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Spatio-Temporal Residential Land-Use Change in District Abbottabad by Using Machine Learning Model from 1992-2022, Pakistan

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Abstract

A city not only grows in population but also changes in spatial dimension. Land transformation is a natural phenomenon that can not be stopped but may be regulated. Land is one of the most important sources for human survival and other activities, including its ecosystem. All humans benefit from the available resources on land, which is called land use. The purpose of the study is to monitor land use and land cover in District Abbottabad, focusing on the major transformation in different types of land use changes from 1992 to 2022 by using Geographic Information Systems (GIS), Remote Sensing (RS) technologies, and data visualization performed by Phython Libraries in Machine learning. Supervised digital classification using a maximum likelihood classifier was applied to prepare a land use/land cover map. The land was classified into five categories: settlement, forest, water bodies, barren land, and vegetation cover. Resultant land cover land use overlay maps were generated in ArcMap to indicate the significant shift from Vegetation to Settlement. Analysis revealed that vegetation and forest areas have improved in the study area at a greater pace due to the billion Tsunami project, but settlement is increasing drastically and barren land is also reducing due to urbanization. Water bodies are also being adversely affected due to increasing settlement. The city is facing water stress and a shortage of drinking water. One of the main causes of Population growth is migration from rural and other catering area.

Keywords: Land Use Land Cover change (LULC), Geographic Information System (GIS), Remote Sensing (RS).

1 Introduction

Human beings are continuously changing the shape of the Earth for their use, which has become a critical threat to maintaining balance on the Earth's surface, as well as unchecked human migration and other natural species loss and shifts, becoming a challenge for the natural environment (Rimal, 2011), (Kamarudin et al., 2018). These changes are among the main factors responsible for transformations, particularly in relation to climate, and are essential variables influencing various aspects of human and environmental conditions on planet Earth (Verburg et al., 2011). Change in land structure due to over-exploitation is a critical issue in global environmental change (Findell et al., 2017), with shifts in both land cover and land use becoming increasingly recognized as significant environmental change in their own right over the past 15 years (Rimal, 2011). Rapid economic growth and population expansion drive urbanization and cause substantial changes in land use and land cover (LULC), impacting the environment and resource management. These positive and negative transformations significantly impact LULC dynamics and the structure and function of ecosystems (Turner, 2002). Humans play a key role in regional LULC changes, with anthropogenic influences playing a central role in reshaping landscapes (Butler et al., 2005; Zhang et al., 2020)[7,8]. The detrimental effects of natural environment exploitation, including urban growth, agricultural land fragmentation, and the loss of green areas, destabilize local ecosystems (Yin et al., 2011). Rapid urban expansion is a primary factor for the depletion of agricultural land and green spaces (Turner, 2002; Yin et al., 2011; Zhang et al., 2020), with considerable repercussions for climate and human well-being (Gibson et al., 2018; Khawaldah, 2016).

Socioeconomic development and industrialization have fueled population growth and urban expansion, particularly in peri-urban zones, where facilities related to health and education increase, and cities dramatically alter the urban environment (Liu et al., 2005). Globally, changes in land cover patterns are categorized into two primary types: intensification, which encompasses the removal of forest for urban centers, clearance of land for agricultural expansion, and urban development, which pertains to afforestation and land conservation measures. Intensification denotes the swift encroachment of urban and agricultural zones into natural environments. In contrast, extensification emphasizes approaches to alleviate the effects of rapid land use and land cover shifts on the ecosystem (Qiao et al., 2020; Wang et al., 2018). Currently, over 55% of the worldwide population inhabits metropolitan regions, a statistic projected to increase to 70% by 2050 (Jogun et al., 2019; Silva et al., 2018). Urbanization is progressing at a rate twice that of global population growth (Dıaz et al., 2011; Gu, 2019). In developed countries, urbanization tends to follow a more synchronized pattern, stabilizing at certain levels (Rimal et al., 2020; Seto et al., 2012), whereas developing countries often experience either over-urbanization or under-urbanization (Chan, 2010; Yang et al., 2014). Urbanization is closely linked to socioeconomic development, with urbanization driving further economic growth (Nations, 2019). Cities contribute to nearly 80% of the global GDP (Grubler & Fisk, 2012).

Human-induced environmental changes significantly contribute to biodiversity loss up to 10% of the world's natural species (Gainsbury et al., 2022; Yang et al., 2022). Urban forests provide a range of ecosystem services (ES) that not only support urban biodiversity but also help mitigate air pollution and other environment-related burning issues (Al-Faraj & Scholz, 2015; Gainsbury et al., 2022; Yang et al., 2022). The reduction of these urban forests markedly decreases the diversity of natural species (Al-Faraj & Scholz, 2015; Yang et al., 2022). This results in disturbances in the behaviors of indigenous species, including aging, locomotion, and reproduction. The determinants of land use and land cover changes are influenced by diverse research emphases, spatiotemporal fluctuations, and geographic locations (Rimal, 2011). Although prior research has examined the historical determinants of land use and land cover (LULC) modification, the precise factors affecting future LULC alterations, especially in urban forests, are still ambiguous. Comprehending the elements that influence urban forest dynamics can yield significant insights for policymaking and planning initiatives focused on ecosystem conservation (Veldkamp et al., 2017; Wasige et al., 2013).

1.1 Study Area

Abbottabad District is situated in the Hazara Division of Khyber Pakhtunkhwa, Pakistan, and extends from 34°09’21” N Latitude and 73°13’10” °E longitude, covering an area of 1,967 km² as shown in Figure 1. District Abbottabad is encircled by the District Mansehra in the north, Muzaffarabad (Azad Kashmir) in the east, Rawalpindi in the south, and District Haripur in the west. Renowned for its pleasant climate and breath-taking landscapes, Abbottabad attracts both tourists and residents, with tourism playing a crucial role in its economy. During the hot summer months, when temperatures in Pakistan’s plains soar above 45 °C, people from far-flung areas flock to Abbottabad to escape the intense heat. Despite its reputation for a temperate climate, Abbottabad has largely been spared from the pressures of rapid population growth, which has been reshaping the environmental landscape in many other regions. Once covered with lush pine forests, the district is now undergoing significant land use changes due to the expansion of residential and commercial developments. Historically a peaceful region known for its favorable climate and abundant natural beauty, Abbottabad has undergone notable transformations in recent years. Factors such as the 2005 earthquake, the district’s attractive climate, and the growth of higher education institutions between 1992 and 2022 have fueled an influx of migrants. This population growth has driven housing societies and commercial spaces, driving up land prices. The rapid urbanization, coupled with inadequate land-use planning and sustainable development practices, has introduced several environmental challenges, including declining water levels, drinking water contamination, lack of proper drainage systems, increased risk of flooding, increased traffic, and rising air pollution—issues that were once absent in Abbottabad.

