MONITORING DEFORESTATION AND URBANIZATION GROWTH IN RAWAL WATERSHED AREA USING REMOTE SENSING AND GIS TECHNIQUES

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ABSTRACT

The Rawal watershed in Pothwar region of Pakistan has undergone significant changes in its environmental conditions and landuse activities due to numerous socio-economic and natural factors. These ultimately influence the livelihood of the inhabitants of the area. The connected environmental changes are resulting in accelerated land degradation, deforestation, and landslides. In the present study, spatio-temporal behaviour of landuse/landcover in the Rawal watershed area was investigated using Remote Sensing (RS) and Geographical Information System (GIS) techniques. Satellite image data of LANDSAT ETM+ of 1992, 2000 and 2010 periods were processed and analyzed for detecting landuse change and identifying risk prone locations in the watershed area.

The study results revealed significant changes in the coverage of conifer forest (34 % decrease), scrub forest (29 % decrease) and settlement (231 % increase) during the decade 1992-2010. The rate of decline in conifer class is about 19 ha/annum while that of scrub class is 223 ha/annum. In both the cases, the rates of decrease were higher during the period 1992-2000 than the period 2000-2010. The Agriculture land has shown an increase of about 1.8 % while built-up land had increased almost four folds, i.e. from 2.6 % in 1992 to 8.7 % in 2010. The growth in urbanization may result in further loss of forest cover in the watershed area.

The findings of the study could help in developing effective strategies for future resource management and conservation, as well as for controlling land degradation in the watershed area.

Keywords: *Deforestation, Urbanization, Rawal Watershed Area, Remote Sensing, Geographical Information System (GIS).*

1. INTRODUCTION

The forest and agricultural lands are a vital resource of Pakistan, which is being degraded with time. The loss of a forest cover from a steep slope often leads to accelerated surface erosion, and dramatically increases the chances of landslides as well as surface runoff. The consequences of deforestation include raised riverbeds due to increased channel siltation, which ultimately leads to more flooding in low-lying areas; destruction of aquatic habitat and deterioration the quality of water. Increase in population leads to urbanization and conversion of agricultural land into built-up land, as well as forest land into agricultural/built-up land, etc. The Rawal watershed is facing risks of rapid urbanization and deforestation, due to which landuse of watershed is changing. This situation is ultimately affecting climate and watershed health, i.e. Rawal lake storage-capacity has been reduced by 34 % due to sedimentation (IUCN, 2005).

Comprehensive information on the spatial and temporal distribution of land use/landcover is essential for planning, utilization and better management of land resources, especially for developing countries. Monitoring of landuse/landcover is useful to plan development activities, such as major schemes for community requirements and sustainable watershed management. This information is also helpful in monitoring the dynamics of landuse resulting from the growing needs of the population growth. There is no systematic study carried out to document the landuse variability in the Rawal watershed yet.

Rawal dam, which is the main source of water supply for Rawalpindi city of Pakistan, generates almost 33,995 hectares feet of water in an average rainfall/year and 83 million liters/day to fulfill drinking and other household needs (IUCN, 2005). It also provides a limited water supply for irrigation to downstream areas. Many recreational initiatives have been developed in the watershed, e.g. Lake View point, Chatter and Valley parks, etc., and agricultural and residential activities in progress in the watershed area. The spatial and temporal landuse of watershed is changing rapidly due to different human and natural activities that are also degrading the watershed health (Aftab, 2010). The watershed land is being degraded due to conversion into settlements, ultimately resulting in forest-cutting. Population is increasing due to migrations from rural/other cities due to better provision of services/facilities and employment opportunities in the study area. Mushrooming of residential and commercial buildings in the area is occurring (IUCN, 2005). Also, well-off and elite families of these areas are migrating to the capital of Pakistan, Islamabad, which occupies 47 % area of Rawal watershed. Due to high cost of land, many poor people of the area are selling their inherited lands to start businesses for improved livelihoods. Many

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housing schemes and real estate agencies are promoting agricultural farmhouses in the watershed. Illegal wood cutting continues in the watershed area to meet the construction needs of houses for the local population due to high value of forest wood. These activities are resulting in accelerated deforestation in the watershed area. So far, there is no systematic study carried out to document the landuse variability in the watershed area. To assess the spatial and temporal urban and forest landuse/landcover, the role of Remote Sensing (RS) and Geographic Information System (GIS) is very important.

2. REMOTE SENSING APPLICATION IN LANDUSE MONITORING

Satellite imagery is a useful source for landcover information, and urban landcover has been identified and mapped using remotely sensed data with a fine spatial resolution (Yang, 2002; Tapiodor and Casanova, 2003). In recent years, there has been an increasing awareness of the effects of geographical variables in eco systems. In particular, fundamental variables, such as scale and spatial patterns, have become increasingly important in a vast array of ecological research (Drakare Lennon and Hillebrand, 2006; Agrawal, et al., 2007). RS now regularly provides agricultural scientists and ecologists with information on the earth and its environment at scales from the local to global. GIS provides, among other things, a means to store analyze and visualize spatial data including those derived from remote sensing together with associated advancements in computational facilities and specialist tools, such as methods for spatial analysis (Austin, 2007; Osborne, Foody and Seoane, 2007).

