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MONITORING TRENDS OF LAND USE LAND COVER AND URBAN SPRAWL SINCE 1989 IN RAPIDLY GROWING CITIES OF PAKISTAN USING MULTI-TEMPORAL REMOTE SENSING DATA

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Abstract

Urbanization is becoming one of the major cause of land use land cover change particularly in developing countries and this transformation of land to urban and constructed-up is altering an area's overall climate and physical features. To study the relationship between population growth, urban sprawl, conversion of land use, and its effect on the environment, the land cover analysis and its transformation are the main factors considered. The present study utilizes the Landsat data (TM and OLI) for the years 1989,1999,2013 and 2019 to detect the land use changes (Urbanization, vegetation, barren land, and water) in 11 different fast-growing cities in Pakistan using the supervised image classification method and to understand how these cities have been spreading. Later, the impact of population growth was examined with an increase in urbanization using Pearson's correlation. The results indicated that the built-up areas within these cities have been expanding significantly as the population has grown over this period. In fact, there is a clear and moderate positive connection of R^2=0.392 between the growth in population of 1998 and the expansion of urban areas in 1999. Similarly, a correlation of 0.697 (R^2= 0.50) between 2017 census data and 2019 urban area characteristics implies a recognizable relationship between the demographic composition of the population and the corresponding urban attributes. To enhance the full benefits of urbanization in Pakistan, it is essential to undergo a significant transformation in the governance of cities. Despite their considerable economic contributions, cities have been absent from broader policy discussions. Furthermore, the failure to acknowledge the continuous growth of cities hinders urban planners and city managers from adopting a holistic and adaptive approach to address urban challenges. The lack of data on cities and faulty methods for estimating urbanization further complicate the issue, resulting in an understatement of the truth of urbanization. The capacity to effectively address the needs of cities remains uncertain and challenging.

Keywords: Land Use Land Cover Change, Urban Sprawl, Population, Remote Sensing.

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1. INTRODUCTION

As the human population increases, demand for housing and other necessary infrastructure to make life comfortable becomes high. Consequently, rural areas become urbanized to meet the growing demand [1]. Approximately 54% of the world's urban population lies in Asia United Nations, Department of Economic and Social Affairs, Population Division, 2018), where urbanization is rapidly converting agricultural land to build up area thus altering an area's overall climate and physical features [2].

Urban expansion can be described as a particular form of urban development, including either commercial or industrial development, less compact or single-use development, leapfrog or scattered development and lack of access and open spaces due to uncontrolled and unplanned growth [3,4]. The Earth's surface, including forests, mountains, and water, is called "land cover" (LC).

However, land use (LU) refers to human-caused changes to land cover (LC), such as road and urban infrastructure construction. The impact of human activities on ecosystem processes, biodiversity, hydrology, and climate is significant [5,6,7]. Despite different views on the change in land patterns over the past few years in developing nations, urbanization is found as the primary factor responsible [8,9].

The integration of Geographic Information Systems (GIS) and Remote Sensing (RS) techniques enables the acquisition of accurate and up-to-date information regarding the spatial patterns of Land Use and Land Cover (LULC) transformations in extensive areas. They offer expedited and streamlined alternatives to conventional survey techniques for investigating expansion, urbanization, and alterations occurring on the Earth's surface, employing varied time intervals [10].

The Earth Resource Technology Satellite (ERTS), later known as Landsat 1 launched in 1972 has contributed significantly to the development of remote sensing applications viz., Land Use Land Cover (LULC) classification, monitoring land cover, and identifying spatio-temporal changes [11,12].

Land use and land cover (LULC) changes affect natural landscapes worldwide hence they have been studied more in recent decades. The intricate interaction between environmental variables and human activities at multiple spatial and temporal scales causes urban development. Urban sprawl has its great environmental and political impact [13,14].

Pakistan is experiencing rapid urbanization in South Asia because of population expansion, industrialization, increased economic and social engagement, and intensified land utilization. According to a study conducted, Pakistan experiences an annual urban population growth rate of 3% [15].

Several studies have been done on the land use and land cover (LULC) alterations in metropolitan regions of Pakistan. It has been reported that there will be an expansion of both cultivable and built-up land in all regions of metropolitan centers in Pakistan, with a particular focus on the province of Punjab [16].

