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Analyzing the decadal transformation of the LULC from tillage to a townified area in the Lower Himalayan Region, Pakistan

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Abstract: Land use land cover change (LULC) has become part of the global science agenda and the understanding of LULC change is vital for planning sustainable management of natural resources. The study has employed multi-temporal satellite imagery to examine the LULC change in the Abbottabad District from 1989 to 2019. Images from Landsat-5, Landsat-7, and Landsat-8 Thematic Mapper (TM) for the same season were acquired from the USGS for the years of 1989, 1999, 2009 and 2019. The images were pre-processed by atmospheric correction, extraction of the study area and band composite. The supervised image classification using Maximum Likelihood Classifier and accuracy assessment were applied to prepare LULC maps of the Abbottabad District. In the last three decades, the study area witnessed number of changes in the pattern of LULC due to population growth, rapid urbanization and increased development of infrastructure, which cumulatively led to the emergence of new patterns being employed for land use. Results of the analysis involving the classified maps show that agricultural land and bare land have decreased, respectively 15.73% and 3.81%, whereas water resources have decreased significantly by 0.58%. This study reveals that GIS can be used as an informative tool to detect LULC changes. However, for planning and management, as well as to gain better insight into the human dynamics of environmental variations on the regional scale, it is crucial to have information about temporal LULC transformation patterns in the study area.

Keywords: decadal transformation, land use land cover change (LULC), Lower Himalayan region of Pakistan, multi-temporal satellite imagery

INTRODUCTION

Globally, LULC changes have attracted the attention of policy makers and practitioners. Land use land cover change (LULC) has become part of the global science agenda. It is driven by human activities [Hua *et al.* 2017] and it is associated with negative impacts on ecosystems observed at local, regional and global scales [Barlow *et al.* 2016]. The interaction between nature and human has transformed the face of the earth as no other living species have ever done [Melaku 2016]. Satellite based imaging as a source of generating useful information for LULC is widely acknowledged by scholarly cohorts [Hathout 2002; Herold *et al.* 2003; Saadat *et al.* 2011; Yuan *et al.* 2005] despite of the fact that initial attempts to apply various interpretation techniques in LULC mapping have been made since mid-seventies [Anderson 1976; Colwell 1983]. With the advancement in science and technology, various LULC techniques have been identified and applied all over the world in the last few decades [Jia *et al.* 2014; Jin *et al.* 2013; 2017; Lv *et al.* 2018; Phiri, Morgenroth 2017; Sekertekin *et al.* 2017; Wu *et al.* 2018; Zhang *et al.* 2014; Zhu, Woodcock 2014].

Globally, the impact of different categories of land use on rapid replacement of land cover is generally observed [Geist, Lambin 2001]. Although LULC changes on the surface of the earth are often used interchangeably [Dimyati *et al.* 1996], these are basically two different but interrelated concepts [Barnsley *et al.*

2001]. Furthermore, sustainable management of natural resources and effective planning inevitably depend on examining LULC and it is primarily regarded as a baseline requirement for planning and management of natural resources [Lambin *et al.* 2000; Petit *et al.* 2001; Read, Lam 2002; Verburg *et al.* 1999]. The landscape diversity and changing pattern in the landscape structure is monitored by multi temporal analyses of the land in combination with Geographical Information System (GIS) and historical documents [Yan *et al.* 2009].

GIS and remote sensing techniques are considered the most accurate and cost-effective methods to understand the dynamics of landscape. In order to understand the dynamics of landscape, detect changes, identify maps and monitor variations in LULC patterns over time, digital image detection based on multi-temporal and multi-spectral remotely sensed data has demonstrated a huge potential. Water resources are severely disturbed by human interaction with the environment, i.e. agriculture, deforestation, and urbanization [ILEC 2005; Kaushal *et al.* 2017]. In the past few decades, both developed and developing countries have experienced a widespread expansion in built-up area on previously fertile and agricultural land. The urban sprawl and loss of agricultural land have significant environmental and socio-economic consequences for local communities [Beckers *et al.* 2020]. Rapid surge in population and urbanization coupled with profound changes in LULC have serious impact on water quality [Xiang *et al.* 2016]. LULC change over the past half millennium is considered to be one of the prime causes of natural resource degradation, and such changes induced by LULC dynamics are the most widely studied factors of environmental degradation across the globe [Kindu *et al.* 2018; Wang *et al.* 2015a].

