keeping in view the geomorphological (Meraj et al. 2015) and the geological setup (Chandra et al. 2018) of the region. However, to curb the encroachment, the demarcation of the current wetland extents as per the revenue records has been recently taken up by Revenue

Department under the administrative control of Deputy Commissioner's office. There is no perspective plan or an ecozonation plan from any governmental agency for conservation of this socio-culturally important heritage wetland of Srinagar city.

With the unceasing expansion and spreading of city, most of the wetland area and agricultural fields have been taken over by settlements. More than 50% of the wetland areas have vanished over the past century in and around Srinagar city (Rashid and Naseem 2008). Wetland areas around Srinagar city that traditionally used to act as flood buffers have been taken over by residential colonies and government departments (Kuchay and Bhat 2014; Rashid and Aneaus 2019). The encroachment and filling of Mar Canal has severely impacted the wetland health by not only reducing the water holding capacity of this wetland but also affecting the hydrological connectivity. This was clear during the September 2014 deluge of Srinagar City when the areas around wetland got severely inundated (Romshoo et al. 2017). Additionally, the discharge of untreated domestic sewage and the effluents from stables of livestock have led to acute water pollution which has not only destroyed the aesthetic beauty of the wetland but also its hydrobiological set up (Fig. 14a, b). The reckless unplanned development around the wetland has not only caused deterioration of chemical quality of water but also turned the wetlands peripheries into easily amenable solid waste dumping sites. The plastics and other solid wastes find their way directly into the wetland choking some of the important waterways (Fig. 14c). It is pertinent to mention that while built-up is the predominant land use type occupying ~42% of the immediate catchment of Khushalsar, there is no sewage treatment plant for decontaminating the domestic sewage that pours into the wetland.

The WT of the wetland is related to the climate/ambient air temperature of the Kashmir valley, with higher temperatures in summer season and lower temperatures and short photoperiods in winter season (Ganai and Parveen 2014; Dar et al. 2020b). The slight alkaline nature of the water of the wetland is attributed to the presence of calcium rich rocks in catchments of Kashmir wetlands and lakes (Zutshi et al. 1980). Modest seasonal fluctuations in pH are attributed to buffering capacity of water (Boven et al. 2008). The high values of EC, TDS and Salinity are attributed to the addition of ions, silt load and sewage inflows from residential areas and discharge of pollutants from the immediate catchment having high concentration of ions (Badar et al. 2013b; Parvez and Bhat 2014). SDT was generally low over sites because of absorption of light by heavy load of particulate and dissolved organic matter (Khanday et al. 2018; Harvey et al. 2019). The transparency values were compared with trophic classification scheme proposed by Organisation for Economic Cooperation and Development (OECD 1982) and it was found that the wetland falls in hyper-eutrophic category. The low depth value across all sites is ascribed to depleting streamflows (Romshoo et al. 2015), buildup of organic matter (Khanday et al. 2018), and sediment load from the Dal lake. The absence and relatively lower concentration of DO ≤ 4 mg L^{-1} in spite of rich macro-vegetation can be related to hyper-eutrophic condition of the wetland which is the result of high rates of decay of organic material throughout the year (Siraj et al. 2010) (Fig. 14d). The presence of F-CO_2 throughout the year indicates high organic load to the wetland (Mir et al. 2016).

The high Cl content in the wetland indicates the presence of organic matter, pollution and flow of sewage (Rather et al. 2016). Among various nitrogen species, NH_3-N was found to be the dominant form in the wetland and is related to sewage ingress from adjoining settlements (Parvez and Bhat 2014). The higher concentration of NO_3^--N in the wetland is related to wastes from slaughter houses coming all along the Nallah Amir Khan which forms the inlet for wetland and also to direct disposal of defecation wastes into wetland (Showqi et al. 2018) (Fig. 15a). The high values of TKN during autumn are related to high load of animal parts and visceral organs dumped to wetland and were witnessed during water sampling (Fig. 15b). TN content in wetland is related to the high effluent load of organic wastes, sewage and fertilizer runoff from nearby agricultural fields to the Khushalsar wetland. The relatively higher values of TP concentration (725.2-2113.2 μg L^{-1}) are related to the high effluent load of phosphorus from washing ghats, animal wastes and domestic sewage to the wetland which indicates the hyper-eutrophic nature of the wetland (OECD 1982). Human activities appear to be the main cause for the excessive TP concentration in the wetland. Surface runoff from agricultural fields and discharge of domestic sewage (Pullanikkatil et al. 2015) and the release of detergents during washing (Xu et al. 2008) especially the washing ghats at the inlet are the major sources of phosphorus to the wetland. Chl_a concentration in the wetland is related to the high concentration of TP and phytoplankton population in the wetland (Abubakr and Kundangar 2008).

The analysis of water quality data sets revealed that there has been a progressive increase in concentration of various parameters like TA, NH_3-N, NO_3^--N, Ortho-P, and TP than the earlier records of Pandit and Yousuf (2002); Abubakr and Kundangar (2008). NH_3-N increased from 425.9 μg L^{-1} in 2002 to 563 μg L^{-1} in 2018. NO_3^--N increased from 219 μg L^{-1} in 2008 to 433 μg L^{-1} in 2018, and TP increased from 135.4 μg L^{-1} in 2002 to 1236 μg L^{-1} in 2018 (Fig. 16). This increase in the above parameters is attributed to the urbanization in the wetland vicinity (Haidary et al. 2013; Rashid et al. 2017). The annual mean of the water quality parameters has increased in the wetland. This is related to the filth resulting from transformation of open spaces into built up areas, storm-water runoff from urban areas and to direct ingress of sewage and fecal matter, nutrient and sediment loadings to the wetland (Romshoo et al. 2011; Romshoo and Muslim 2011).

The eutrophic to hyper-eutrophic state based on TSI_{SDT} values is attributed to the luxuriant growth of macrophytes and dominance of algal populations. The hyper-eutrophic state based on TSI_{TP} is related to the phosphorus inputs from detergents and animal wastes. Based on TOT_{TSI} values, the present hyper-eutrophic state can lead to vanishing of the wetland given the proliferation of macrophytes, expansion of marsh lands, ingress of solid wastes including animal wastes into the wetland. The prevalence of hyper-eutrophic state in the wetland provides impetus for reduction of oxygen levels harmful for wetland biota. As a result, the fish populations have been completely driven out of the Khushalsar wetland, similar findings have been reported from other lakes and wetlands of Kashmir Himalaya (Rumysa et al. 2016).

Cluster 1 comprises sites near human habitation that receive pollutants from non-point sources. Cluster 2 comprises sites on the northern side of the wetland and receive pollutants and wastes from slaughterhouses along the inlet water channel Nallah Amir Khan. Cluster 3 comprises high polluted sites along the southern area of the wetland. These sites receive direct discharge of fecal matter, urine and sewage from human habitations and cowsheds. Cluster 4 comprises sites along the outlet on the western side of the wetland receiving runoff from agricultural fields. Wilk's λ quotient clearly highlights that there is a combined role of most of the water quality parameters; both ions and nutrients in the formation of clusters. This is attributed to the fact that the waters of the Khushalsar wetland, besides being very hard and well buffered, face significant anthropogenic pressures by way of dumping large quantities of untreated sewage. The positive loading of ions and nutrients in 1st PC is attributed to the high discharge of sewage and untreated fecal matter from the neighboring settlements, besides erosion and dissolution of minerals from catchment areas. The negative loading of WT in the first PC is associated with the climate of the valley (Jayaraman et al. 2003). The positive loadings of D, TKN, and TN in the 2nd PC represents organic pollution, as the wetland gets filled with wastes of organic nature. The strong loadings of NO_3-N in the 3rd PC is due to anthropogenic influences.

Conclusions

The natural area of the wetland was lost significantly due to unplanned land transformation practices largely related to urbanization. The environmental deterioration assessed in terms of water quality of wetland showed severe degradation of the wetland related to the untreated sewage ingress and solid waste dumping into the wetland. The high Phosphorus and Nitrogen concentration in the Khushalsar wetland are responsible for the present hyper-eutrophic condition of the wetland. The blocking of the inlet along south of the wetland is responsible for high concentration of physico-chemical parameters in that portion of the wetland. The wetland degradation has severe implications not only on the livelihoods of local population dependent upon various goods provided by the wetland but also on the water holding capacity of the wetland during floods. There is an immediate need of restoration of this socio-ecologically important heritage ecosystem. The wetland area needs to be immediately demarcated to prevent any illegal encroachments. Additionally, high resolution earth observation data on a monthly interval could also be used to check any miniscule changes in the vicinity of Khushalsar and other wetlands in Srinagar city. The present study highlights a need for having an effective wetland information system, utilizing data from remote sensing platforms, field surveys, lab-based analysis, interviews, scientific discussions and legal policy framework, to check the reckless land transformation and water quality deterioration for conservation and management of Khushalsar wetland. Pollutants discharged from residential houses, slaughter houses and washing ghats need to be treated before being discharged to the wetland while an ecologically friendly development plan be framed to conserve this dying wetland.