Considering the spectral resolution of the RS data, the technique has high potential for monitoring landcover/landuse behaviour, natural resource environment and risk of land degradation at watershed area in Pakistan. RS and GIS can contribute to monitoring landuse/landcover in a wide variety of ways. RS has frequently been used to derive landcover information. Changes in landuse and landcover are major variables affecting ecological systems. Landcover types, for example, differ greatly in their biogeochemical cycling, and thus knowledge of their distribution is important in many environmental modeling studies. Landcover change has major impacts on issues ranging from climate change to biodiversity conservation. Given that the remotely sensed response is essentially a function of landcover type, there has been considerable interest in using remotely sensed data as a source of information on landcover.

To assess the spatial and temporal urban and forest landuse/landcover, the role of RS and GIS is very important. Zafar, Baig and Irfan (2011) studied landuse changes using satellite RS data for management zoning of the Margalla Hills National Park based on different environmental factors. Rabab (2011) used time-series RS data for discrimination of Rabi crops and associated landcovers. Wheat yield was estimated based on the interpretation and analysis of the image. Ashraf, Naz and Mustafa (2011) studied satellite image data of drought (2001) and post drought (2006) periods in order to assess changes in landuse and vegetation cover through hybrid (visual and digital) interpretation technique.

Diallo and Zhengyu (2010) used RS technology to assess Bamako's landcover change in China within a 20 year period. Issa (2009) utilized change detection techniques to assess land development achievements on Al Sammalyah Island, off the coast of Abu Dhabi, capital city of United Arab Emirates. Kamran and Jamil (2008) used RS and GIS techniques for the detection of urban growth in Islamabad and its impacts on climate. Malik and Husain (2006) used SPOT XS (multi-spectral) satellite image data for mapping different landuses/landcovers in the suburbs of Rawalpindi to assess the impact of urbanization on the scrub forest dominated by Acacia modesta. Roohi, Ashraf and Ahmed (2004) conducted a study to evaluate the capability of LANDSAT-TM data for identification of various landuse and vegetation covers, like forest, crop, shrubs and grasses near Fatehjang area. Singh and Khanduri (2011) studied landuse/landcover of Pathankot and Dhar Kalan tehsil using RS data of 1991, 2002, and 2006 periods in order to detect changes that had taken place particularly in the built-up and forest areas and evaluate socio-economic implications of the predicted changes.

In the present study, an attempt has been made to investigate the status of landuse/landcover and changing behaviour particularly of the built-up, agricultural and forest land in the Rawal watershed area during the last two decades. The risk-prone areas were identified and causative factors of land degradation were studied. The findings of this study would provide basis to organize better management strategies for the watershed area.

3. MATERIALS AND METHODS

3.1 Study Area

Rawal watershed lies within longitudes 73º 03´ - 73º 24´ E and latitudes 33° 41´ - 33° 54´ N in the Pothwar region of Pakistan (Figure-1). It has an undulating topography with terraced land for agriculture, high slopes and dissected patches under natural vegetation. It covers an area of about 272 sq. km out of which 47 % lies in the Islamabad Capital Territory, 43 % in Punjab and the rest 10 % in the Khyber Pakhtunkhwa (KPK) province. It is well connected through Murree Road and Express Highway with Islamabad and Rawalpindi. Physiographically, the watershed area comprises of 34 % hilly area (<700 m), 62 % Middle mountains (700-2000 m) and 4% high mountains (>2000 m). The elevation ranges from 480 m to 2,168 meters above sea level (m.a.s.l).

Korang River is the main channel flowing in the watershed. The soil in steep southern and western slopes was extremely thin and sterile (Rasheed, et al., 1988). The soils formed over shale are clayey and have a weak coarse and medium sub-angular blocky structure. Soils developed on the sand stone are moderate to weak medium sub-angular blocky in structure and sandy loam to sandy clay loam in texture (Shafiq, et al., 1997).

The area lies in sub-humid transitional to humid sub-tropical continent with highest rainfall during monsoon season. The hottest months are May, June, and July in the study area. Average high temperature exceeds 38 ºC. The winter months are from October to March. During winters temperature in area remains mild, with occasional snowfall over the Margalla Hills. There are two distinct rainy seasons, one in summer (Kharif) with a peak in July-August and the other in winter (Rabi) with a peak in February-March. Mean annual rainfall is about 1,202 mm. Mean annual maximum temperature is 23.75 ºC, while mean annual minimum is 2.06 ºC. The average temperature ranges from 15 ºC in January to 37 ºC in June. The highest temperature was recorded at 46.6 ºC in 2005 and the lowest was recorded at -3.9 ºC in the year 1967.

3.2 Vegetation and Landuse

The flora is mainly natural with xeric characteristics, broad-leaved deciduous, evergreen trees and diverse shrubs on the southern slopes. The dominating plant species are *Olea ferruginea* (Wild Olive), *Carissa spinarum* (Granda) and *Dodonaea viscose* (Sanatha). Transition zone scrub occurs in the higher and cooler altitudes. Vegetation is open with scattered patches of pine trees. Sub-tropical pine zone stretches over higher elevations. The dominant plant species present are *Pinus Roxburghi, Quercus Incana and Myrsina Africana*. Due to extensive cattle grazing and wood

