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Influence of changes in watershed landuse pattern on the wetland of Sultanpur National Park, Haryana using remote sensing techniques and hydrochemical analysis

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ABSTRACT

Change in water supply and drainage patterns of surface and subsurface moisture zones are greatly enhanced due to anthropogenic activities. Monitoring changing wetland ecosystems helps to determine their tolerance to such anthropogenic activities.

Sultanpur National Park, a wetland ecosystem located in Gurgaon district of Haryana state is such an ecosystem, harbouring plant and animal biodiversity. Increase in agriculture and builtup area in the surrounding region along with artificial deepening of the lake area for rainwater accumulation has led to the degradation of the central lake both in terms of quantity and quality. The anthropogenic influence was validated by landuse landcover mapping (through K-means unsupervised classification) of LANDSAT data within the wetland catchment for year 2000 and 2015 having an overall accuracy of 89.45% for 2000 and 80.48% for 2015.

A declining trend in the total area under water cover in postmonsoon with a final area reduction of ~66% was observed from the year 1995–2015. Rampant agriculture and builtup land adjacent to the lake as well as artificial pumping of groundwater are major reasons for the deterioration of the lake water quality further posing major threats to the wetland ecosystem.

Siltation from erosion and surface runoff due to mining and agriculture have led to the input of ionic components resulting in lake water quality deterioration as well as reduction in the depth of the lake available for rainwater accumulation. It has been inferred that high concentrations of nitrate (50% of samples above permissible limit ($>$ 45 ppm)) and phosphate (50% of samples above permissible limit ($>$ 0.1 ppm)) ions within the lake water is due to input from surface run off from the surrounding agricultural cropland within the lake catchment further leading to lake eutrophication and habitat loss suitable for plant and animal biodiversity.

1. Introduction

Ecosystems are in a continuous state of flux due to natural or anthropogenic agents or a combination of both over a range of spatial and temporal scales. Wetland ecosystems are highly dynamic constituting lakes, marshes, peatlands, floodplains and mangroves which are constantly or periodically submerged under flowing or still fresh, salty, or brackish water (Syphard and Garcia, 2001; Smith et. al, 1995). They are considered important ecosystems for the conservation of biodiversity as they support a wide variety of flora and fauna. They are amongst the most productive and economically valuable ecosystems in the world known to provide critical ecosystem goods and services such as carbon storage, biodiversity conservation, fish production, fuel production, water purification, flood and shoreline surge protection, erosion control and recreation.

Anthropogenic modifications, for example agricultural expansion, or natural modifications, for example flooding, are likely to be temporary and self-correcting (Bruzzone and Smits, 2001). Modifications due to anthropogenic activities generally remain much longer and the associated degradation can be sudden, as exemplified by fire; or

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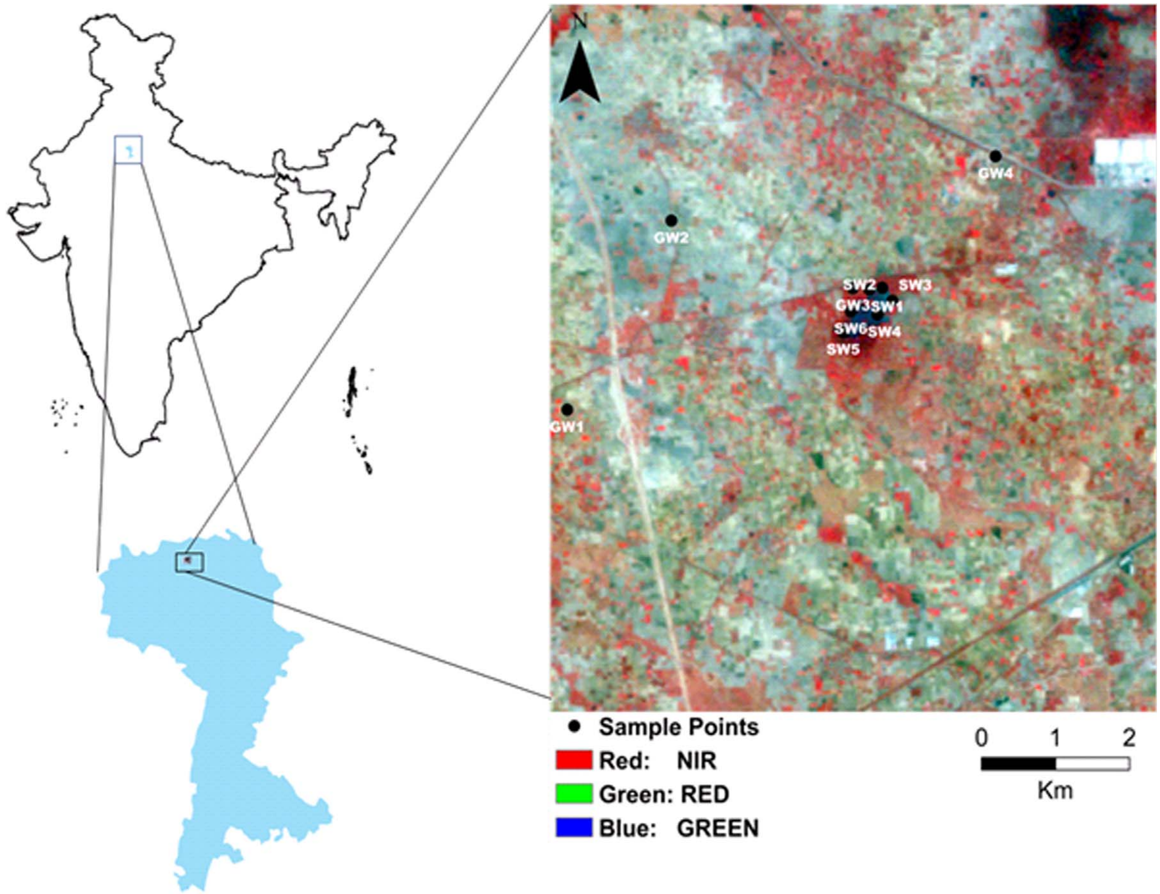


Fig. 1. Study Area.

gradual, such as biomass accumulation, eutrophication etc. (Bruzzone and Smits, 2001). Degradation of ecosystems can be brought about by either Land-cover conversion (which describes the total replacement of one land cover type with another) or land-cover modification (which depicts gradual changes affecting the character of the land cover without changing its overall classification) which can both be distinguished using satellite based changes. Land-cover modifications are generally more prevalent.

