GIS Project

Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan.

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Introduction:

Changes in land use can be categorized by the complex interaction of structural and behavioral factors associated with technological capacity, demand, and social relations that affect both environmental capacity and the demand, along with the nature of the environment of interest (Verburg et al., 2004).Ecologists pay considerable attention to the land use change impacts predominantly with respect to its effects on biodiversity and aquatic ecosystems (Turner et al., 2001). Changes in the land use in a watershed can affect water quality and supply. For instance, land use patterns change due to watershed development frequently resulting in increased surface runoff, reduced groundwater recharge and transfer of pollutants (Turner et al., 2001). Thus, the assessment of land use patterns and their changes at the watershed level is crucial to planning and management of water resources and land use of the particular watershed.

Analysis of detected change is the measure of the distinct data framework and thematic change information that can lead to more tangible discernment to underlying process involved in upbringing of land cover and land use changes (Ahmad, 2012). Change analysis of features of Earth's surface is essential for better understanding of interactions and relationships between human activities and natural phenomena. This understanding is necessary for improved resource management and improved decision making (Lu et al., 2004; Seif and Mokarram, 2012). Change detection involves applying multi-temporal Remote Sensing information to analyze the historical effects of an occurrence quantitatively and thus helps in determining the changes associated with land cover and land use properties with reference to the multi-temporal datasets (Ahmad, 2012; Seif and Mokarram, 2012; Zoran, 2006).

Various studies have been conducted all over the world regarding the change analysis of watersheds through different methods. They are important to develop effective management strategies for watersheds worldwide (Ashraf, 2013; Bazgeera et al., 2008; Caruso et al., 2005; Dietzel et al., 2005; Fortin et al., 2003; Gajbhiye and Sharma, 2012; Hu et al., 2012; Kearns et al., 2005; Parker and Meretsky, 2004; Stewart et al., 2004; Wang et al., 2004). Watershed management is necessary because a watershed is not merely a hydrological unit (Singh et al., 2014) but also socio-ecological being which plays a vital role in determining economical, food and social security and provision of life support services to local residents (Wani et al., 2008). Changes in land cover/land use in watershed area including urbanization and de(/re)forestation continuously affect the water availability as well as the nature and extent of surface and subsurface water interactions thus influencing watershed ecosystems and the services provided by them. With proper understanding of the spatial and temporal variations occurring in a watershed over time and the interaction of the hydrological components of a watershed with each other, better water conservation strategies can be formulated (Ashraf, 2013).

Remote Sensing (RS) has been used to classify and map land cover and land use changes with different techniques and data sets. Landsat images in particular have served a great deal in the classification of different landscape components at a larger scale (Ozesmi and Bauer, 2002).

Recently several change detection techniques have been developed that make use of remotely sensed images. A variety of change detection techniques and algorithms have been developed and reviewednfor their advantages and disadvantages. Among these Unsupervised classification or clustering, Supervised classification, PCA, Hybrid classification and Fuzzy classification are the most commonly applied techniques used in classification (Lu et al., 2004; Rundquist et al., 2001; Zhang et al., 2000).

A variety of supervised classification methods have been applied extensively for the land use change analysis throughout the world. This technique depends on a combination of background knowledge and personal experience with the study area to a greater extent than other areas. Thus per-pixel signatures are taken and stored in signature files by using this knowledge and the raw digital numbers (DN) of each pixel in the scene are therefore converted to radiance values (Jensen, 2005; SCGE, 2011). Similar technique was used to detect changes observed in a nearby watershed (Rawal watershed, Islamabad, Pakistan) and achieved up to 95% accurate results (Butt et al., 2015). Several other researchers have employed the same technique and achieved highly satisfactory results including Rawat and Kumar (2015), who applied the same technique to monitor land use/land cover change in Hawalbagh block, district Almora, Uttarakhand, India. Boori et al. (2015) analyzed the land use/land cover disturbance caused by tourism using a number of Remote Sensing and GIS based techniques including supervised classification. Rawat et al. (2013) also applied the same technique for Ramnagar town area, Uttarakhand, India to track the changes observed in the area between the time period of 1990 and 2010.