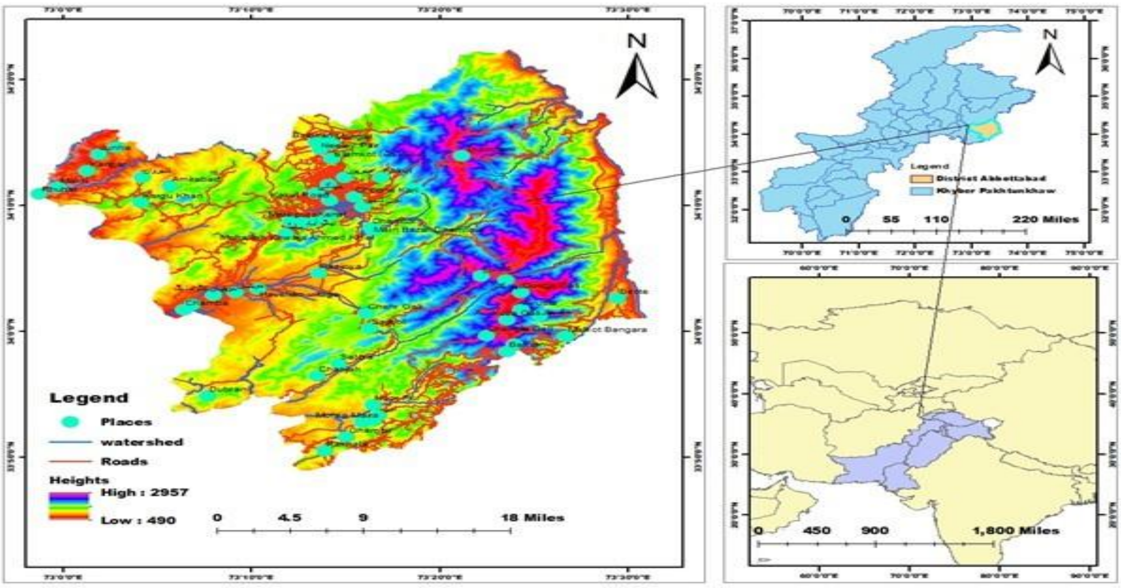

Fig. 1 Study Area of District Abbottabad

These changes threaten to disrupt the long-standing balance between the people and their environment, underscoring the need for comprehensive land-use planning to address growing resource demands and improve human welfare (Chang, 2019). Additionally, such data is critical for monitoring the dynamic shifts in land use driven by population growth and evolving socio-economic needs.

Geographic information systems and remote sensing technologies provide cost-effective, multi-temporal, and real-time data that help detect spatio-temporal dynamics in land-use patterns (Green et al., 1994; Michalak, 1993; Walter, 2004). RS methods offer abundant data from various spectral and temporal perspectives, which can be transformed into actionable information for monitoring and understanding land development (Chang, 2019; Pijanowski at al., 2002). This paper will highlight the land use changes in the Abbottabad district using GIS and RS techniques. No prior research has been conducted on land use changes in this area for the past three decades. This study, being the first of its kind, provides valuable insights for future urban planning and development in Abbottabad. The main objectives of this research area are:

- to analyze land use changes in the district over the past 3 decades.
- to determine the land use transitions between various land use types over the 30 years (1992-2022).

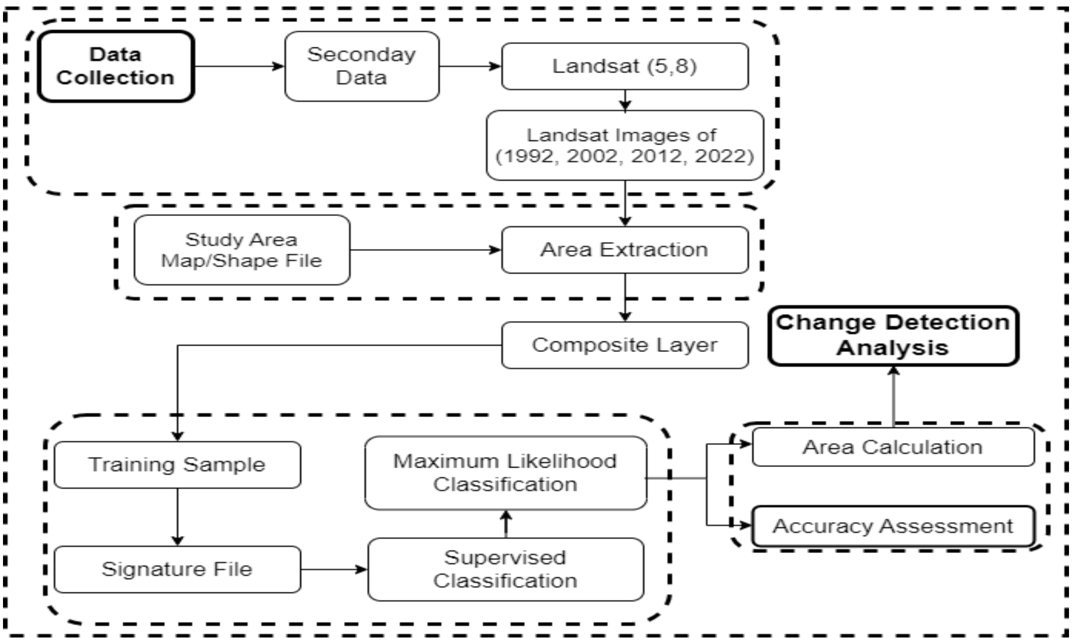

Fig. 2 Methodological Framework

2 Methods and Materials

2.1 Data Acquisition

For the years 1992, 2002, 2012, and 2022, as shown in Figure 2, we obtained Landsat TM, TM, and ETM+ images from the United States Geological Survey (USGS) (Raza et al., 2012). The USGS provides free imagery for research purposes; we were able to obtain reasonably high-resolution images from the Landsat dataset. The satellite images were captured during the autumn seasons of 1992,2002, 2012, and 2022. Bands 3, 2, and 1 were utilized for the red, blue, and green channels, respectively. Additionally, we obtained a map of the Abbottabad district, including general topographic information (GT), road networks, forests, and water bodies, from the Survey of Pakistan.