Anthropogenic activities such as urban development, agricultural management, road building have caused a significant loss of wetlands (Syphard and Garcia, 2001). Water supply and drainage patterns of surface and subsurface moisture are further altered due to such anthropogenic activities which also reduce the size and distribution of ecosystems dependent on these water sources (Ehrenfeld, 2000). Monitoring these changing ecosystems therefore determines their tolerance to sudden or gradual changes both due to natural or anthropogenic factors (Ghermay et al., 2000).

Wetland restoration is therefore attempted to recover the physical, chemical and biological processes lost because of destruction or degradation. However this approach does not usually restore the ecosystem structure and functions to the original condition. These ecosystems often continue to provide effective water purification and storage functions until they are overwhelmed by pollution or excessive runoff (Ghermay et al., 2000; Mitsch and Gosselink, 2000; Wang et al., 2001). Further, geochemical analysis of water from both surface and subsurface zones gives an idea of the water quality of such wetland ecosystems. Presence of various chemical pollutants, such as heavy metals which interfere with the physiological process within the living system of an animal, helps to determine the suitability of the water as a habitat for various species of animals and birds. The largest proportion of this pollution is accounted for by chemical pollutants, nutrient discharge and sediment loading which are attributed to landuse practices such as agriculture (Wang et al., 2001).

Digital landuse classification and change detection helps in the quantification of temporal phenomena from multi-date imagery, most commonly acquired by satellite-based multi-spectral sensors (Coppin et al., 2004). Landuse/ Landcover changes can therefore be studied by classification of multidate images to study ecosystem degradation or modification within a period of time.

Water accumulates along the flow paths dictated by the terrain of the region defined by the flow direction. This along with flow accumulation helps to estimate the drainage basin of the wetlands which can be mapped to assess the water flow and accumulation through various sources, eg. flood, rainfall, etc. In the present study, ASTER 30 m DEM is used to infer the drainage basin of the Sultanpur wetland to infer the influence of anthropogenic sources of lake area reduction as well as water pollution within the lake. A digital elevation model (DEM) consists of terrain elevations for ground positions at regularly spaced horizontal intervals generally used to generate three-dimensional graphics displaying terrain slope, aspect (direction of slope), and profiles between selected points (Mukherjee and Das, 2005). Using these images, water flow direction is estimated to infer the drainage area and flow lengths. An integrated understanding of the geohydrological and ecological conditions is therefore required to determine the link between geohydrology and aquatic ecosystems and the response of wetland habitat to changes in climate as well as different management practices (Smith et al., 1995). This study therefore aims at estimating the influence of changing landuse pattern within the drainage of the Sultanpur wetland on the central lake.

2. Study area

The wetland of Sultanpur National Park, within Gurgaon district of Haryana state covers an area of approximately 13.727 ha, including its core area of 1.43 ha (Islam and Rahmani, 2004). The wetland consists of low-lying marshes carved out of the land of villages Sadharan, Chandu, Bamripur and Saidpur. Sultanpur national park (28°28′N 76°53′E, c.25 km south-east of Delhi) located in a predominantly agricultural landscape, crisscrossed by irrigation canals (Fig. 1). The region was notified as a bird sanctuary by the Haryana state government in 1971 (Kalpvriksh, 1994) and further declared as a national park in 1991 popularly known for giving shelter and breeding ground for around 250 bird species (some resident, others migratory).

The group of shallow freshwater lakes and associated marshes flood during the monsoon and in years of adequate rainfall. They retain water until at least March or April (Urfi et al., 2004). In recent years of low rainfall only a few small pools remain by midwinter, some 30 cm. in depth. Consequently, pumping of ground water is undertaken each year to maintain some waterfowl habitat. In years of adequate rainfall, Sultanpur becomes a very important wintering area for a wide variety of waterfowl; notably, pelicans, ducks, geese and cranes.

The core area is managed mainly as a waterfowl reserve and tourist attraction. The buffer zone encompasses 17 revenue villages. There is high level of disturbance from tourist activity, particularly when water levels are low and birds are concentrated in a small area. Moreover, siltation caused by soil erosion from construction and agriculture in the catchment area has also increased over the years. The excavation of sand from nearby lime and brick industries further poses a serious threat to the National Park. Heavy grazing, change in cropping pattern, expanding settlements and construction of farm houses and buildings have further led to heavy siltation impeding the natural flow of water into the lake. In addition, the climate and soil of the region are not conducive to the existence of permanent water bodies, and thus saline flashes predominate by late winter even in years of normal monsoon rainfall (Urfi et al., 2004).

It has been proposed that rampant agriculture and built-up activity leading to siltation has reduced the depth of the wetland causing greater evaporative loss of water from the lake. The watershed of the Sultanpur National Park wetland is depicted in Fig. 2.