Conflict of interest: The authors declare that they have no conflict of interest

Data availability: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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List of Tables

Table 1 Details of the datasets used in this study

Sensor	Acquisition Date	Spatial Resolution	Source
CORONA	07 October 1980	Resolution: 1.87 m	http://earthexplorer.usgs.gov/
High resolution Basemap	13 September 2017	Panchromatic: 0.46 m Multispectral: 1.65 m Accuracy: 8.47 m	ESRI Basemap
GPS data	Oct-Nov 2017	Point data	Ground survey
Field photographs	2017-2018	Point data	Ground survey

Table 2 Methodology employed for analysis of physico-chemical characteristics of water samples of Khushalsar wetland

S. No.	Parameter	Method Used (APHA 2017)
1.	Dissolved oxygen (DO)	Winkler's method
2.	Free carbon dioxide (F-CO_2)	Titrimetric method
3.	Total alkalinity (TA)	Titrimetric method
4.	Total hardness (T Hard)	Complexometric method
5.	Calcium hardness (Ca hard)	EDTA Titrimetric method
6.	Magnesium hardness (Mg hard)	EDTA Titrimetric method
7.	Calcium content (Ca)	EDTA Titrimetric method
8.	Magnesium content (Mg)	EDTA Titrimetric method
9.	Chloride (Cl)	Argentometric method
10.	Ammoniacal-nitrogen (NH_3-N)	Phenate Spectrophotometric method
11.	Nitrite-nitrogen (NO_2^--N)	Sulphanilamide Spectrophotometric method
12.	Nitrate-nitrogen (NO_3^--N)	Salicylate method
13.	Total kjeldhal nitrogen (TKN)	Semi-Micro kjeldhal method
14.	Total nitrogen (TN)	Kjeldhal method
15.	Ortho phosphorus (Ortho-P)	Ascorbic Acid method
16.	Total phosphorus (TP)	Ascorbic Acid method
17.	Chlorophyll-a (Chl-a)	Acetone extraction method

Table 3 Carlson's Trophic State classification criteria (Carlson, 1977)

TSI	Classification	Description
>30-40	Oligotrophic	Clear water, dissolved oxygen available throughout the year in the hypolimnion, deep lakes still exhibit classical oligotrophy, but some shallow lakes might become anoxic during the summer season
40 – 50	Mesotrophic	Water moderately clear, increasing probability of anoxia in hypolimnion during summer.
50 - 70	Eutrophic	Dominance of Blue Green algae, algal scum, and excessive macrophytes.
>70	Hyper-eutrophic	Heavy algal blooms possible throughout the summer season, dense macrophytic beds but extent limited by light penetration.

Table 4 Area under different land use-land cover classes within Khushalsar wetland from 1980-2017

LULC type	Area (ha)		Change (1980-2017)	% Change
	1980	**2017**		
Aquatic vegetation	64.3	39.9	-24.4	-37.9
Built-up	-	9.8	9.8	NA
Cropland	-	0.3	0.3	NA
Green space	-	0.5	0.5	NA
Marshy land	38.2	45.4	7.2	18.8
Open space	-	1.5	1.5	NA
Open water	7.1	6.4	-0.7	-9.8
Plantation	-	5.6	5.6	NA
Road	0.2	0.4	0.2	100
Total area	109.8	109.8		

Table 5 Area under different land use-land cover classes in immediate vicinity of Khushalsar from 1980-2017

LULC type	Area (ha)		Change (1980-2017)	% Change
	1980	2017		
Aquatic vegetation	64.9	40.9	-24	-37
Built-up	74.6	163.4	88.8	119
Cropland	34.9	18	-16.9	-48.4
Green space	11.6	14.8	3.2	27.6
Marshy land	38.5	38.9	0.4	1
Open space	61.5	45.5	-16	-26
Open water	7.6	6.4	-1.2	-15.8
Plantation	83.6	40.7	-42.9	-51.3
Road	13.7	22.3	8.6	62.8
Total area	390.9	390.9		

Table 6 Error matrix showing per class accuracy of 2017 dataset

Classification Data	AV	BU	CL	GS	M	OS	OW	P	R	Row Total	User's Accuracy (%)
AV	**9**	0	0	0	0	0	0	0	0	9	100
BU	0	**42**	0	0	0	1	0	0	0	43	97.7
CL	0	0	**9**	0	0	0	0	0	0	9	100
GS	0	0	1	**16**	0	1	0	0	0	18	88.9
M	0	0	0	0	**14**	0	0	0	0	14	100
OS	0	2	1	1	0	**31**	0	0	2	37	83.7
OW	0	0	0	0	0	0	**9**	0	0	9	100
P	0	0	1	0	1	0	0	**21**	0	23	91
R	0	1	0	0	0	1	0	0	**68**	70	97
Column Total	9	45	12	17	15	34	9	21	70	**232**	
Producer's Accuracy (%)	100	93	75	94	93	91	100	100	97		
Overall accuracy= (9+42+9+16+14+31+9+21+68) /232 = 94.39%											

Table 7 Wilki's lambda statistics for water quality parameters for the data set

Parameter	Wilk's lambda
WT	.358
SDT	.073
D	.261
pH	.336
EC	.013
TDS	.036
Sal	.056
DO	.020
FCO_2	.044
Alk	.216
TH	.043
Ca-Hard	.020
Mg-Hard	.074
Cl	.068
NH_3-N	.396
NO_2-N	.041
NO_3-N	.533
TKN	.398
TN	.398
Ortho-P	.040
TP	.081
Chl_a	.375

Table 8 Principal component loadings for water quality parameters for the entire data set

Parameter	Component		
	PC1	PC2	PC3
WT	**-.762**	.173	-.285
SDT	**-.925**	.238	.156
D	**-.601**	**.737**	-.142
pH	**-.704**	-.017	.527
EC	**.958**	-.226	-.079
TDS	**.950**	-.224	-.016
Sal	**.918**	-.283	-.027
DO	**-.976**	-.127	.063
FCO_2	**.979**	.141	.009
Alk	**.926**	-.127	-.091
TH	**.938**	-.225	.172
Ca-Hard	**.978**	-.102	.126
Mg-Hard	**.857**	-.339	.211
Cl	**.980**	-.023	.094
NH_3-N	**.803**	.507	.175
NO_2-N	**-.789**	-.422	.086
NO_3-N	-.468	.107	**.825**
TKN	**.658**	**.728**	-.021
TN	**.658**	**.728**	-.021
Ortho-P	**.949**	.168	.130
TP	**.886**	.337	.209
Chl_a	**.779**	-.196	-.075
Eigen values	15.9	2.7	1.3