2.2 GIS Data Processing

Georeferencing is crucial for accurately positioning the coordinates of scanned topo-graphic maps. Once georeferencing was completed, we created GIS layers using ArcView 3.1 (Hill & Sturm, 1991), which were then used to identify land use classes.

2.3 Remote Sensing Image Processing

Before interpretation, the satellite images were first clipped to the study area, i.e., Abbottabad district, from the larger image using ArcMap 10.8 (Franklin & Giles, 1995). The image processing included georeferencing, radiometric correction (Paola & Schowengerdt, 1995) and image enhancement. The corrected image was used for band composite and then masking the area of interest, i.e., Abbottabad. For geometric correction, we used the random distortion method.

2.4 Satellite Image Classification

Five land use categories in the Abbottabad district, Settlement, Vegetative Land, Forest, Water Body, and Barren Land, were used for this study. Furthermore, satellite images were classified into land use classes by using the Maximum Likelihood Classification (MLC) decision rule (Jogun et al., 2019).

2.5 Accuracy Check

We use Google Maps Pro to validate the accuracy of classified images. Google Maps Pro can integrate Maximum Likelihood Classification (MLC) results with KML (Keyhole Markup Language) by importing the classified data as KML files, allowing spatial visualization of classified regions. The MLC results, once exported to KML format, can be overlaid on ArcGIS 10.8 to represent different land cover classes for analysis and decision-making. The accuracy of classification is highly linked with the analyst's understanding of the distinguishing features of land use classes and the ability to identify small variations in reflectance values. When overlaying the classified image on the original satellite image, the land use classes closely matched the actual features on the ground, as shown in Table 1.

Table 1 Classification Results (1992, 2002, 2012, 2022)

YEAR	User Accuracy %	Producer Accuracy%	Overall Accuracy	Kappa Coefficient
1992	86	91	90	0.9
2002	84.3	83.5	90	0.82
2012	87.3	86.0	93.33	0.86
2022	85	90	90	0.9

3 Results and Discussion

3.1 Land Use Distribution for the Years 1992, 2002, and 2012, 2022

Data were evaluated using GIS and remote sensing techniques to successfully detect changes in the Abbottabad district. The precision of the outcomes is predominantly contingent upon the analyst's proficiency in recognizing and distinguishing land use categories from satellite imagery. We computed the area and % coverage for each land use category using the categorized pictures from three decades. The recognized land use categories were Settlement, Vegetation, Water, Forest, and Barren Land, as shown in Table 2.

Table 2 Description of LULC Classes in the Study Area

LULC Classes	Description
Settlement	Settlement and urban structure, including houses
Water	Water bodies, including Kunar and Siran
Vegetation	Typically, land devoted to agriculture and other grazing land
Barren land	Bare hills and areas with no vegetation
Forest	A large area dominated by dense trees

Table 3 summarizes the area and percentage covered for each class in the years 1992, 2002, 2012, and 2022. In Table 3, an increase in settlements in 2012 and 2022 can be seen. This can be attributed to increased migration due to the provision of facilities in the education and health sectors, increased developmental activities, and more pleasant weather conditions.

Table 3 Showing area in Square km and % change over the years

	1992		2002		2012		2022	
LULC Classes	Area(Km^2)	%	Area(Km^2)	%	Area(Km^2)	%	Area(Km^2)	%
Settlement	157.07	7.99	189.17	9.62	250	13	500	25.42
Water	81.42	4.14	144.04	7.33	296	15	362	18.4
Vegetation	360.26	18.31	841.34	42.77	640	32	507	25.78
Barren land	426.33	21.67	332.48	16.9	191	10	158	8.03
Forest	941.92	47.89	459.97	23.38	590	30	440	22.37
Total	1967	100	1967	100	1967	100	1967	100

Following the 2005 earthquake, a noticeable migration trend was seen in Abbottabad, as the region, though impacted by the earthquake, suffered comparatively less severe damage than other affected areas. Besides migration, there has been a rapid expansion of facilities like higher education institutions and improved health facilities in the district.