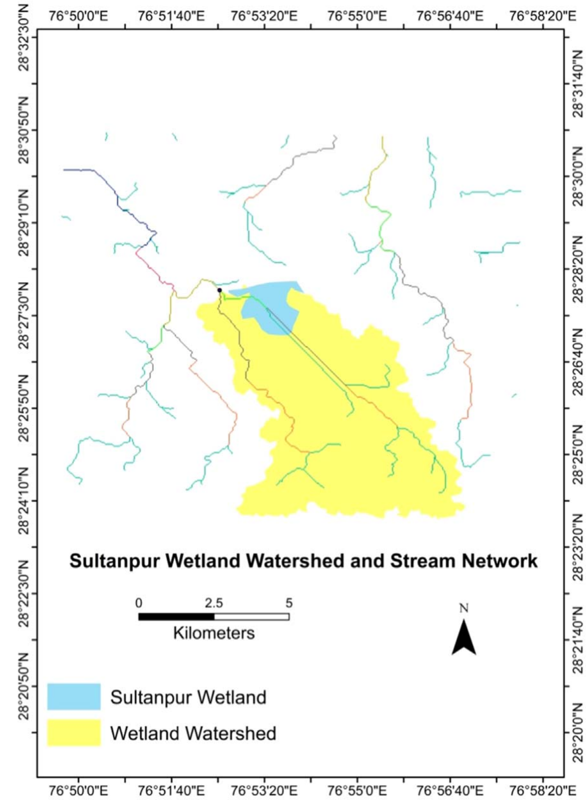


Fig. 2. Watershed basin of the Sultanpur National Park.

2.1. Hydrometeorology

The climate of the region is tropical steppe, semi-arid and hot which is mainly characterized by extremely dry air except during monsoon months (CGWB Information Booklet Gurgaon, 2013). The region experiences intensely hot summers and cold winters. During three months of south west monsoon from last week of June to September, the moist air of oceanic origin penetrates into the district causing high humidity, cloudiness and monsoon rainfall. The monsoon sets in the last week of June and withdraws towards the end of September contributing about 85% of the annual rainfall. The normal annual rainfall in the area is about 596 mm spread over 28 days with July and August being the wettest months. 15% of the annual rainfall occurs during the non-monsoon months in the wake of the thunder storms and western disturbances. The period from October to December constitutes post monsoon season. The cold weather season prevails from January to the beginning of March, followed by the summer season which lasts upto the last week of June. The mean maximum temperature is in the months of May and June at 40 °C and the mean minimum temperature is in January at 5.1 °C (CGWB Report, Gurgaon, 2013).

2.2. Geomorphology, hydrogeology and soil types

Gurgaon district has a fairly flat topography; however in the north-eastern part small isolated hillocks of Precambrian rocks are exposed. The soil of the study area is sandy loam to coarse loamy in texture. The district is occupied by Quaternary alluvium and Pre-Cambrian meta-sediments of Delhi Super Group. The alluvium comprises of thick beds of fine to coarse-grained sand with alternating layers of thin clays. Sandy layers at major depths form major water bearing horizons above the crystalline basement. Groundwater in the block consists in unconfined and semi-confined conditions with the upper zone of saturation consisting of fine sand and silt varying from place to place (Ground Water Board Yearbook of Haryana State, 2014–2015).

3. Methodology and data sets

Multitemporal satellite images of LANDSAT for the years 1995, 1996, 2000, 2002, 2004, 2007, 2009, 2011, 2013 and 2015 were analysed for the calculation of total wetland area under water cover in the postmonsoon season for estimation of change in effective water body area available for rainwater accumulation over the monsoon season (Table 1).

In order to delineate the effective water body surface area of the wetland, the images were taken in the postmonsoon season (Nov-Dec) when maximum water accumulation has taken place due to precipitation in the monsoon season. The region of interest was subset from the images for the calculation of change in effective water body area. The water body extraction from landsat images was done using tasselled cap transformation (TCT). Tasselled Cap transformation was developed from multivariate statistical methods to convert the data from a multispectral sensor into an image with three output indices for brightness, greenness and wetness. These three components highlight three physical feature classes: band 1 (brightness which gives a measure of soil), band 2 (greenness which gives a measure of vegetation) and band 3 (wetness which gives the interrelationship of soil and canopy) (Wang and Zhu, 2010; Gao et al., 2016).

The wetness component of TCT can characterize the outline of wet regions effectively so that rivers and other water bodies can be extracted integrally. Unsupervised K-means classification was applied

Table 1
Satellite data products used for Water Area Coverage, LULC classification and watershed delineation.

Year	Satellite	Sensor	Data Acquisition date	WRS Path/ Row
1995	Landsat 5	TM	11/11/1995	147/40
1996	Landsat 5	TM	13/11/1996	147/40
2000	Landsat 7	ETM+	2/12/2000	147/40
2002	Landsat 7	ETM+	22/11/2002	147/40
2004	Landsat 7	ETM+	11/11/2004	147/40
2007	Landsat 5	TM	20/11/2007	147/40
2009	Landsat 7	ETM+	18/11/2009	147/40
2011	Landsat 7	ETM+	15/11/2011	147/40
2013	Landsat 8	OLI	12/11/2013	147/40
2015	Landsat 8	OLI	18/11/2015	147/40
2011 (Watershed Delineation)	Terra	ASTER GDEM	20/10/2011	147/40
2000 (LULC Classification)	Landsat 7	ETM+	13/09/2000	147/40
2015 (LULC Classification)	Landsat 8	OLI	15/9/2015	147/40

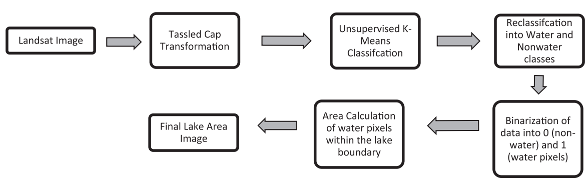


Fig. 3. Flowchart of Methodology for wetland water extraction.

post tasselled cap transformation to isolate pixels showing water. The images were then reclassified and binarized into water and non-water pixels (Fig. 3).