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The accelerated transformation of land use and land cover (LULC) has resulted in various ecological implications, including the decline in habitat integrity and the degradation of landscape conditions [17].

Pakistan comes at number five in the list of most populous countries in the world (Pakistan Economic Survey 2019–20). The rapid rate of population growth and urbanization has increased the demand for housing and concrete buildings in cities.

As a result of this exceptional population growth and level of urbanization, many functions of the environment viz., the formation of soil, its protection, agriculture, and consumption of energy [18,19], quality and quantity of water are worsening [20,21].

The goal of this study to use remotely sensed data to classify LULC changes and nature of urban sprawl since 1989 in response to population growth in eleven fast growing cities of Pakistan.

1.1 Objectives

1) To calculate the spatio-temporal distribution of urban sprawl in 11 rapidly growing cities of Pakistan.
2) To calculate the correlation between urban sprawl and population growth from 1989-2019.

2. MATERIAL AND METHODS

Multi-temporal remote sensing data has been utilized to track urban sprawl from 1989 till 2019. This includes the classification of time-series satellite data, the change detection and the correlation between urbanization and population data.

2.1. Study area description

Pakistan is rapidly becoming more urbanized, with an annual growth rate of 2.7%, making it one of the fastest-growing South Asian countries in terms of urbanization according to the Pakistan Bureau of Statistics (PBS). Both natural city growth and rural-to-urban migration are responsible factors. The metropolitan areas are expanding faster than their surrounding municipalities [22].

Eleven rapidly growing cities of Pakistan were selected including ten major cities viz., Faisalabad, Gujranwala, Hyderabad, Karachi, Lahore, Multan, Peshawar, Murree, Islamabad, Quetta and Rawalpindi.

Karachi, is the most populous city with a total population of twenty million [23]. Murree is one of the largest tourist attractions of Pakistan and has undergone rapid urbanization in the last decade (Fig 1).

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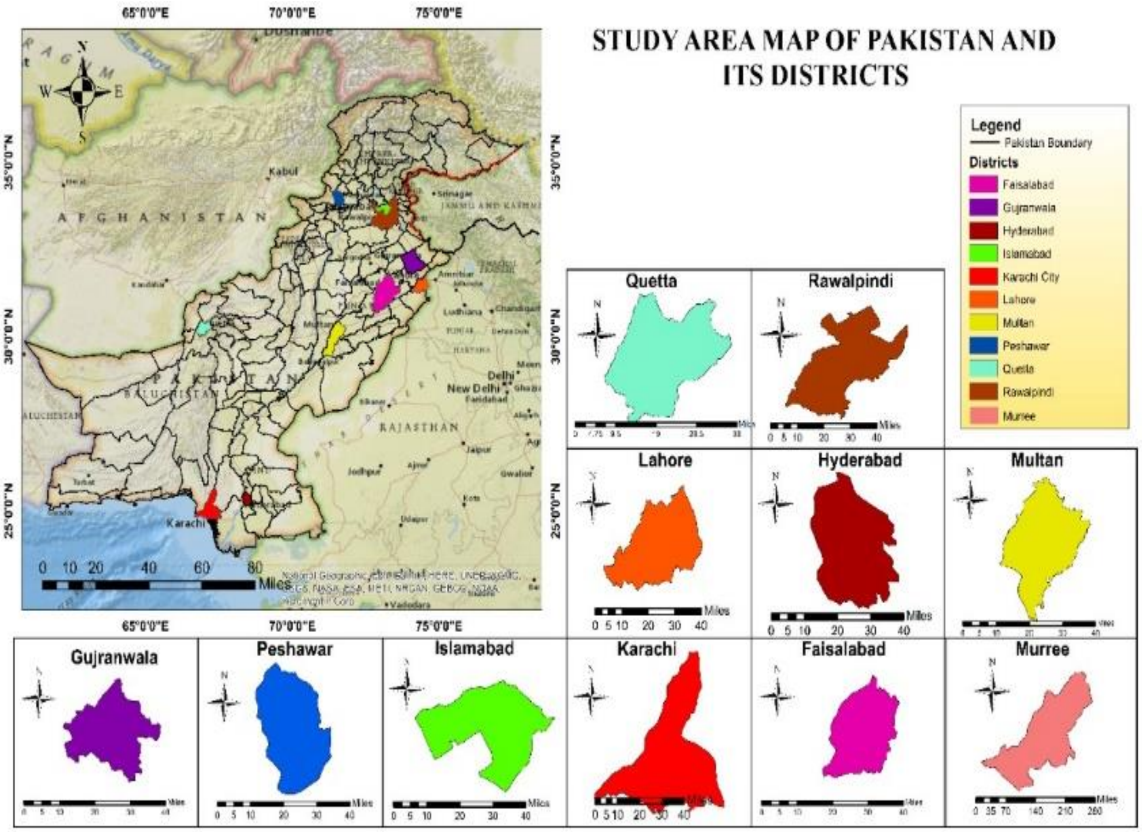