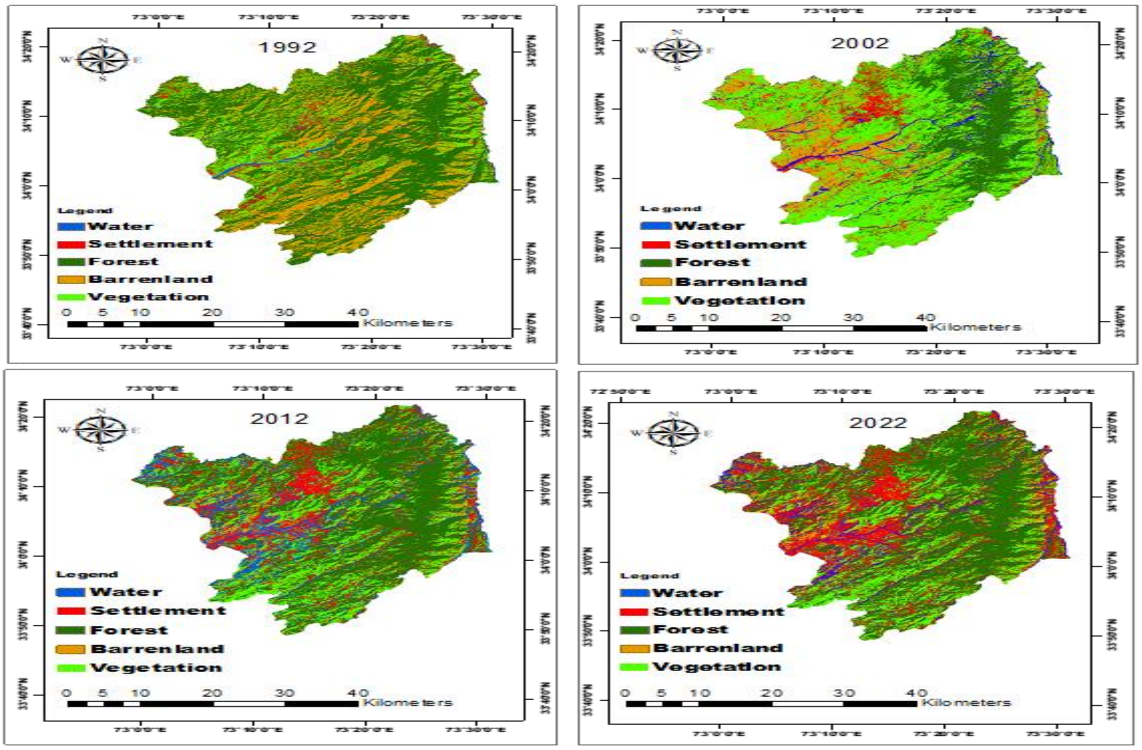

Fig. 3 Land Use Change Detection in District Abbottabad (1992-2022)

3.2 Analysis of Land Use Classes Using Change Detection

The analysis of land use classes through change detection is crucial for understanding the direction and dynamics of land use changes over time. The change detection reveals both desirable and undesirable shifts in land use, helping to identify land use classes that have remained stable or experienced significant changes. Examining this change detection can help us better understand the processes driving land use transitions in the district. We computed the change detection by using Python 3.11, a statistical software that allows us to track land use conversions between different classes between 1992 and 2022.

3.3 Observed Changes and Distribution of LULC

LULC is not a static phenomenon; it is dynamic and always challenging. Figure 4 shows the percentages of different LULC classes for the corresponding years. From 1992 to 2022, forest and vegetation showed an increasing and decreasing trend. Settlement showed an increasing trend, and this trend drastically changed after the earthquake in 2005. Settlement in 1992 was observed at 7.99%, in 2002 at 9.62%, in 2012 at 13%, and in 2022 at 25.42%. Similarly, water bodies showed an increase of 4.14, 7.33, 15, and 18.4 in the respective years from 1992, 2002, 2012, and 2022. Similarly, vegetable production showed an increase of 18.31% to 23.38%, and after 2012, it showed a prominent decrease of 32% and 25.78%. Baren land was observed in decline mode in 1992. It was 21.67% in 2002, 16.9% in 2012, 10%, and 8.03%, respectively. Forests are considered the backbone of any place; in the district Abbottabad, a sharp decrease from 1992 to 2024 was observed. Results showed 47.89% in 1992, followed by a decline to 23.38% in 2002. In 2012, a slight increase of 30 % occurred, and then the values declined to 22.37% in 2024.

Figure 5 shows the change detection analysis for land use classes between 1992 and 2022, which shows significant shifts across different periods. From 1992 to 2022, the Settlement class experienced a positive increase of 20.44%, continuing with a higher increase of 32.16% from 2002 to 2012 and a significant jump of 100% from 2012 to 2022, indicating consistent growth over the periods. It shows clear urban expansion from 2012 to 2022. However, the Forest class experienced a sharp decline of -51.17% from 1992 to 2002, recovered slightly with an increase of 28.27% from 2002 to 2012, and then saw another decline of -25.42% from 2012 to 2022, reflecting a complex trend with both losses and gains in different periods, from 1992 to 2002. The Water class saw a substantial rise of 76.91% from 1992 to 2002, followed by an even larger increase of 105.50% from 2002 to 2012, but there was a slight decline of 22.30% from 2012 to 2022. In contrast, the Vegetation class showed significant growth of 133.54% between 1992 and 2002, followed by a decline of -23.93% from 2002 to 2012 and a further decrease of -20.78% from 2012 to 2022, indicating a shift toward negative trends in the more recent years. Barren Land faced a consistent decline across all periods, with a decrease of -22.01% from 1992 to 2002, -42.55% from 2002 to 2012, and -17.28% from 2012 to 2022, showing a persistent decrease, though at a slower rate in the last period. These trends highlight the ongoing shifts in land use, with significant implications for environmental management and urbanization. Figure 5 shows that the settlement area in 1992 was 157.07 km2, and by 2024, it had increased to 500 km2, indicating a total change of 17.42%. The increase in settlement area indicates a positive transformation, reflecting the significant growth of urban and residential areas relative to the total land area in 1992. This change highlights the increasing demand for land for settlement purposes over the past few decades. The water area in 1992 was 81.42 km^2, and by 2024, it expanded to 362km^2, for an overall percentage change of 14.31%. The increase in water area represents a positive transformation, indicating the expansion of water bodies, which may be attributed to factors such as water conservation efforts, the creation of artificial lakes, or changes in climate patterns. This growth shows a positive shift in land use towards more water coverage.

$$\text{Overall Percentage Change} = \frac{A2022 - A1992}{A1992} \times 100 \qquad (1)$$