The landuse/landcover classification (LULC) was done using unsupervised classification with K-mean classifier method for the year 2000 and 2015. The landuse/landcover pattern of the area has been classified into six classes namely: Agricultural land, fallow land, barren land, builtup land, vegetation and water. Accuracy assessment was carried out using Kappa analysis which is a discrete multivariate technique. The result of Kappa analysis is a KHAT statistic with the values ranging from +1 to −1 (Congalton and Green, 1977). The range of KHAT values fall under three categories: values greater than 0.80 (> 80%) show strong agreement; between 0.40 and 0.80 (40–80%) show moderate agreement; and values below 0.40 (< 40%) represent poor agreement (Landis and Koch, 1977).

The drainage basin of the wetland was delineated using ASTER 30 m DEM. The watershed of the lake and stream network can be seen in Fig. 2 (Mukherjee and Das, 2005).

3.1. Water Analysis

The surface water samples were collected from the lake in the month of November 2012 (postmonsoon) in polypropylene plastic bottles rinsed 2–3 times with the water being sampled. The surface water samples were collected from the lake by removing the top layer of leaves, algae or any other biomass collected on the surface and the bottle submerged to achieve a representative sample of the lakewater. Groundwater from the region surrounding the lake was collected from borewells after the water was allowed to run for approximately two minutes before collecting the sample to minimize the impact of iron pipes and avoid collection of stagnant water within the pipes. The location for each sample was mapped by Garmin global positioning system (GPS) by recording the coordinates (Fig. 1). Six surface water samples and four groundwater samples were collected from the study area. The samples were analysed for pH, EC and TDS on the field using handheld thermo fischer probe for pH, EC and TDS. The sample bottles for cation analysis were preserved by adding 2 drops of pH < 2 HNO_3 (Nitric acid). All samples were stored at 4 °C until analysis was done. All chemical analysis was done using the standard methods described in APHA (2005) and the methods described in Diatloff and Rengel (2001).

3.2. Sodium and potassium ion analysis

The sodium and potassium ion concentration was analysed using Table top flame photometer (CL378). Standards of 0.5, 1, 2.5 and 5 ppm were prepared to calibrate the system. Acidified samples were then analysed to measure the concentration of Na^+ and K^+ ions.

3.3. Nitrate and phosphate ion analysis

Spectrophotometry is a common method to estimate the concentration of organic and inorganic substances. Nitrate and Phosphate analysis was done using Perkin Elmer Lambda 35 spectrophotometer.

3.3.1. Nitrate ion analysis

Nitrate measurement was done based on the nitration of salicylic acid. TRI solution was made by dissolving sodium salicylate, sodium chloride and ammonium sulfamate in 0.01 M sodium hydroxide. Standards of 0.4, 0.8, 1.2, 1.6 and 2.0 mM concentrations were prepared from a stock of 10 mM concentration. Standards as well as samples were then prepared using TRI solution, concentration sulfuric acid, MilliQ and NaOH. A standard curve was made using the readings of the standards taken at 410 nm. Sample absorbance readings were used to measure the respective concentration of nitrate within the samples using the standard curve (Diatloff and Rengel, 2001).

3.3.2. Phosphate ion analysis

Phosphate in water samples was analysed using UV spectrophotometer based on the deprotronation of malachite green by the molybdophosphate complex. Reagents used were Malachite green by dissolving ammonium molybdate, conc. sulfuric acid and malachite green. Polyvinyl alcohol reagent (PVA) and malachite solution were mixed just prior to use. Standard stock solution of phosphate was prepared by using potassium hydrogen phosphate. Standards with concentrations of 2, 4, 6, 8, 10 µM were prepared using the stock. Standard curve was prepared using the absorbance of the standards read at 640 nm. Samples were then prepared and readings recorded to determine phosphate ion concentrations using the standard curve (Diatloff and Rengel, 2001).

4. Results and discussion

4.1. Landuse/ Landcover classification and its correlation with water quality parameters

The landuse/landcover (LULC) classification of the area occupied by the watershed basin of the lake was done to estimate the approximate area occupied by the different classes and the change seen from the year 2000 to year 2015 (Fig. 4, Table 3).

The overall accuracy for year 2000 was 89.45% and for 2015 was 80.08% (Table 2). The LULC pattern of the study region around the Sultanpur wetland is majorly occupied with fallow land at 44.19% in 2000 and 42.36% in 2015 respectively. Next, agricultural land occupies 44.68% in 2000 and 27.42% in 2015 of the total area. There is a 17.26% reduction in agricultural land from 2000 to 2015; however built-up land has doubled from 2000 to 2015 from 2.02% to 4.47% (Fig. 4; Table 2). The watershed of the wetland has streams which drain water in the form of surface runoff from the surrounding agricultural land bringing in agrochemical pollutants rich in nutrients from the agricultural crop fields falling within the watershed. This in turn increases the nutrients in the lake water leading to lake eutrophication (Table 3).