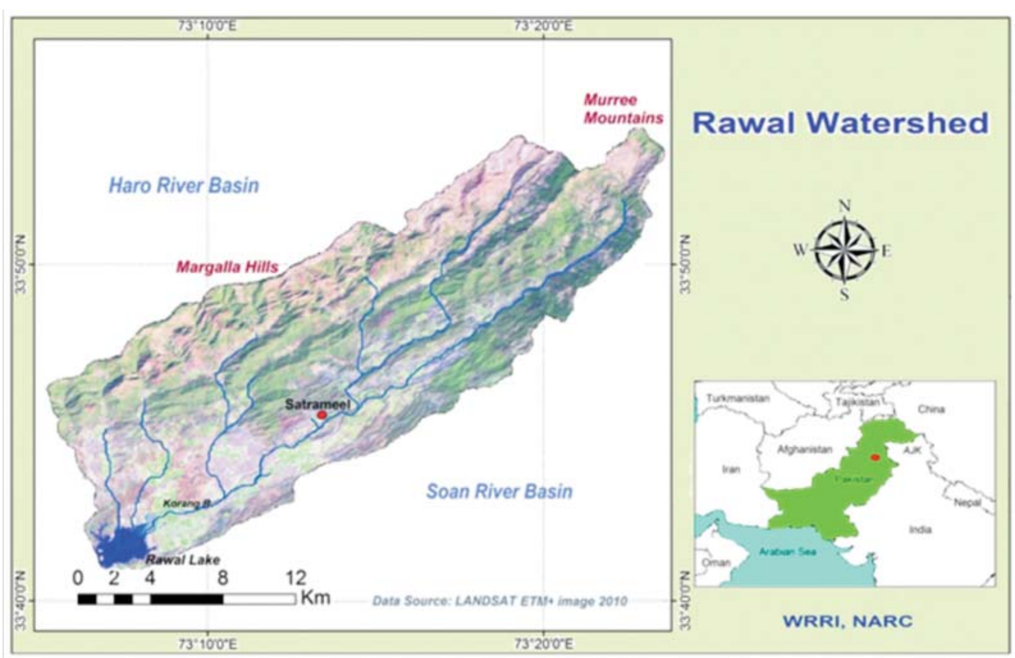

Figure-1: Location Map of the Study Area

cutting by the communities, many plants have been deformed to bushes (Shafiq, et al., 1997).

3.3 Data Used

The RS images of LANDSAT-ETM+ (Enhanced Thematic Mapper Plus) having path-row, 150-37 of 1992, 2000 and 2010 periods were used in the present study. These images were corrected geometrically and radiometrically using toposheets of the area and ground control points (GCPs) collected through Global Positioning System (GPS) survey (Figure-3). The coordinate system of Universal Transverse Mercator (UTM) (Zone 43: 72º -78º Northern Hemisphere) was used.

3.4 Data Preparation

The base map of the study area was prepared by generating and integrating thematic data of elevation, physiographic map, infrastructure using Arc GIS 9.3 software. The boundary of the watershed area and sub basins was delineated using Aster 30 m DEM of the area in HEC-GeoHMS extension in Arc View 3.2 GIS software. Elevation range map was prepared from DEM data to analyze vertical behaviour of landuse/landcover in the watershed area. The major elevation classes include >1600 m, 1200-1600 m, 800-1200 m and <800 m range (Figure-2). The image data was geo-referenced using Universal Transverse Mercator (UTM) coordinate system (Zone 43 North). For the present study, seven major landuse classes were selected based on their distinct reflectance characteristics and ecological importance in the watershed area. These classes include: conifers forest, scrub forest, agriculture, rangeland, soil/rocks, settlement and water. Following criteria was adopted for defining different landuse/landcover classes.

The dense forest appearing in dark green color and having more than 60 % coverage of large woody trees, i.e. usually over 7 m height at high altitude of mountainous terrain, were classified as conifer forest. There was a mixing of shadow and scrub pixels in this class. The low to medium dense woody forest consisting of trees/plants of around 3 m height appears in plain green to bluish green color in the image. The forest cover is classified as scrub forest. This class also contains some misclassified pixels of shadow, agriculture and rangeland classes. Scrub and rangeland classes were mixing with agriculture. Soil, rocks, and settlement classes were mixing in rangeland. Agriculture (or cropland) class appears in light green color pixels with arranged pattern of