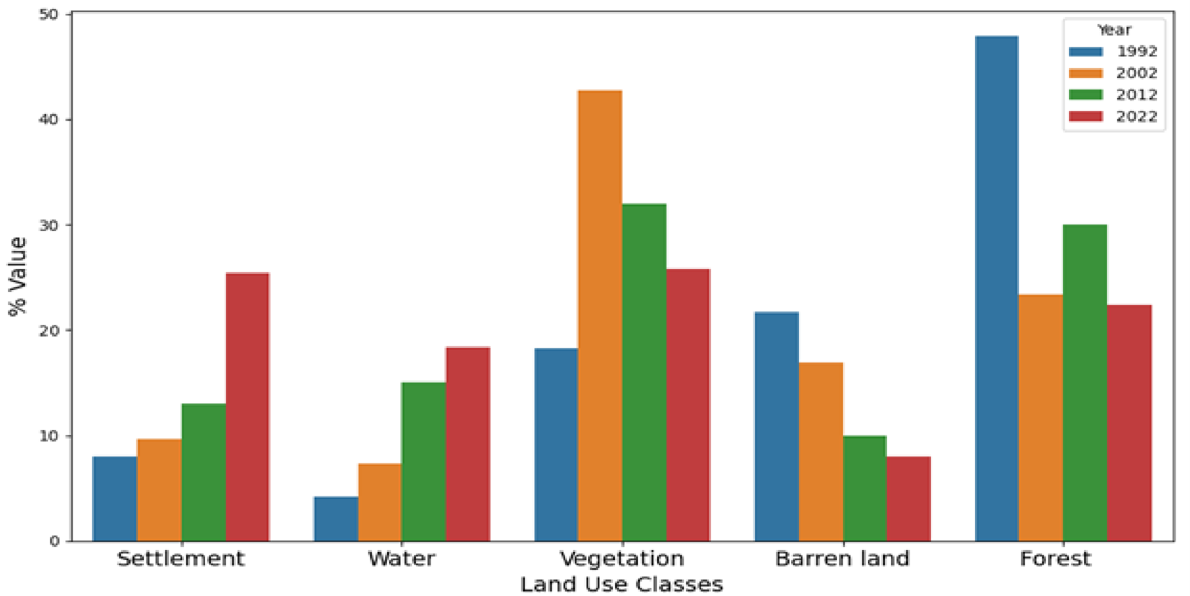

Fig. 4 Land Use classes change % from (1992-2022)

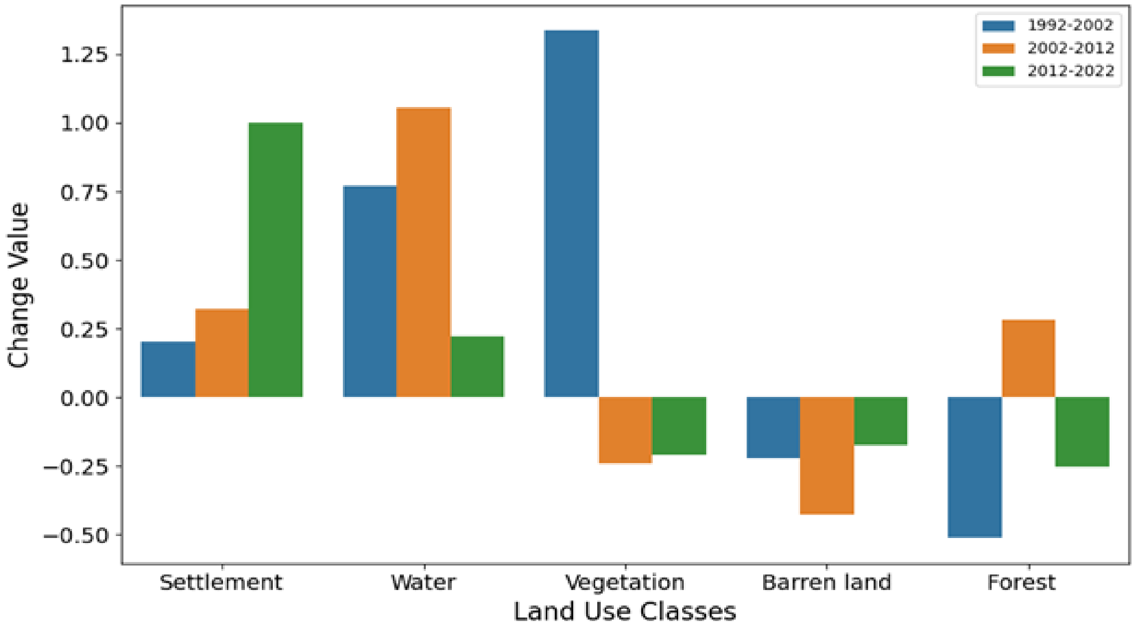

Fig. 5 Percentage Change Detection from (1992-2022)

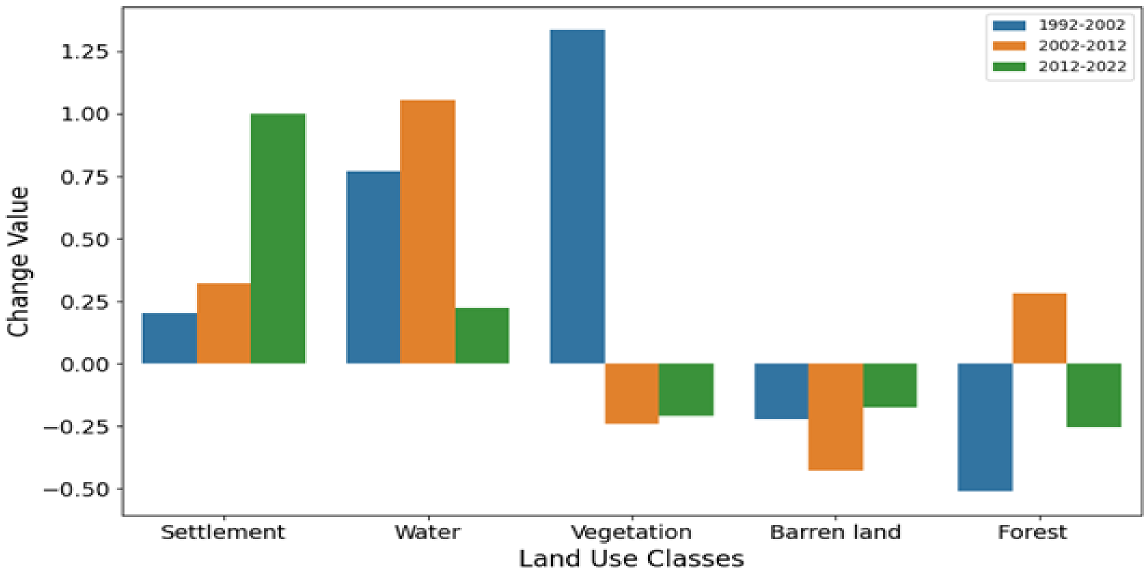

Fig. 6 Positive and negative transformation of Land use changes(1992-2022)