Problem Statement:

The study area was selected for change detection because of being subjected to urbanization, sewage discharges without treatment, active water and soil erosion, over grazing, cutting of trees, non-existence of any cooperative communal structure and reduced livelihood opportunities. Along with these, rapid discharge of pesticide residues and poultry discharge in the streams is also one of the major concerns faced by the Simly watershed due to the rapidly increasing agricultural activities and number of poultry farms in the study area (IUCN, 2005; Mangrio et al., 2011). The rapid urban development taking place in the study area has led to environmental problems as well, encompassing, fragmentation of aquatic habitats, soil erosion, and water pollution due to deforestation and discharge of municipal garbage and industrial waste (Hagler Bailly, 2007; Tanvir et al., 2006).

Objectives:

The main objective of the present research was to utilize GIS and Remote Sensing applications to discern the extent of changes occurred in Simly watershed, Islamabad, Pakistan over 20 years' time period. However the specific objectives included (i) to identify and delineate different LULC categories and pattern of land use change in watershed from 1992 to 2012 (ii) to examine the potential of integrating GIS with RS in studying the spatial distribution of different LULC changes (iii) to determine the shift in LULC categories through spatial comparison of the LULC maps produced.

Methodology:

Study area:

Situated in Pothwar Plateau, the study area is geologically composed of Tertiary sandstone, limestone and alluvial deposits. These sandstones apparently belong to the Sirmar and Siwalik series of the sub Himalayan system. Climate of the area is humid subtropical. May, June, and July are the warmest months with average temperature ranging from 36 °C to 42 °C with extremes sometimes as high as 48°C . While the coldest months are December and January, with mean minimum temperatures ranging from 3°C to 5.5 °C. Simly watershed starts at Simly lake which is around 40 km north-east of Islamabad (at latitude 33°43' N and longitude 73°90' E), near Bhara Kahu. It stores the perennial water flow from Murree springs/Patriata mountain aquifer and a substantial amount of flood water of the Soan River. It is the largest drinking water reservoir for the residents of Islamabad and is recognized mostly as Simly Dam. Two main streams feed the Simly Dam catchment namely the Soan Nullah and the Khad Nullah. The area surrounding the Dam has esthetic value and attracts tourists by the beautifully planted ornamental trees, resort, and picnic points (Daaira, 2012; Groupin, 2011; Hagler Bailly, 2007; IUCN, 2005). The map of the study area is shown in Fig. 1.