% of Variance	72.28	12.38	5.94
Cumulative %	72.28	84.66	90.61

List of Figures

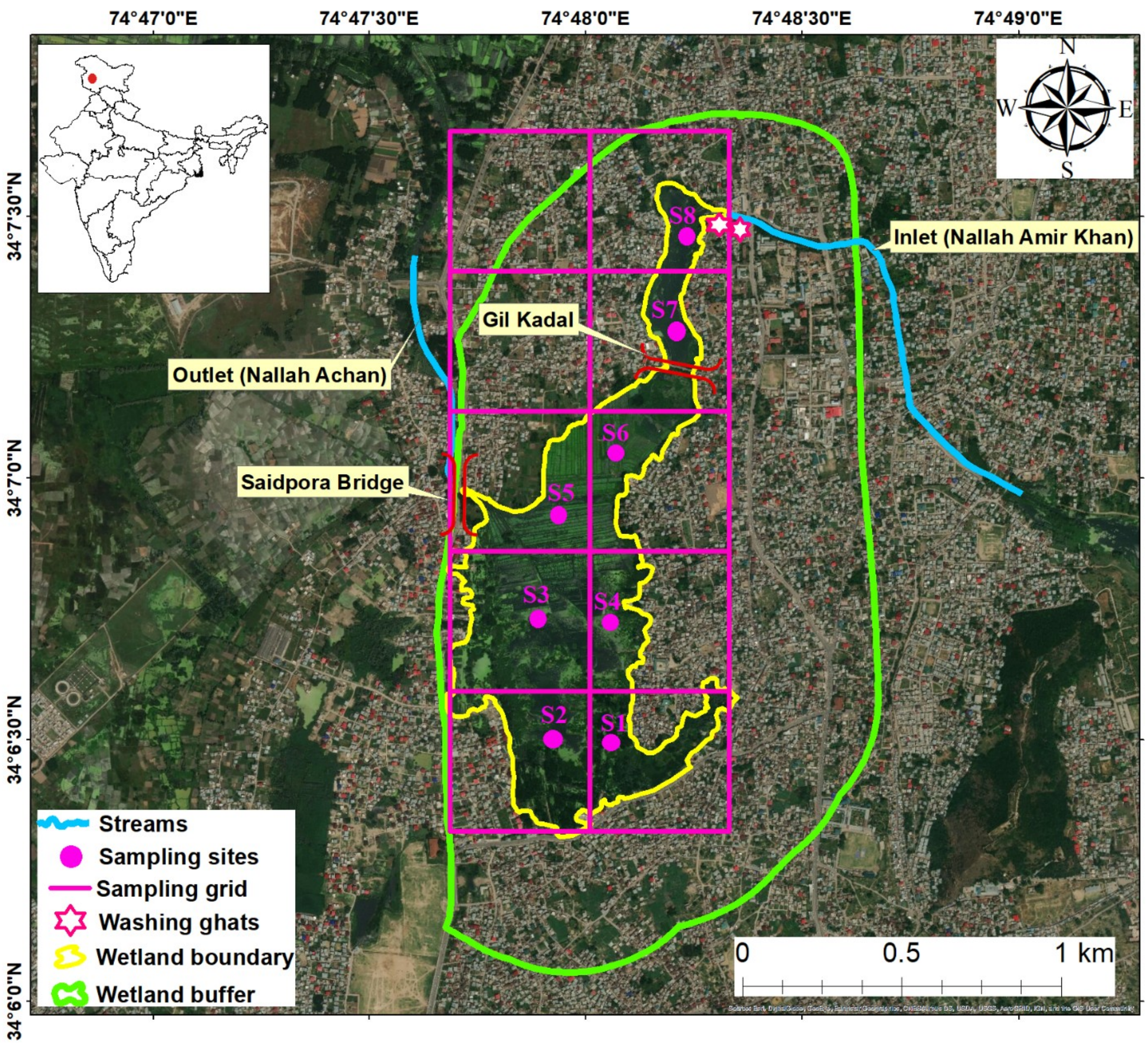


Fig. 1

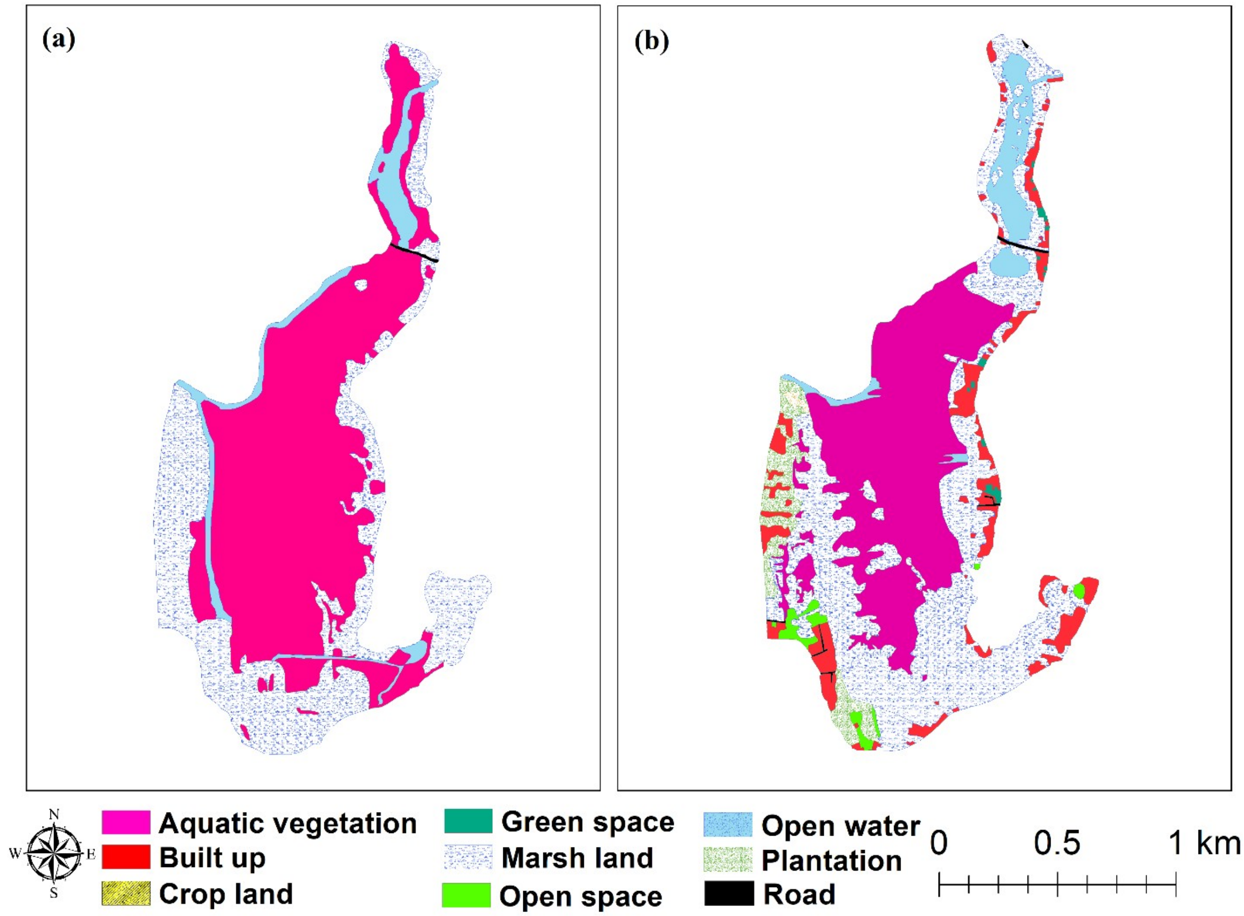

(a)
(b)
N
S
E
W
Aquatic vegetation
Built up
Crop land
Green space
Marsh land
Open space
Open water
Plantation
Road
0
0.5
1 km

