

Assessment of land use/land cover dynamics vis-à-vis hydrometeorological variability in Wular Lake environs Kashmir Valley, India using multitemporal satellite data

Fayma Mushtaq · Arvind Chandra Pandey

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Abstract Wular Lake, one of the largest freshwater lakes of Jhelum River Basin, is showing signs of deterioration due to the anthropogenic impact and changes in the land use/land cover (LULC) and hydrometeorological climate of the region. The present study investigated the impacts of temporal changes in LULC and meteorological and hydrological parameters to evaluate the current status of Wular Lake environs using multisensor, multitemporal satellite and observatory data. Satellite images acquired for the years 1992, 2001, 2005, and 2008 were used for determining changes in the LULC in a buffer area of 5 km² around the Wular Lake. LULC mapping and change analysis using the visual interpretation technique indicated significant changes around the Wular Lake during the last two decades. Reduction in lake area from 24 km² in 1992 to 9 km² in 2008 (−62.5 %) affected marshy lands, the habitat of migratory birds, which also exhibited drastic reduction from 85 km² in 1992 to 5 km² in 2008 (−94.117 %). Marked development of settlements (642.85 %) in the peripheral area of the Wular Lake adversely affected its varied aquatic flora and fauna. Change in climatic conditions, to a certain extent, is also responsible for the decrease in water level and water spread of the lake as witnessed by decreased discharge in major tributaries (Erin and Madhumati) draining into the Wular Lake.

Keywords Wular Lake · Lake environs · Land use/land cover change · GIS · Multitemporal satellite data

Introduction

Freshwater ecosystems are considered as one of the most important natural resources for the survival of all the living organisms of the biosphere. The alarming rate of deterioration of the water quality of freshwater resources like lakes, ponds, rivers, etc. is now a global problem. Overexploitation and pollution of water are responsible for making it scarce and unfit for consumption (Shah and Pandit 2012). Lakes are extremely fragile and sensitive ecosystems on earth that host rich aquatic biodiversity. Besides being the key components of our planet's hydrological cycle, they provide important social and ecological functions (Ballatore and Muhandiki 2002). Despite the fact that freshwater bodies are very limited and sensitive resources that need proper care and management, they are probably the most neglected and mismanaged natural resources. While some problems originate in a lake itself, the vast majority of problems originate from activities on the surrounding land (International Lake Environment Committee (ILEC) 2005). Due to the accelerated rate of human intervention and human-induced modification of natural processes, today, water bodies are under acute seasonal water scarcity. Permanent and seasonal changes within water bodies occur in response to a range of external factors such as the changes in the land system at the catchment scale, fluctuations in water table, climate change, or other associated human activities (Romshoo and Rashid 2012). Resource development, wise use, and judicious conservation of lakes have been major challenges across the continents, particularly with regard to satisfying human needs within, and sometimes beyond, the lake basin (Badar et al. 2013).

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different periods; it involves the ability to quantify temporal effects using multitemporal datasets (Othman et al. 2013). Land cover change refers to the complete replacement of one cover type

F. Mushtaq · A. C. Pandey (✉)
Department of Remote Sensing, Birla Institute of Technology,
Mesra, Ranchi 835215, India
e-mail: arvindchandrap@yahoo.com

F. Mushtaq
e-mail: fayma1987@gmail.com

by another and is the result of the interplay between socioeconomic, institutional, and environmental factors (Lesschen et al. 2005). Land use/land cover (LULC) change by humans from the last few decades is one of primary factors responsible for degradation. Urbanization and agriculture present both direct problems of habitat conversion and indirect effects of chemical pollution and disturbance of water and nutrient cycles (Li et al. 2009). Remote sensing technology is supporting research in LULC dynamics with data sources from space that provide information to monitor and estimate changes on the surface (Badreldin and Gossens 2013).

The Kashmir Valley is well known for its beautiful lakes, and these lakes vary from being oligotrophic to eutrophic, while others are in the process of continuous change toward eutrophication (Kaul 1979; Khan 2008). While these changes result in part from the natural course of biotic, climatic, and other environmental factors, in recent times, the intensity of such changes increased primarily because of human interferences. Eutrophication and dwindling of lake ecosystems in Kashmir Himalayan lakes is a recent event of the past 10–30 years, coinciding with a marked civilization evolution in the lake drainage basins (Pandit 1998). Since there has not been much development as regards industrialization in the Kashmir Valley, the main contributors toward the eutrophication of the water bodies are land use changes in the catchment, unplanned urbanization, increased sedimentation, and flow of fertilizers and pesticides from the catchment (Pandit and Qadri 1990; Badar and Romshoo 2007). Socioeconomic activities and encroachment of the lake area by the lake dwellers has also contributed to the deterioration of these once pristine lakes.

