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Full Length Research Paper

Geoinformatics for characterizing and understanding the spatio-temporal dynamics (1969 to 2008) of Hokersar wetland in Kashmir Himalayas

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In the present study, the Hokersar wetland, in Kashmir Himalayas, that is abode to millions of migratory birds, has been chosen to assess the changes in the land use/land cover and areal extent of the wetland during the last four decades. Topographic maps of 1969 and the remote sensing data for 1992, 2001, 2005 and 2008 was used for determining the spatio-temporal dynamics of the wetland. Significant changes in the Hokersar wetland and in the surrounding uplands were observed from the analysis of the data during the last four decades. The wetland area has reduced from 1875.04 Ha in 1969 to 1300 Ha in 2008 with drastic reduction in the open waters in the wetland. Results from this study show that the encroachment by farmers, sediment load carried by Doodhganga River and extension of willow plantations in the wetland are the main causes responsible for the wetland depletion. The marshy lands, the habitat of the migratory birds, have reduced from 754 Ha in 1969 to 610 Ha in 2008. In addition, the increasing development of settlements around the wetland over the past few decades has adversely affected its varied aquatic flora and fauna. Apart from these causes, change in climatic conditions in the study area is also responsible for decreasing the water level and water spread in the wetland. These changes in the composition and structure of the wetland have affected its functionality and are manifest in the deterioration of water quality and changes in the aquatic vegetation composition.

Key words: Geoinformatics, land use/land cover, urbanization, remote sensing, biodiversity, water quality.

INTRODUCTION

Sustainable management of wetland ecosystem is necessary as wetlands provide a variety of services and functions and contribute tremendously to the human wellbeing (Costanza et al., 1997; Hruby, 1995). Most important wetland ecosystem services affecting the human wellbeing involve fisheries, fresh water supplies, water purification and detoxification, hydrological services and global climate change regulation (MEA, 2005; Bullock and Acreman, 2003). Further, wetlands are among the most productive ecosystems and a rich repository of biodiversity and are known to play significant role in carbon sequestration (Kraiem, 2002). Permanent and seasonal changes within wetlands occur in response to a range of external factors, such as fluctuations in water table (Funk et al., 1994), climate change (Kraiem, 2002), land use and land cover (Dooner, 2003), urban expansion (Gillies et al., 2003) or other associated human activities (Kraiem 2002). Lack of understanding of the values and functions of the wetlands have led to their conversion for agriculture, settlements, plantations and other development activities (Wetlands International, 2007; Joshi et al., 2002). The need for management and protection of these valuable systems, as well as the need to understand the wetland hydrology and ecology, has

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spurred the investigation of new technologies for mapping and monitoring of wetlands (Hess, 1995). There is insufficient information on the extent of wetlands in Indian Himalayas and how they have been changing over the time (Anon, 1990; Garg et al., 1998). It is therefore important to use a time series of satellite data for generating spatio-temporal information on various aspects of the wetlands to improve our understanding about the distribution, structure and functionality of these important ecosystems (Bourgeau-Chavez et al., 2001; Munyati, 2000).

In the present study, we used a time series of multi-sensor satellite data to determine the spatio-temporal changes in and around Hokersar wetland that has tremendous eco-hydrological and socio-economic importance. Most of the studies conducted on the Hokersar, the Queen of wetlands in Kashmir Himalayas are either focused on the hydrobiology or hydrochemistry (Kaul and Zutshi, 1967; Pandit, 1980; Kaul 1982; Pandit and Kumar, 2006). However, very few studies have used the geoinformatics approach to study spatio-temporal dynamics and limnological variables of the Hokersar wetland (Joshi et al., 2002). The present study assumes significance, in view of the fact that a longer time series of data stretching from 1969 to 2008 has been used to monitor and assess the spatio-temporal evolution of the wetland for the last four decades and the changes that have occurred in the land use and land cover types within and around the wetland during the period. Further, the climate change impacts are quite clear and loud in the Kashmir Himalayan region and have adversely impacted the water resources, including wetlands, in the region (Fowler and Archer, 2006; Romshoo, 2009). Therefore, a time series of the precipitation and river discharge from 1979 to 2009 was analyzed to investigate the linkages between the changing climate in the region with the observed changes in the water extent and water depth.

STUDY AREA

Hokersar wetland (34° 06' N lat., 74°05' E long.), located in Kashmir Himalayas, India is a perennial, protected wildlife reserve, situated about 10 km south of Srinagar city at an altitude of 1584 m (a.m.s.l.). The wetland harbours about two million migratory waterfowl during winter that migrate from Siberia and the Central Asian region. The wetland is fed by two inlet streams- Doodhganga (from east) and Sukhnag Nalla (from west). The water drains out through an outlet channel having a needle gate to regulate the water level during winter. The lake attains a maximum depth of 2.5 m in spring due to appreciation in discharge from the snow-melt water in the upper reaches of its catchment. The water depth at autumn is minimum of 0.7 m. The average rainfall, as observed from the nearest meteorological station at Srinagar is 650 mm and average temperature ranges from 7.5°C in winter to 19.8°C in summer (Pandit and Qadri, 1990). Figure 1 shows the location of the study area.

MATERIALS AND METHODS

Datasets used

Multi-temporal datasets from various sources were used for the set research objectives. Survey of India (SOI) topographical maps at 1: 50, 000 scale were used for generating the base map of the Hokersar wetland mapped in 1969. Time series of satellite data from various satellites was chosen for monitoring the spatial and temporal changes in the wetland. In order to minimize the impacts of the changing season on the mapping, it was ensured, wherever possible, to use the data of the same season with minimum possible gaps between them. We used Landsat TM (15th October, 1992), Landsat ETM (30th September, 2001), IRS LISS-III (19th October, 2005) and IKONOS (11th January, 2008). Though, all the satellite data, except IKONOS, pertain to the autumn season, when the discharge and water depth of the wetland is at the minimum. However due to unavailability of the cloud free satellite data in autumn, we used the January IKONOS data for monitoring the changes in the wetland in 2008. Further, in order to investigate the causes of the water depletion in the wetland, we used a time series of the precipitation and discharge data to infer any link between the climate change and the depletion of the wetland.

Data analysis

For the analysis, the multi-source and multi-temporal spatial data were converted to a common image format. The flowchart of the methodology adopted in this research is given in the Figure 2. The analog topographic map of the wetland was scanned for digital input and processing. All the satellite data were pre- and post-processed using various digital image processing techniques (Jensen, 1996; Lillesand and Kiefer, 1987). The topographic map was geometrically corrected using map to image algorithm so that the corrected image has the geometric integrity of the topographic map (Jensen, 1996). The RMSE error achieved for the georeferencing of the scanned topographic map was less than pixel. Using 18 ground control points, all the four satellite images were then georeferenced to the scanned map using image-to-image algorithm to ensure the geometric integrity of all the input data. Various image enhancement techniques were then applied to the images to increase the interpretability of the image data (Starck et al., 1998).