Fig. 2

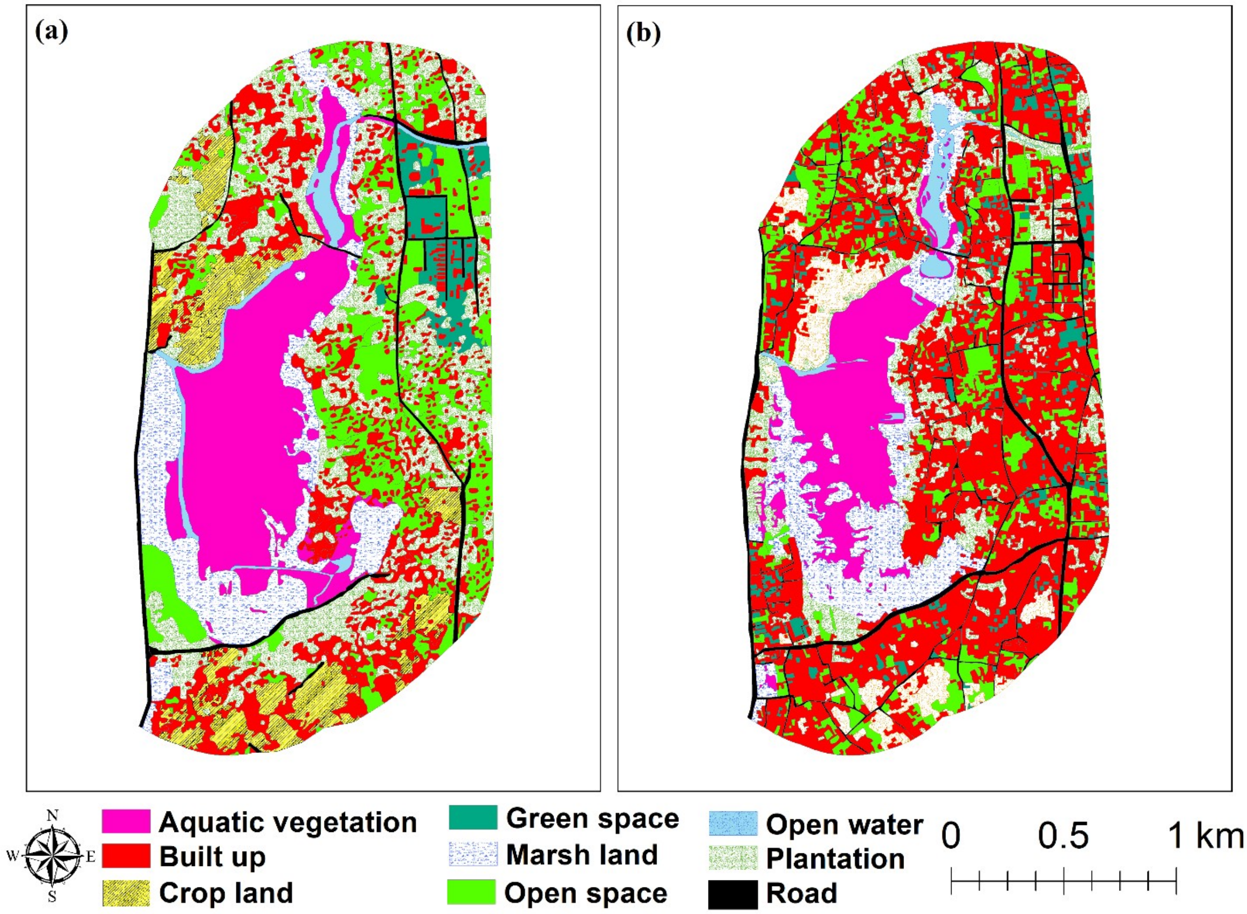
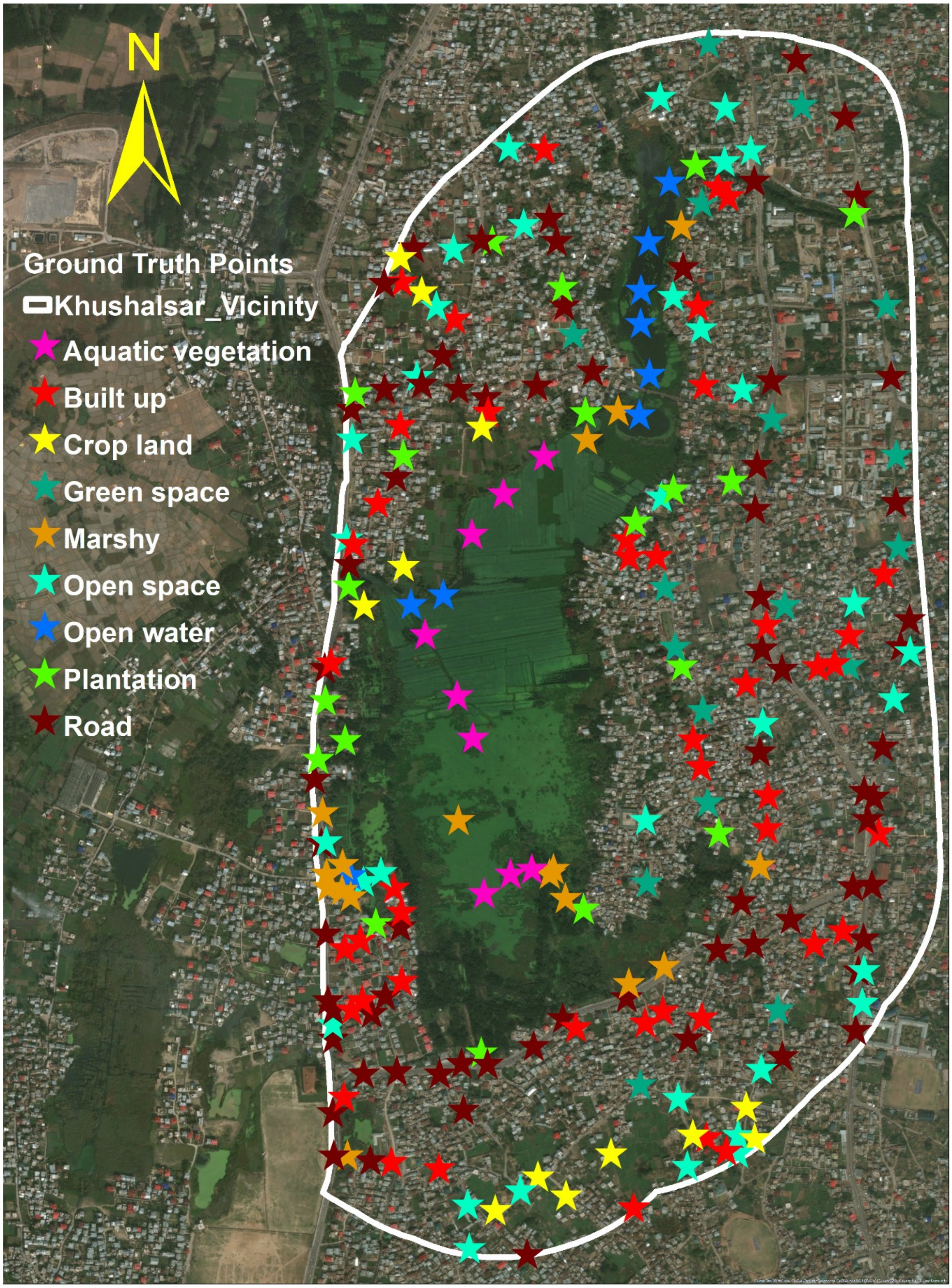

(a)
(b)
N
W
E
S
Aquatic vegetation
Built up
Crop land
Green space
Marsh land
Open space
Open water
Plantation
Road
0
0.5
1 km

Fig. 3


N
Ground Truth Points
Khushalsar_Vicinity
Aquatic vegetation
Built up
Crop land
Green space
Marshy
Open space
Open water
Plantation
Road

905

Fig. 4

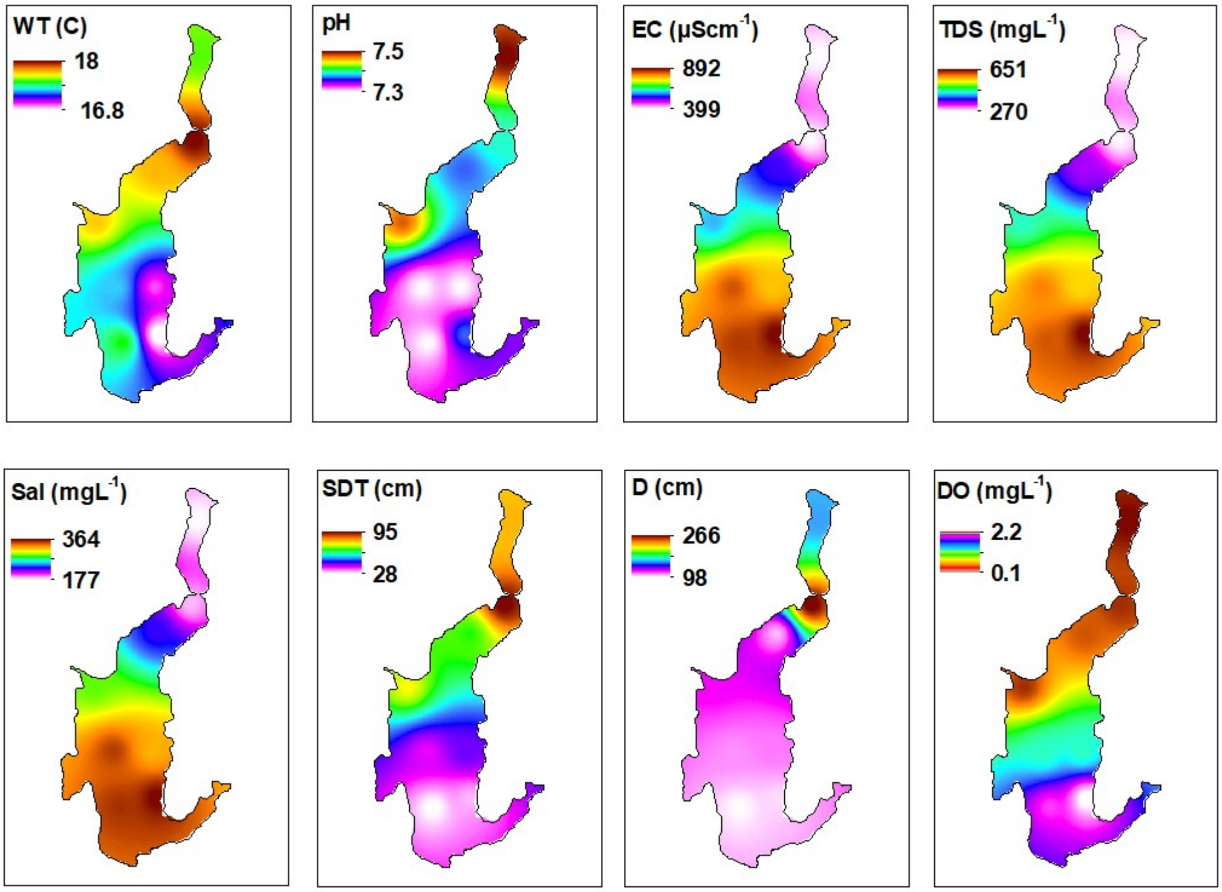

WT (C)
18
16.8
pH
7.5
7.3
EC (μScm-1)
892
399
TDS (mgL-1)
651
270
Sal (mgL-1)
364
177
SDT (cm)
95
28
D (cm)
266
98
DO (mgL-1)
2.2
0.1