Wular Lake, the largest freshwater lake within Jhelum River Basin which plays a significant role in the hydrography of the Kashmir Valley by acting as a huge absorption basin for flood waters (Dar et al. 2013), is at the verge of extinction. The lack of understanding of the value and function of Wular Lake and its associated wetlands led to the conversion of its large area for agriculture, settlements, plantation, and other developmental activities (Wetlands International 2007). The lake with its associated wetlands is an important habitat for migratory waterbirds within the Central Asian Flyway and supports rich biodiversity.

The present study focused on the temporal LULC changes around Wular Lake as mapped through satellite images of the years 1992, 2001, 2005, and 2008 using geospatial techniques to evaluate causative factors coupled with the impact of hydrometeorological variability toward such changes.

Study area

The area under investigation around Wular is located between 34°15′–34°36′ N and 74°30′–74°54′ E, covering an area of 425 km² in state of Jammu and Kashmir (Fig. 1). The Wular Lake located in Kashmir Himalayas is one of the largest

freshwater lakes in Asia, situated about 50 km northwest of Srinagar city at an altitude of 1,530 m (a.m.s.l.). The lake is mono basined, is elliptical in shape, and is of fluvial origin, formed by meandering of Jhelum River with a maximum length of 16 km and breadth of 7.6 km. It falls under the jurisdiction of Bandipora district which shares the international border in the northeast with Skardu district, Pakistan. The climate of the area is temperate cum Mediterranean type with average minimum and maximum temperatures recorded in the region varying from –5 to 32 °C. The area receives an average annual precipitation of about 1,200 mm in the form of rain and snow for about 60 days.

Data used and methodology

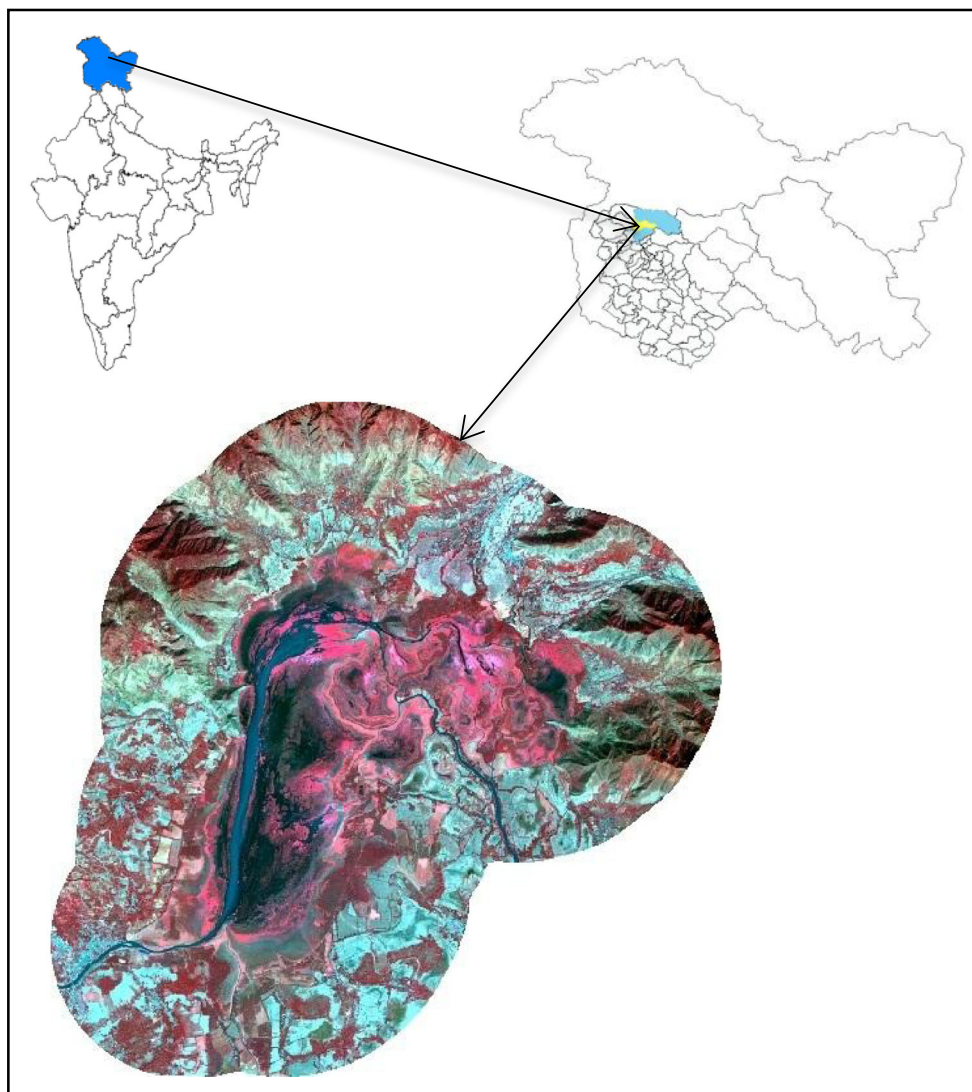
The satellite images provide a primary source of data for mapping LULC for a region during the time of their acquisition from space. In addition, the topographical maps prepared from aerial photographs provide additional source of primary data for mapping LULC (Table 1).