The expansion of human settlement is a universal phenomenon. These activities are converting agricultural and barren land into built-up areas. Built-up areas with spatial expansion are linked with various geographical, socio-economic aspects and rapid population increase, which are major driving forces behind this phenomenon in developing countries, like Pakistan [Adeel 2010]. According to 2017 census, Pakistan has become the 6th largest country in the world in terms of its population, as well as the fastest growing urbanized country. This rapid urbanization has resulted in a shift from agriculture to industry while seeking a new life style [Arif, Shahnaz 2009; Toh *et al.* 2018]. Khyber Pakhtunkhwa (KP) constitutes 16% of the Pakistan's total area with 5260.9 km^2 of reported agricultural land, 22% forest, 23% crop cultivation and 22% of land that is not utilized due to water shortage [Khan 2012; Malik *et al.* 2015].

Moreover, during the last 20 years, the population in the district of Abbottabad has rose from 0.8 to 1.3 million, which produced urbanization, expansion in the city area and reduced biodiversity [PBS 2017]. Sajid *et al.* [2017] reports 10% decrease in agriculture land, 18% in barren land in the district of Abbottabad due to increase in built-up area by 8%. This study collects and employs satellite images taken in 1989–2019 to analyze spatial and temporal variations in land use land cover in the study area. Cloud-free Landsat satellite images (Landsat 5, Landsat 7, Landsat 8) from 1989, 1999, 2009 and 2019 were used for multi-temporal change detection. Land use land cover changes during the study period for the assessment of image were classified into vegetation, barren, water, built-up, and agricultural areas.

MATERIALS AND METHODS

STUDY AREA

The Abbottabad District is situated in the Hazara Division, Khyber Pakhtunkhwa, and encompasses an area from 33°50' and 34°23' North longitude and 73°35' and 73°31' East latitude (Fig. 1). The total population of Abbottabad is 1.3 million [PBS 2017], with 83% of the population living in rural areas [World Bank Group 2014]. Moreover, the district occupies 1967 km^2 and is predominantly surrounded by mountains and rugged terrains, whereas 20% of the total area is covered by forests, 48% is used for agriculture, and the remaining area is mostly shrub land and range land with thin vegetation.

Abbottabad is a serene valley with a beautiful landscape, pleasant weather, rainfall and snowfall. It is as a renowned and attractive tourist spot for domestic as well as foreign tourists, which makes the tourism sector one of the vital sources of income for inhabitants [IUCN 2004]. In addition, the Abbottabad District is host to some of the best higher education institutions in Pakistan, which are considered as academic centers, especially for students from adjoining districts. This trend, coupled with the population growth, has intensified the need and demand for residential and commercial areas, despite the fact that the soil in the district is quite fertile and naturally enriched by essential nutrients.

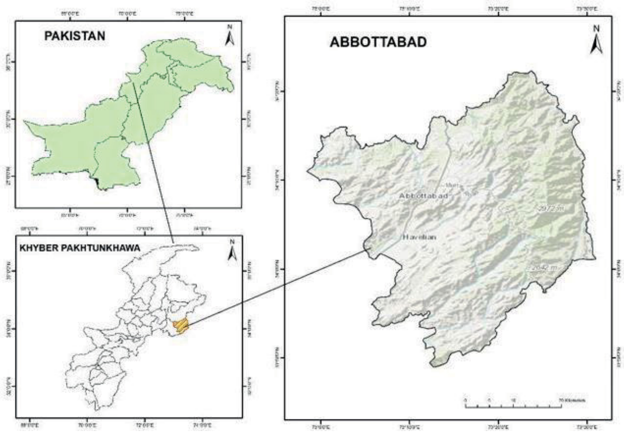

Fig. 1. Location map of Abbottabad District; source: own elaboration

DATA ACQUISITION

For the purpose of multi-temporal change detection, Cloud-free Landsat Thematic Mapper (TM) imagery was used. The source for land and land cover dynamics was freely downloaded from http://earthexplorer.usgs.gov. The detail satellite data are presented in Table 1. Landsat 5, Landsat 7 and Landsat 8, path/row of 150/36 with 30 m spatial resolution were acquired on 28 Sept. 1989, 8 Oct. 1999 19 Sept. 2009, 4 Sept. 2019. The images were processed using ArcGIS10.4. While, the methodological workflow for the purpose of data acquisition pre-processing and post-processing shown in Figure 2.