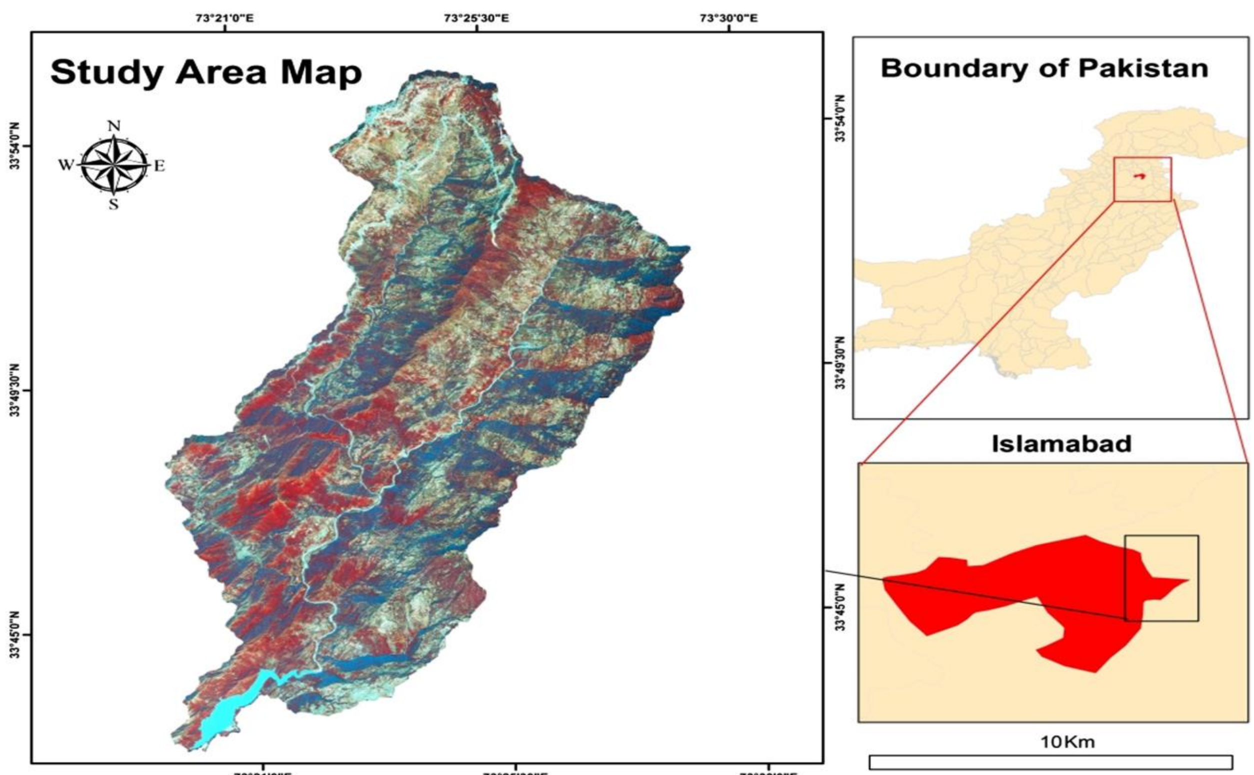

Figure 1 Study area map showing Simly watershed

Data collection:

The data used in this research were divided into satellite data and ancillary data. Ancillary data included ground truth data for the land cover/use classes, aerial imagery of watershed and its surrounding area, topographic maps. The ground truth data were in the form of reference data points collected using Geographical Positioning System (GPS) from March to October 2012 for 2012 image analysis, used for image classification and overall accuracy assessment of the classification results. Satellite data for 2 years on the other hand consisted of multi-spectral data acquired by Landsat satellite for the month of September provided by USGS glovis. Specifications of the satellite data acquired for change analysis are given in Table 1.

Table 1 Satellite data specifications.

Data	Year of acquisition	Bands/color	Resolution (m)	Source
Landsat 5 TM imagery	1992	Multi-spectral	250	USGS glovis
SPOT imagery	2012	Multi-spectral	2.5	SUPARCO

Image pre-processing and classification:

Satellite image re-processing prior to the detection of change is immensely needed and has a primary unique objective of establishing a more direct affiliation between the acquired data and biophysical phenomena (Coppin et al., 2004). Data were preprocessed in ERDAS imagine 12 for geo-referencing, mosaicking and subsetting of the image on the basis of Area of Interest (AOI). All satellite data were studied by assigning per-pixel signatures and differentiating the watershed into five classes on the bases of the specific Digital Number (DN) value of different landscape elements. The delineated classes were Agriculture, Bare soil/rocks, Settlements, Vegetation and Water class (Table 2). For each of the predetermined land cover/use type, training samples were selected by delimiting polygons around representative sites. Spectral signatures for the respective land cover types derived from the satellite imagery were recorded by using the pixels enclosed by these polygons. A satisfactory spectral signature is the one ensuring that there is 'minimal confusion' among the land covers to be mapped (Gao and Liu, 2010). After that maximum likelihood algorithm was used for supervised classification of the images. It is the type of image classification which is mainly controlled by the analyst as the analyst selects the pixels that are representative of the desired classes.

To improve classification accuracy and reduction of misclassifications, post-classification refinement was therefore used for simplicity and effectiveness of the method (Harris and Ventura, 1995). Moreover, using data having mediumspatial resolution such as that of Landsat mixed pixels are a common problem (Lu and Weng, 2005); especially for the urban surfaces that are a heterogeneous mixture of features mainly including buildings, grass, roads, soil, trees, water (Jensen and Im, 2007). The problem of mixed pixels was addressed by visual interpretation. For the enhancement of classification accuracy and therefore the quality of the land cover/land use maps produced, visual interpretation was very important. Thus, visual analysis, reference data, as well as local knowledge, considerably improved the results obtained using the supervised algorithm.