When utilizing spatial data from diverse sources, it is required that all datasets should accurately spatially overlap with each other. This requires georeferencing of all the maps to a common projection system. Georeferencing is a process of transforming an uncorrected, raw image from an arbitrary coordinate system into a map projection coordinate system. Image pixels are positioned and rectified to align and fit into real world map coordinates. The resampling process was performed using the nearest neighborhood technique. The false color composite images created using select bands of satellite data were used for onscreen visual interpretation for mapping various LULC classes within the buffer distance of 5 km from the Wular Lake boundary as shown in the survey of India topographical map on 1:50,000. Ground validation was carried out to acquire field characteristics of various mapped land cover classes and to relate them with corresponding image characteristics. Finally, the area coverage of visually interpreted LULC classes was computed using GIS. The percentage of LULC change statistics during different time periods was assessed by the following formula:

$$K = \frac{U_b - U_a}{U_a} \times 100$$

where K is the percentage of land use change and U_a and U_b are the land use types at the beginning and at the end of a period, respectively. Positive values of this expression indicate an increase in the land use area with reference to the previous year, and negative values indicate a decrease in the land use area with reference to the previous year. Further time series of the hydrometeorological data was examined to infer cause and

Fig. 1 Location of the study area



effect relationships between the climatic variability and the LULC change. The flowchart of the methodology adopted in the present study is given in Fig. 2.

Results

Visual interpretation of satellite images using elements of image interpretation, viz. tone, texture, pattern, association, etc. to

Table 1 Details of satellite data used in the study

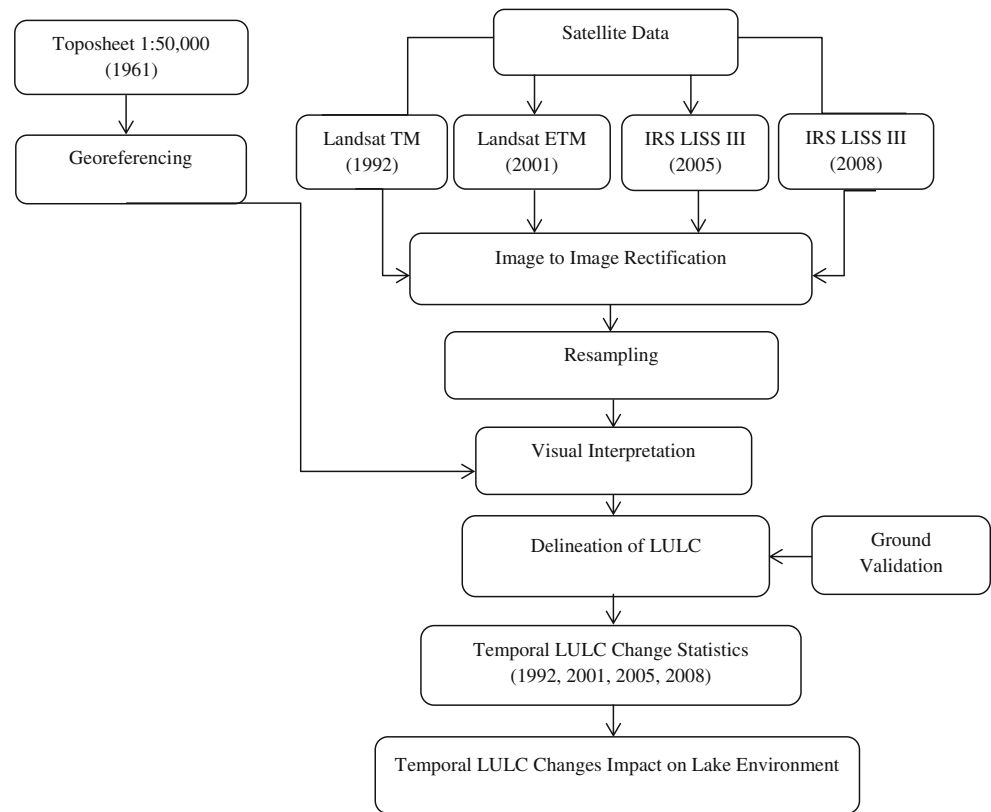
Sensor	Date of acquisition	Spatial resolution (m)
Landsat TM	15 Oct. 1992	30
Landsat ETM+	30 Sept. 2001	30
IRS-P4 LISS III	6 Oct. 2005	23.5
IRS-P6 LISS III	3 Oct. 2008	23.5

delineate various LULC classes using prior knowledge of the study area. The satellite images were interpreted to delineate various LULC classes, viz. build up, agriculture, plantation, forest, water body, aquatic vegetation, scrub, and marshy.