In 1992, the vegetation area was 360.26 km^2, and by 2022, it had increased to 507 km2. The overall percentage change in vegetation area is 7.47%, reflecting both positive and negative transformations in vegetation cover. This increase suggests some level of environmental recovery or expansion of green spaces, but it also shows a decline, meaning that due to migration and urban expansion, vegetation started declining after 2012, although the growth is relatively modest compared to other land use categories. The barren land area in 1992 was 426.33 km^2, and by 2022, it had decreased to 158 km^2. This result is an overall percentage change of -

13.64%, indicating a negative transformation. The reduction in barren land suggests either the reclamation of barren areas for other uses, such as agriculture or urban development, or natural changes that have rendered those areas more productive. This negative transformation is a significant shift in the land use pattern, reflecting a decrease in the proportion of unproductive land. The forest area in 1992 was 941.92 km^2, and by 2022, it had decreased up to 440 km^2. The overall percentage change in forest area is -30.34%, representing a negative transformation. The reduction in forested areas indicates deforestation or conversion of forests to other land uses such as agriculture or urbanisation. This significant decline in forest area raises concerns about environmental sustainability and the loss of biodiversity in the region.

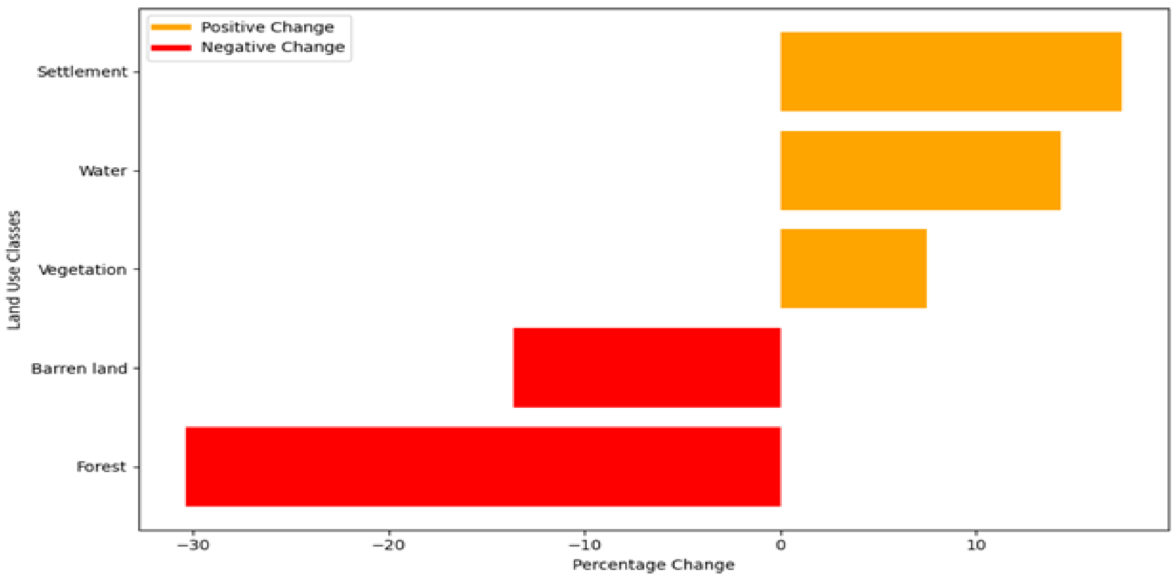

Fig. 7 District Abbottabad shows a varying trend across the entire district from 1992 to 2022 in land use classes

3.4 Settlement

There has been a steady increase in settlement areas over the years. From 1992 to 2002, the settlement area increased by 32.1 km^2, which was a 20.45% rise. This trend continued from 2002 to 2012, with an increase of 60.83 km^2 (32.18% rise). The sharpest increase occurred between 2012 and 2022, with the settlement area growing by 250 km^2 (100% increase). This suggests an accelerating trend in urbanization or infrastructure development in the region.

3.5 Water

The area of water bodies has shown a consistent increase across all periods. From 1992 to 2002, the water area grew by 62.62 km^2 (76.90%). This trend continued into the following decade (2002 to 2012) with an increase of 151.30 km^2 (105.91%). However, the rate of increase slowed down between 2012 and 2022, with an additional increase of 66 km^2 (22.97%), still showing a growth pattern, though at a slower pace.

3.6 Vegetation

Vegetation experienced a dramatic increase from 1992 to 2002, with an increase of 481.08 km^2 (133.52%). This was followed by a decrease from 2002 to 2012, when the area shrank by 201.34 km^2 (-23.88 %). The decline continued between 2012 and 2022, with a further decrease of 133 km^2 (-20.83%), which could be attributed to deforestation, urbanization, or other land use changes reducing vegetative cover in the area.

3.7 Barren Land

Barren land areas have significantly decreased over the years. Between 1992 and 2002, barren land shrank by 93.85 km^2 (22.02%). The reduction continued through 2002 to 2012, with a further decline of 141.48 km^2 (42.58%). Between 2012 and 2022, barren land decreased by 33 km^2 (17.25%), suggesting possible land reclamation or natural processes reducing barren land.