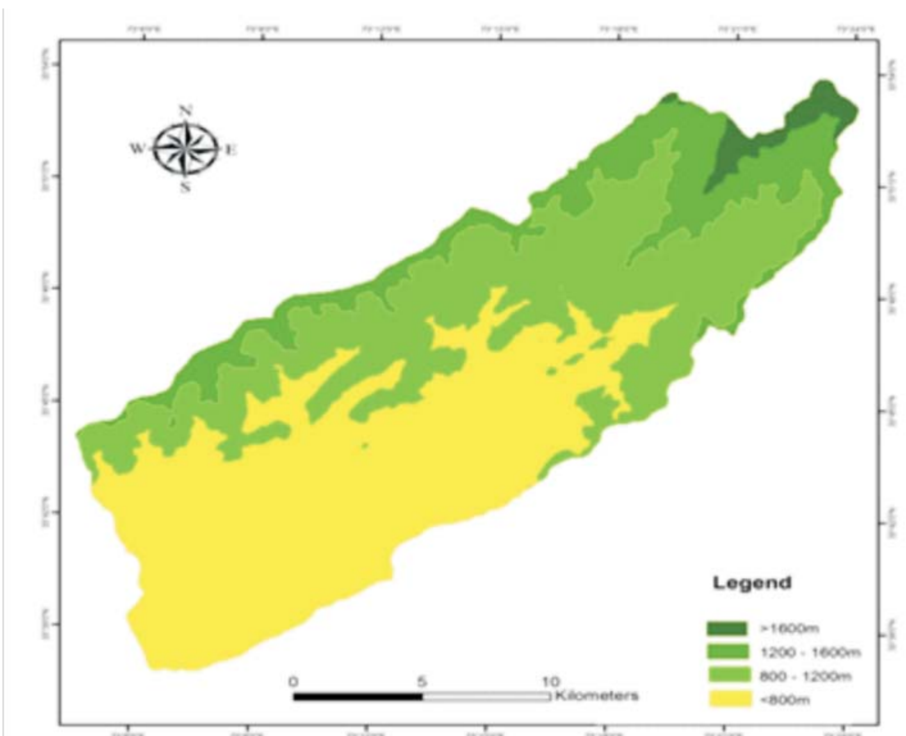

Figure-2: Elevation Ranges in Rawal Watershed Area

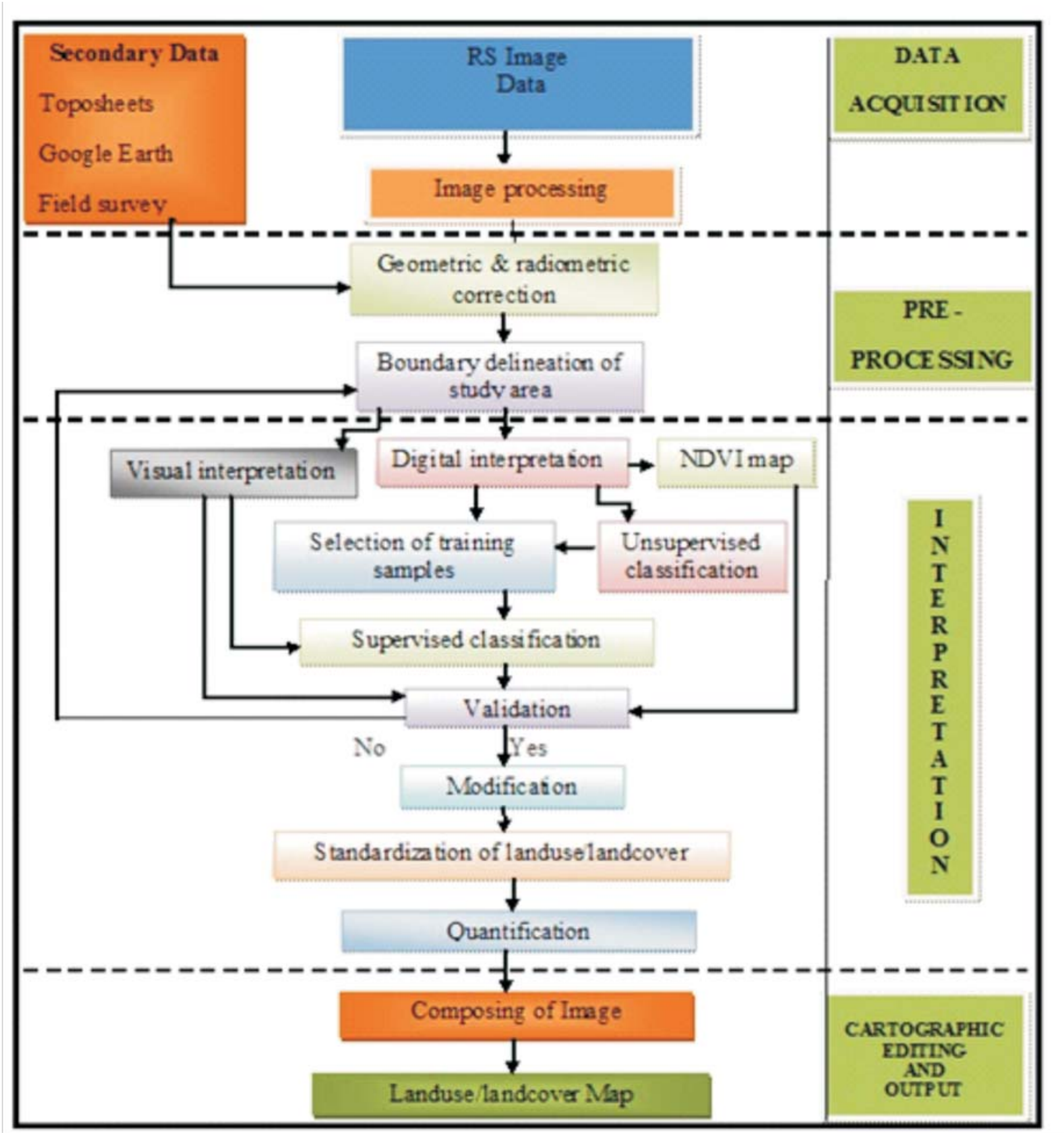

Figure-3: Methodology Adopted for Landuse/Landcover Assessment

vegetation in distinct field boundaries. The rangeland class consisting of various types of grasses and shrubs appears in yellow green, pale and blue green colors in the false color composite image due to mixing of wet and dry biomass, background reflectance of soil/rocks under thin and sparse vegetation cover. At some locations, rangeland class pixels mixed with settlement and soil/rocks classes.

Light pink and white color pixels were classified as settlements. The built-up landuse/landcover includes, not only urban infrastructure within towns and cities, but also individual dwellings, roads linking settlements, and other structures built by humans. At some locations, built-up class mixes with the soil/rocks class due to similarity in reflectance. Soil and rocks were appearing in reddish brown to pink colors that show a close resemblance, so these were merged into a single class of soil/rocks due to their similarity in reflectance and minor areal coverage. Although it may consist of less than 10 % vegetation cover, but areas cleared off from vegetation for development, through natural process, i.e. landslides, erosion in the valleys and slopes, and some fallow land as well as exposed bare rocks include in it. The dark blue and black color pixels of water class were mixing with shadow and conifer forest. The shadow areas in the hilly terrain were eliminated considering their association with the surrounding landcover.