LULC during 1992

In the year 1992, the total water spread area of Wular Lake mapped from Landsat TM satellite image was 24 km² comprising 5.65 % of the study area, whereas the marshy land surrounding the water body covered an area of 85 km² (20 %) and associated with aquatic vegetation comprising 9 km² (2.11 %). Majority of the area was under agriculture land use (125 km²) with agricultural plantation (75 km²), whereas land cover was dominated by forest (93 km²). Scrubland and build up covered minor areas of 7 km² each, respectively. The LULC statistics clearly indicates that, during the year 1992, there was less anthropogenic impact on the lake environment (Fig. 3a).

Fig. 2 Flowchart of the methodology

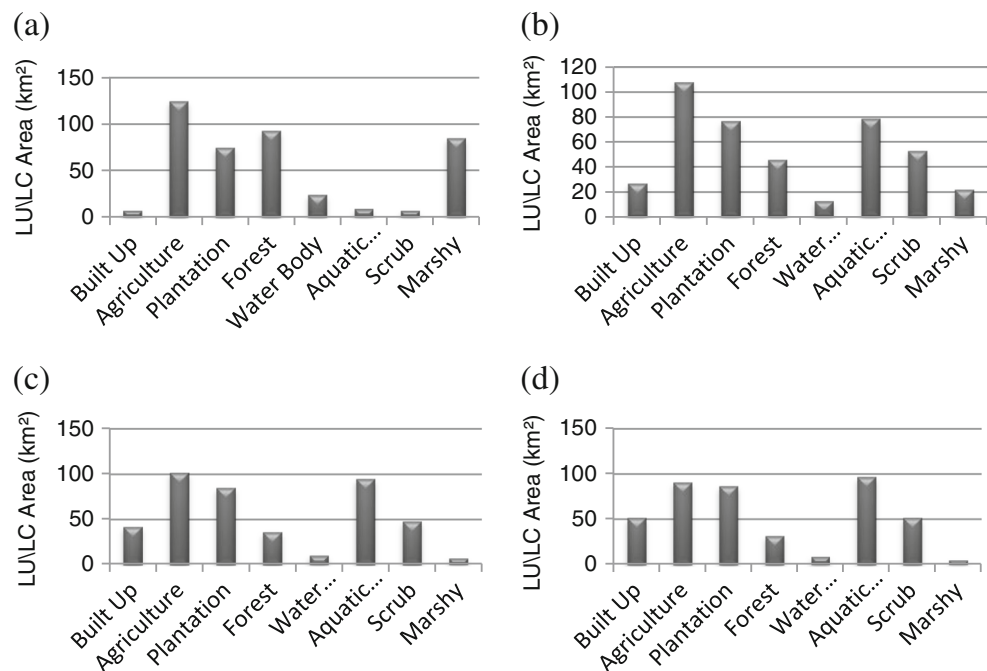


LULC during 2001

In the year 2001, the total area of Wular Lake recorded from Landsat ETM+ satellite image was 13 km² (3.05 %) which is surrounded by 79 km² aquatic vegetation (18.58 %) and 22 km²

marshy land (5.17 %). Although there was reduction in the area covered by agriculture from the years 1992 to 2001, agriculture still comprises the dominant class (108 km²), followed by 77 km² agriculture plantation and 46 km² forest. Scrubland and build up covers 53 and 27 km², respectively. LULC statistics

Fig. 3 Distribution of LULC classes: **a** year 1992, **b** year 2001, **c** year 2005, and **d** year 2008