Post-processing. The data obtained from all satellite imagery was examined by earmarking per-pixel signatures and transforming land area into six classes contingent upon

Table 1. Description of satellite images used in the study

S. No.	Image	Resolution (m)	Sensor	Path	Row	Acquisition date
1	Landsat 5	30	TM	150	36	28 Sep. 1989
2	Landsat 7	30	TM	150	36	8 Oct. 1999
3	Landsat 5	30	TM	150	36	19 Sep. 2009
4	Landsat 8	30	TM	150	36	4 Sep. 2019

Source: USGS earthexplorer.usgs.gov.

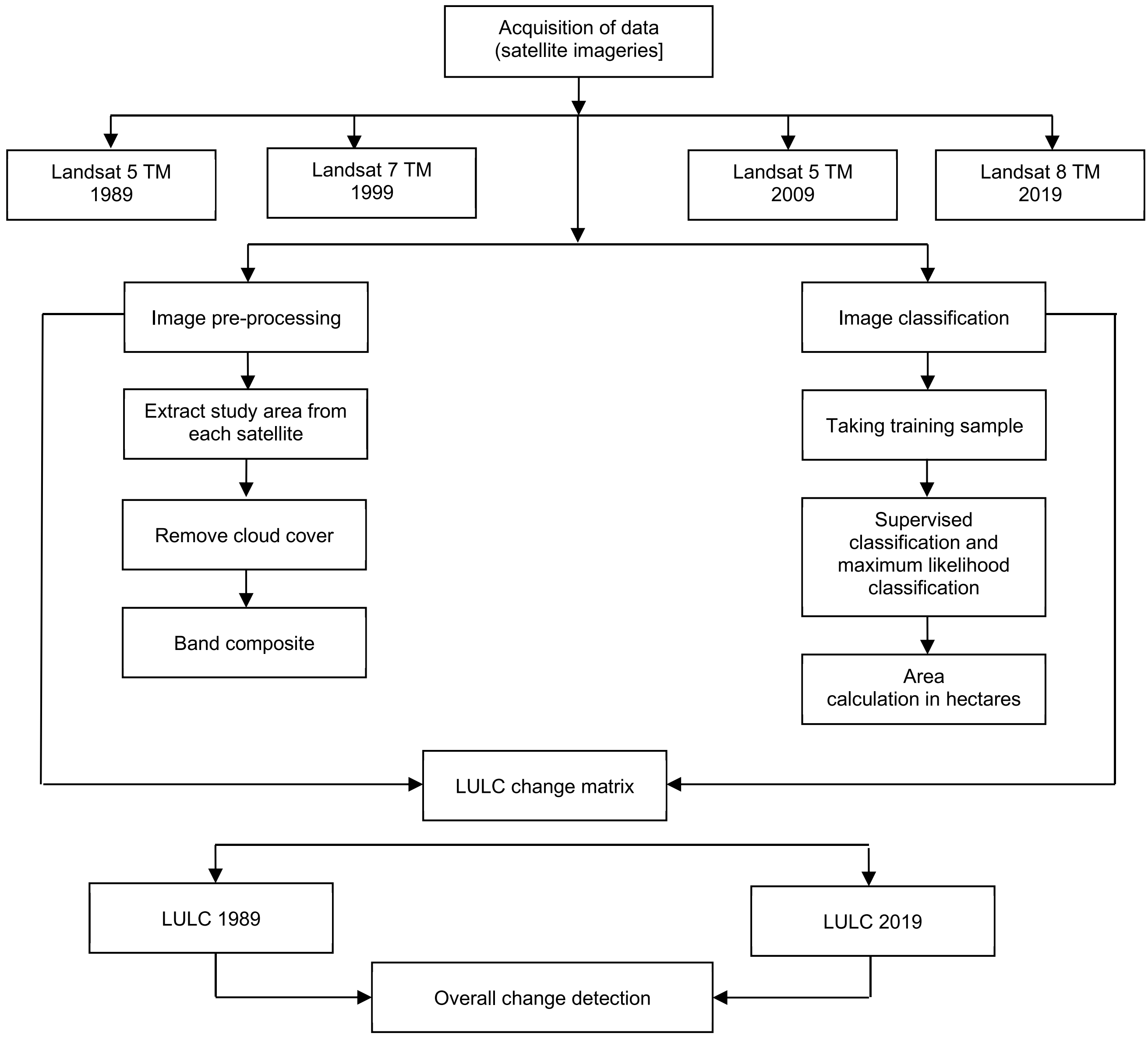

Fig. 2. Methodological workflow and data analysis; source: own elaboration

the specific digital number (DN) value of various landscape components. The classes included "Agriculture", "Built-up area", "Forest", "Vegetation", "Water bodies" and "Barren area" (Tab. 2). Moreover, each class was allotted a particular color in order to retain the distinctive identity and isolate them from each another. Furthermore, training samples for each of the prearranged land cover type were picked by delineating polygons around representative sites. In total, 150 training samples have been extracted from the image of each class which made 850 training samples for the four-year imagery. Subsequent to these, signatures were developed for each training sample using feature space. In the last step, the image was classified using respective signatures and a maximum likelihood classification technique.

Table 2. Description different land use land cover change (LULC) categories

Classes	Description
Agriculture	agricultural area, crop fields, fallow lands and vegetable lands
Barren areas	area with very little or no vegetation cover on the surface of the land; it consists of vulnerable soil to erosion and degradation; it also includes bedrock which is unable to support cultivation
Built-up areas	residential, commercial and services, industrial, transportation, roads, mixed urban, and other urban
Forest	forest, mixed forest lands
Vegetation	vegetation cover, shrub, grass land and others
Water bodies	surface water; it includes pond water, rivers, lakes and streams

Source: own elaboration

ACCURACY ASSESSMENT

Accuracy assessment is crucial for individual classification and its effectiveness in change detection [Xian *et al.* 2006]. In order to represent various land cover classes of the area, random method was employed for accuracy assessment of land cover maps excerpted from the satellite imagery. In addition, because of visual interpretation of ground truth data, 50 points were used for assessing the accuracy.