For delineating the wetland boundary from the topographic, we used the onscreen digitization method. Using the digitized boundary of the wetland from SOI map as the base map, the wetland boundary extents at different points in time were delineated from the satellite images. The land use and land cover types within the wetland boundary were also digitized from the scanned map and the satellite images in order to determine the spatio-temporal changes that have occurred during the observation period (1969 to 2008). For extracting the land use and land cover information in the immediate surroundings of the wetland (5 km from the lake boundary), supervised image classification technique based on the maximum likelihood classifier was used (Tso and Mather, 2001). National natural resources management system (NNRMS) standards (ISRO, 2005) were used for categorizing land use and land cover around the wetlands. While choosing various training samples for the maximum likelihood classifier, homogeneity of the samples was ensured for achieving higher classification accuracy. The maximum likelihood classifier estimates the probability of a pixel belonging to each of a predefined set of cover types and the

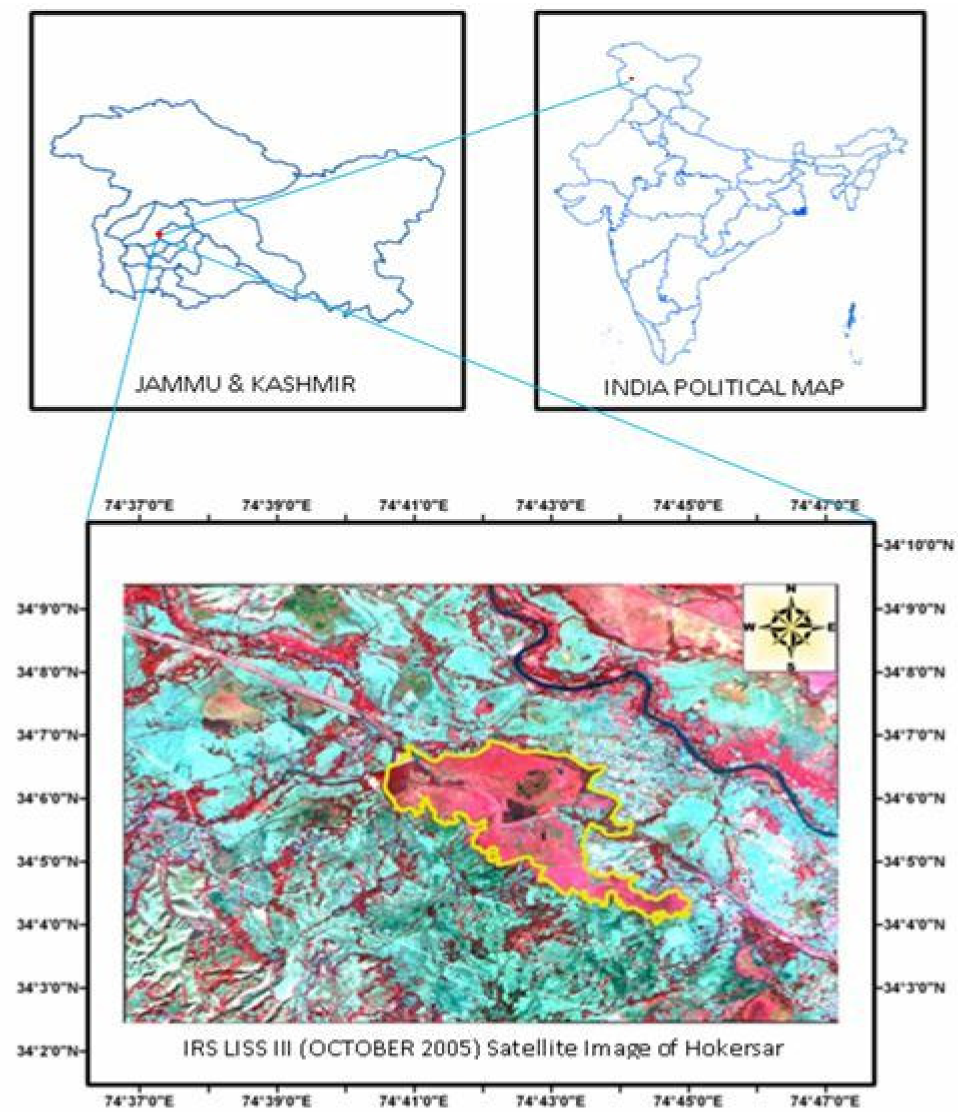

Figure 1. Showing the location of the study area.

pixel is then assigned to the class for which the probability is the highest. The land use and land cover map of 2005 was validated in the field to determine its accuracy. 71 sample points were chosen for verification of the land use and land cover map in the field. The accuracy estimation is essential to assess reliability of the classified map (Foody, 2002). Kappa coefficient (Jensen, 1996), the robust indicator of the accuracy estimation for the final land use and land cover map was estimated at 0.935. The wetland boundary and the land use and land cover types within the wetland were verified w. r. t. 2008 data only. In order to determine the changes in the land use and land cover, that have occurred over the observation period from 1969 to 2008, change detection analysis was performed (Baker et al., 2007; Schmid et al., 2005).

For the time series analysis of precipitation and river discharge data, trend analysis (Von and Navarra, 1995) was adopted to infer the changing climate trends from the data. The daily precipitation from one meteorological observation station and the river discharge data from two gauging stations were categorized into monthly and yearly averages to detect the linear trends in the data. The trends detected in the hydrometeorological data were then related to the decreasing trends of the water extent and depth in the Hokersar wetland.

RESULTS

Wetland depletion

The wetland has shrunk and depleted over a period of time. During the observation period from 1969 to 2008, the spatial extents of wetland have reduced from 1875.04 Ha in 1969 to 1300 Ha. As is evident from the data, an area of 575.04 Ha has been lost during the last four decades. Figure 3 shows the thematic representation of the Hokersar boundary extents at different points in time. There is progressive depletion of the wetland area from