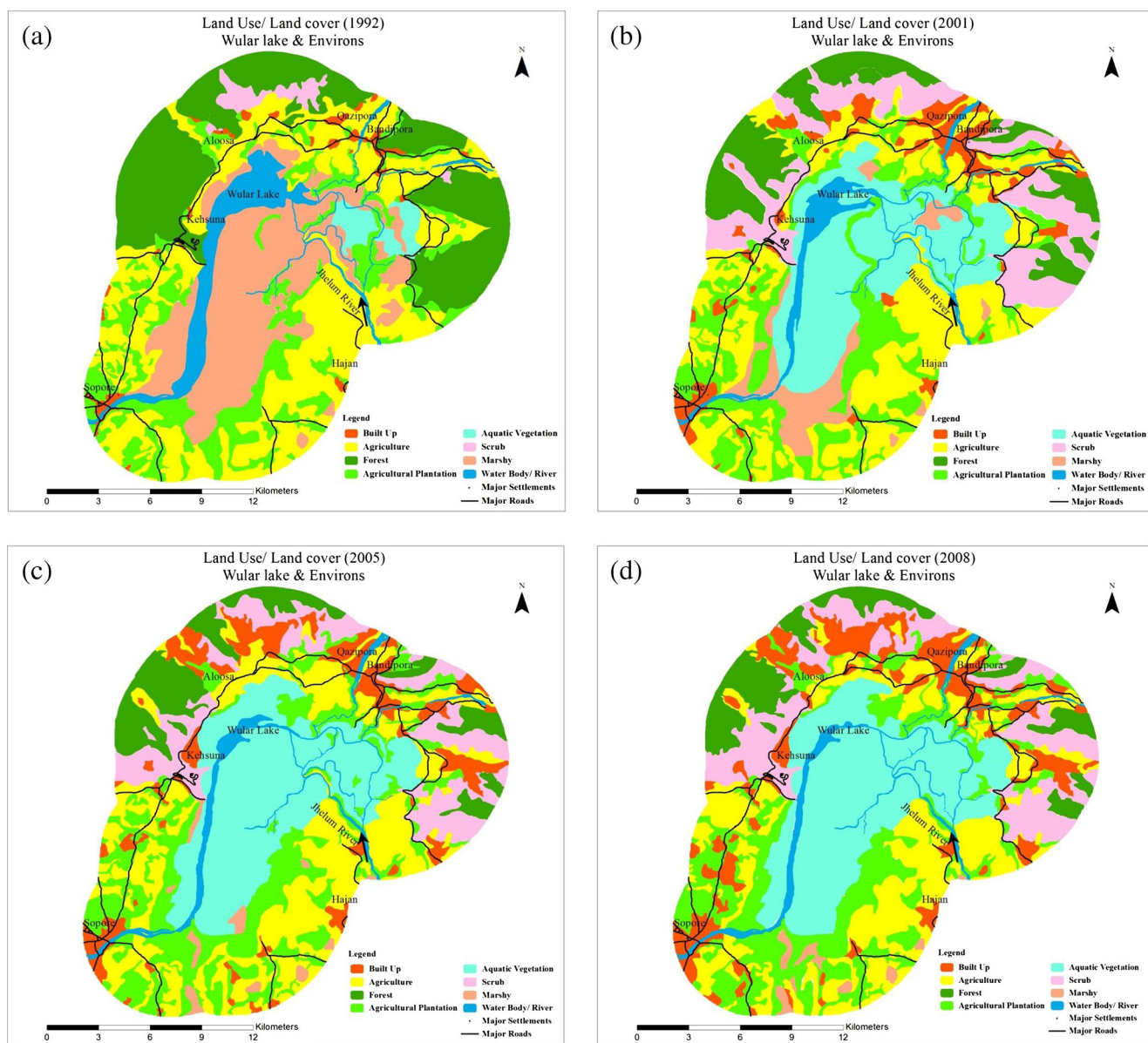


Fig. 4 LULC map of Wular and environs: **a** 1992, **b** 2001, **c** 2005, and **d** 2008

indicates that, during the year 1992, changes occurred in the land use categories with increase in the build up, aquatic vegetation, plantation, and scrubland and decrease in the water body, marshy land, forest, and agriculture (Fig. 3b).

LULC during 2005

In the year 2005, Wular Lake area further decreased to 10 km² (2.35 %), whereas a very high increase in the aquatic vegetation to 95 km² (22.35 %) was recorded partially at the expense of a decrease in marshy area to 7 km² (1.64 %). During 2005, the build up area and the plantation exhibit an increase to 42 and 85 km², respectively, while the agriculture area was decreased to 102 km² (Fig. 3c).

LULC during 2008

The area of Wular Lake in the year 2008 marginally reduced from 2005 to 9 km² (2.11 %). The area under aquatic

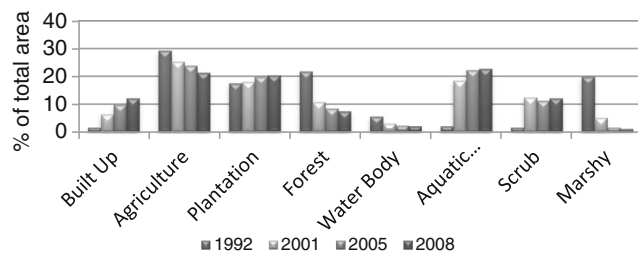
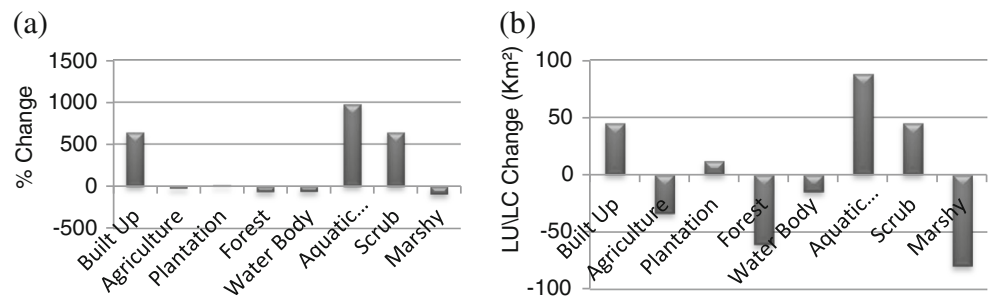


Fig. 5 Distribution of LULC classes in percentage

Fig. 6 Distribution of LULC change in various classes: **a** change in square kilometers and **b** percent change



vegetation covers a large area of 97 km² (22.82 %), whereas the marshy area decreased to 5 km² (1.17 %). Forest cover also decreased to 32 km², with concomitant increase in scrubland to 52 km² (12.23 %). During 2008, the build up expanded to 52 km² (12.23 %) of the area. The agriculture land decreased to 91 km², whereas the agricultural plantation increased to 87 km² (Fig. 3d).