Confusion metrics were produced by using these training samples for each land use classification, and then overall accuracy, user accuracy, producer accuracy and kappa coefficient were calculated for all classification types (Tab. 3). Moreover, the study area involved the use of mountainous topography and ground reference data in the classification of the study area with the help of visual interpretation of images using Google Earth Pro, and the current reference data used for the classification of the study area. All the processing and post-classification steps were completed using the software ArcGIS 10.4.

RESULTS AND DISCUSSION

DECADAL LAND USE LAND COVER CHANGE

The study of land use and cover in the Abbottabad District over past three decades has been quite remarkable. Interaction with landowners and inhabitants revealed changes posing serious challenges for the agriculture sector. This area was totally dependent on agriculture and biodiversity of nearby forest which changed its shape. The land cover started changing rapidly since the late eighties. The major reason for this is massive population increase and shrinking water resources. The water table in the region lowered to a great extent, thus affecting the agriculture production. Table 4 shows results from classified maps for the year 1989, 1999, 2009 and 2019. Results from classified maps indicated that in the 1989 area was occupied by different classes, such as agricultural land (31.41%), barren land (20.45%), built-up area (0.892%), forest (12.02%), and vegetation and water (33.61% and 1.59% respectively). On the other hand, in 1999, agricultural

Table 3. Accuracy assessment of land use land cover change (LULC) in term of confusion matrix

Years	User (%)	Accuracy		
		producer (%)	overall (%)	kappa coefficient
1989	79.66	91.11	86.66	0.83
1999	92.10	93.66	90.00	0.87
2009	86.93	88.55	83.33	0.79
2019	85.95	91.80	90.00	0.87

Source: own study.

Table 4. Land use land cover change (LULC) distribution in Abbottabad District

LULC	Area							
	1989		1999		2009		2019	
	ha	%	ha	%	ha	%	ha	%
Built up	1 504	0.892	2 694	1.59	4 640	2.75	6 779	4.02
Agriculture	52 953	31.41	41 909	24.86	29 977	17.78	26 433	15.68
Barren land	34 488	20.45	31 392	18.62	31 081	18.43	28 059	16.64
Vegetation	56 661	33.61	68 553	40.66	76 485	45.37	80 368	47.67
Water bodies	2 689	1.59	2 493	1.47	2 162	1.28	1 711	1.01
Forest	20 275	12.02	21 529	12.77	24 225	14.37	25 220	14.96

Source: own study.

land witnessed a decrease by about 13% and its area covered 19.35% of the total. Barren and built-up areas covered 18.62% and 1.59% respectively.