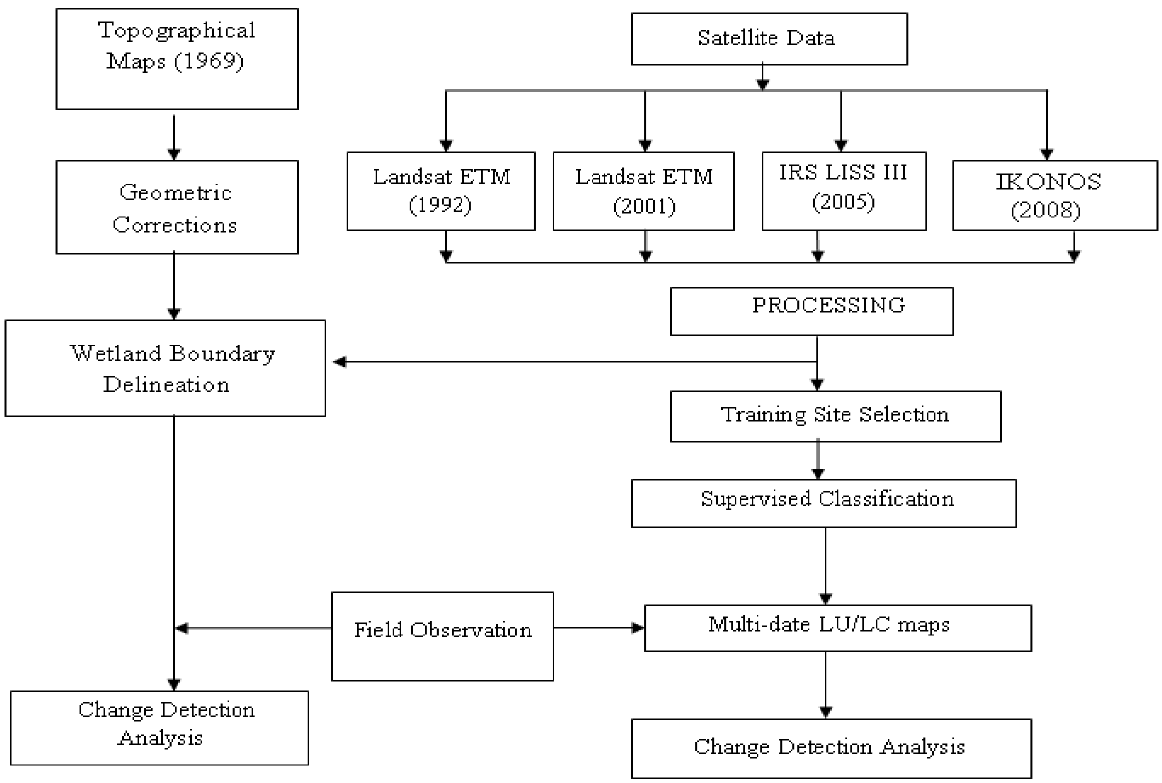

Figure 2. Research methodology adopted in the current study.

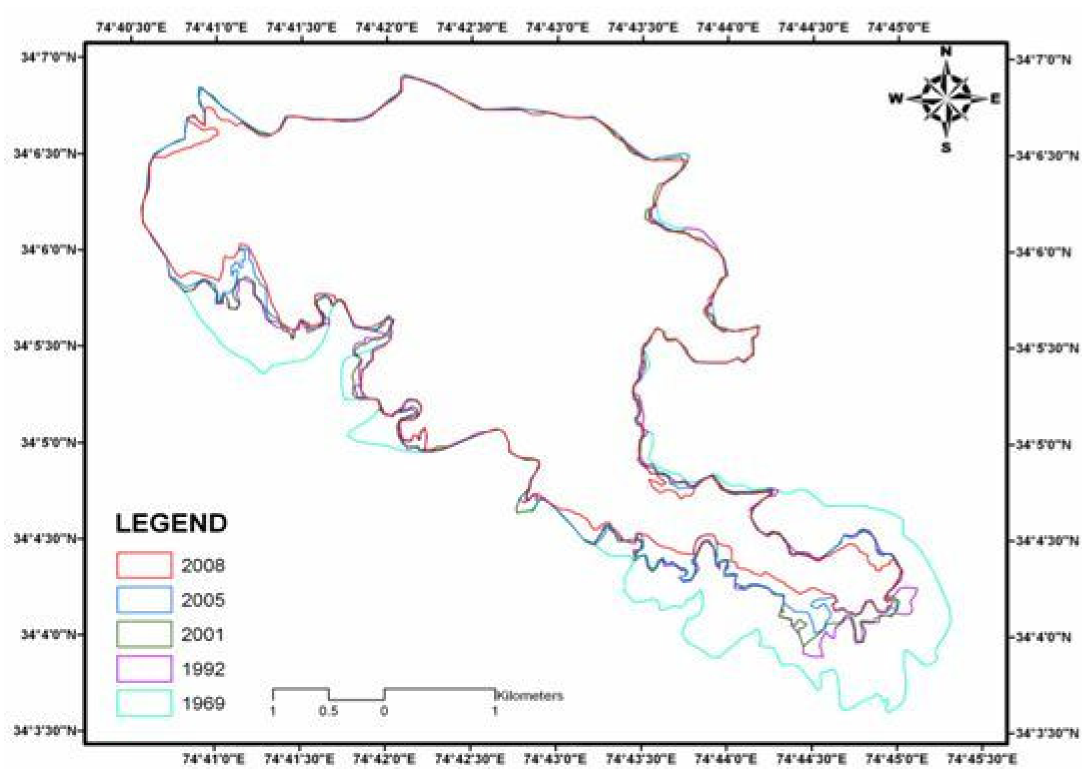

Figure 3. Hokersar wetland boundary at different points in time.

Table 1. Extent of wetland at different points in time.

Year	Area (Ha)	Change in area (Ha)
1969	1875.04	0
1992	1495	380.04
2001	1457	418.04
2005	1360	515.04
2008	1300	575.04

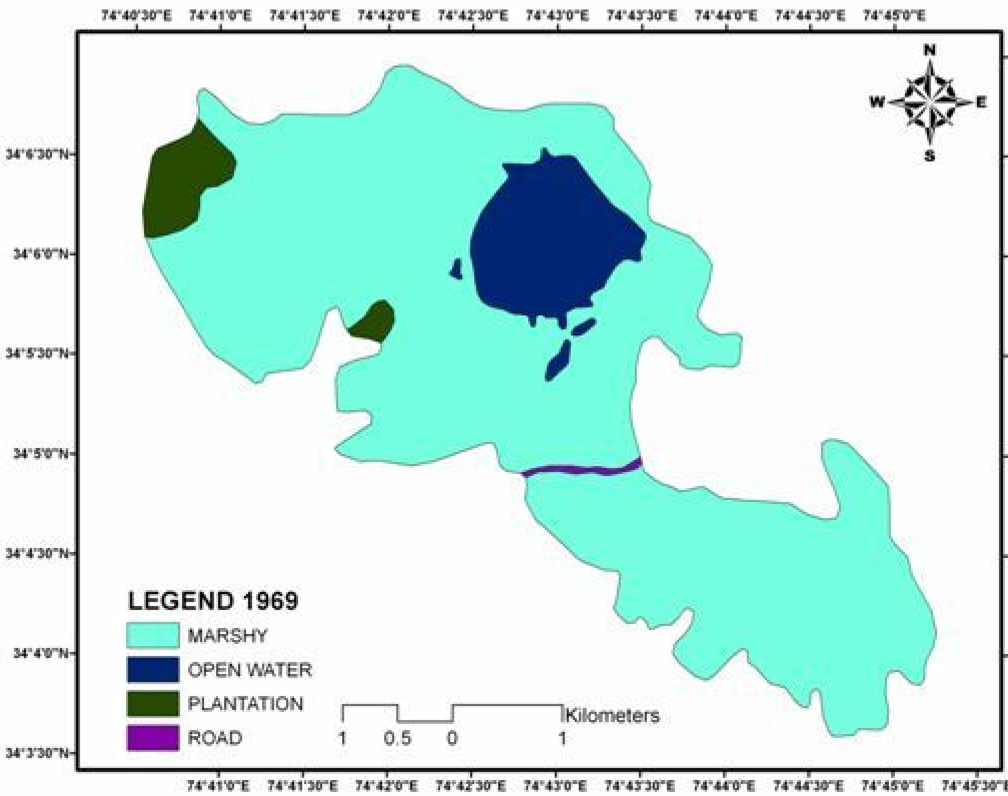

Figure 4. Land use Land cover of the Hokersar wetland from the topographic map (1969).