Land use changes

LULC change has important impacts on the functioning of socioeconomic and environmental systems (Lesschen et al. 2005). Land use change includes the modification of land cover types. LULC changes are the result of the interplay between socioeconomic, institutional, and environmental factors (Lesschen et al. 2005). In the present study, LULC change was analyzed to understand the impact of LULC changes on the dynamics of the lake environment.

During 1992 to 2001, major area changes were observed in build up, aquatic vegetation, and scrubland followed by marshy, forest, water body, and agriculture, whereas minor changes occurred in plantation (Fig. 4a, b). The 1992–2001 period exhibits major changes in the LULC of Wular Lake environs. During 2001 to 2005, maximum changes were observed in build up, aquatic vegetation, and marshy area. During the period 2001–2005, the aquatic vegetation showed a sharp increase, while marshy land declined due to their conversion to

aquatic vegetation (Fig. 4b, c). Apparently minor changes occurred in agriculture, plantation, and scrubland. Water body exhibited a gradual shrinkage, resulting in the decrease in the area of water spread and depth of Wular Lake. During 2005 to 2008, major changes were observed in the built area and agriculture (Fig. 4c, d). The build up area expanded, while the agricultural area exhibited decrease. In other classes, minor change occurred compared to previous years (Fig. 5).

Based on the analysis for the period 1992–2008, the results suggest that the rate of change of LULC classes was high. It has been observed that the area of the land use type for ecological uses (water body, forest, and marshy) tend to decrease, but the area of the land use types like agricultural plantation and human settlement tend to increase (Fig. 6a). The percentage of change in build up, plantation, aquatic vegetation, and scrubland was observed as 642.85, 16, 977.77, and 642.85 %, respectively, whereas for agriculture, forest, water body, and marshy area was observed as -27.2, -65.59, -62.5, and 94.11 %, respectively (Fig. 6b; Table 2).

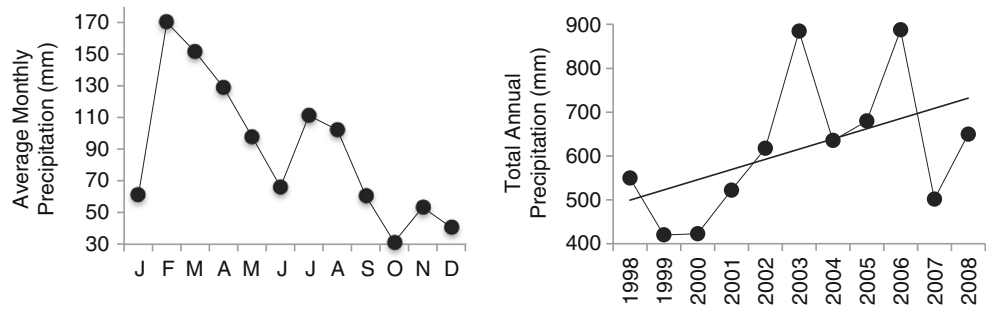
Discussion

The spatial analysis of the multitemporal LULC maps of the Wular Lake and its environs revealed that significant changes occurred during the period 1992 to 2008. The type and distribution of LULC substantially affected a number of hydrological

Table 2 LULC statistics of Wular and its environs during 1992–2008

Year	1992		2001		2005		2008		Total change	
	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)	Area (km ²)	Area (%)
Build up	7	1.64	27	27	42	9.88	52	12.23	45	642.85
Agriculture	125	29.41	108	108	102	24	91	21.41	-34	-27.2
Plantation	75	17.64	77	77	85	20	87	20.47	12	16
Forest	93	21.88	46	46	36	8.47	32	7.52	-61	-65.59
Water body	24	5.64	13	13	10	2.35	9	2.11	-15	-62.5
Aquatic vegetation	9	2.11	79	79	95	22.35	97	22.82	88	977.77
Scrub	7	1.64	53	53	48	11.29	52	12.23	45	642.85
Marshy	85	20	22	22	7	1.64	5	1.17	-80	-94.11