Accuracy assessment:

Assessment of classification accuracy of 1992 and 2012 images was carried out to determine the quality of information derived from the data. If the classification data are to be useful in detection of change analysis, it is essential to perform accuracy assessment for individual classification (Owojori and Xie, 2005). For the accuracy assessment of land cover maps extracted from satellite images, stratified random method was used to represent different land cover classes of the area. The accuracy assessment was carried out using 100 points, based on ground truth data and visual interpretation. The comparison of reference data and classification results was carried out statistically using error matrices. In addition, a nonparametric Kappa test was also performed to measure the extent of classification accuracy as it not only accounts for diagonal elements but for all the elements in the confusion matrix (Rosenfield and Fitzpatirck-Lins, 1986). Kappa is a measure of agreement between predefined producer ratings and user assigned ratings. It is calculated by a formula (Eq. (1)):

$$|K = P(A) - P(E)/1 - P(E) \qquad (1)$$

Where P(A) is the number of times the k raters agree, and P(E) is the number of times the k raters are expected to agree only by chance (Gwet, 2002; Viera and Garrett, 2005).

Land use/cover change detection:

Post-classification change detection technique, performed in ArcGIS 10 was employed by the study. Post classification has been successfully used by various researchers in urban environment due to its efficiency in detecting the location, nature and rate of changes (Hardin et al., 2007). Another technique used to obtain the changes in land cover/land use during the specified time period was overlay procedure. A two-way cross-matrix was obtained by the application of this procedure and was used to describe the main types of change in the study area. In order to determine the quantity of conversions from a particular land cover to other land cover category and their corresponding area over the evaluated period, cross tabulation analysis on a pixel-by-pixel basis was conducted. Thus, a new thematic layer was also produced from the two five-class maps, containing different combinations of ‘‘from– to’’ change classes.

Analysis, Discussion and Results:

The classified LULC map of Simly watershed of years 1992 and 2012 is given in Fig. 2. The achieved overall classification accuracies were 95.32% and 95.13% and overall kappa statistics were 0.9237 and 0.9070 respectively for the classification of 1992 and 2012 images. According to Lea and Curtis (2010), accuracy assessment reporting requires the overall classification accuracy above 90% and kappa statistics above 0.9 which were successfully achieved in the present research.

The classification results for 1992 and 2012 are summarized in Table 3. Percentage of classes based on these results show the land cover/land use practices observed in watershed area during 1992 and 2012.

Table 3 Land cover/land use classes and areas in hectares.

Land cover/use classes	1992		2012	
	Area (ha)	%	Area (ha)	%
Agriculture	1775	11	4681	29
Bare soil/rocks	1648	10	2691	16
Settlements	1038	6	1870	11
Vegetation	11,342	69	7008	43
Water	603	4	155	1

The results show that major decline with respect to area coverage in Simly watershed was observed in Vegetation and Water classes whereas, the area of Settlements, Bare soil/rocks and Agriculture classes was increased. Vegetation land shrank from 69% to 43% of the total area while Water class, which was least area covering class in 1992, further lost area under its cover and reduced from 4% to 1%. The share of Settlements was 6% of the total area which increased up to 11%. The Agriculture class was increased from a share of 11% to 29% and the Bare soil/rocks faced an increment in the total share from 10% to 16%.

The comparison of each class of 1992 and 2012 showed that there has been a marked land use and land cover change during the study period of 20 years. During the 1992–2012 period the percentage area covered by Agriculture class in watershed increased by 163.7%. This increasing trend of land cover/land use change in the watershed's area reinforces that economic forces are commonly a major stimulus on anthropogenic change of land (Wang et al., 2008) and it is the main reason why the area near and around the main water-bodies and streams in the watershed has shifted from other land covers to Agriculture cover. At start the overall agricultural production and expansion were only subjected to peripheral lands on steep slopes until biophysical limitations like steep slopes and thin fertile topsoil limited further expansion and Agriculture land was pushed into formerly wooded areas. It has also been observed in watershed that the Settlements or Built up areas are mostly surrounded by Agricultural area, especially in the catchment area and by the main streams. It means the area near the population has been cleared for the production of crops in order to fulfill the basic necessities of life (Hagler Bailly, 2007).