Fig. 5

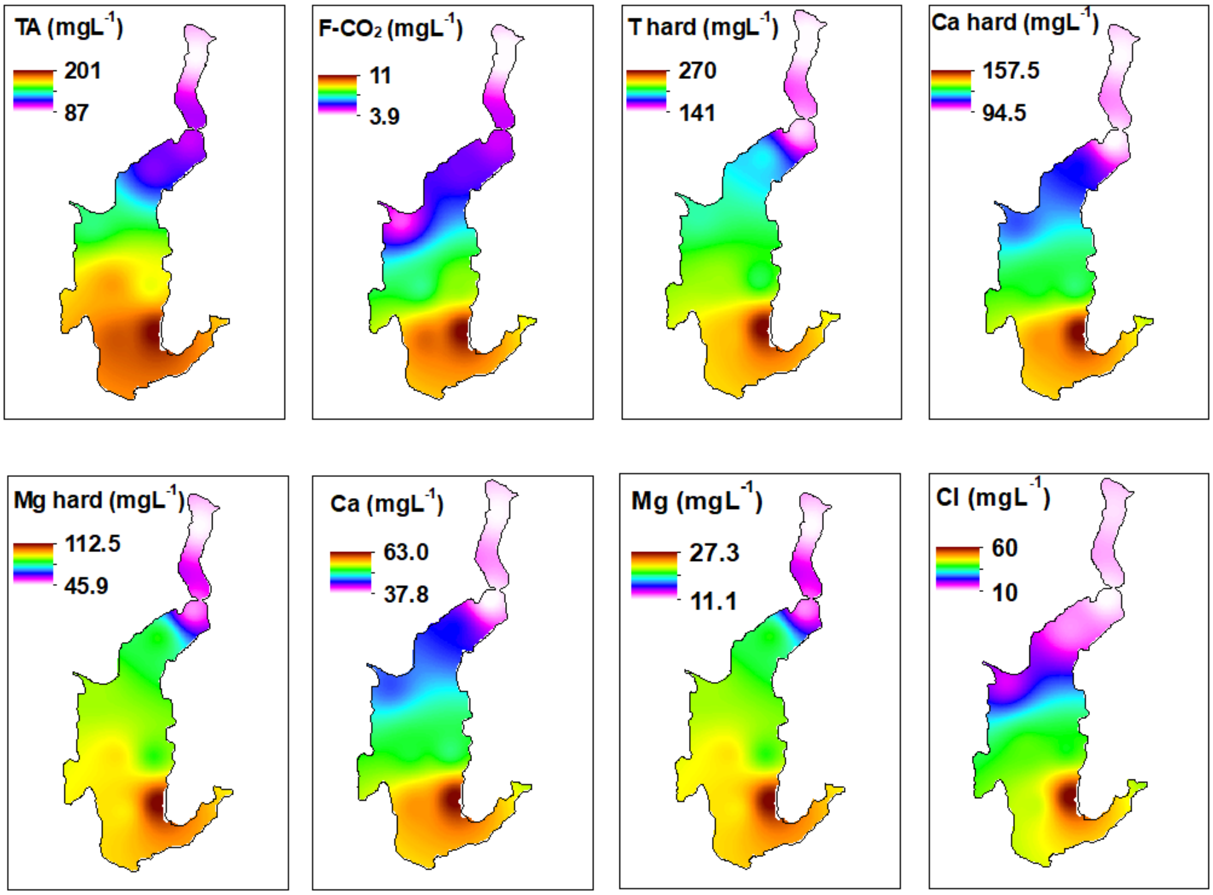

TA (mgL-1)
201
87
F-CO2 (mgL-1)
11
3.9
T hard (mgL-1)
270
141
Ca hard (mgL-1)
157.5
94.5
Mg hard (mgL-1)
112.5
45.9
Ca (mgL-1)
63.0
37.8
Mg (mgL-1)
27.3
11.1
Cl (mgL-1)
60
10

Fig. 6

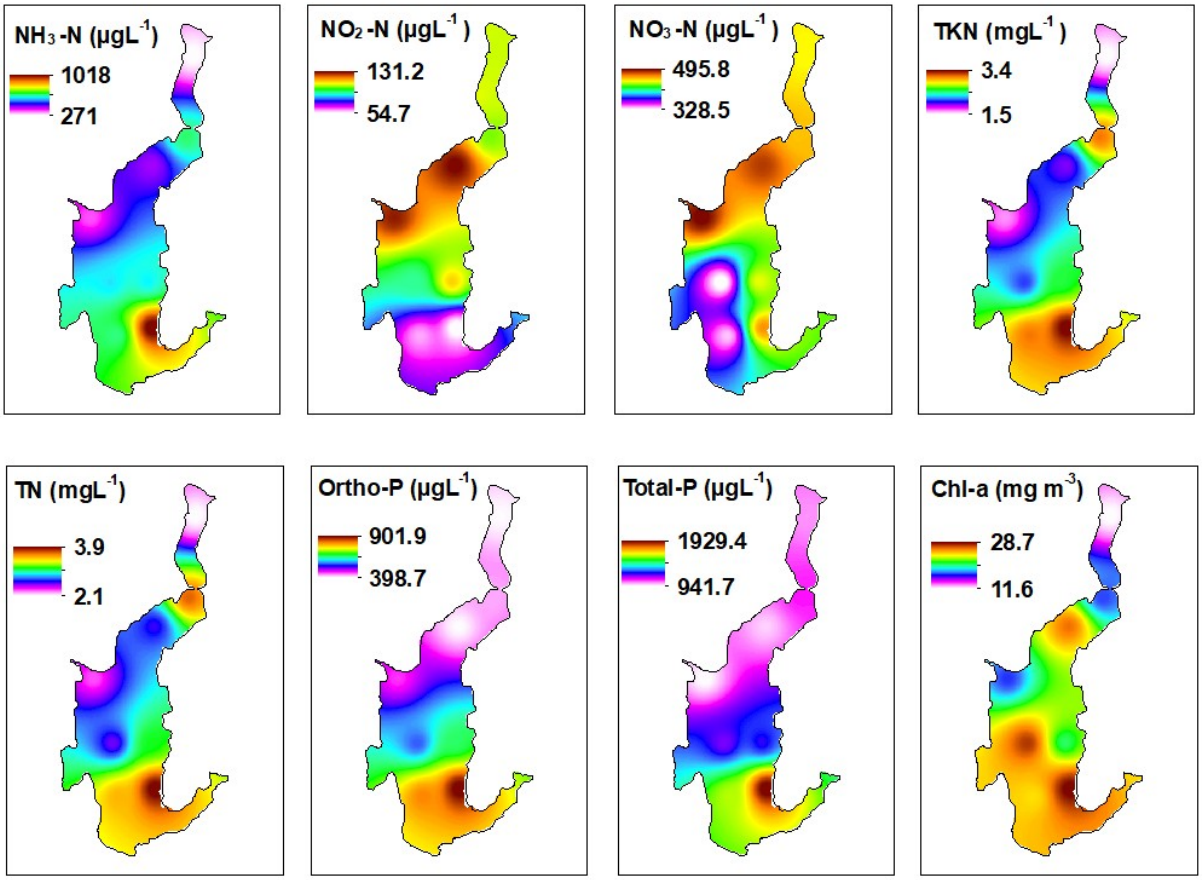

NH_3-N (μgL^{-1})
1018
271
NO_2-N (μgL^{-1})
131.2
54.7
NO_3-N (μgL^{-1})
495.8
328.5
TKN (mgL^{-1})
3.4
1.5
TN (mgL^{-1})
3.9
2.1
Ortho-P (μgL^{-1})
901.9
398.7
Total-P (μgL^{-1})
1929.4
941.7
Chl-a (mg m^{-3})
28.7
11.6