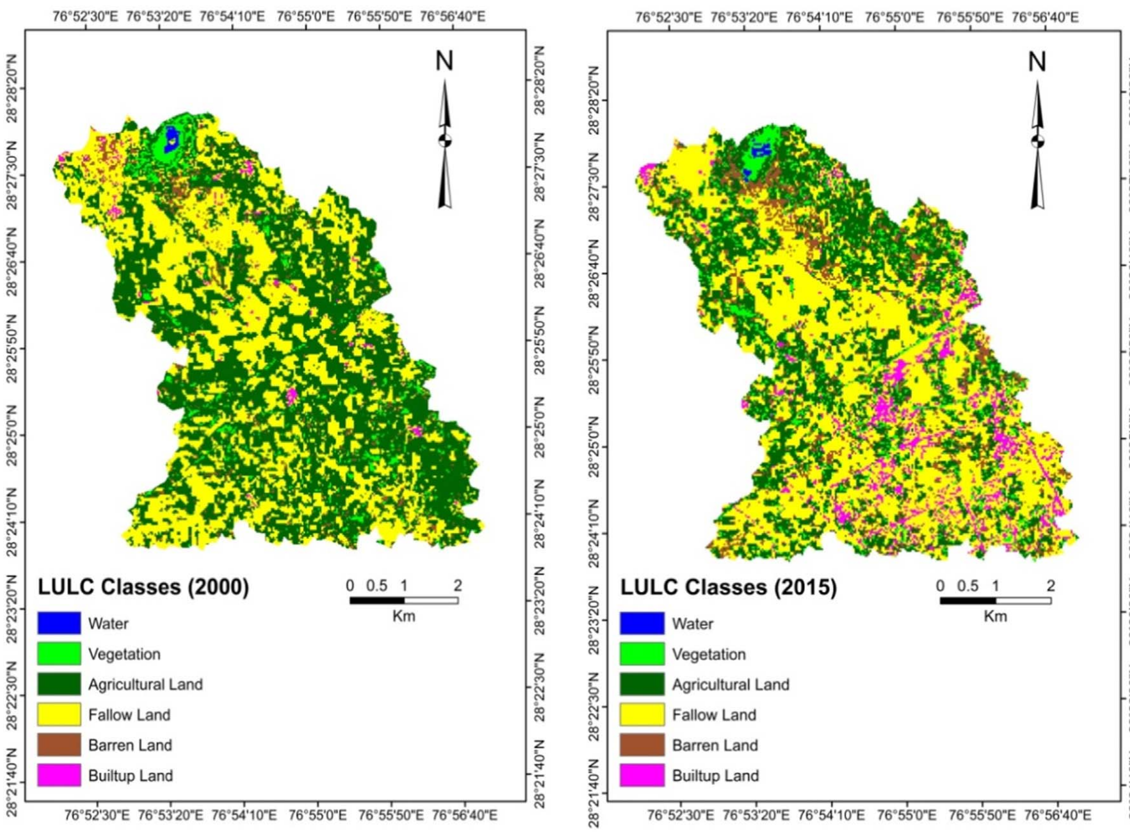


Fig. 4. Landuse/Landcover classification for a. 2000 and b. 2015.

Table 2
Accuracy Assessment of LULC for 2000 and 2015.

Kappa and overall accuracy LULC Classification of year 2000 and 2015		
Year	Overall accuracy (%)	Kappa statistics
2000	89.45	0.8297
2015	80.08	0.7270

Table 3
Area covered by LULC classes for 2000 and 2015.

	(Year 2000)		**(Year 2015)**	
LULC Classes	**Area (Ha)**	**Area %**	**Area (Ha)**	**Area %**
Water	8.5	0.23	8.91	0.245
Vegetation	131.2	3.607	285.48	7.849
Agricultural Land	1872.8	51.49	1057.05	29.06
Fallow Land	1453.9	39.97	1675.44	46.066
Barren Land	133.8	3.678	363.06	9.98
Builtup Land	36.8	1.01	247.06	6.79

High concentration of nitrate ion in the lake water therefore is probably due to the nutrient rich runoff draining into the lake, thereby polluting the lake water. Further, this input of nutrients also leads to eutrophication causing decrease in the aquatic life and species diversity due to decrease in the dissolved oxygen content essential for growth (Baker et al., 2007). The Landuse and Landcover pattern also shows that from the year 2000–2015 built-up land has doubled which is also a reason for the deterioration in lake water quality due to increase in soil erosion and subsequent siltation within the lake primarily due to increase in construction activity. The barren land has increased from 3.87% in 2000 to 10.42% in 2015, owing to the increase in land being

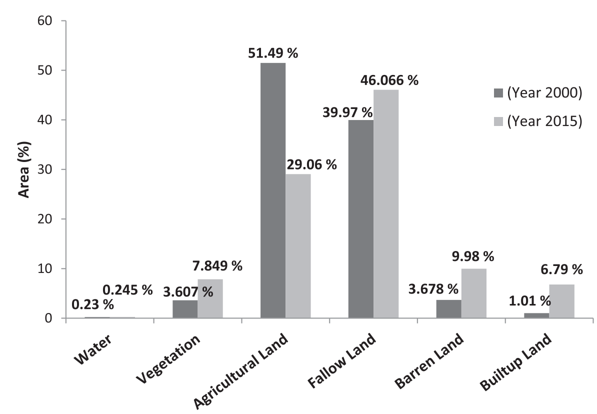


Fig. 5. Comparison of Area (%) change in LULC classes from 2000 to 2015.

cleared for construction both for residential and industrial purposes (Fig. 5).