1969 to 2008 as shown in the Table 1.

Land use and land cover changes within the wetland

Eight types of land use and land cover classes were delineated from the satellite data (1992, 2001, 2005 and 2008) and the scanned topographical map (1969) at 1: 25, 000 scale. For delineating the land use and land cover types from the images, image elements and other contextual information was used for improved accuracy. Figure 4 shows the land use and land cover types delineated from the scanned topographic map that has symbols for these types. From the analysis of Figure 4 and Table 2, we can see that the area under Marshes was 1630.59 Ha, Plantation was 64.29 Ha, open water was 174.17 Ha (which includes flood channel 7.18 Ha) out of the total area of 1875.04 Ha. There is no built up, agriculture, fallow and aquatic vegetation category shown on the topographic map and hence these three categories are missing in the Figure 4. It could be assumed that there was no built-up, agriculture and fallow within the wetland in 1969. However, the Marshy land category shown on the map may constitute some aquatic vegetation as well that has been shown under Marshy land.

From analysis of the 1992 data, as shown in the Figure 5 and Table 3, all the eight categories of the land use and land cover types are present in the wetland. Marshy lands dominate the wetland area covering an area of

Table 2. Land use land cover (1969).

Land Use / Land cover category	Area (Ha)
Marshy	1630.59
Open water	174.17
Plantation	64.299
Road	5.988

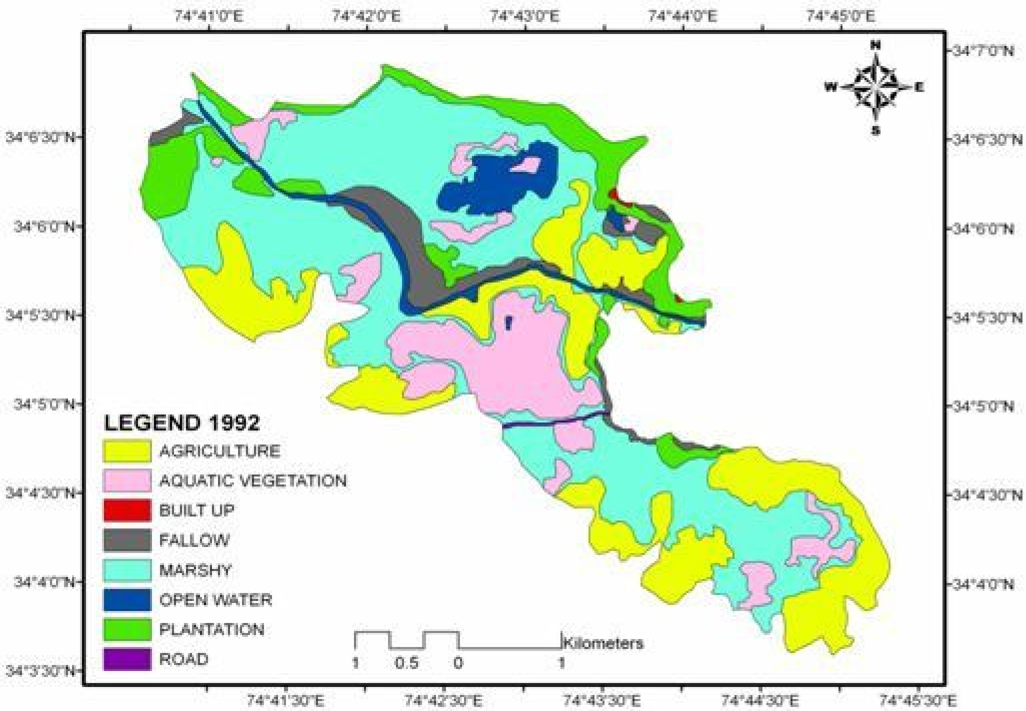

Figure 5. Land use and land cover of the Hokersar wetland generated from 1992 satellite image.

Table 3. Spatial distribution of land use and land cover classes within Hokersar wetland from 1992 to 2008.

Class name	Area (Ha) 1992	Area (Ha) 2001	Area (Ha) 2005	Area (Ha) 2008
Agriculture	426.324	369.307	323.535	495.420
Aquatic vegetation	250.302	348.300	456.071	445.788
Built up	1.682	5.283	12.475	11.347
Fallow	88.329	21.213	27.178	48.732
Marshy	774.112	806.133	727.061	562.397
Open water	85.684	43.691	31.115	36.583
Plantation	182.911	218.156	232.469	216.304
Road	3.280	3.251	2.682	0.960

774.11 Ha that constitutes 42.7% of the wetland area. Agriculture, that was non-existent in 1969, is the 2nd major land use type in the wetland covering about 23.5% of the wetland area. Similarly, the Built up has emerged within the wetland that was not present before 1969 and covers an area of 1.18 Ha (0.09%). The area under the open waters has also drastically reduced in 1992 compared to the baseline data (1969). The open water body within the wetland has drastically reduced from 203.13 Ha in 1969 to 85.68 Ha in 1992. The details of the

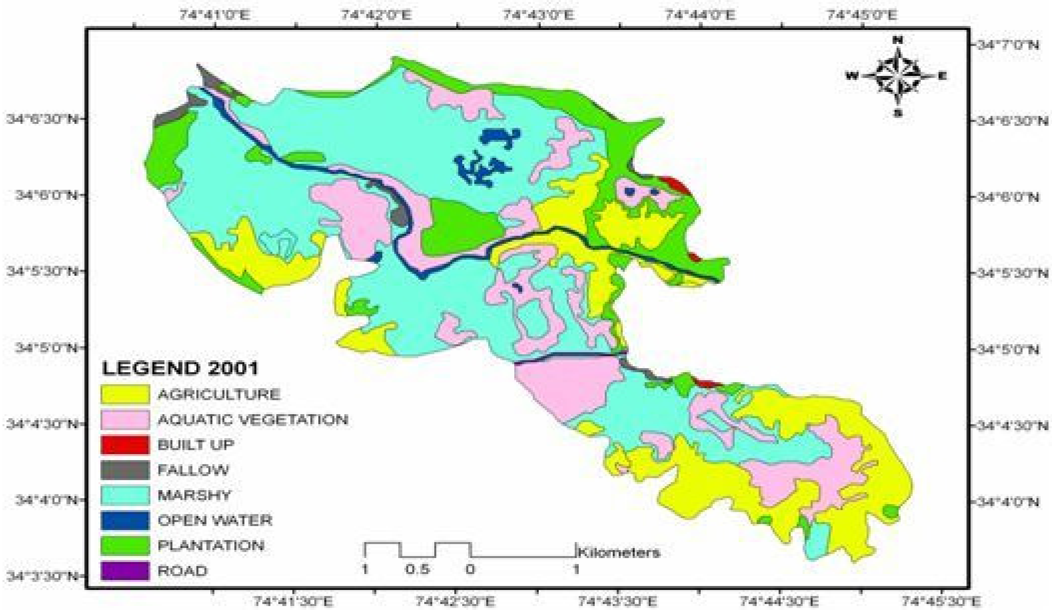

Figure 6. Land use and land cover of the Hokersar wetland generated from 2001 satellite image.