Fig 1: Study area map of Pakistan and its major cities

2.2. Data Acquisition

The research employed satellite data spanning a duration of thirty years (1989-2019) obtained from the Landsat satellite data archives of USGS https://earthexplorer.usgs.gov/. The satellite imaging data was collected by accessing the website The data required, its specification, source, and purpose have been listed in Table 1.

Table 1: Data sources and purpose

Sr. no	Data	Acquisition Year	Purpose	Source
1.	Landsat 4-5 MSS	1989	Land Use Land Cover Classification	Earth Explorer (USGS)
2.	Landsat 7 ETM+	1999	Land Use Land Cover Classification	
3.	Landsat 8 OLI	2013	Land Use Land Cover Classification	
4.	Landsat 8 OLI	2019	Land Use Land Cover Classification	
5.	Census data	1998 and 2017	Correlation between urban sprawl and population	Pakistan Bureau of Statistics (PBS)

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2.3 Data Analysis

The initial stage of the classification process involves the pre-processing of satellite imagery. The pre-processing steps viz., layer stacking, mosaicking and creation of subsets on the Area of Interest (AOI) was conducted using ERDAS Imagine14 software.

Land use land cover classification was done by collecting training samples and four land use land cover classes, barren land, built up, vegetation and water bodies were identified. Barren land is comprised of barren rocks or dirt with little or no vegetation. Built up involves buildings residential, commercial, and industrial districts with human-made structures and features.

Vegetation includes woods, meadows, and agricultural fields with native or cultivated plants. Water bodies include Rivers, lakes, and reservoirs support aquatic ecosystems as natural and man-made water bodies. Each class was selected with maximum accuracy by applying different band combinations to the images [24]. The Maximum Likelihood Algorithm was used to get the classified images [21].

The significance of accuracy is widely recognized in the evaluation of various image processing techniques for image categorization. The standard error matrices, which serve as accurate evaluation statistics, are computed by employing consistent data references for every image [25].

The matrices in question are employed for the purpose of assessing several performance metrics, including overall accuracy, user accuracy, producer's accuracy, error of commission (EC), error of omission (EO), and kappa coefficient. The term "overall accuracy" (OA) denotes the proportion of correctly classified instances in relation to the total number of samples present in the categorized image.

$$OA = (Sum\ of\ diagonal\ tallied\ (correctly\ identified)\ /\ Total\ number\ of\ samples) \times 100$$

$$UA = (Samples\ correctly\ identified\ in\ the\ row\ /\ Row\ total) \times 100$$

$$PA = (Samples\ correctly\ identified\ in\ the\ column\ /\ Column\ total) \times 100$$

$$EO = (\sum of\ off - diagonal\ elements\ of\ Column\ /\ Column\ Total) \times 100$$

$$Kappa's\ Coefficient\ KC = (N * \sum ri = 1\ xii - \sum ri = 1\ (xi + \times\ x + 1))\ /\ (N\hat{}2 - \sum ri = 1\ (xi + \times\ x + 1))$$

To evaluate the accuracy of land use/land cover (LULC) maps derived from Landsat imagery, a stratified random approach was employed to represent different LULC classes within the designated study region.

The post-classification change detection has been done in various studies in the past [26,27,28]. The process of change detection was used to assess the urban sprawl and land use changes during the period 1989-2019 [28]. Additionally, this process helped in learning how much a class has changed during the course of study [29].