4.2. *Change in effective lake surface Area*

Water shortage is a common phenomenon in (semi)-arid regions where rapid population/industrial growth, along with intensive land use, low precipitation and harsh climatic conditions increases the incidence of drought. As such, valuable wetland ecosystems in especially semi-arid regions have become ever more fragile and vulnerable to climate change scenarios. It was observed that the effective lake area has gradually reduced from year 1995 to 2015 (Figs. 6 and 7). Water body extraction to delineate the water body area submerged in the postmonsoon season for the years 1995, 1996, 2000, 2002, 2004, 2007, 2008, 2011, 2013 and 2015 was done to observe the declining trend in the effective wetland available for water accumulation. The lake is drying, killing the fish and microscopic organism population which

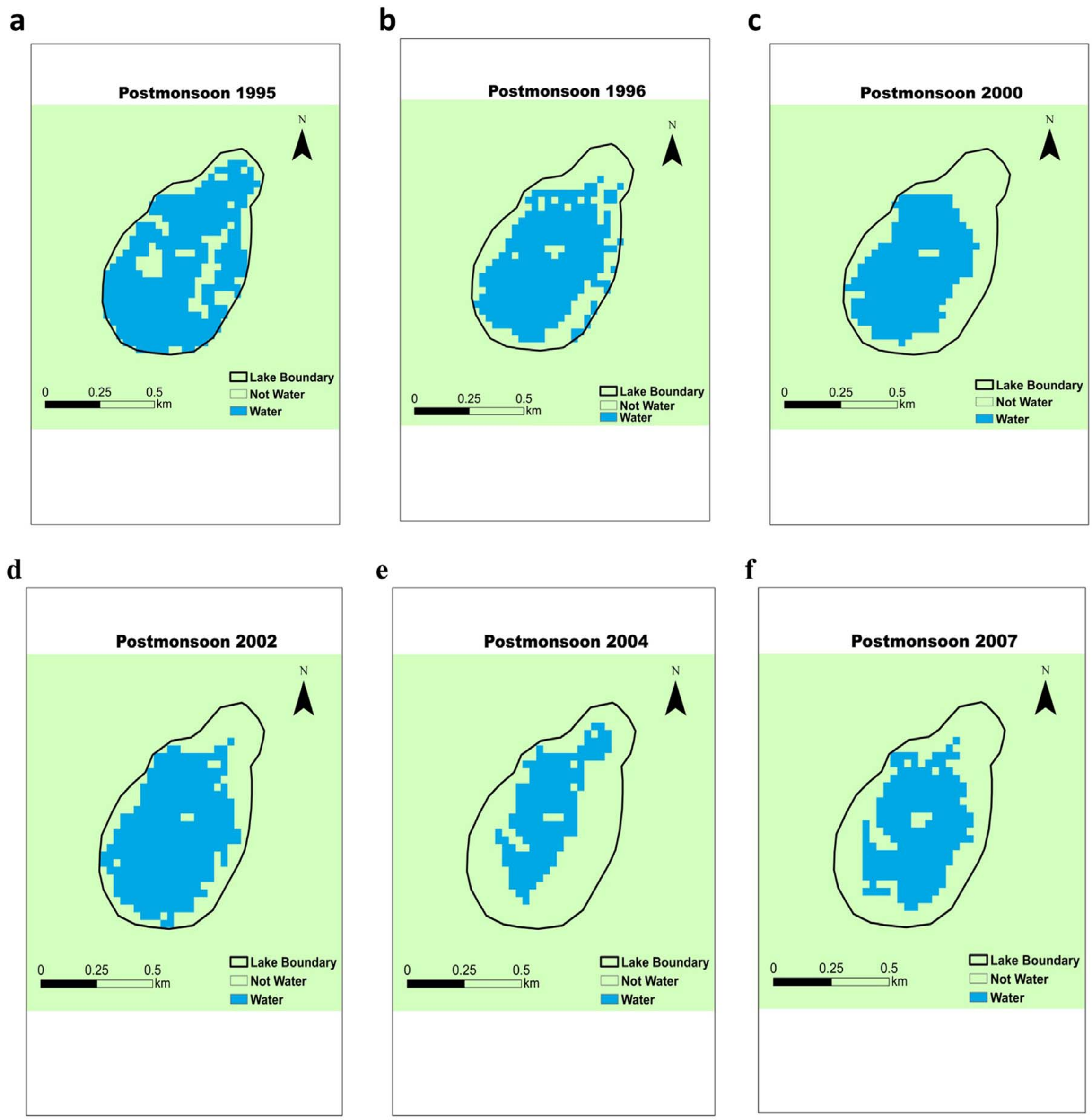


Fig. 6. Effective lake surface area for the year a. 1995, b. 1996, c. 2000, d. 2002, e. 2004, f. 2007, g. 2009, h. 2011, i. 2013 and j. 2015.,.

serve as food for a number of migratory bird species (Gaston, 1994). Moreover, failure to supply water through irrigation canals and decrease in rainfall also serve as factors for the decline in lake water quantity. Increase in built-up activity within the drainage basin of the wetland also leads to siltation due to soil erosion. All these activities, together have led to the reduction in the extent of effective water body area of the wetland. Efforts such as input of water from irrigation canals and groundwater pumping into the lake as well as deepening of the lake also do not seem to be sustainable efforts as the effective lake surface area is continuously reducing over the years.

4.3. Water analysis

The chemical budget of ions in the lake depends primarily on factors such as minerals present in geological formations, evaporation, precipitation and anthropogenic activity. The values of pH, EC, TDS, Na^+, K^+, PO_4^{3-} and NO_3^- ion concentrations for the surface and groundwater samples collected have been tabulated in Table 4 along with the Bureau of Indian Standards (BIS) and World Health Organisation (WHO) drinking water permissible limits for the respective parameters (Table 5).

The pH levels for the lake water was slightly alkaline ranging between 7.6 and 8.72 with only one sample falling beyond the permissible range of 6.5–8.5. The groundwater on the other hand was slightly acidic with all values falling within the permissible limit. The TDS for the lake samples were well below the permissible limit with the values ranging from 139 to 182 ppm. The TDS for the groundwater was above the permissible limit for one out of four samples. The EC values for the lake water were all below the permissible limit. For the groundwater samples, all samples are above the permissible limit ranging from 1100 to 4170 µS/cm.