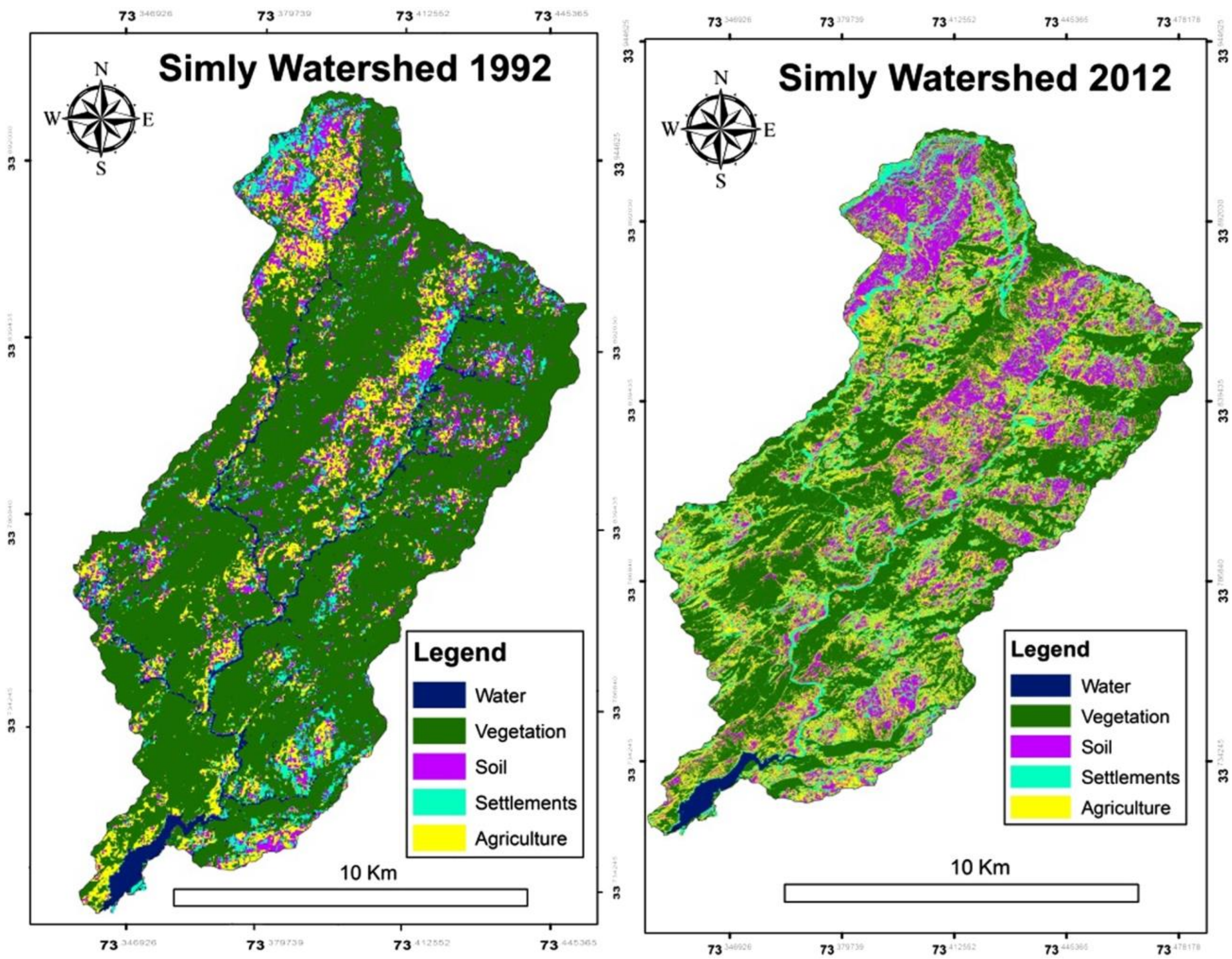

Figure 2 Classified maps of Simly watershed (1992 and 2012).