Similarly, in 1999, forest covered about 12.77%, and vegetation having the largest share occupied 40.66%, while water bodies exhibit a declining trend and covered an area of 1.47%. In 2009, results from the classified maps show further decline in agriculture which covered 17.78% of the total area. On the contrary, built-up area covered about 2.75% showing an increase of almost 1% in one decade. Barren land and vegetation accounted for 18.43% and 45.37% respectively, while open forest and water, which marked a declining trend, covered an area of 14.37% and 1.28% respectively. Following a similar pattern, in 2019, agricultural land dropped to 15.68%, and built-up area rose to 4.02% showing further increase of 1%. Barren land and vegetation covered about 16.64% and 47.67% respectively, whereas the share of water bodies decreased to 1.01%, while open forest covered an area of 14.96%.

LAND USE LAND COVER CHANGE (LULC) DETECTION MATRIX IN 1989 AND 2019

The increase in the population translated into a demand for more houses and infrastructure. The developing housing sector consumed sizeable portion of agriculture land. Although government made all out efforts to increase forest, the timber mafia reduced some existing forest to meet their ulterior motives. An analytical view of respondents approach reveals that people of the Abbottabad District gradually shifted their livelihood practices from farming to other sources of income due to the shortage of agriculture land. Increase in population has been the main reason behind the reduction of agriculture land and most of this land was utilized for building houses, commercial hubs, and infrastructure. The shortage of land forced people to seek other sources of their income. Another aspect was the development of mining in the Abbottabad District. The mining industry has been also growing which further reduces agricultural land, specially at foothills.

The change detection matrix between initial stage (1989) and final (2019) stage (Fig. 3) was calculated using Arc GIS.10.4 and Microsoft Excel. Results obtained from the LULC change matrix shows significant land cover changes in the District of Abbottabad in the study period. Table 5 shows the shift in land cover over a 30-year period. In the agriculture class, 14 317.84 ha of land remained in the same class in 2019, while 11 276.07 ha were converted to bare land, 3 221.44 were converted to built-up areas, 790.14 to forests, 23 170.43 to vegetation and 177.04 ha were converted to the water bodies class.

For the bare land from 1989, 13 619.39 ha area retained its class in 2019, 6 432.24 ha converted to agriculture, 1 994.03 ha to built-up, 453.24 ha were converted to forest, 11 869.01 ha to vegetation and 120.18 ha were converted to water bodies in 2019.