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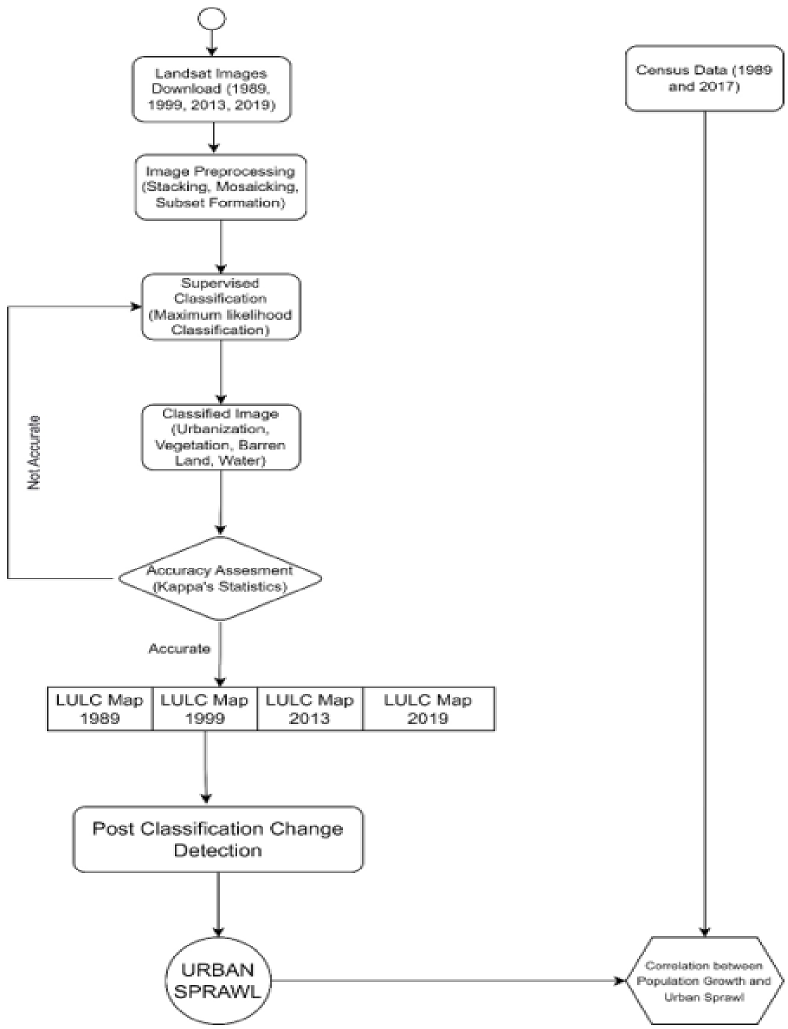

Fig 2: Flowchart of Methodology adopted in this study

3. RESULTS AND DISCUSSION

3.1 LULC Changes in Faisalabad

Land use and land cover (LULC) in Faisalabad between 1989 and 2019 showed significant changes in various categories, highlighting urbanization's impact on the city's physical environment. The study of barren land, urbanization, vegetation, and water bodies revealed complex changing patterns. Barren land has been contracted by 297.75 sq. kilometers, a 19.92% decrease.

Urbanization, which expands metropolitan areas and turns barren land into developed ones is accompanied by a 33.45% growth in urbanization, measuring 500.08 sq. kilometers (Fig 3). Urban expansion is affected by demographics, economic activity, and infrastructure development [30]. However, the decline in vegetation coverage, 198.01 sq. kilometers or 13.25% of the total area, raises ecological concerns.

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Clearing land for urban development and agriculture reduces vegetation. The changes may disrupt local biological systems, affecting species, soil quality, and ecosystem services [31]. Urbanization also has affected hydrological systems by reducing the water body surface area by 4.27 sq. kilometers, or 0.29% of the total area. Impervious surfaces increase with urbanization, disrupting water flow and increasing surface runoff. This drainage change may increase flooding [32]. During the years 1989-1999, a total of 106 km2 shift was observed from vegetation to urbanization and 666 km2 from vegetation to barren land. Overall, there was a prominent increase in urbanization that explains the decreased percentage of barren land. In the year 2013, major changes can be seen in the categories of urbanization and vegetation.