The second class which faced an increment in the total area was Bare soil/rocks with 63.3% increase in the overall area during the study period. This increase in the bare soil area was due to rapid deforestation in the area which removed the Vegetation cover from the land and rendered it barren and exposed. The losses of soil from these practices thus ensued less productive lands which were ultimately abandoned by farmers for crop production due to economic inefficiency, resulting in a large increase in barren land area. Similar trends have been observed in the study of District Swat conducted by Qasim et al. (2011). Classification results supported the above mentioned facts that Vegetation area decreased over the past 20 years by 38.2% from 1992 to 2012. Vegetation in the study area mainly includes lower vegetation, Patriata forest, rangelands, conifer forest and dry semi evergreen forest. A complete checklist of climbers, wild trees and shrubs in the study area was prepared by Nasir and Akhtar (1987). This class was also replaced by Settlements and Agriculture class. In addition to deforestation, cutting of fuel wood by the local communities and extensive cattle grazing have deformed the plants present in the area to small bushes and in some areas have left only barren lands (Arfan, 2008; Shafiq et al., 1997). Ali et al. (2008) reported that if the built up area in and around Rawalpindi and Islamabad continued to increase at a rapid rate as observed now, it would result in increased surface runoff and a significant decrease in forest and arable land. According to IUCN (2005) and Tanvir et al. (2006) the major accelerators of forest decline in the watershed's area are the human activities like illegal forest wood cutting due to high market value and also the rigorous use of forest wood for fulfilling household requirements like cooking and heating and also for timber production. In addition to these, ineffective management of forests and forest disease also play an important role in forest decline.

According to the information revealed by classification results, the Settlements or built up area showed 80.1% increase from 1992 to 2012. Reasons were a number of new housing schemes, farmhouses and recreational pursuits that have been developed in and around area in the past 20 years. Along with these developments, there is an incline toward the construction of new pavements, highways, roads and other structures to access these areas. Another developmental activity in the Simly watershed area is ''New Murree''. NESPAK (2004) reported that it will spread over Patriata forest and the proposed plan would remove 5–8% of the trees present in the area. This would affect the snow melt and rain fall driven surface runoff. However, a study conducted on Zone IV of Islamabad by Adeel (2010) concluded that Settlements or built up areas located near Simly dam have a very little further future development potential due mainly to the steep topography and relatively poor approachability to the area.