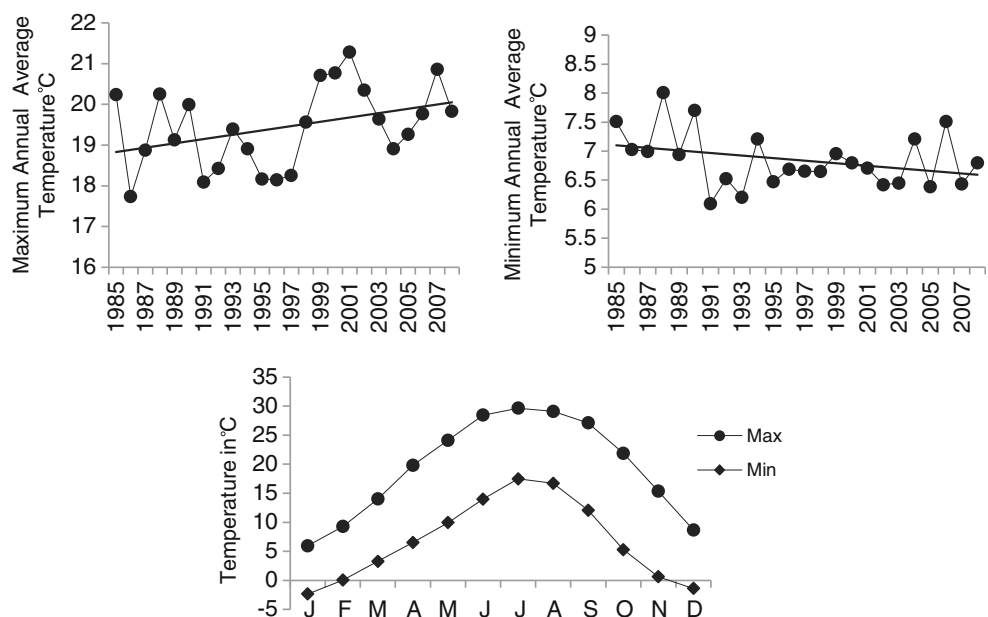
Fig. 7 Graphs showing average monthly precipitation and total annual precipitation



processes such as runoff, erosion, and sediment loadings which in turn profoundly affected lake ecosystems (Matheussen et al. 2000; Fohrer et al. 2001; Quilbe et al. 2008). The growing population and increasing build up land use in the region significantly altered the natural landscape and resulted in the loss of natural vegetation, agricultural lands, and water bodies. The changes in LULC are primarily the consequence of human activities due to which forest land decreased from 93 to 32 km². The rapid degradation of forests indicates their exploitation for fuel wood and overgrazing of pastures, which in turn lead to soil erosion and consequent sedimentation and loss of water-holding capacity of the lake (Wetlands International 2007). Wular Lake decreased from 24 to 9 km² during last two decades. The overall reduction in the lake area and the associated marshy land is due to their conversion to agricultural land and forest plantation. Due to its shrinkage, the role of the lake in regulating flows also reduced, which indicates the possibility of increased flood in the downstream areas. Drastic reduction in the marshy area (-94.12 %) would exert profound impact on migratory birds nesting and feeding in these areas. The decrease in the agricultural land (-27.2 %) is attributed to limited irrigation facilities, causing a shift in the pattern from cropland to horticulture. The

build up area expanded from 7 to 52 km² largely in the vicinity of Wular Lake. Anthropogenic activities such as agriculture and urbanization due to population growth accelerated the deterioration of the structure and function of the lake. Khan (2010) demonstrated the adverse impacts of the human influences on the wetlands all over the world. The hydrological alterations caused by human activities also affected water supply and drainage patterns. Drastic increase in the scrubland area from 7 to 52 km² largely in the vicinity of Wular Lake due to the decline in the forest cover rendered the large area in the Wular Lake catchment vulnerable to increased erosion, sediment yields, as well as increased runoff (Shah and Bhat 2004). Economic benefit in the horticulture crops resulted in significant increase in plantation (75 to 87 km²); this leads to increased application of pesticides and other chemicals, which finally leach into the lake water, leading to the deterioration of water quality (Shah and Pandit 2012). An increase in aquatic vegetation from 9 to 97 km² exhibits the dominance of the species of alligator weed *Alternanthera philoxeroides*, which forms dense mats and thereby disrupts the aquatic environment by impeding the penetration of light and gaseous exchange, as well as promoting sedimentation (Masoodi and Khan 2012). Increase in the area of aquatic

Fig. 8 Graphs showing maximum and minimum average annual and monthly temperature



vegetation also indicates accelerated nutrient enrichment of the Wular Lake due to the incoming effluents from the surroundings of the lake. It can be remarked that LULC changes during the last two decades in the surroundings of Wular Lake resulted in its deterioration. Coupled with the shrinkage of the lake, the decrease in the water level in the lake led to the decline in fish and waterbird diversity, shifting of vegetational belts, and drastic loss in productivity of some economically important species. LULC dynamics indicated that the area under water body, forest, and agriculture decreased at the expense of scrubland, plantation, and build up development, indicating anthropogenic influences.