Fig. 7

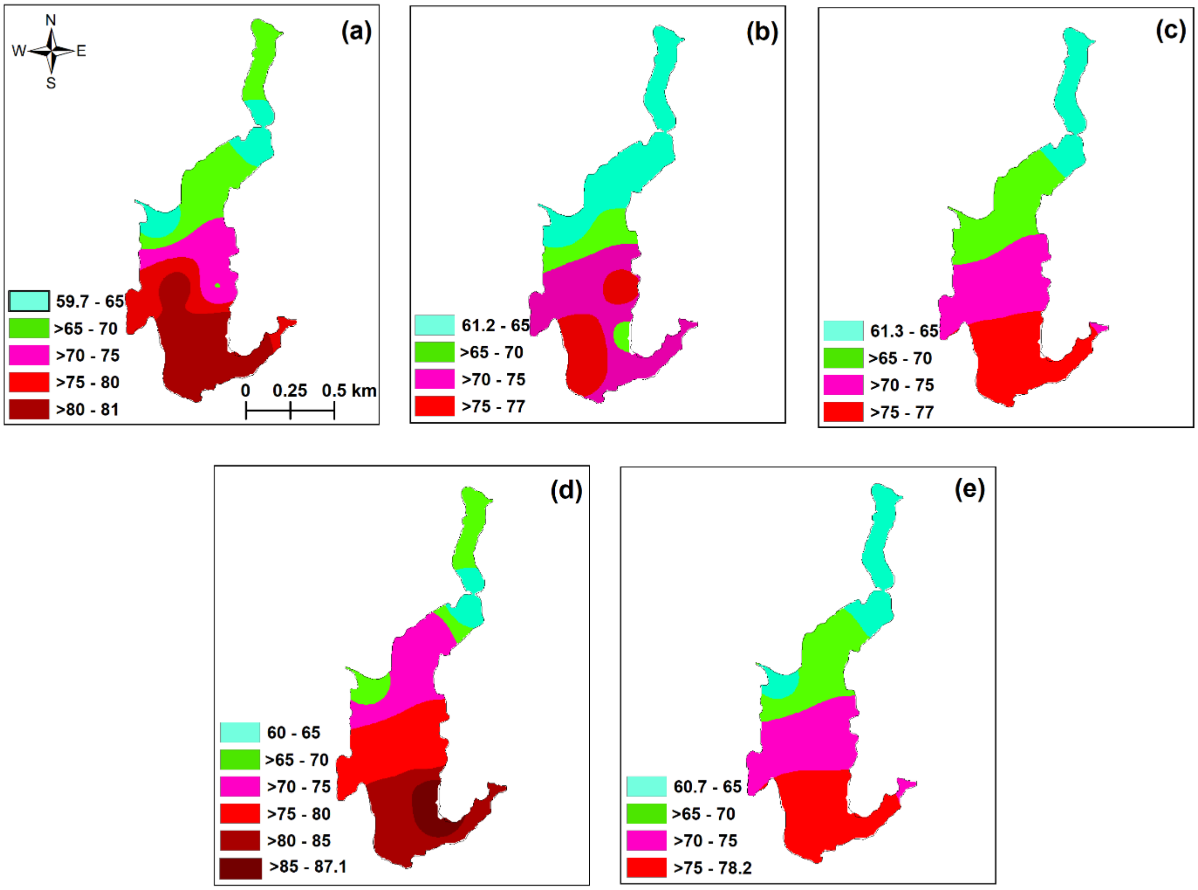

(a)
N
W
E
S
59.7 - 65
>65 - 70
>70 - 75
>75 - 80
>80 - 81
0 0.25 0.5 km
(b)
61.2 - 65
>65 - 70
>70 - 75
>75 - 77
(c)
61.3 - 65
>65 - 70
>70 - 75
>75 - 77
(d)
60 - 65
>65 - 70
>70 - 75
>75 - 80
>80 - 85
>85 - 87.1
(e)
60.7 - 65
>65 - 70
>70 - 75
>75 - 78.2

Fig. 8

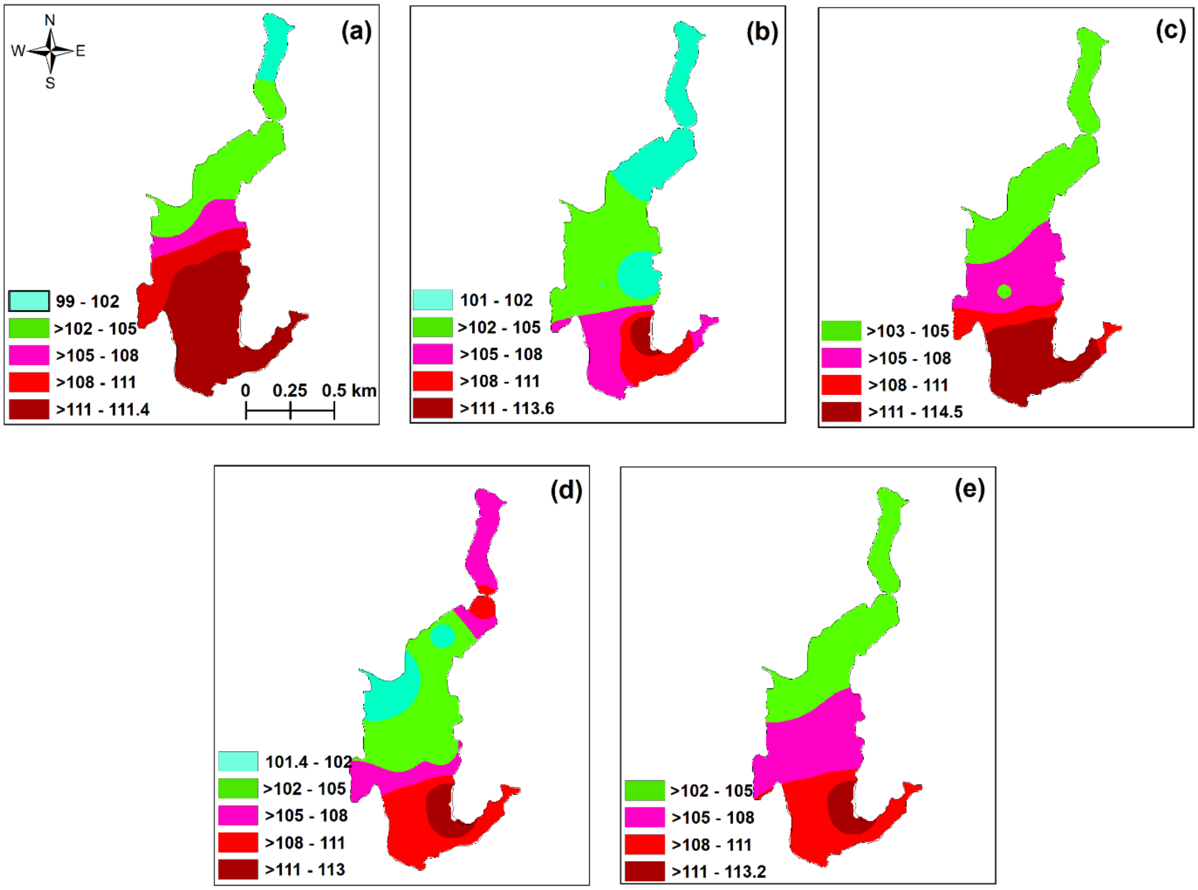

(a)
N
W
E
S
99 - 102
>102 - 105
>105 - 108
>108 - 111
>111 - 111.4
0 0.25 0.5 km
(b)
101 - 102
>102 - 105
>105 - 108
>108 - 111
>111 - 113.6
(c)
>103 - 105
>105 - 108
>108 - 111
>111 - 114.5
(d)
101.4 - 102
>102 - 105
>105 - 108
>108 - 111
>111 - 113
(e)
>102 - 105
>105 - 108
>108 - 111
>111 - 113.2