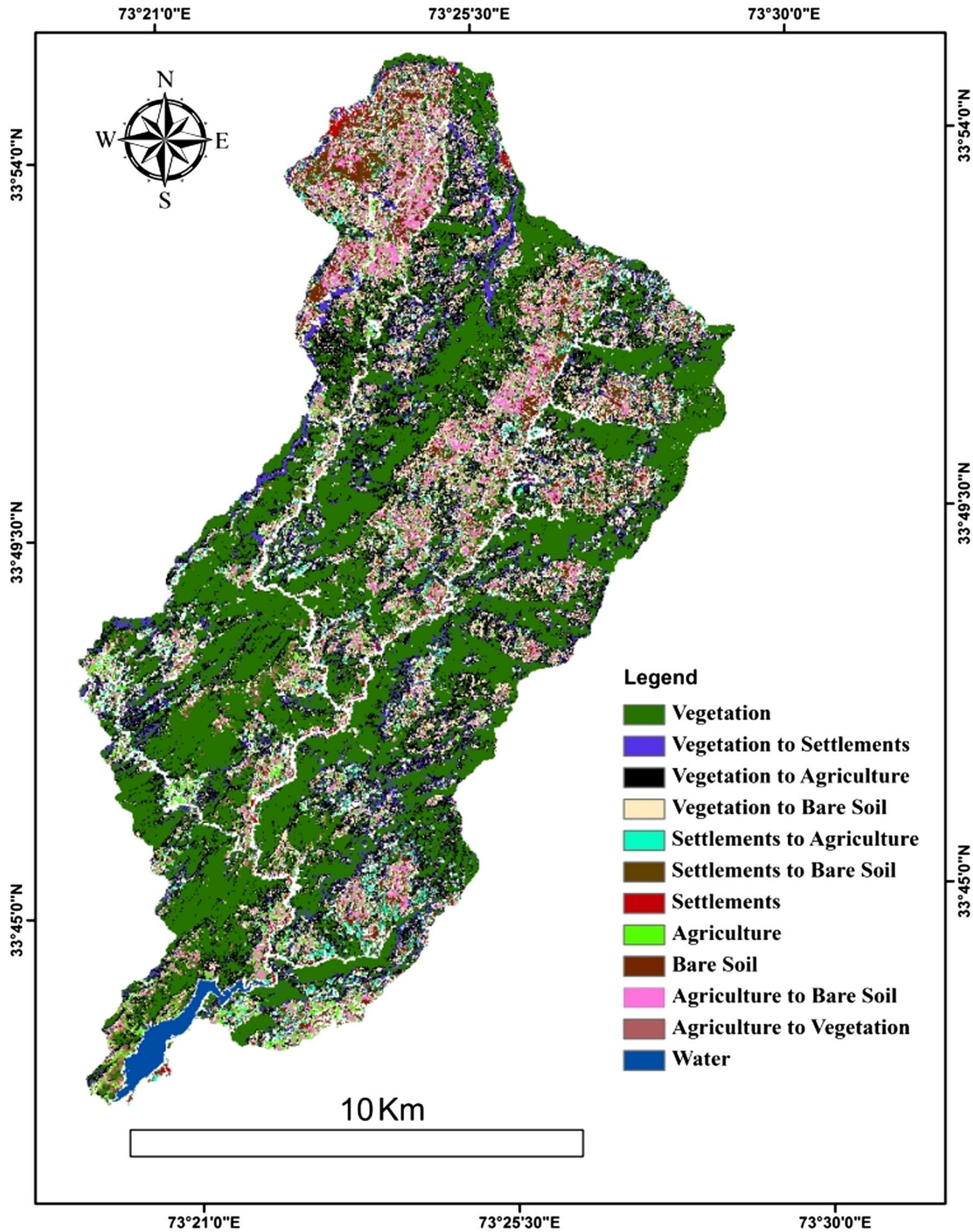

Figure 3 Major land use conversion in Simly watershed from 1992 to 2012.

The area covered by Water class has also witnessed a decrease from 1992 to 2012. The percentage decrease in land area covered by this class was 74.3%. The land cover/land use changes observed in all other classes affected the Water class during two decades. Easy accessibility of water resulted in the depletion of water and ended in dried up tributaries and its replacement by either compact surfaces or barren land. Another reason for the shrinkage was an increased rate of surface runoff due to lack of plant roots to withhold the water. As the runoff exceeded recharge capacity of ground water it resulted in the lowering of water table. Increased deforestation rate also contributed to the increase in surface runoff and is responsible for down flow of nutrients and sediments (Ali et al., 2008; Hagler Bailly, 2007; Mendoza et al., 2011).

Table 4 Cross-tabulation of land cover classes between 1992 and 2012 (area in ha).

		1992					
		Agriculture	Bare soil/rocks	Settlements	Vegetation	Water	Total
2012	Agriculture	560	562	378	3047	134	4681
	Bare soil/rocks	748	622	278	1021	22	2691
	Settlements	212	283	245	982	148	1870
	Vegetation	253	180	133	6286	155	7008
	Water	2	0.3	4	5	144	155.3
	Total	1775	1648	1038	11,342	603	16405.3

Moreover, the change in the total area of Simly lake was also observed. Classification indicates that the lake covered 148 ha area in 1992 constituting about 0.9% of the total area of watershed and this area was reduced to 139 ha in 2012 covering 0.8% of the total area of Simly watershed. Thus, approximately 6% of the lake area diminished in 20 years.

Simly dam is one of the three major sources supplying water to Islamabad and Rawalpindi. It not only supplies water to ever increasing population of twin cities but also supplies it for irrigation purposes. Along with the loss due to agriculture and urbanization demands, evaporation, seepage and percolation are also leading causes of quantitative decline of water in the reservoir (Ashraf et al., 2007; Hagler Bailly, 2007; Keller et al., 2000). Rapid expansion of urbanization and agriculture practices not only depletes the water quantitatively but also plays a leading role in polluting the water (IUCN, 2005). The extensive use of herbicides and pesticides in agriculture is a toxic pollution source. Increase in the agricultural land use and nutrient losses associated with it, are the chief driver of water quality degradation and inherently increase the vulnerability of water that transports these nutrients. Researchers conducted on Simly Lake by Ahad et al. (2005) and Iram et al. (2009) concluded that the pesticide residues present in the lake exceed the European Union (EU) standards.