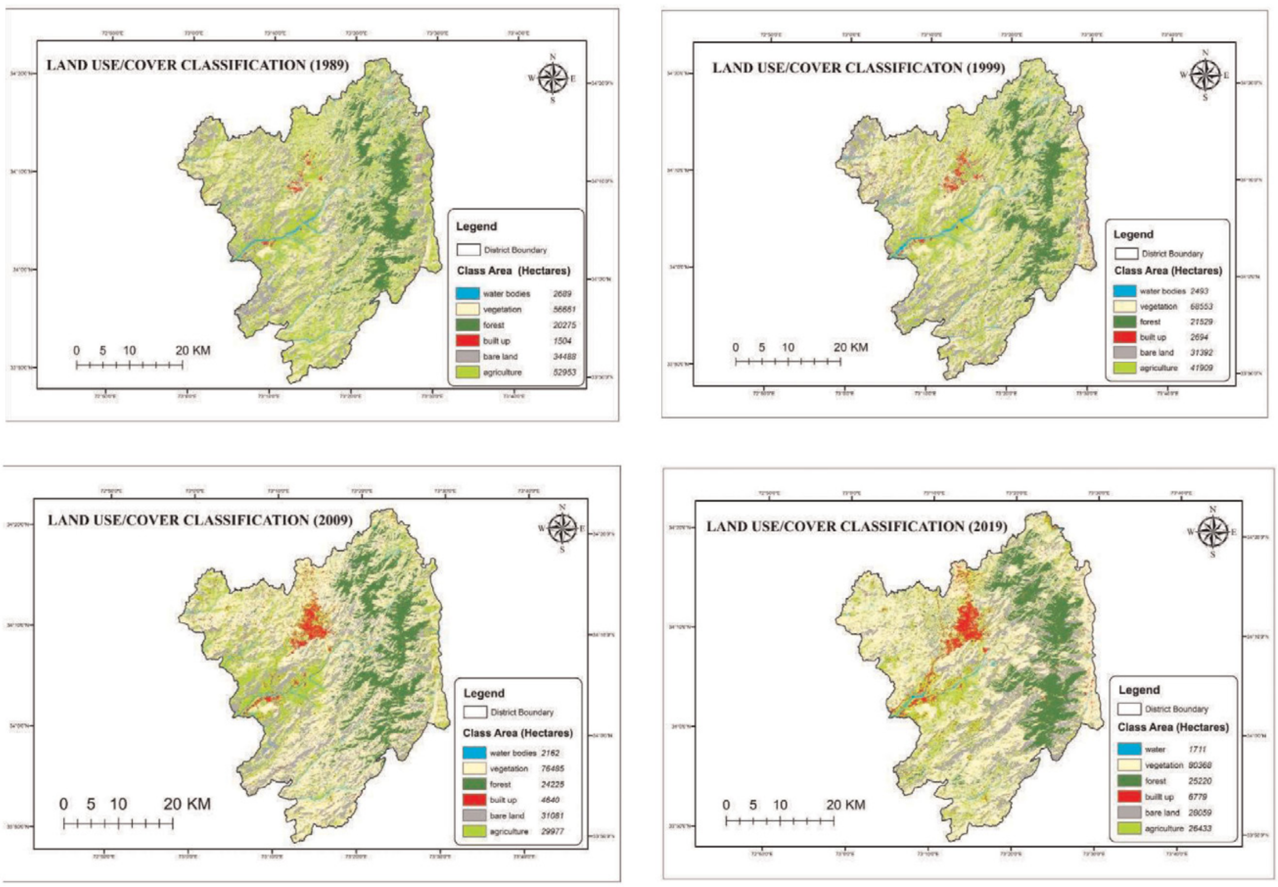

Fig. 3. Land use land cover in different categories during years: 1989, 1999, 2009, and 2019 in District Abbottabad; source: own study

Table 5. Land use land cover change (LULC) matrix between 1989 and 2019 in the District of Abbottabad

Land use / cover class		Land cover 2019						Grand total 1989
		agriculture	bare land	built up	forest	vegetation	water	
Land cover 1989	agriculture	**14 317.84**	11 276.07	3 221.44	790.14	23 170.43	177.04	52 952.99
	bare land	6 432.24	**13 619.39**	1 994.03	453.24	11 869.01	120.18	34 488.11
	built up	230.10	205.26	**669.74**	12.26	354.37	32.14	1 503.89
	forest	40.76	30.10	169.72	**1 4978.32**	5 056.02	0.54	20 275.48
	vegetation	5 691.88	2 531.17	2 852.08	1 991.01	**43 282.05**	313.14	56 661.37
	water bodies	621.14	96.20	333.14	65.59	747.13	**825.08**	2 688.31
Grand total 2019		27 333.99	27 758.21	9 240.19	18 290.58	84 479.03	1 468.14	**168 570.17**

Source: own study.

While 669.74 ha of built-up area remained in the same class in 2019, 230.10 ha were replaced by agriculture class, 205.26 by bare land, 12.26 by forest, 354.37 ha by vegetation and 32.14 ha were replaced by water bodies class in 2019. Similarly, 14,978.32 ha of forest area remained in the same class in 2019 and the rest of area was replaced by other classes, with 40.76 ha of forest converted to agriculture, 30.10 ha to bare land, 169.72 ha to built-up class, 5 056.02 ha to vegetation and 0.54 ha of forest area converted to the water bodies class. In the vegetation class, 43 282.05 ha retained the same class in 2019 as it was in 1989, while 5 691.88 ha area was replaced by agriculture, 2 531.17 ha by bare land, 2 852.08 by built-up area, 1 991.01 by forest and 313.14 ha of vegetation land was replaced by water bodies.

Lastly, 825.08 ha area of water bodies retained the same class in 2019, while 621.14 ha were converted to agriculture, 96.20 ha to bare land, 333.14 to built-up and 65.59 ha to forest, 747.13 ha were converted to vegetation in 2019.

OVERALL GAIN AND LOSS

The study shows an overall reduction of agriculture land of 15.73% and barren land 3.81%. Agriculture was the most common source of income in the Abbottabad District until the eighties. The agriculture system consisted of a mix, including farming, agroforestry, horticulture, floriculture, livestock and animal husbandry in the study period. Although the pattern of land use is basically affected by the increase in population, natural calamities also forced the changes. The primary causes of the land-use change include human decisions resulting in changes in the natural environment. One of the major natural phenomena witnessed in Pakistan was the 2005 earthquake which predominantly altered the pattern of land use in the Abbottabad District.