3.5 Image Analysis

The satellite images data were analyzed to observe spatial variability of landuse through visual and digital interpretation techniques. The visual interpretation was performed for qualitative analysis while digital interpretation for quantitative analysis of the image data. Satellite images have been studied thoroughly to ascertain the probable landuse classes and their respective range of reflectance values (DN values). The normalized difference vegetation index (NDVI) technique was used to separate the spectral reflectance of the vegetation from background reflectance of soil and water. Roohi, Ashraf and Ahmed (2004) compared the results of NDVI and supervised classification method and found them relating to each other. Bashir (2009) identified protected vegetation cover using NDVI technique for soil erosion analysis in Rawal watershed area. NDVI values give the density of green vegetation cover in the area. To determine the NDVI, band 3 and band 4 of LANDSAT ETM+ are used as:

$$NDVI = (TM4 - TM3) / (TM4 + TM3) \quad \text{.....................(a)}$$

Initially, unsupervised classification was applied on multi-temporal RS images. It aggregates them into a number of classes based on natural grouping or cluster present in image values. The classes that resulted from unsupervised classification are spectral classes. Supervised classification has been performed for various images. The supervised classification results were supported with NDVI data and map output. To enhance the classification accuracy, knowledge-based expert system was used for post-classification refinement of initially classified outputs. Initially, the algorithm was developed through supervised training process, after collection of parametric and nonparametric signatures (training samples). Signatures are further evaluated using error matrix, which contain the number and percentage of pixels that are classified as expected. Signatures are refined, deleted, renamed and merged after evaluation to ensure the uni-modelity of their histograms, statistical parameters and error matrix. Overall accuracy of the signatures evaluated of three images through error matrix was more than 95 per cent. After evaluating the accuracy of signatures, final classification of the images was performed. Later, filtering technique was applied to remove noisy/misclassified pixels of the classes from the recoded image data. The doubtful areas of classes were modified after ground truthing, i.e. performing field validation survey and using Google Earth imageries. The landuse/landcover change has been detected between 1992 and 2010 periods using the respective images. Image processing and data manipulation in GIS were carried out using Erdas Imagine 9.2 and Arc GIS 9.3 softwares.

4. RESULTS AND DISCUSSION

Image analysis was performed through visual and digital interpretation of the RS data. Through visual interpretation of RS data, different land features like infrastructure, boundaries of built-up land, cropping fields, tree/plantation cover and drainage pattern of the study area were investigated. In False color composite of 5, 4, 2 (RGB) of LANDSAT image data, the landcover is visible in true color, i.e. vegetation in green, soil in pale to reddish brown, and water in shades of blue. The built-up area can be identified in white, brown, and purple colors due to variation in density of constructed area, mixing of new and old settlements, presence of variable land features, i.e. lawns, parking sides, water ponds, mettled and non-mettled roads, etc.

The landuse/landcover condition of the watershed was estimated for different time periods, i.e. 1992, 2000 and 2010 (Figure-4). In the year 1992, scrub forest was found dominant over 55 % of the total watershed area. Conifer forest indicated coverage of about 4 % in the upper half of the watershed area (Table-1 and Figure-5). The rangeland class was found in scattered form over 30 % in the study area. Settlement class stretched over 2 % area mainly in patches and scattered form. The agriculture class was found over 6 % area generally in the vicinity of settlement class. Agriculture is practiced in small to medium farms in plains and in patches over hill terraces in the watershed area.

In year 2000, scrub forest was dominant, covering over 45 % of the study area (Figure-5). The conifer forest was found over 3 % area mainly in the upper half of the watershed area. Rangeland was found in scattered form over 36 % of the study area. Settlement