The sodium ion concentration is well below the permissible limit for the lake water samples whereas three out of four groundwater samples are falling above the permissible limit. The phosphate ion concentration is above the permissible limit for three out of six lake water samples and for two out of four groundwater samples.

Potassium concentration for surface water ranged from 2.5 to 3.9 ppm whereas for ground water the value ranged from 2.6 to 12.5 ppm. Potassium concentration is generally low in groundwater because of the high degree of stability of potassium-bearing aluminosilicate minerals (Anshumali and Ramanathan, 2007). Soil leaching is also one of the sources of potassium. It is also an important fertilizer

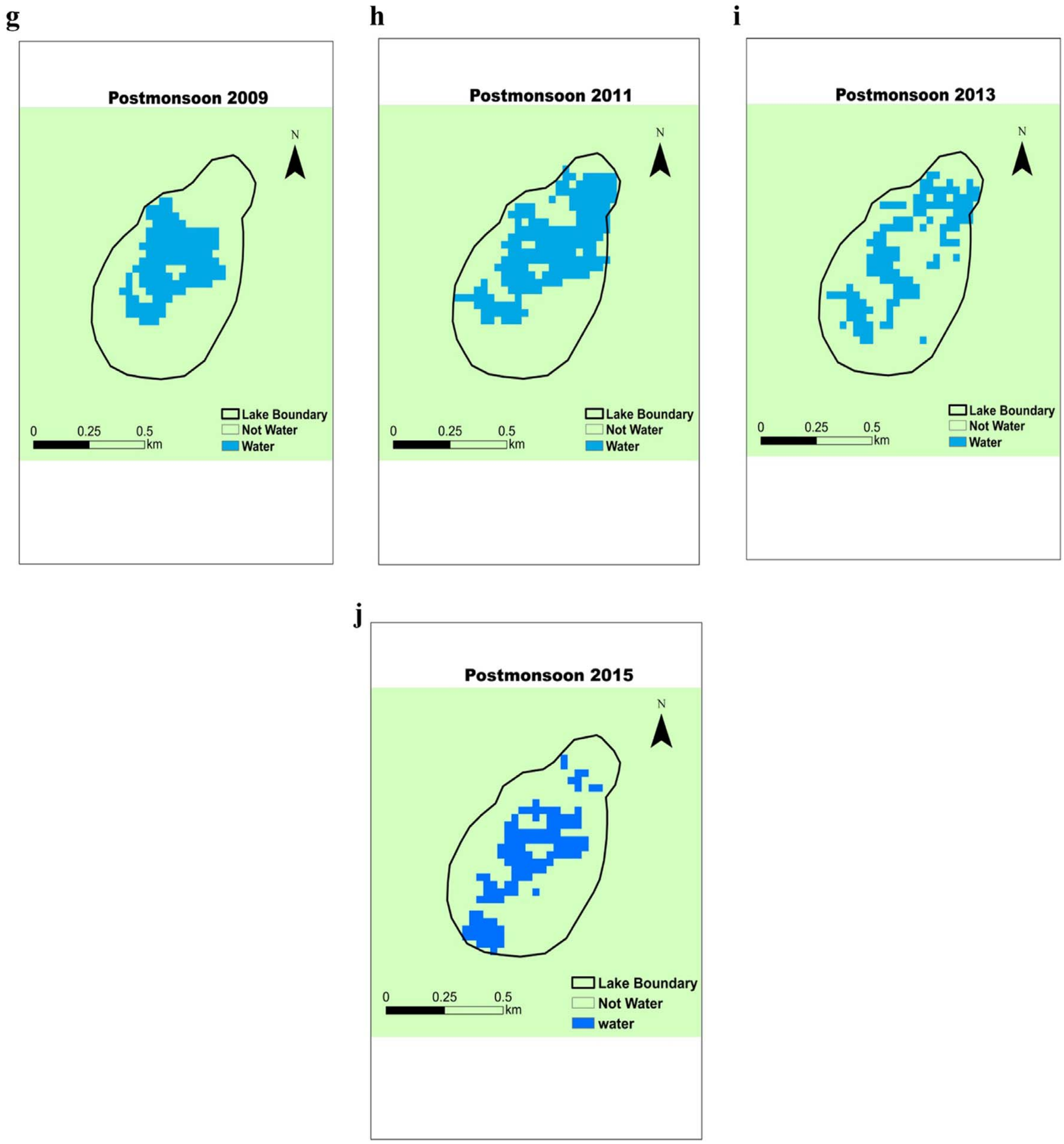
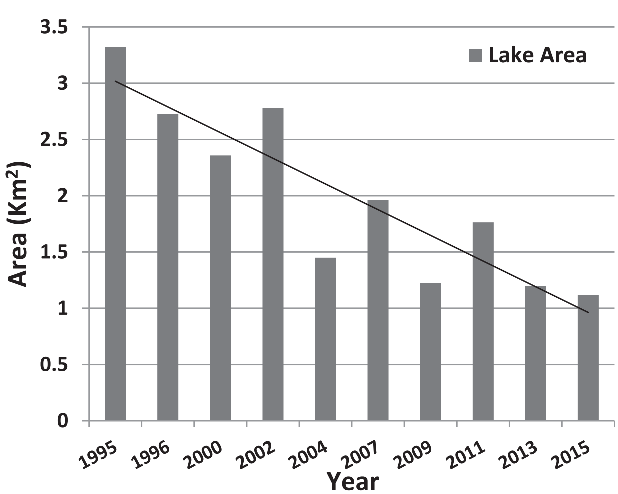


Fig. 6. (*continued*)



Year	Area (Km^2)
1995	3.321
1996	2.727
2000	2.358
2002	2.781
2004	1.449
2007	1.962
2009	1.224
2011	1.764
2013	1.197
2015	1.116

Fig. 7. Histogram chart showing declining trend in effective lake area from year 1995 to 2015.