Similarly a developmental activity, ‘‘New Murree Project’’, spread over Patriata forest, which was envisioned to be a tourist city of international standards by NESPAK (2004) has no facilities for waste management in and around the planned locality of New Murree. Thus, the generated waste by the local inhabitants and tourists is dumped on the slopes in the Patriata area and as share of the runoff from Patriata ridge comes to Simly Dam and pollutes dam’s water. Thus the sewage waste along with the pesticide and fertilizer residues viz., Nitrates and Phosphates flow into the main streams and ultimately ends up in the main water body and cause an increase in algal bloom. These causes of water pollution are verified by Gliessman (2006).

GIS was used for the post-classification comparison of the detected change, producing change map for comprehending the spatial pattern of change between years (Fig. 3). The two classified maps were overlaid to produce the land use and land cover change map, in addition to the cross tabulation matrix between the two dates. The cross-tabulation matrices (Table 4) show the nature of change of different land cover classes or in other words the shift in the land cover classes. Out of the 1775 ha that was Agriculture area in 1992, 560 ha was still Agriculture area in 2012 but 748 ha was converted to Bare soil/rocks, and rest to Vegetation and Settlements. At the same time the increase of Agriculture, from 1992 to 2012, was mainly from Vegetation (3047 ha). Vegetation out of 11,342 ha in 1992 lost area mainly to Agriculture as mentioned before, Bare soil/rocks, Settlements and retained 6286 ha of total in 2012. Settlements increased from 1038 ha in 1992 to 1870 ha in 2012. It retained 245 ha of it and was mainly replaced by Agriculture and Bare soil/rocks. The class which Settlements mainly replaced in 2012 was Vegetation (982 ha) (Table 4). Water class retained only 144 ha of the total 603 ha in 1992. It was reduced to 155 ha and mainly replaced by Vegetation, Settlements and Agriculture in 2012 (Table 4). The area of other land cover classes replaced by water was small.

This study elucidates the significance of incorporating Remote Sensing and GIS for change detection study of land cover/land use of an area as it offers crucial information about the spatial distribution as well as nature of land cover changes. Overall 95% accuracy of the land use/land cover maps indicates that the integration of supervised classification of satellite imagery with visual interpretation is an effective method for the documentation of changes in land use and cover of an area.

Conclusion:

Based on the results obtained by employment of GIS and RS applications to achieve the specific research objectives, it is concluded that the land cover/land use practices in the study area have altered significantly in 20 years. The LULC shift in the watershed area was evident by the decline in the area of Vegetation and Water class (38.2% and 74.3% respectively) and augmentation of area covered by classes of Settlements (80.1%), Agriculture (163.7%) and barren land (63.3%). The haphazard expansion of Settlement and Agriculture area in the watershed was mainly due to lack of proper management and land use planning since no EIA report is generated prior to land development in the study area. The major impact of this expansion was subjected on Vegetation and Water class to deforestation and water depletion respectively. Additionally, all these alterations in the land cover and land use patterns adversely affected water quality and accessibility by 2012 which may prove a limiting factor in the future for both urban growth and agriculture practice and May also is responsible for further loss of already shrinking Vegetation cover in the watershed areas. Hence, proper management of these water resources is required because without proper management, this valuable water resource will soon be lost or will no longer be able to play its required role in agriculture production and socio-economic development of the area. Having said all that, there are several recommendations based upon the conclusion of the present study for the proper management and conservation of the forest, water and soil resources subjected to decline in the watershed.

- An effective water management practice could be breaking down major river basin into sub-watersheds and prioritizing the sub-watershed for conservation and management based on degradation level so as to conserve and minimize the human induced impacts faced by it.
- Tree planting should be promoted by the Government officials and they must collaborate with non-governmental organizations.
- Another step forward in protecting and restoring the forest would be providing incentives to the local people for guarding the new plantations.
- Government should take appropriate steps to restore the degraded lands specially degraded soil, water and forest lands and their further degradation must be prevented.
- Proper land use planning should be done for the watershed prior to any developmental project being conducted in the area and must be preceded by a proper Environmental Impact Assessment (EIA).