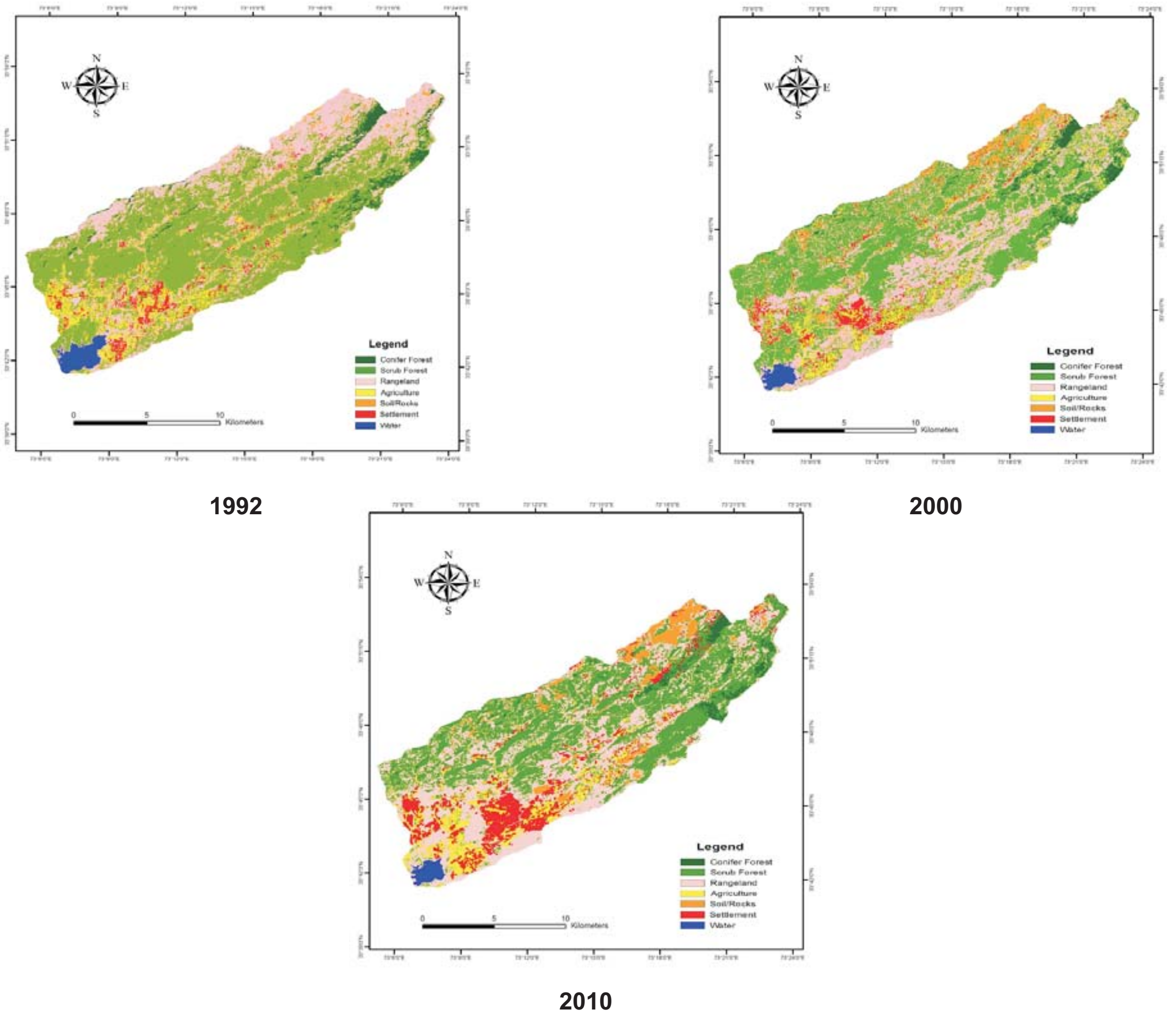

Figure-4: Temporal Variation in Landuse/Landcover of Rawal Watershed Area

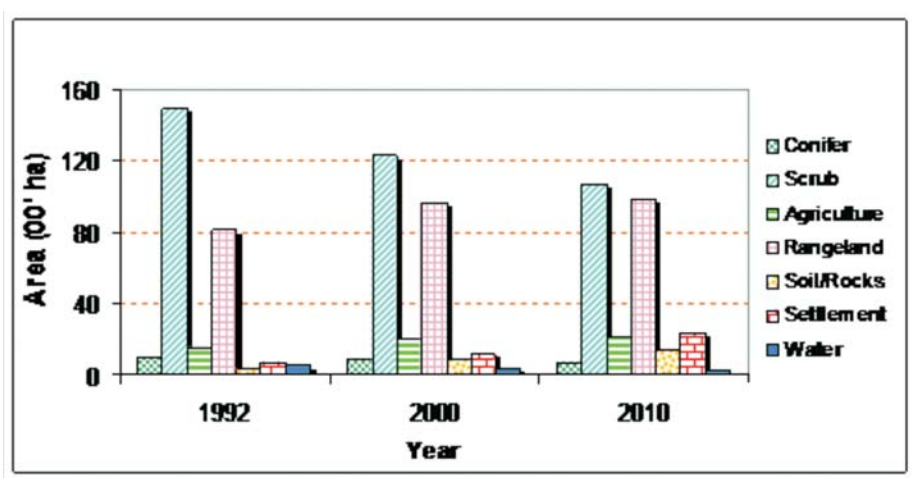

Figure-5: Temporal Variation in Landuse during 1992-2010

Table-1: Landuse Variations Detail during 1992-2010 Period

Landuse	1992		2000		2010		1992-2010	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Change (ha)	Change %
Conifer	1038	3.8	860	3.2	680	2.5	-358	-34
Scrub	14878	54.7	12317	45.3	10634	39.1	-4244	-29
Agriculture	1545	5.7	1970	7.2	2041	7.5	496	32
Rangeland	8159	30.0	9653	35.5	9863	36.3	1704	21
Soil/Rocks	336	1.2	939	3.5	1317	4.8	981	292
Settlement	717	2.6	1144	4.2	2374	8.7	1657	231
Water	528	1.9	318	1.2	290	1.1	-238	-45
Total	27200	100	27200	100	27200	100		