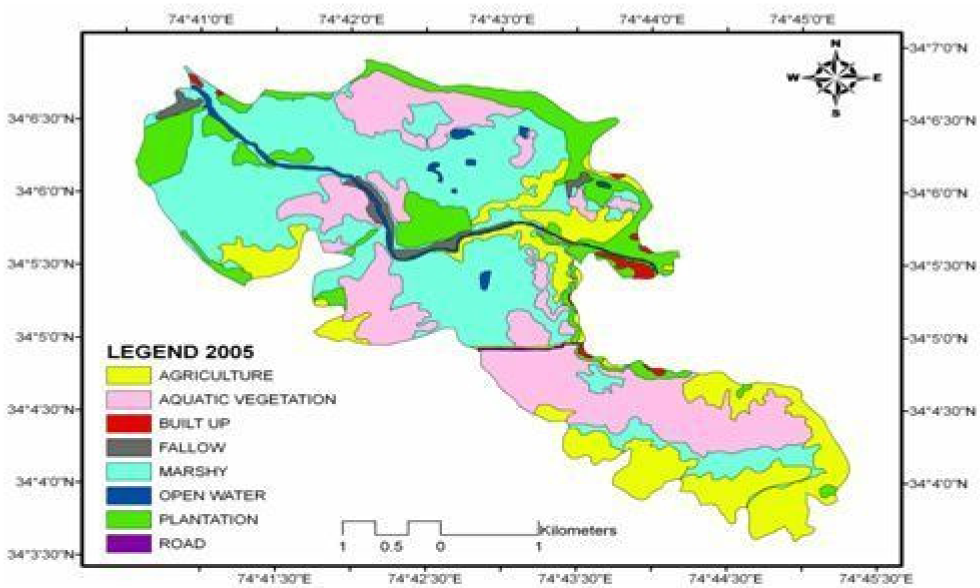

Figure 7. Distribution of the land use and land cover types of Hokersar mapped during the 2005.

area covered by different land use and land cover types in 1992 are given in Table 3. Figure 6 shows the spatial distribution of the land use and land cover data for the year 2001 mapped from the LANDSAT ETM data. All the eight land use and land cover types, mapped in 1992, are present in the wetland. From the analysis of the data in Table 3, we observe that Marshy lands are predominant in the wetland followed by Agriculture. The area under Built up has increased from 1.68 Ha in 1992 to 5.28 Ha in 2001. However, the open water body has shrunk by more than a half from 85.68 Ha to 43.69 Ha. The details of the areal coverage and proportion of different land use and land cover types found in 1992 are given in the Table 3.

The distribution of the land use and land cover types mapped during the 2005 is shown in the Figure 7. The areal estimates and the proportionate statistics are given in the Table 3. From the analysis of the data, it is observed that the area under the Aquatic vegetation has

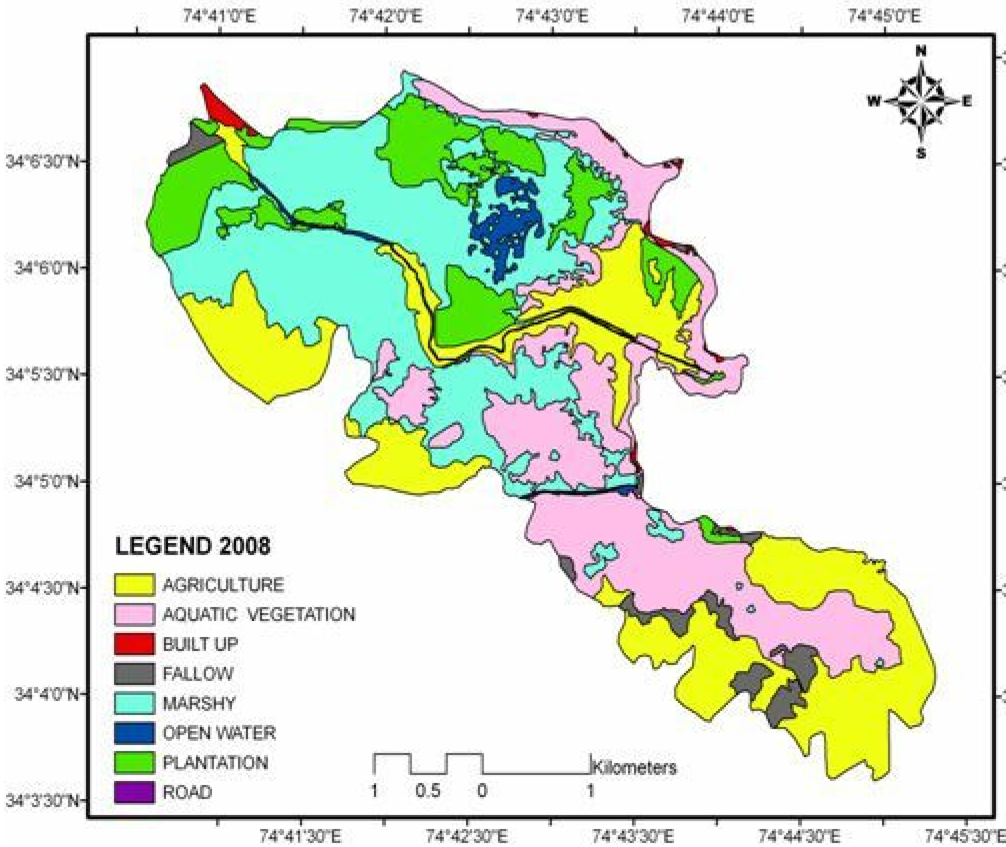

Figure 8. Distribution of the land use and land cover types of Hokersar delineated from 2008 IKONOS data.

significantly increased from 348.3 Ha in 2001 to 456.07 Ha in 2005. Similarly, the built-up is showing an increase. Marshy lands that have tremendous ecological importance for the migratory birds as they nest and breed in these areas, they are showing a decrease from 806.13 Ha to 727.06 during 2001 to 2005 period.

The land use and land cover information within the wetland for the year 2008 was generated from the IKONOS data. Figure 8 shows the areal distribution and Table 3 gives the areal estimates and the proportionate statistics for each of the land use and land cover types observed within the wetland. From the analysis of the data, it is observed that the areal estimates of the land use and land cover types derived from 2008 high resolution IKONOS data are not showing the consistent trend observed from 1969 to 2005 except for Marshy and aquatic vegetation categories. In fact, due to different image acquisition date of 2008 data, that is, January, when the water discharge is usually a bit higher than the autumn when it is at the minimum, there is increase in the water extent observed from the 2008 data. However, compared to the areal estimates of the dominant land cover types observed in 1969, there is sharp changes in the open water body, Marshy lands, Aquatic vegetation and Built up area observed in 2008.