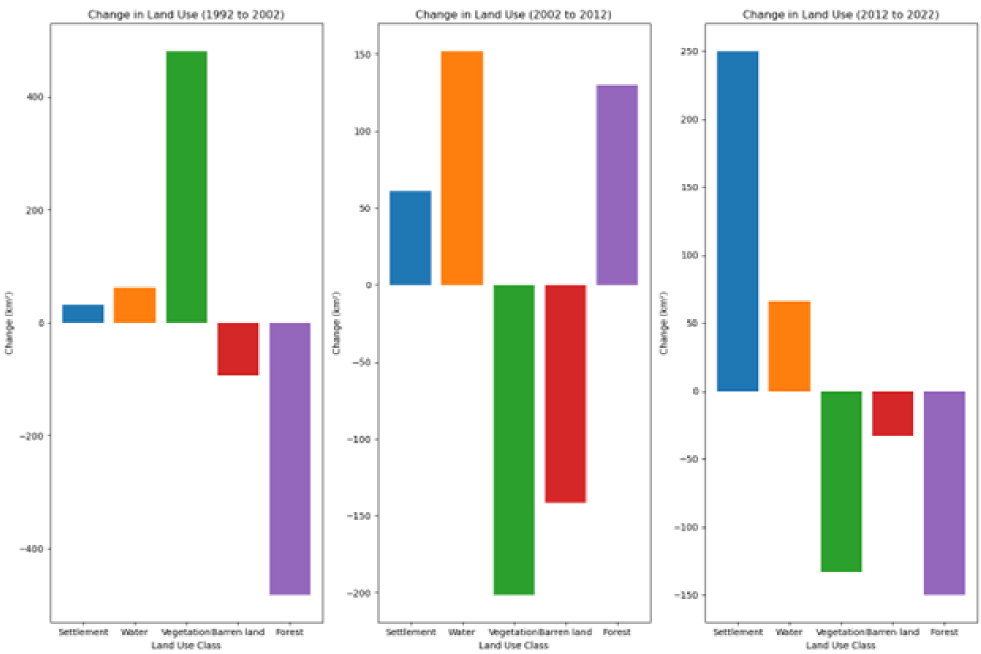

Fig. 8 Observed changes over time (1992-2022)

3.8 Forest

Forest cover declined across all periods. From 1992 to 2002, forest areas decreased by 481.95

km^2 (-51.17%). Between 2002 and 2012, the decline slowed, with a reduction of 131.93 km^2 (-28.30%). From 2012 to 2022, the decrease was 150 km^2 (-25.42%), indicating continued loss of forest areas or land conversion for other uses.

Figure 8 illustrates the changes in land use over the period from 1992 to 2022 for five land use classes: Settlement, Water, Vegetation, Barren Land, and Forest. From the graph, it is clear that the Settlement area has experienced significant growth, particularly from 2012 to 2022, with an increase from 250 km^2 to 500 km^2. In contrast, Vegetation shows a decline in area, especially from 2002 to 2012, when it decreased from 841.34 km^2 to 640 km^2, and continued to decline to 507 km^2 by 2022. The Water area has seen steady growth over the years, with a noticeable increase between 1992 and 2002, growing from 81.42 km^2 to 144.04 km^2. The Barren Land category also saw a significant decrease, from 426.33 km^2 in 1992 to just 158 km^2 in 2022, reflecting a substantial reduction in this land use class. Lastly, Forest cover has fluctuated over the years, showing a sharp decline from 941.92 km^2 in 1992 to 459.97 km^2 in 2002, before recovering slightly to 590 km^2 in 2012, and then decreasing again to 440 km^2 by 2022. These trends indicate significant shifts in land use, with urbanization and water bodies expanding, while vegetation and barren lands have reduced. Forest cover has been notably affected over the three decades.

4 Discussion

The imminent expansion of settlement and cultivation has been observed across the sub-catchments, with notable changes in land use and land cover (LULC) patterns driven by economic forces. The demand for agricultural land and residential purposes is increasingly influencing land use decisions. This is evidence that different land use types are being converted, particularly from natural areas into cultivated and residential land.

From 1992 to 2022, settlement areas saw a substantial increase, growing from 157.07 km^2 (7.99%) in 1992 to 500 km^2 (25.42%) in 2022, driven by the growing need for housing and agricultural land due to population growth. Similarly, water bodies expanded, with upstream areas decreasing by 68% and downstream by 10%, leading to an overall increase in water bodies from 81.42 km^2 (4.14%) to 362 km^2 (18.4%) over the same period. This growth is likely a result of changes in water management and land use practices.

However, vegetation areas experienced a noticeable decline over the years. The area covered by vegetation dropped from 360.26 km^2 (18.31%) in 1992 to 507 km^2 (25.78%) in 2022, reflecting the pressures of agricultural expansion and urban development. Barren land also decreased significantly, from 426.33 km^2 (21.67%) in 1992 to 158 km^2 (8.03%) in 2022, as the land was increasingly converted into cultivated areas. Forested areas, crucial for maintaining ecological balance, also saw a reduction, with forest cover shrinking from 941.92 km^2 (47.89%) in 1992 to 440 km^2 (22.37%) in 2022, highlighting the impact of deforestation driven by agricultural and settlement needs.

5 Causes of Land Use Change

5.1 Natural Forces

One major natural event that greatly impacted the district of Abbottabad was the 2005 earthquake, which altered land use patterns in the region. Post-earthquake, some land use changes appear to reverse, particularly in the settlement and vegetative land categories, besides landslides in the hilly stations. After the earthquake, settlement in the district increased dramatically by 5.41%. This can be attributed to the migration of people from earthquake-affected areas, who sought refuge and eventually settled in Abbottabad.

Post-earthquake landslides caused a decline in vegetative land and forest. These landslides caused erosion of green areas, leaving the land barren. The earthquake also contributed to increased deforestation and the conversion of vegetative land into built-up areas, as people cut down trees for fuel and to create new residential spaces.

5.2 Demographic Pressure

Demographic factors significantly influence land-use change, with population growth increasing pressure on land resources. According to the 1998 census, the population of District Abbottabad was 880,666 and by 2009, this figure had risen to 1.2 million.

5.3 Establishment of Educational Institutes

In the past decade, the establishment of numerous higher education institutions in the district has attracted people from all over the country. These institutions have contributed to the population growth in Abbottabad and raised land values. As a result, development activities have surged, particularly in areas near universities. Many agricultural lands around COMSATS and PMA have been converted into unplanned residential areas, leading to various environmental and management issues.

5.4 Climatic Conditions

District Abbottabad is renowned for its breathtaking beauty and tourist attractions. The district has become a hub for tourism, attracting people from across the country who visit to enjoy its weather and natural surroundings. After retirement, many individuals, especially from the armed forces, prefer to settle in Abbottabad due to its favorable climate. This has contributed to the population increase and further driven land-use changes in the area.