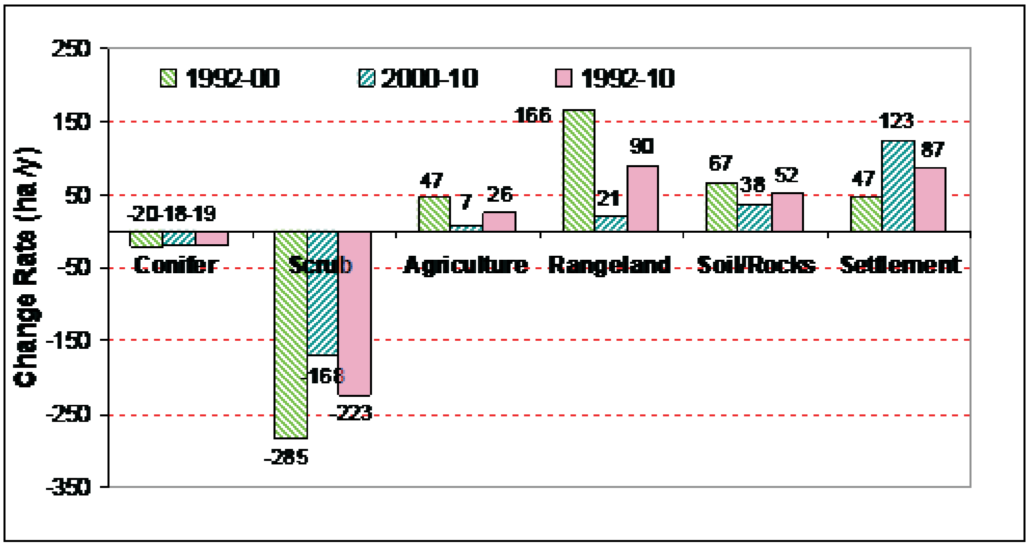

Figure-6: Annual Rate of Change in Landuse Coverage during Different Periods.

class stretched over 4 %, while agriculture class over 7 % area generally association with each other. About 4 % soil/rocks were found mainly in the upper left corner of the study area and water bodies occupied 1 % area.

In year 2010, scrub forest was a dominant class covering about 39 % of the study area. Conifer forest stretched over 2 % area while rangeland over 36 % area of the watershed. The NDVI has improved the segregation of vegetative and non-vegetative, i.e. bare ground. The NDVI values that range greater than 0.4 were categorized as high dense green-cover mainly containing thick scrub and conifer forest, while values that range between 0.24 to 0.4 were categorized as medium density green-cover, consisting of grown-up crops and shrubs in the watershed. Sparse vegetation like grasses, stunted shrubs and bushes, etc. was found under low-density green cover class (NDVI range 0.17-0.24) in the area. These results are in conformance with findings of Naseem (2008), which shows NDVI values ranging from 0.2 to 0.41 for the forest area in Murree and Margalla Hills.

Settlement occupied almost 9 % area while agriculture about 8 % of the study area, mainly in patches and strips over terraces of the hills. The built-up and agriculture land are mainly concentrated in the lower half of the study area. The soil/rocks were found in nearly 5 % area mainly in the upper half of the study area (Table-1).

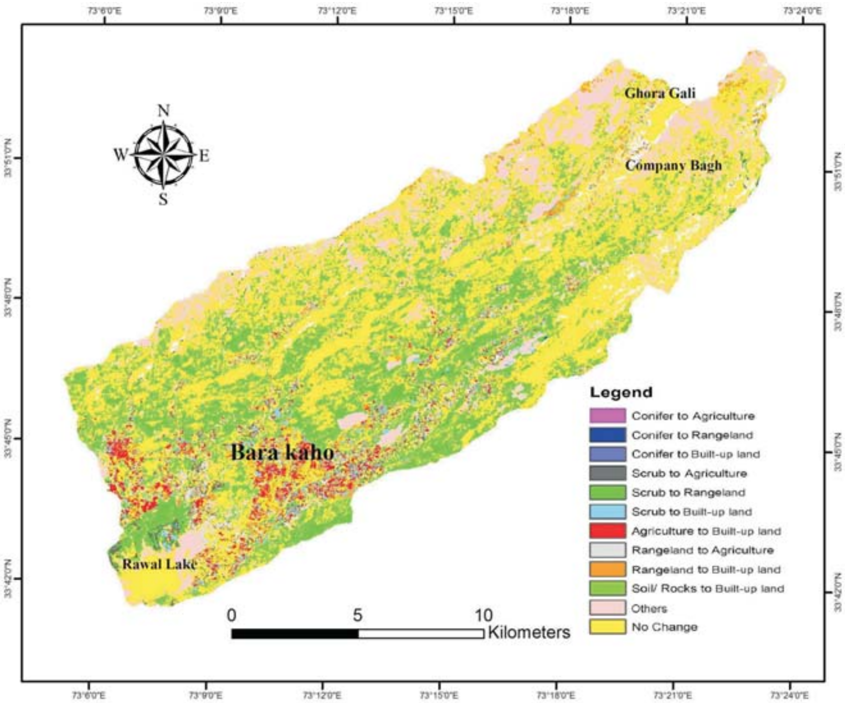

Figure-7: Spatio-temporal Change in Landuse during 1992- 2010

Major landcover change was observed in scrub forest class that indicated a reduction of about 4,244 ha in coverage during 1992-2010 period. The rate of decrease in scrub cover was higher during 1992-2000, i.e. about 1.9 % per year, than it was during 2001-2010, i.e. about 1.1 % per year. The scrub wood is mostly used as fuel at local level due to non-availability of other energy sources in the area. Due to extensive wood cutting, scrub forest has changed into rangeland and a major part of it had been converted into agriculture and built-up land. These results are verified by the study of Arfan (2008), which highlighted maximum decrease in scrub forest during 30-year period, i.e. 1977-2006 in Rawalpindi watershed area.

Similarly, conifer forest had shown higher rate of decrease, i.e.1.9 % per year during 1992-2000 than about 1.7 % per year in the preceeding decade. The results are in conformance with the findings of FAO (2005) that reported deforestation in the country at a rate of 1.5 % annually between 1990 and 2000. There are many factors involved in degradation of the forest cover like illegal cuttings due to its high value in the market, intensive use of forest wood for household needs (cooking, heating, timber, etc.), as well as forest disease and ineffective forest management, etc. The forest cover had been cut down for construction of Express Way from Satrameel to Lower Topa, Murree, after 2000 (IUCN, 2005). According to Ali and Benjaminsen (2004), it is commercial and illegal harvesting that has left the forest in such a depleted state that it can no longer withstand the pressure from local use.