Land use and land cover around the wetland

In order to analyze the causes of this deterioration and depletion of the Hokersar wetland, multi-temporal land use and land cover of the immediately surrounding of the wetland spread all along the periphery of the wetland covering 5 km on each side was determined using the same four date satellite data from 1992 to 2005. Seven land use and land cover classes were delineated from all the satellite data. Figure 9 shows the thematic map of the land use and land cover types of 1992. It is observed that Fallow was the dominant class covering 30.90% of the surrounding area. Marshy lands covered 14.29% of the area while as the area under built up was 10.44%. Table 4 shows the area under each of the seven land use and land cover classes. The land use and land cover map of 2001 is shown in Figure 10 while as the areal estimates under each of the seven land use and land cover types observed around the wetland are shown in Table 4. From the analysis of the thematic and the tabular data, it is observed that the area under Agriculture and Fallow, taken together, has marginally decreased between 1992 and 2001. Similarly the area under the aquatic vegetation has almost remained static. The areas under the open water and marshy lands have shown a significant decline.

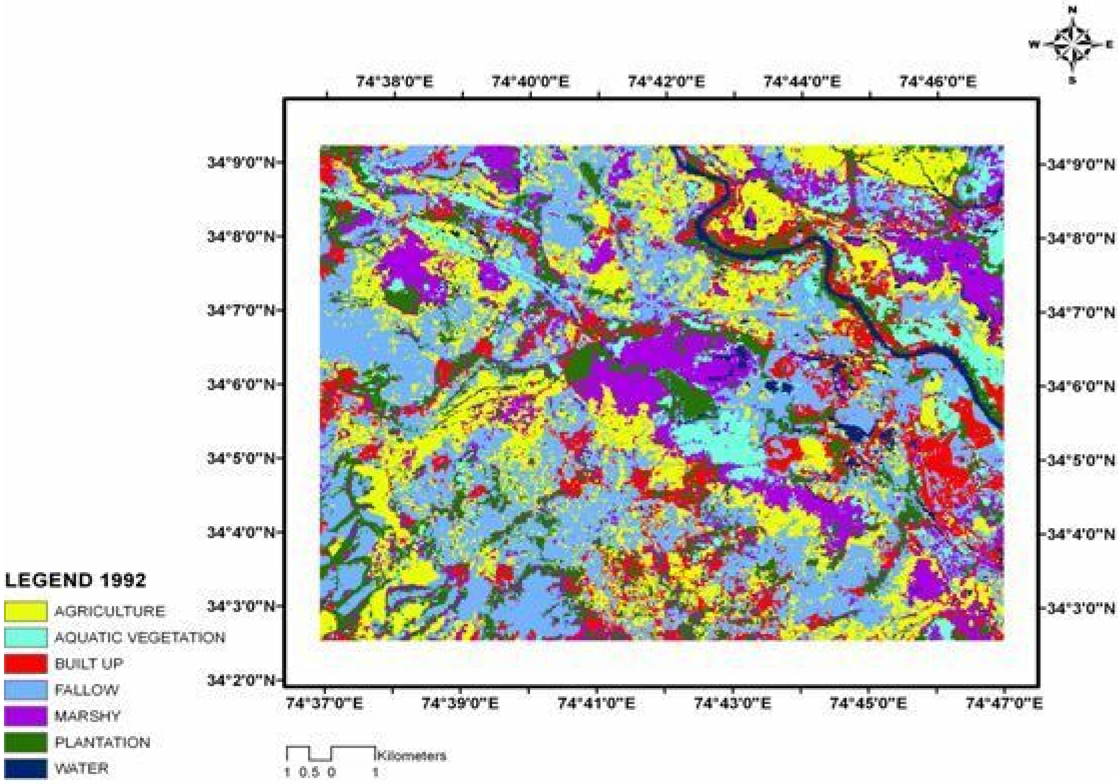

Figure 9. Thematic map of the land use and land cover types of 1992 (around Hokersar).

Table 4. Spatial distribution of land use and land cover classes around Hokersar wetland 1992 to 2005.

Land-use category	Area (Ha) 1992	% (1992)	Area (Ha) 2001	% (2001)	Area (Ha) 2005	% (2005)	Change (Ha) (1992-2005)	% Change (1992-2005)
Fallow	5924	30.90	3232	16.85	4956	25.85	-944	-5.50
Plantation	2438	12.71	3621	18.88	3726	19.43	1288	+6.72
Aquatic vegetation	1457	7.60	1361	7.10	2215	11.55	758	+3.95
Agriculture	4033	21.03	6215	32.47	3539	18.46	-494	-2.57
Built up	2002	10.44	2491	12.99	2870	14.97	868	+4.53
Water	577	3.00	261	1.36	322	1.67	-255	-1.33
Marshy	2740	14.29	1990	10.38	1543	8.04	-1197	-6.25

The built-up area has significantly increased from 2002Ha to 2491 Ha. Similarly, the land under plantations has shown marked increase in area.

Figure 11 shows the spatial distribution of the land use and land cover types delineated from the 2005 IRS LISS-III data. Table 4 gives the quantitative estimates of the area under different land use and land cover categories. From the analysis of the data, it is evident that the agriculture and fallow, taken together, show a decrease in areal extent. The area under built-up has increased to 2870 Ha. The Marshy land around the wetlands are showing decline. For areal estimates of the other land use and land cover categories (Table 4).

Hydrometeorological data analysis

A time series of the hydrometeorological data comprising of precipitation and river discharge data from 1979 to 2009 was analyzed to investigate if, there is any link between these two parameters and the declining water extent of the Hokersar wetland. The precipitation data shows a declining trend, even though week, as seen from the Figure 12(a) with r^2 of 0.15. Similarly the analysis of the time series of the discharge data of the Doodhganga tributary from 1970 to 2009, the main feeder tributary of the wetland, from at both the head and tail indicate decreasing tendency of the river discharge with r^2 of 0.26