A time series of hydrometeorological data comprising of temperature (1985–2008), precipitation (1998–2008), and river discharge data (1990–2012) was analyzed to investigate the relationship between the climatic variability and the LULC changes. The analysis of hydrometeorological parameters indicated that the precipitation shows an increasing trend (Fig. 7). The highest precipitation of 884 mm was recorded in the year 2008, while 1999 recorded the lowest precipitation of 420 mm. The average precipitation recorded for the period 1998–2008 was 89 mm. The average monthly precipitation is maximum in the month of February (170 mm) and lowest in the month of October (31 mm). The maximum annual average temperature indicates an increasing trend with reference to average values. The period from 1991 to 1997 shows a low temperature regime, whereas post-1997, a very high temperature trend is noticed. The minimum temperature trend indicates a minor decreasing trend. Very high variability was observed during the period 1985–1993. During the period 1995–2003, a stable temperature regime was observed and moderate variability was observed for the period 2003–2007. Maximum and minimum temperatures recorded in the month of June were 30 and 20 °C, respectively. Minimum temperature recorded in the months of December and January was –2 °C (Fig. 8). The analysis of the time series of the discharge data of Madhumati tributary from 1990 to 2012 clearly indicates fluctuating discharge pattern with minor decreasing trend over the years. The average discharge recorded during 1990–2012 was 513.97 cusecs, with maximum discharge in the month of May (Fig. 9). In the case of Madhumati tributary,

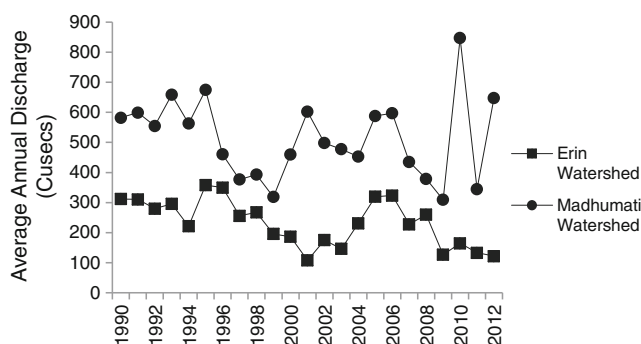


Fig. 9 Graphs showing average annual discharge of Erin and Madhumati stream

the broad peak pattern of discharge indicates contribution from the snow melt dominating over rainfall. Similarly, the analysis of the discharge data of Erin tributary indicates the decreasing tendency of river discharge (Fig. 10). The highest rate of discharge was recorded in the month of May which onward decreases up to December. A very sharp peak indicates discharge contribution largely from rainfall, as discharge pattern also coincides with the rainfall pattern. The contribution of snow melt in discharge generation is minimal. The reduced runoff from major tributaries of Wular Lake over the last decades indicates reduction in the surface water supply to augment lake regeneration. To regulate the lake environment, desilting of the lake beds would be used to regulate flow and reduce eutrophication of the lake.

Conclusion

Various LULC changes around the Wular Lake that have tremendous ecological and socioeconomic importance depict the ill treatment of precious water bodies. Deterioration in the water quality of the lake coupled with changes in the composition and distribution of vegetation significantly affected the biodiversity of the lake. Depletion of the water body exhibits serious implications not only on our flora and fauna but also on the livelihood of the people dependent on the service and goods provided by the lake. In addition, the lake has long since served an important reservoir for flood waters during the periods of peak discharge in the Jhelum River, the main tributary of the upper Indus basin. The depletion and degradation of Wular Lake would adversely impact on the efficacy of the lake in retaining flood waters during peak discharge and flash floods and thus endanger the lives and property of the Srinagar city dwellers. The degradation of the marshy land-forming habitat of millions of migratory birds has affected the arrival of these birds as noticed by their less numbers in the recent years (Wetlands International 2007). The present study indicated that the main reasons for the deterioration of the Wular Lake are increase in the nutrient and silt load from the catchment areas due to deforestation and reckless use of pesticides and fertilizers,

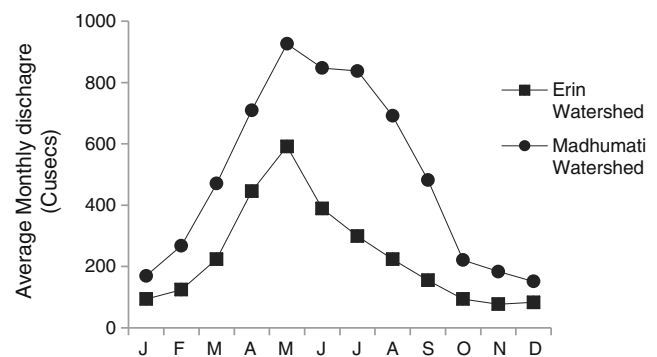


Fig. 10 Graphs showing average monthly discharge of Erin and Madhumati stream

encroachment, and unplanned urbanization in the vicinity of the lake. It is suggested that an appropriate mechanism be established for continuous monitoring of the lake for its land cover, hydrochemistry, biodiversity, and wetland hydrology so that a robust strategy and action plan can be developed for the conservation and restoration of this important lake.

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