The agriculture land has shown an average increase at a rate of about 26 ha per year during 1992-2010, which was about 47 ha per year during 1992-2000 and 7 ha per year during 2001-2010 period (Figure-6). The settlement area had shown higher rates of increase, i.e. about 123 ha per year during 2001-2010 than during 1992-2000 with average increase at rate of 87 ha per year during 1992-2010 period. The growth in urbanization was indicative from almost four-fold increase in built-up land, i.e. from 2.6% in 1992 to 8.7 % in 2010 (Table-1). The change in water class is due to seasonal variation in lakes surface area.

The landuse/landcover change had been detected in about 53 % of the study area while remaining 47 % area was found unchanged during 1992-2010 period (Table 2). Overall scrub class has shown highest conversion to agriculture class, i.e. about 3 % of the total watershed area followed by rangeland indicating conversion of about 2.3 % land into agriculture class. The conversion of conifer class to agriculture was very low. The conversion of landuse into settlement class

Table-2: Summary of Conversions of Landuse Classes from 1992 to 2010

Sr. No	Landuse Change from	Area (ha)	Area (%)
1	Conifer to agriculture	1	0.003
2	Conifer to range	35	0.13
3	Conifer to settlement	12	0.04
4	Scrub to agriculture	802	2.95
5	Scrub to range	5,447	20.03
6	Scrub to settlement	662	2.43
7	Agriculture to settlement	558	2.05
8	Rangeland to agriculture	616	2.27
9	Rangeland to settlement	709	2.61
10	Soil/Rocks to settlement	33	0.12
11	Other	5,560	20.42
12	No change	12,767	46.94
Total		**27,200**	**100.0**

was high from rangeland class, i.e. about 2.6 % of the area, followed by scrub forest, which indicated transformation of 2.4 % area into settlement class. Also about 2 % land under agriculture was converted into settlement class during 1992-2010 period. The spatial change of different landuse/landcover classes in the study area is shown in Figure-7.

The changes in landuse/landcover were variable on different elevation ranges. The conifer forest has shown a decrease from 134 ha to 102 ha at greater than 1600 m elevation range, while from 343 ha to 238 ha within 1200-1600 m elevation range during 1992-2010. The scrub class indicated decrease of about 11 per cent within 800-1200 m range, while 65 % in less than 800 m elevation range. Contrary to this, agriculture class had shown increase of about 65 % within 800-1200 m range while 29 % in less than 800 m elevation range during 1992-2010.

The agriculture class had shown an increase of about 496 ha in coverage, i.e. at annual rate of about 1.7% during the last two decades. The rate of its increase was higher during 1992-2000, i.e. about 3 % per year, than during 2000-2010 period, i.e. 0.5 % per year. This indicates that there was intense agriculture activity in the former decade that was replaced by rapid growth in urban development in the later decade. Due to increasing population food needs are also increasing and thereby increase in the agricultural development in the watershed area. The settlement class had shown an increase of almost four times, i.e. from 717 ha to 2,374 ha between 1992-2010 period. The rate of increase in this class area was very high during the last decade (2000-2010), i.e. over 17 % per year, which was about 7% per year in the 1992-2000 period. This situation indicates rapid development of built-up land due to various factors like increasing population, migrations from rural to urban areas, and developments of different housing societies, better job opportunities, provision of better medical and education facilities, etc. in the study area. One more reason is that built-up area is mostly increasing in the capital city, Islamabad. Similarly ,infrastructure developments like Lake View Point and some new roads (Express Way) in the area have greatly contributed in the growth of built-up land. These factors are also supported by the report of IUCN (2005); Kamran and Jamil (2008); Arfan (2008); and Tanvir, Shahbaz and Sulehri (2006), which concluded that urban development is increasing at very high rate in Islamabad and Rawalpindi areas. According to Tanvir, Shahbaz and Sulehri (2006), intensive use of forest wood for household needs (cooking, heating, timber, etc.) and ineffective forest management strategies by the forest department were some of the key reasons of deforestation in the study area.

5. CONCLUSIONS

During the last two decades, built-up land has shown an increase from 717 ha to 2,374 ha indicating rapid urbanization in the Rawal watershed area. This rapid growth in urbanization needs to be monitored on regular basis in future using RS technique. Overall, 53 % area of the watershed has undergone landuse/landcover change during 1992-2010 period. The conifer class and had shown a decrease of 34 % and 29 % in coverage, respectively, scrub class during 1992-2010 period. The decline in forest cover is likely due to changing socio-economic and environmental conditions in the watershed area. Haphazard, and uncontrolled urbanization and illegal wood cuttings should be controlled by involving local communities and other stakeholders. Similarly, environmental laws should be reinforced fully to control deforestation and loss of biodiversity in the watershed area. The risk-prone areas can be managed through afforestation and adopting suitable soil-water conservation techniques. Mass awareness and media campaigns should be launched periodically to encourage people to protect natural resource heritage of the nation. The RS and GIS techniques can be effectively used for regular monitoring of landuse/landcover changes and natural environment of the watershed area. These techniques could be integrated with advance modeling tools to study impacts of landuse change on the hydro-environment of the watershed area.

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