5.5 Human Activities

Human activities are often considered the primary drivers of land-use change. Key activities such as agriculture, livestock raising, urbanization, deforestation, construction, and development significantly alter land-use patterns. Our analysis shows a 17.47% overall increase in settlement, a clear indication of urbanization. This process results in the conversion of agricultural and grassland areas into urban settlements.

Urbanization is linked to development, and as new commercial plazas are constructed on previously fertile land, the pressure on local resources intensifies. Results show that 48% of the vegetative land from 1992 had been converted into settlement areas by 2012. Additionally, the forest areas have been cleared to make way for new settlements, contributing to deforestation and soil erosion, as in Gumawan. These environmental changes have far-reaching impacts on public health, safety, and the local economy.

5.6 Mining

Numerous minerals, including barite, gypsum, limestone, and coal, are extracted, with more than 300 mining permits granted in the district. Many of the mines are located in elevated regions near water bodies, resulting in the contamination of drinking water sources, which poses a threat to 108 communities that indulge in mining and the rest of the population. About 18% of the mines are located in landslide-prone zones, and 52%. According to (SMEDA KPK) mining activities pose a significant risk to both the environment and local communities' safety, as 4.8% of the area is exposed to mining.

5.7 Cultural Changes

Cultural shifts also play a role in land-use changes. In the past, extended families in Abbottabad lived together in one household. However, due to modern influences, many families are now breaking into smaller nuclear units. This societal change is responsible for an increase in the demand for housing, thereby contributing to the growth of settlements in the district. Impacts of Land-Use Change in Abbottabad Land-use change can provide some economic benefits but also destroy the natural environment. There is a need to guide decision-makers in creating effective policies to mitigate the adverse effects of land-use changes and preserve the district's natural beauty for future generations.

5.8 Climate Change

Changes in land use have a direct impact on the climate. Various natural processes are interconnected, meaning changes in one process often affect others. For example, human-linked activities such as fossil fuel burning, removal of forests, and clearance of lands for agriculture release carbon dioxide (CO2) and greenhouse gases, contributing to global warming. In Abbottabad, the settlement area has increased by 9.62% since 2002, reflecting population growth and mounting pressure on natural resources. This has led to a decrease in vegetative land and barren land. Population growth directly correlates with increased fuel consumption for cooking, heating, and transportation, releasing more CO_2 into the atmosphere. This contributes to rising temperatures in the region. In the past, Abbottabad experienced significant snowfall; however, urbanization, transportation, and increased fossil fuel burning have reduced snowfall in the city. In contrast, the surrounding mountains continue to receive substantial snowfall, helping to moderate summer temperatures in the city.

Mining activities, particularly in areas like Ghomanwan and Thandiani, have caused the complete removal of hills, altered the landscape, and released large quantities of particulates into the air. These particulates absorb solar radiation, further raising atmospheric temperatures and posing serious health risks.

5.9 Landslides

Deforestation and vegetation removal significantly increase soil vulnerability to erosion, leading to a rise in landslides in Abbottabad. Our findings show that vegetated land decreased between 1992 and 2002 due to land-use changes. Additionally, agricultural practices on steep terrain destabilize soil, making it more prone to erosion. Mining operations, especially in landslide-prone areas, further contribute to soil instability. Around 18% of mining activities in Abbottabad are the major cause of landslides.

5.10 Pollution

Pollution is contamination that badly affects human health and is also linked to changes in land use. Abbottabad has also started becoming the hub of this.

5.10.1 *Water Pollution*

Urbanization has significantly impacted water resources and quality. From 1992 to 2022, settlement areas in Abbottabad increased by 7 to 25%, water increased by 4.14to 18.4%, while vegetative land 18 to 42%, dropping to 32 and then 25 up to 2022, showing a decrease and increase from 1992 to 2002 and 2012, forest and barren land decreased by 30.34% and -13.64%, respectively. This land conversion has led to an increase in impervious surfaces, altering the area's natural hydrological balance. This, in turn, increases surface runoff during heavy rainfall and reduces groundwater recharge, as evidenced by Abbottabad's recurrent flooding during the rainy season.

Impervious surfaces trap pollutants, including heavy metals, sediment, oil, grease, pesticides, and faecal coliform bacteria, which are then carried into water bodies during rainfall, compromising water quality. In Abbottabad, the proximity of sewage and drinking water pipes often leads to contamination, contributing to waterborne diseases like typhoid fever. Open drains are another common issue, with examples like the blocked drains on COMSATS University Road, which exacerbate waterlogging, create health risks, and damage the area's aesthetic quality. Mining operations also threaten water quality. Mines in Abbottabad are located within 2 kilometers of water bodies from Harno to Gumawan, and the residues from these mines often pollute drinking water sources.

5.10.2 *Air Pollution*

The growth of settlements has led to an increase in vehicles and fuel combustion, contributing to poor air quality in Abbottabad. Additionally, mining activities release dust particles that deteriorate air quality. These pollutants can penetrate deep into the lungs, causing severe health issues.

During summer, the influx of visitors to Abbottabad adds to the pollution caused by vehicles. Unfortunately, the region's infrastructure is not equipped to handle the growing traffic, exacerbating the pollution problem. If urbanization continued unchecked, air quality may worsen, creating long-term environmental and health challenges.

6 Conclusion

Over the past three decades, Abbottabad has undergone prominent and significant land-use changes driven by Population increase and environmental and anthropogenic factors. The 2005 earthquake played a role in these changes as people from catering areas moved toward Abbottabad. This resulted in reduced vegetation and bare land and an increase in settlements, but stress was placed on forests, vegetation, and water bodies. Specifically, barren land and forest decreased from 2002 to 2012; bare land decreased from 21.67% to 16.9%, and forests decreased from 48% to 23%. The unchecked and uneven land-use changes in Abbottabad have led to severe environmental consequences, including water contamination, poor air quality, and changes in the local climate. These changes pose significant risks to the health and well-being of the local population. If this trend continues, future generations may not experience the same environmental richness and beauty that Abbottabad once offered. This study provides valuable information on land-use changes, their impacts, and trends, which can help to inform urban planners and policies to mitigate environmental degradation. By understanding these changes, local authorities can work towards improving environmental sustainability and achieving a more balanced future for Abbottabad.

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