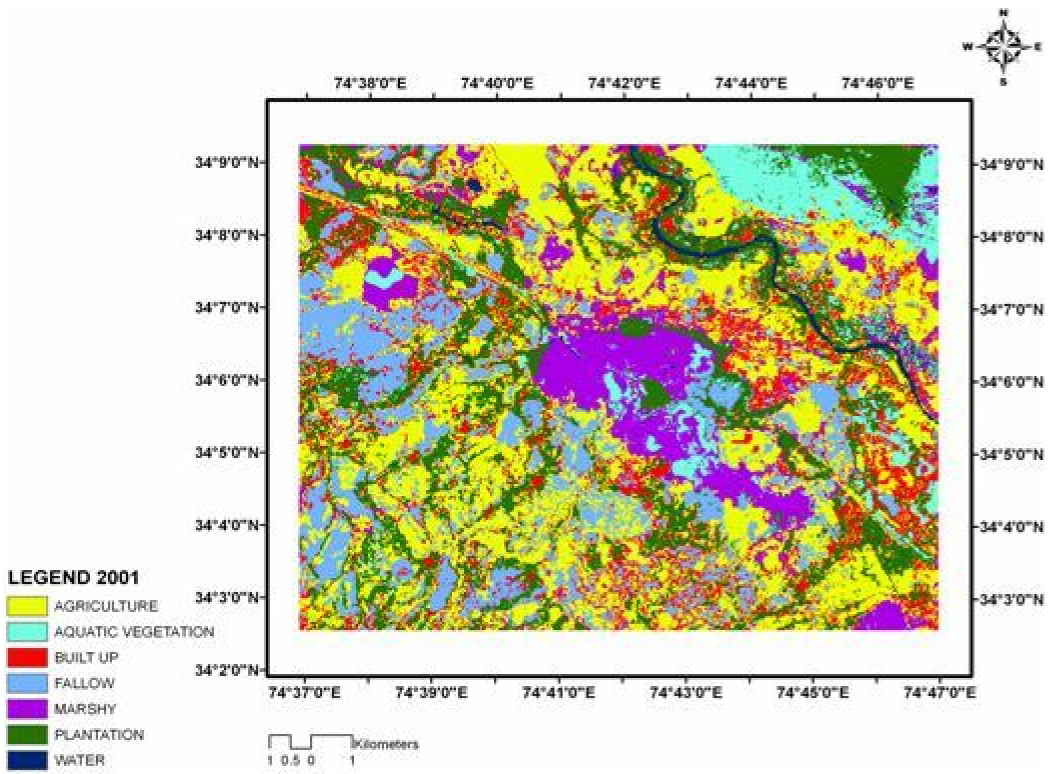

Figure 10. Land use and land cover map of 2001 (around Hokersar).

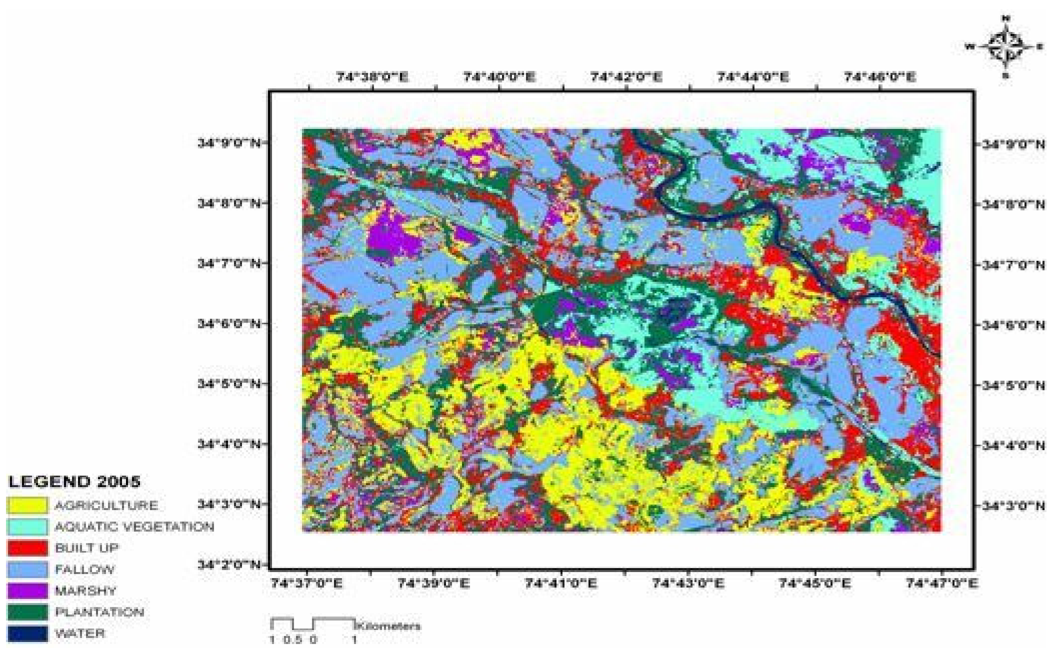

Figure 11. Spatial distribution of the LULC types delineated from the 2005 (around Hokersar).

and 0.15 respectively (Figure 12b and C). The decreasing extent of water spread and depth of the Hokersar could partly be attributed to the changing climate in the Himalayan region.