Fig. 9

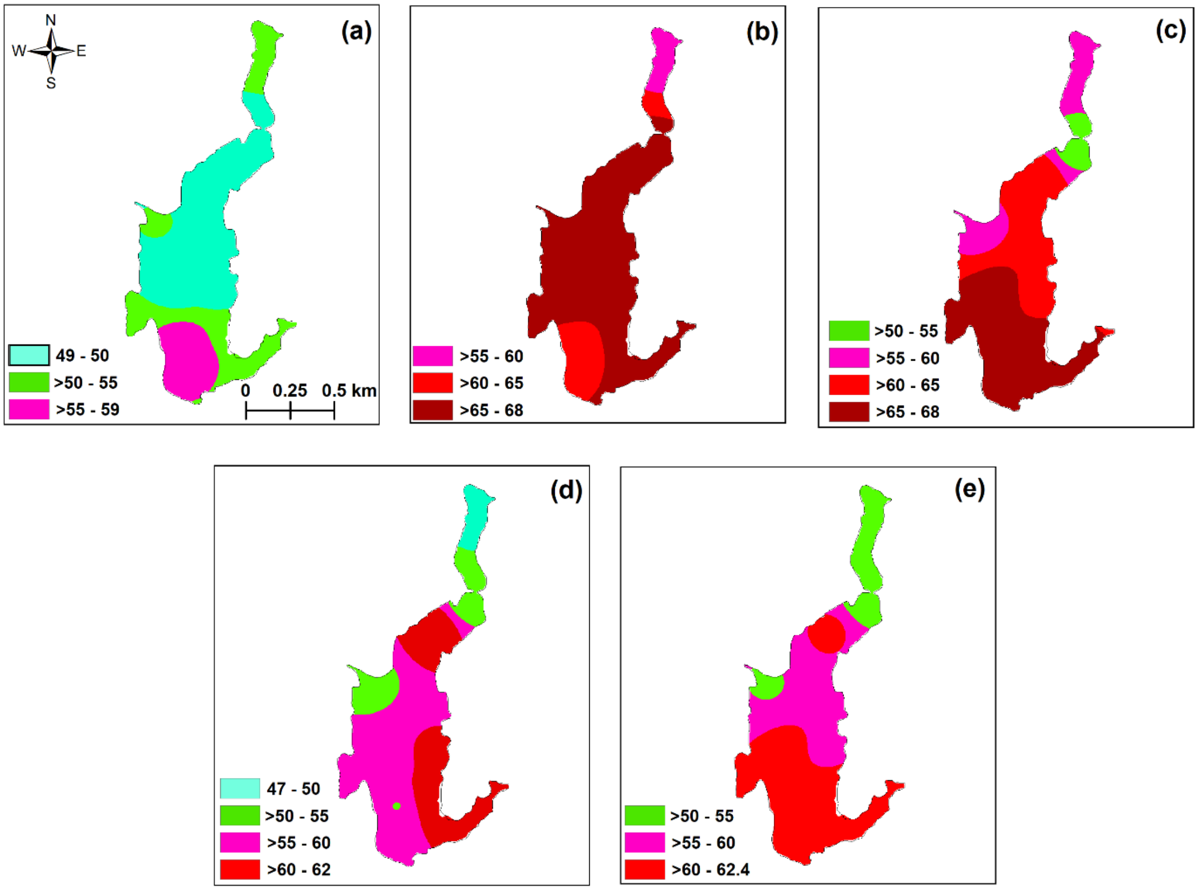

(a)
N
W
E
S
49 - 50
>50 - 55
>55 - 59
0 0.25 0.5 km
(b)
>55 - 60
>60 - 65
>65 - 68
(c)
>50 - 55
>55 - 60
>60 - 65
>65 - 68
(d)
47 - 50
>50 - 55
>55 - 60
>60 - 62
(e)
>50 - 55
>55 - 60
>60 - 62.4

Fig. 10

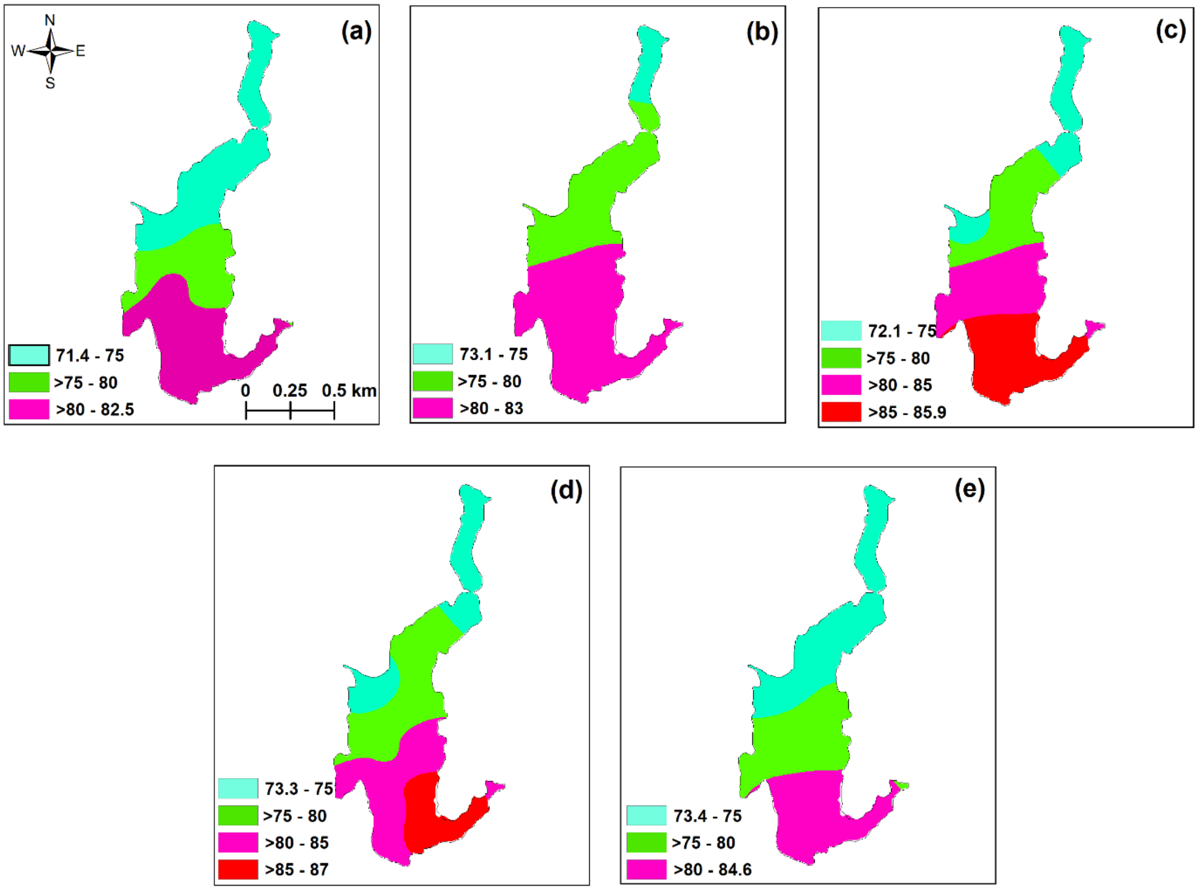

(a)
N
W
E
S
71.4 - 75
>75 - 80
>80 - 82.5
0 0.25 0.5 km
(b)
73.1 - 75
>75 - 80
>80 - 83
(c)
72.1 - 75
>75 - 80
>80 - 85
>85 - 85.9
(d)
73.3 - 75
>75 - 80
>80 - 85
>85 - 87
(e)
73.4 - 75
>75 - 80
>80 - 84.6

Fig. 11

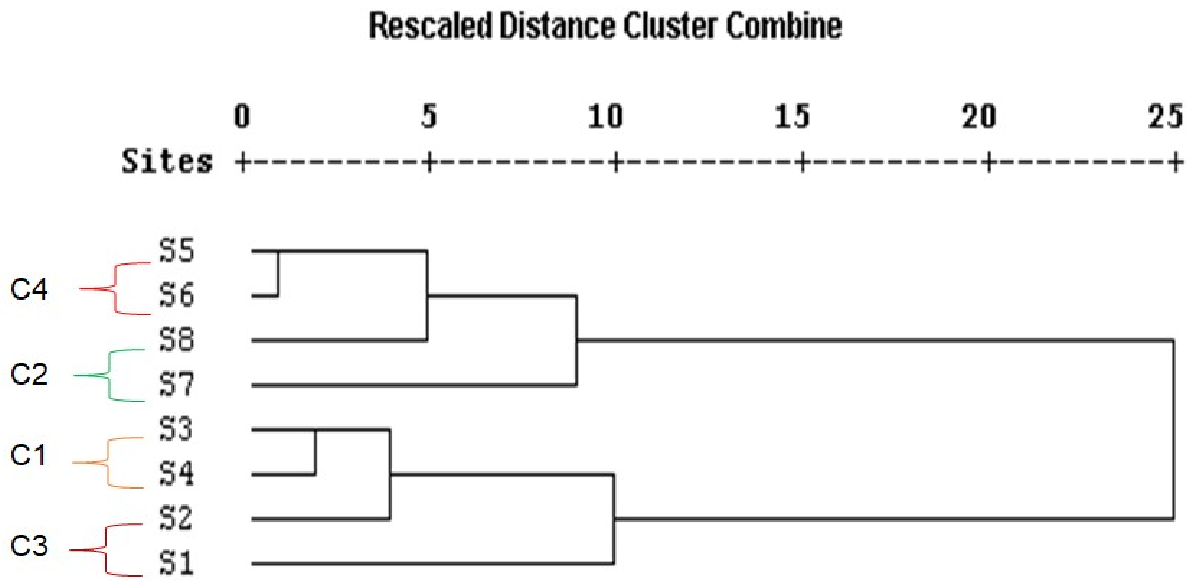

Rescaled Distance Cluster Combine
0
5
10
15
20
25
Sites
S5
S6
S8
S7
S3
S4
S2
S1
C4
C2
C1
C3