In the aftermath of the earthquake, the population surged by 3.12% as a result of huge migration from badly affected areas to the urban region. Then, temporary migration turned into permanent settlement. Besides, much of green areas eroded leaving the land barren due to landslides triggered by the earthquake. The massive increase in population forced the reduction of agricultural land as a result of building construction and infrastructure development. Another major cause of land-use change was forced by demographic changes. According to the 2017 census report, the population of Abbottabad rose from 880,666 in 1998 to 1.2 million in 2009. This translates into an increase of 9.3%. The population growth triggered land use change due to the pressure on land resources. Shelter is a basic human need and the results of the study have shown a tremendous growth in settlement during the last decade. Green areas and bare chalk hills have been converted into a residential area following a common trend. This practice gave rise to the construction of high-rise buildings and wide-spread of residential colonies. Several schools have been established along the famous Silk Route that runs through the Abbottabad city resulting in cutting of trees along the roadside.

A major reason of an abnormal population growth in the district is the establishment of several higher educational institutions, which attracted people from different parts of the country. While some settled temporarily, others chose it for their permanent stay due favorable climate. These settlements contributed to hikes of land price and some of the residential and commercial buildings have been converted into hostels to accommodate students hailing from other parts of the country. The Abbottabad District is well known for its pleasant climatic conditions and breath-taking beauty, which attracts people who come to stay permanently as Abbottabad is also a hub for tourism and a gateway to the northern areas. Human activity also contributed to land use change in the area for variety of reasons. The study shows an increase in settlement due to urbanization. Another factor which boosted the land use change includes cultural changes. Historically, people of the area used to live in a multiple family system, i.e. a couple of families living in a single ancestral house.

This trend is now eroding. The majority of people now live in multiple nuclear families, contributing to an increase in settlement area. The study further reveals that the increase in the forest is 2.94% and vegetation 14.06% due to the extensive Shajar Kari Mohim (plantation) in 1998 and afforestation by a billion-tree project. Decrease in the later years has been attributed to the increase in the built-up area and the 2005 earthquake. The government lunched a billion-tree project to improve the ecosystems in 2014 and address the issue of climate change. Another reason for the reduction in agriculture is the lowering of the water table by 0.58% which adversely affected the production of crops. Additionally, natural calamities directly influenced the pattern of land use and affected the natural environment and forced decisions on changing the use of land.

CONCLUSIONS

The exploration of land use land cover change (LULC) has been quite interesting. The study focused on the monitoring of changes in LULC using satellite images for three decades from 1989 to 2019. The period of study clearly indicates a reduction in agriculture and bare land and increase in urbanization, with buildings and infrastructure developed on agricultural land in the Abbottabad Valley. Currently, there is no law regulating the purchase and utilization of agricultural land, so large sections of agricultural land have been converted to residential and commercial properties. The lowering of the water table also contributed to the reduction of agricultural practices as a source of income due to low yields. A major part of agricultural and forest land was converted into the China–Pakistan economic corridor (CPEC) and the Abbottabad bypass. Most of the plain area utilized for agriculture was utilized by road networks, thus reducing agriculture potential of the district to a similar degree as the deforestation added more barren land which in some areas was re-used for agroforestry. Additionally, due to massive population growth, land is used for housing projects. Many people decided to seek other sources of income instead of agriculture developed by their forefathers. This diversity has brought significant changes in social setups of the rural population.

Overall changes in the LULC intensified the pace of development in the Abbottabad District and boosted the mining sector as an attractive optional source of income. Future studies may focus on minerals mining to meet the growing demand from other countries, e.g. China and European countries. As shown by the study, the last three decades have witnessed a conversion of agricultural land into settlements in the Abbottabad city. Furthermore, reforestation is also visible in different images which means that forest has been expanding in some areas despite deforestation by the timber mafia. Land use land cover changes give rise to various issues and challenges. The study can provide an intellectual insight to plan, select and implement land-use schemes, which will assist policy makers and planners to cope with such issues. Additionally, in order to ensure environmental sustainability of the Abbottabad District, the study supports monitoring of the land-use change as a result of the rapid population growth.

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