Table 4
Values of water quality parameters for samples from study area (all in ppm except EC (μS/cm) and pH.

Sample	pH	EC	TDS	Na^+	K^+	PO_4^{3-}	NO_3^-
SW1	7.68	305.0	182.0	22.00	3.10	0.00	20.90
SW2	8.72	288.0	141.0	22.30	2.60	0.00	96.63
SW3	8.25	279.0	139.0	21.50	2.50	0.00	75.04
SW4	7.65	282.0	142.0	14.70	3.50	0.14	35.31
SW5	7.83	324.0	159.0	15.90	3.90	0.39	158.0
SW6	7.60	315.0	157.0	16.40	3.80	0.24	21.0
Range	**7.6–8.72**	**279–324**	**139–182**	**14.7–22.3**	**2.5–3.9**	**0–0.39**	**20.9–158**
GW1	7.08	1100	555	100.30	2.60	0.05	18.42
GW2	6.92	3420	1710	259	3.00	0.15	12.0
GW3	6.81	4170	2060	299	11.50	0.15	8.0
GW4	6.99	2390	1140	232.90	12.40	0.00	16.0
Range	**6.81–7.08**	**1100–4170**	**555–2060**	**100.3–299**	**2.6–12.4**	**0–0.15**	**8–18.42**

Table 5
BIS and WHO permissible limit for ionic concentrations.

Parameters	BIS	WHO
pH	6.5–8.5	9.2
EC	750 μS/cm	1500 μS/cm
TDS	2000 mg/l	1000 mg/l
Na^+	100 mg/l	200 mg/l
K^+	–	12 mg/l
NO_3^{2-}	45 mg/l	45 mg/l
PO_4^{3-}	–	0.1 mg/l

which is strongly held by clay particles in soil (Prasanna et al., 2011). Therefore, leaching of potassium through the soil profile and into ground water is important only on coarse-textured soils. Also, potassium is common in many rocks which are relatively soluble and therefore the potassium concentrations in ground water increases with time. The drainage basin of the lake is majorly occupied by agricultural land cover with minor builtup land surrounding the wetland region. Prevalence of soil erosion and siltation can also be a significant reason for the leaching of potassium in the surface and groundwater of the study area (Anshumali and Ramanathan, 2007). The pumping of groundwater into the lake in order to compensate for the decline during periods of low rainfall can also be a factor responsible or the increase in the concentration of ions, for example, potassium, which can lead to deterioration in the lake water quality leading to eutrophication from the high nutrient load.

Water naturally contains less than 1 ppm of nitrate. Higher levels indicate that the water has been contaminated. Common sources of nitrate contamination include fertilizers, animal wastes, septic tanks, municipal sewage treatment systems, and decaying plant debris (Prasanna et al., 2011; Rajmohan and Elango, 2005; Brindha et al., 2012). The ability of nitrate to enter well water depends on the type of soil and bedrock present, and on the depth and construction of the well. The nitrate ion concentration is above the permissible limit in three out of six lake water samples and below the limit for all the groundwater samples. High nitrate ion concentration in the lake water is indicative of agricultural influence from surface runoff from nearby fertilizer rich agricultural fields falling in the drainage basin of the wetland (Fig. 2). Alternately, there is increased surface run-off due to construction and builtup activity within the drainage basin of the wetland (Fig. 4b). This further enhances soil erosion and surface runoff leading to greater input of fertilizer rich soil from the nearby agricultural and fallow lands.

Phosphate concentration in the surface water samples from the lake ranged from 0 to 0.39 mg/l. For ground water samples the phosphate concentration varied from 0 to 0.1 mg/l. Phosphate concentration can be attributed to anthropogenic activities, such as input of fertilizers followed by agricultural run-off in the catchment area. Sewage, solid waste disposal and decomposition of organic matter are other sources of phosphate (Anshumali and Ramanathan, 2007; Rao and Prasad, 1996). It is again higher than the WHO permissible limit of 0.1 mg/l in 50% of the lake water as well as groundwater samples. The lake water samples have a higher concentration of phosphate ion as compared to the groundwater samples further validating the influence of agricultural activity as a significant reason for the lake water quality deterioration.

5. Conclusion

Without identification of actual causal factors behind lake degradation (drying of active water body), any efforts for supplying water artificially will remain futile as the system will still be vulnerable to degradation and the active water body of the wetland under study is expected to dry up permanently.

Further, the region occupied by the drainage basin of the lake wetland also needs to be regulated for agricultural and built-up activity to restrict further deterioration in lake water quality. The reported decline in the number of monsoon and winter migratory bird visitors as well as abandoning of their nests could be due to the observed gradual declining trend of the area under water cover. Also, deterioration in the water quality due to input of nutrients through surface runoff from the surrounding agricultural and built-up land further leads to siltation and eutrophication. Eutrophication in turn leads to decline in the dissolved oxygen content of the lake water decreasing the populations of microorganisms and fish populations playing a prominent role in the food chain.

Therefore, sustainable effort for lake rejuvenation should firstly be aimed at understanding the interplay of various factors within the wetland ecosystem. Improper restoration measures could inadvertently reduce the lakes ability to restore itself further making the ecosystem more sensitive to external changes.

Conflict of interest

All the co-authors declare that there are no conflicts of interest.

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