A shift of 230 km2 was seen from vegetation to urbanization. It was also observed that the total area changes from barren land to urbanization also correspond to 128km2. The barren land reduced to 17.10 %, urbanization increased to 34.69 % that accounts for 2-fold increase than 1999, Vegetation accounted for 47.53 % decrease than in year 1999, so we can say that urbanization was the cause of decrease in vegetative land as well as barren land. During the years 2013-2019, urbanization has seen a visible change, 353 km2 area from urbanization to urbanization, 155 km2 change from urbanization to vegetation was also seen, which is a positive change with respect to environment [33].

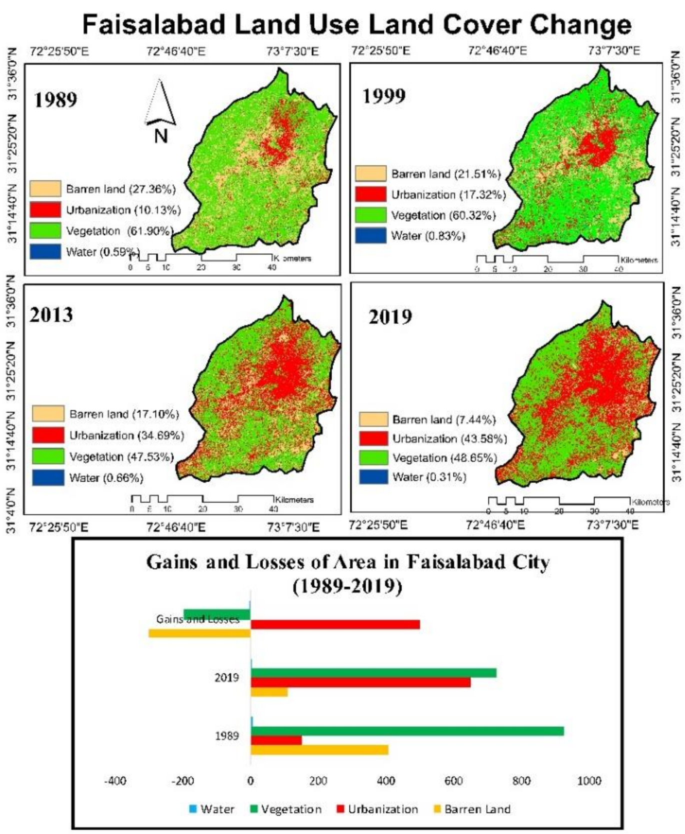

Fig 3: The classified images of Faisalabad city for 1989,1999, 2009 and 2019

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3.2 LULC Changes in Gujranwala

Between 1989 and 2019, Gujranwala's land use and land cover (LULC) patterns changed significantly (Fig 4). The barren land in Gujranwala decreased by 143.89 sq. kilometers (16.64%) over this time. The decline shows how barren regions have been transformed into diversified land uses, with a focus on urbanization and infrastructure. This causes urbanized areas to rise 340.45 sq. kilometers (39.37%) (Fig 4).

However, rapid urbanization depleted greenery. The loss of 203.51 sq. kilometers (23.54% of the total area) of vegetation due to urbanization offers considerable challenges. The removal of natural vegetation for infrastructure and housing has serious ecological effects which affects neighboring ecosystems, biodiversity, carbon storage, and ecosystem services, thus emphasizing the need for balanced urban development to mitigate these effects [34].

Water bodies expanded by 106.93 sq. kilometers, or 0.80% of the total land surface (Fig 4). During the 1989-1999 decade, the changes in Gujranwala land use can be seen significantly. Major shift of 146 km2 can be seen from vegetation to urbanization and 78km2 can be seen from barren land to urbanization respectively. The land adjustments became more obvious during the next decade, the city expanded by 355.27 sq. kilometer (41.09% of the total area) and rural areas shrank by 134.44 sq. kilometer. In this decade, as shown in the graph, 147 km2 area has been converted from vegetation to urbanization.

Then the area shown in map of Gujranwala changed further in 2013 after a decade. Barren area and vegetation were decreased and urbanization showed an increase from 2013-2019. An additional 139 km2 was converted from vegetation to urbanization and 75 km2 from barren land to urbanization respectively. The observed event may be affected by land use changes, hydrological system changes, and metropolitan expansion.