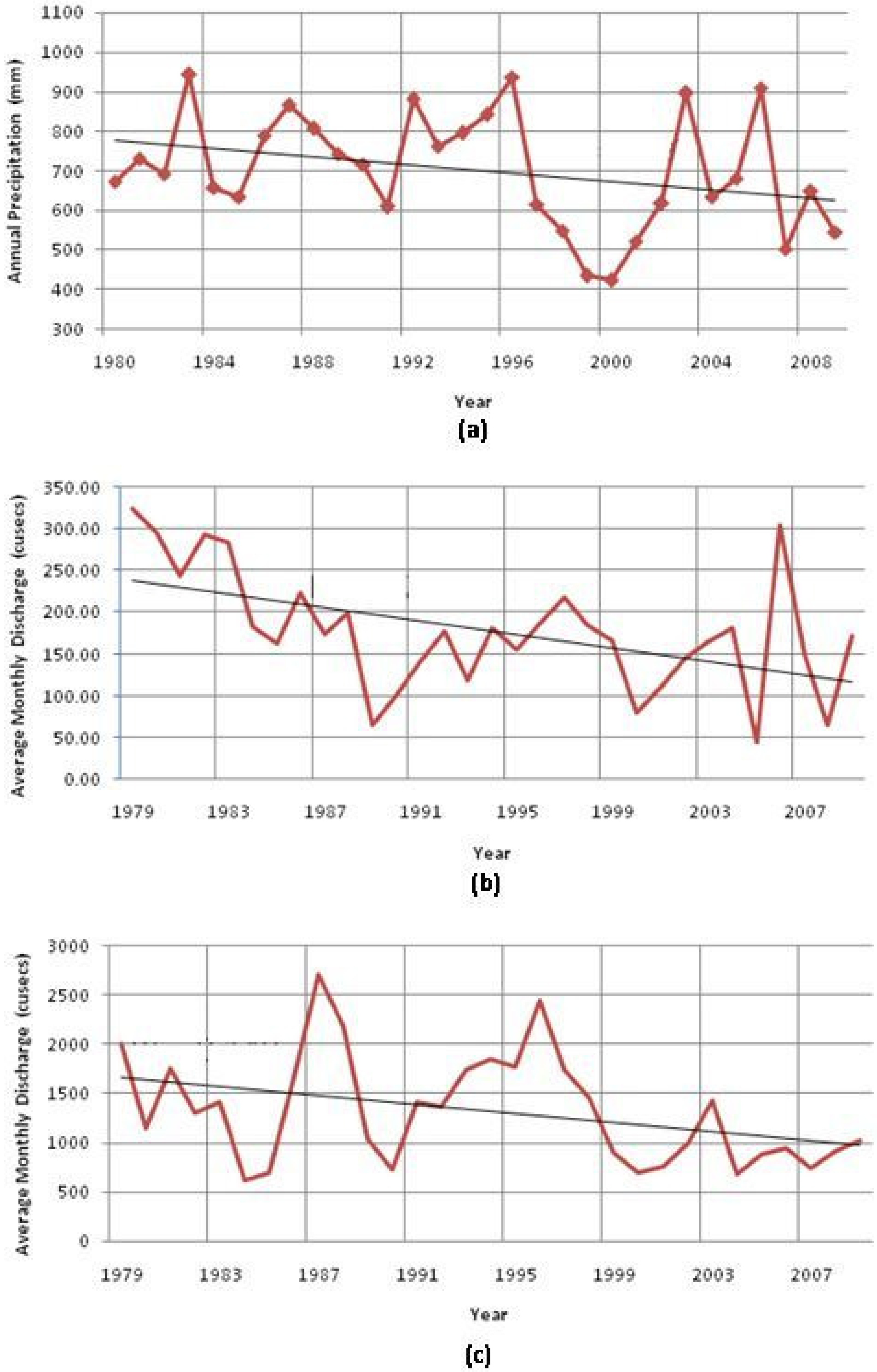

Figure12. (a) Precipitation data; (b, c) Time series of the discharge data of the Doodhganga tributary from 1970 to 2009 at both the head and tail.

DISCUSSIONS

From spatio-temporal analysis of the multi-source satellite and other thematic data, it was found that the wetland has receded consistently by 575.05 Ha from 1969 to 2008. The depletion in the wetland extent are mainly attributed to the encroachment by the farmers, increase in the settlements, conversion of wetland area into agriculture, plantation and built-up and climate change (Joshi et al., 2002; Kraiem, 2002). From the data, it is evident that the open water extent in the wetland has receded from 174.17 Ha in 1969 to 31.11 Ha in 2005. However, the 2008 high resolution IKONOS data shows an increase 5.47 Ha in the water extent w.r.t 2005 data, mainly due to its acquisition in winter when the discharge from the feeder stream higher compared to the autumn season when all other images used in the spatio-temporal analysis were acquired. Similarly, the Marshy lands that have tremendous ecological importance for the migratory birds as they serve as nesting and breeding grounds, have showed consistent decline from 1630.59 Ha in 1969 to 562.4 Ha in 2008. The Marshy land was the predominant land cover in 1969 covering more than 85% of the wetland area. The depletion of the Marshy lands within the wetland has adversely affected the breeding patterns of the migratory birds. The emergence of the built-up areas within the wetland and its immediate surroundings has also been responsible for the destruction of the wetland ecology and functionality. The built up that was non-existent within the wetland in 1969, has emerged and has colonized almost 11 Ha of the wetland in 2008. Due to these encroachments and human settlements, the agriculture and olericulture activity has got a boost within the wetland boundary and large areas of the wetland, spread over an area of 540 Ha, have come under agriculture/fallow since 1969. All these anthropogenic influences within the wetland have accelerated the deterioration of the wetland structure and functions. There are umpteen studies that have demonstrated the adverse impacts of the human influences on the wetlands all over the world (Khan 2010; UNEP 2007)

From the spatial and temporal analysis of the land use and land cover in the vicinity, it is observed that there have been significant changes from 1992 to 2005. There is marked increase in the built-up, aquatic vegetation and plantations while as the area under agriculture, fallow, Marshy land and water resources has decreased. These changes observed in the wetland surroundings, that form a part of its catchment, have adverse impacts on the wetland ecology and hydrology. The impacts of these changes are reflected in the form of changes in the Marshy and aquatic vegetation within the wetland. The changes in the composition and distribution of Marshy land and aquatic vegetation are showing adverse impacts on the migratory birds, hydrobiology and hydrochemistry of the wetland (DEARS, 2001; Pandit and Kumar, 2006).

Further, the symptoms of the wetland deterioration are attributed to the reckless use of fertilizers and pesticides for agriculture and horticulture in the catchment, which ultimately find their way into wetland through Doodhganga River. This fact has been substantiated by the physico-chemical characteristics of the wetland as reported by Pandit and Kumar (2006). The analysis shows an increase for nitrate and ammonical nitrogen from 1978 to 2002. This nutrient enrichment boosts the growth of aquatic vegetation found in the wetland like *Myriophyllum verticillatum*, *Trapa natans*, *Typha augustata* and *Phramites australis* (Dar et al., 2002). Various changes have been observed in the composition and distribution of the aquatic vegetation of the wetland. Some macrophytes like *Nelumbium nuciefera*, *Euryale ferox* and *Acorus calamus* have disappeared and some new species have been observed like *Menynanthese trifoliate* (Kaul and Zutshi, 1967). The main reason for the disappearance of these macrophytes is attributed to the increase of silt load to the wetland brought by Doodhganga Nallah. An increase in the number of macrophytic species from 24 (Pandit, 1980) to 46 (Pandit and Kumar, 2006) has been reported. A possible reason for this may be the improvement in the flood situation following dry weather conditions leading mostly to summer draw-down during the recent years (Pandit and Kumar, 2006). As a result of this increased aquatic vegetation, a drop in the oxygen content has been observed causing eutrophication which has direct effects on aquatic fauna like fishes.

The declining trend observed from the time series analysis of the precipitation and discharge data of the Doodhganga means that the reduction of the water inflow to the wetland, as a consequence of climate change, is partly responsible for the reduction in the depth and spread of the water level of the wetland. The drastic reduction in the area of Marshy lands, the water depth and the water spread, have changed the ecological conditions within the lake and thus, adversely affected the arrival of migratory birds, as less number of water fowl has been reported since the past few years.

Conclusions

Various land use and land cover changes in and around the Hokersar wetland, that has tremendous ecological and socio-economic importance, depicts the way we are treating our wetland ecosystems. The water quality of the wetland has deteriorated and changes in the vegetation composition and distribution have been very significant affecting the biodiversity of the wetland. The wetland depletion has serious implications not only on our flora and fauna but also on livelihood of the people dependent on the service and goods provided by the wetland. In addition, the wetland has, since long, served an important reservoir of flood waters during the peak discharge of the Jhelum, the main tributary of the upper Indus basin. The depletion and degradation of this wetland shall have adverse impacts on the efficacy of the wetland 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 habitat of the millions of the migratory birds from Siberia and Central Asia has affected the arrival of these birds as noticed by their less numbers in the recent years.

From the analysis and discussion of the results, it is thus concluded that the main reasons for the deterioration of the Hokersar wetland are increase in the nutrient and silt load from the catchment due to deforestation and reckless use of pesticides and fertilizers, encroachment, unplanned urbanization in the vicinity of the wetland. The decreasing precipitation and discharge due to changing climate in the region is also partly contributing to the decreasing water extent and depth of the Hokersar wetland. It is suggested that an appropriate mechanism is established for continuous monitoring of the wetland for its land cover, hydrochemistry, biodiversity and wetland hydrology so that a robust strategy and action plan is developed for the conservation and restoration of this important wetland, commonly called Queen of wetland in Kashmir Himalayas.

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