Fig. 12

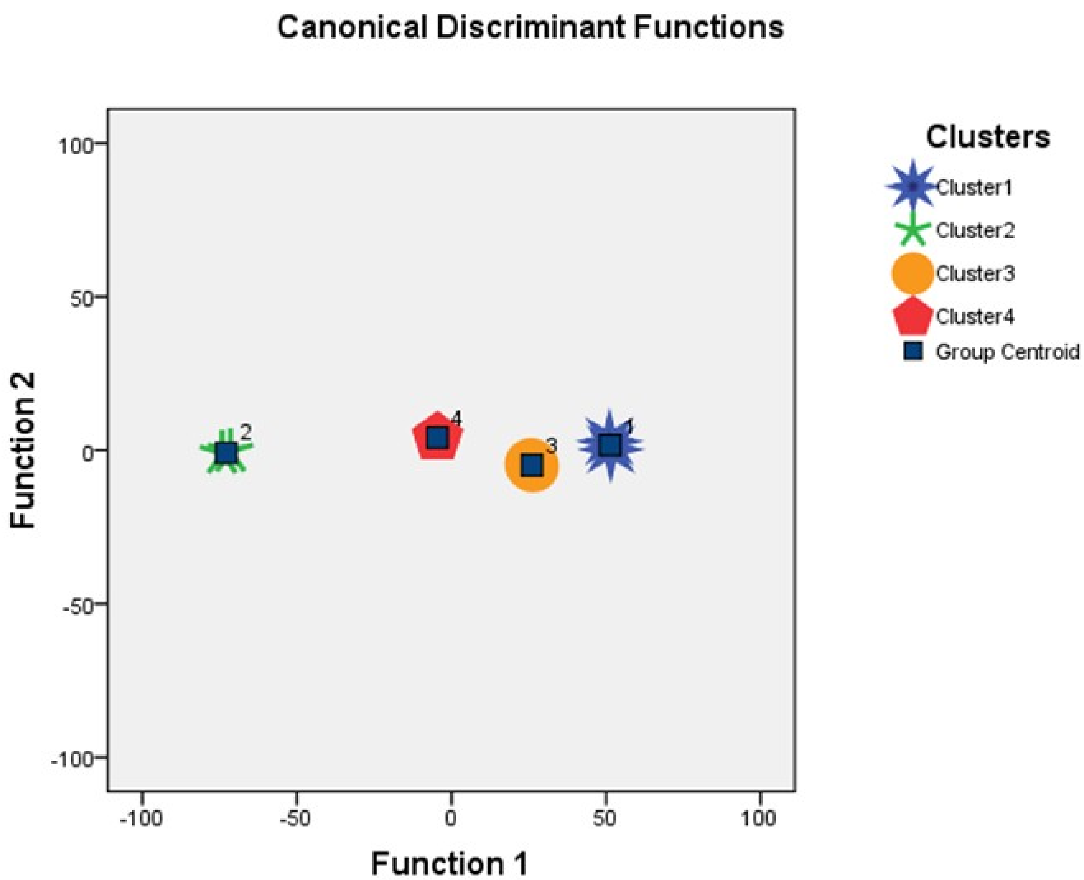

Canonical Discriminant Functions
Clusters
Cluster1
Cluster2
Cluster3
Cluster4
Group Centroid
Function 2
Function 1
100
50
0
-50
-100
-100
-50
0
50
100
2
4
3
1

Fig. 13

Fig. 14

Fig. 15

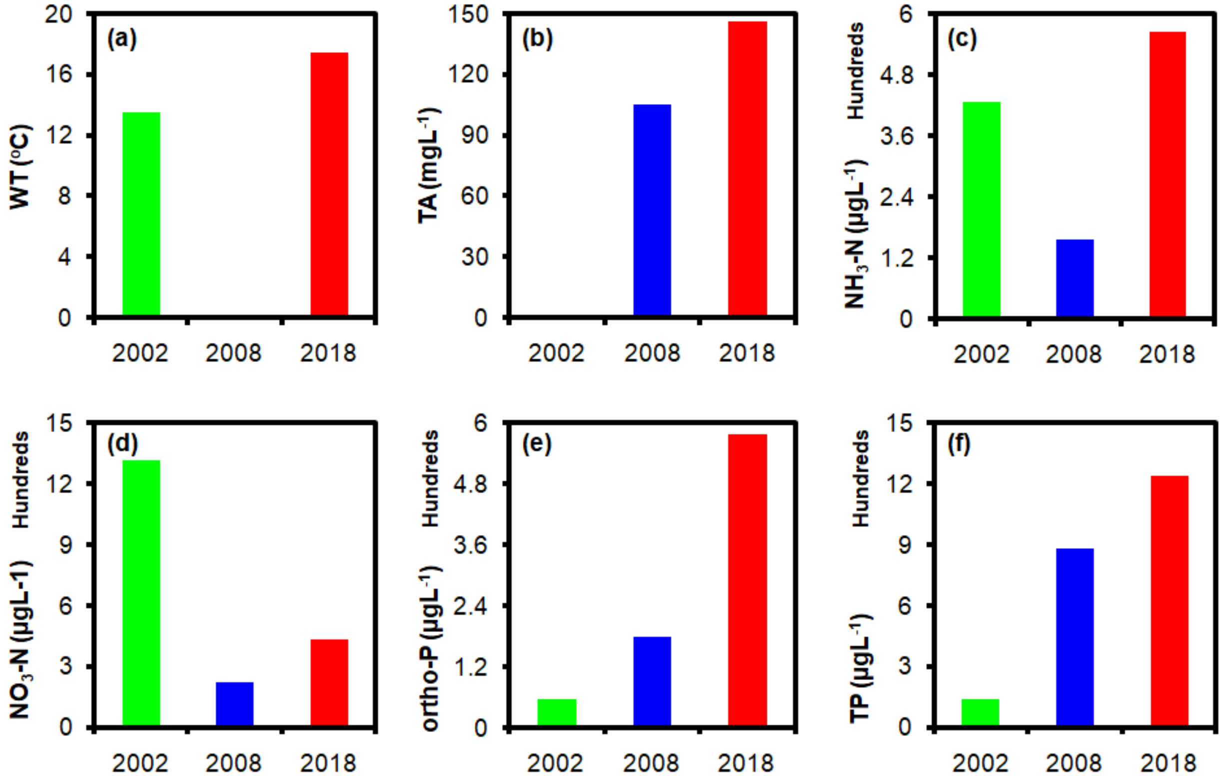

(a)
WT (°C)
20
16
12
8
4
0
2002
2008
2018
(b)
TA (mgL-1)
150
120
90
60
30
0
2002
2008
2018
(c)
NH3-N (µgL-1)
Hundreds
6
4.8
3.6
2.4
1.2
0
2002
2008
2018
(d)
NO3-N (µgL-1)
Hundreds
15
12
9
6
3
0
2002
2008
2018
(e)
ortho-P (µgL-1)
Hundreds
6
4.8
3.6
2.4
1.2
0
2002
2008
2018
(f)
TP (µgL-1)
Hundreds
15
12
9
6
3
0
2002
2008
2018

Fig. 16

Figure Legends

Fig. 1 Location map of Khushalsar wetland showing important features

Fig. 2 Land use land cover within Khushalsar wetland (a) 1980 and (b) 2017

Fig. 3 Land use land cover in the immediate catchment of the wetland (a) 1980 and (b) 2017

Fig. 4 Map showing location of GPS points for validating land use land cover classes of Khushalsar vicinity

Fig. 5 Mean spatial variations in WT, pH, EC, TDS, Sal, SDT, D and DO

Fig. 6 Mean spatial variations in TA, F-CO_2, T hard, Ca hard, Mg hard, Ca, Mg and Cl

Fig. 7 Mean spatial variations in NH_3-N, NO_2^--N, NO_3^--N, TKN, TN, Ortho-P, TP and Chl_a

Fig. 8 Spatial variations in TSI_{SDT} (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average variations

Fig. 9 Spatial variations in TSI_{TP} (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average variations

Fig. 10 Spatial variations in TSI_{Chla} (a) spring, (b) summer, (c) autumn, (d) winter, and (e) annual average variations

Fig. 11 Spatial variations in TOT_{TSI} (a) spring, (b) summer, (c) autumn, (d) winter, and (e) mean annual variations

Fig. 12 Dendrogram of cluster analysis based on surface water quality at eight sampling sites

Fig. 13 Cross validated discriminant results

Fig. 14 Degradation status of Khushalsar captured during field work (a) Sewage discharge from human settlements into the wetland (b) Wastes of animal origin in the wetland (c) Choking of wetland due to plastics and other municipal solid wastes decreasing the water wading area for waterfowl (d) High rates of decomposition of macrophytes and other wastes leading to anoxic conditions in the wetland

Fig. 15 (a) Wastes (blood and visceral) discharged from slaughter houses into Nallah Amir Khan and (b) Dead animals dumped into the wetland

Fig. 16 Comparison of existing water quality with that of Pandit and Yousuf (2002), and Abubakr and Kundangar (2008) (a) water temperature (b) total alkalinity (c) ammoniacal nitrogen (d) nitrate nitrogen (e) ortho-phosphorus (f) total phosphorus