The Gujranwala land use and land cover (LULC) classification has an Overall Kappa score of 0.8021, indicating high concordance between classed data and real-world observations (Fig 4). The LULC changes in Gujranwala are caused by numerous factors. Urbanization and population growth turn barren land into urbanized areas. Economic and infrastructure growth enable expansion.

The land use and land cover changes in Gujranwala over the past three decades reveal the city's urbanization and ecological impacts. The decline in barren land and plant life due to urban expansion highlights the challenges of sustainable development. The growth of water bodies settings requires a new urban design aspect that conserves and restores aquatic ecosystems.

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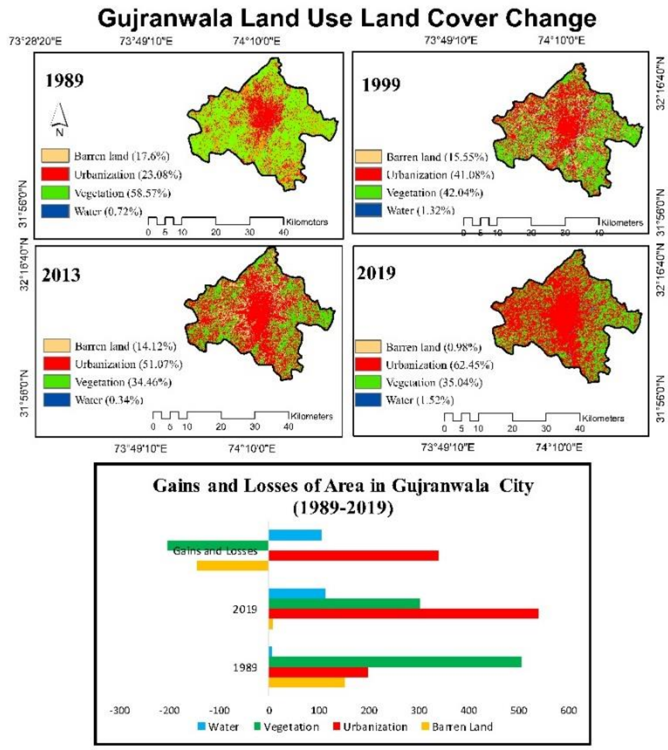

Fig 4: The classified images of Gujranwala city for 1989,1999, 2009 and 2019

3.3 LULC Changes in Hyderabad

Land cover alteration in Hyderabad between 1989 and 2019 shows a tendency toward urbanization and less barren space (Fig 5). Urbanization increased by a total of 101.98 Sq. kilometer, (65.98%) in 2019 (Fig 5). This extension signifies massive urban growth and population growth. The loss of barren land may have contributed to the reported rise in land area of 61.85 sq. km (31.60%) due to infrastructural development and residential use. Urbanization in Hyderabad over the given time reduced barren land. The city's urban expansion and land use changes are due to economic operations, population growth, and development [35]. Over 30 years, Hyderabad's urban areas have grown by 101.98 sq. kilometers, a 9.71% growth rate. The phenomenon is consistent with global urbanization trends driven by population growth and economic growth [36]. The decrease in barren land by 61.85 sq. kilometers, or 6.19% of the total area, suggests urbanization of previously barren regions.

Urbanization sometimes transforms barren or unoccupied areas to accommodate growing populations and infrastructure [37]. Form 1989-1999, 62 km2 area under vegetation has seen a shift to urbanization. During the years 1999-2013, it can be seen that 67 km2 area was converted from vegetation to urbanization, which could be due to the construction of real estate and buildings. The plantation of mangroves by Sindh Forest and Wildlife Department, SCCP, IUCN, WWF etc., and the increase in cultivated land due to 2010 floods, caused a shift to vegetation by 114 km2 [38]. The 1989–2019 land use

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and cover changes in Hyderabad show how urban areas change. The present discourse examines geographical region changes, land cover categorization, and influences, supported by scholarly sources. Urbanization involves people migrating from rural to urban areas, expanding and developing cities. This method reduces barren land, which lacks flora and productivity. The study's high Overall Kappa value of 0.7770 and classification accuracy of 85.40% support its findings. Hyderabad's land use patterns have changed due to urbanization, agricultural development, and land management policies. Urbanization is caused by population growth, economic opportunities, and infrastructure development [39]. Agriculture may also affect land usage since urbanization can encroach on agricultural or natural landscapes [40]. Hyderabad's landscape transformation across the analyzed timeframe shows how urbanization, environmental processes, and socio-economic elements interact, providing an opportunity for the urban planners and developers to take sustainable measures.

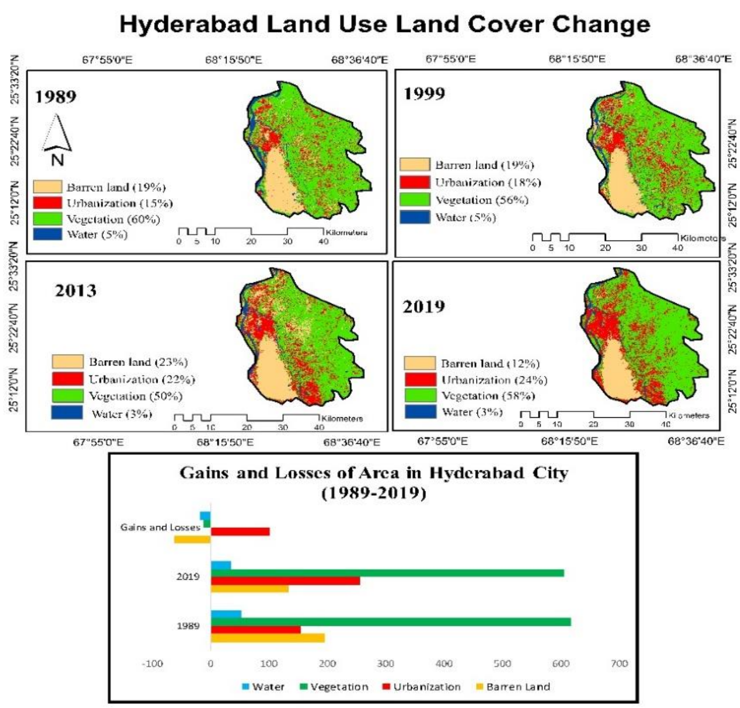

Fig 5: The classified images of Hyderabad city for 1989,1999, 2009 and 2019

3.4 LULC Changes in Islamabad

Despite development, Islamabad boasts a lot of greenery. From 1989 to 1999, urbanization increased by 42.00 sq. kilometer, a (97.97%). This urbanization trend reduced barren land by 39.22 sq. kilometer. The major transformation of 25 km2 occurred from vegetation to urbanization, and of 60 km2 from barren land to vegetation respectively. From the years 1990-2013, major developments occurred in urbanization as well as vegetation. A decrease in vegetation was seen before, but after 2008, the vegetation cover increased. This increase in vegetation cover occurred because of the afforestation activities in the city by both public and private sectors. A program named

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"President Mass Afforestation Program (2008-2013) was started to increase the area under vegetation throughout the country. In Islamabad, large number of trees were planted by the Capital Development Authority (CDA) [21, 41, 42].The 35.80 sq. kilometers (3.98%) increase in vegetation from 1989-2019 indicates efforts to conserve green spaces and improve urban aesthetics (Fig 6). Environmental benefits of green places include air filtration, temperature regulation, and species conservation. Urban solutions that emphasize vegetation integration improve city sustainability and citizens' quality of life [17,43]. In contrast to the trend, Islamabad's water bodies shrank by 2.91 sq. kilometers (0.32%) by 2019 (Fig 6).

This transition could be caused by land reclamation, urban expansion, and hydrological changes. Urbanization and infrastructural development can alter natural drainage systems and water bodies' size and organization [44]. Overall, Kappa and classification accuracy show Islamabad's land cover categorization's trustworthiness. A high Overall Kappa value of 0.8005 and classification accuracy of 87.55% reflect the classification technique's effectiveness. The city's commitment to sustainable urban expansion and environmental protection is shown by the decrease in barren land and the increase in vegetation. However, water, urbanization, and land use affect water bodies (Fig 6). Land use and cover in Islamabad between 1989 and 2019 show a delicate balance between urbanization, conservation, and sustainable development. The city's urban landscape is changing, including less barren land, more urban areas, more vegetation, and water body modifications. The precision of land cover classification emphasizes the necessity of such analyses for effective urban planning and informed decision-making.

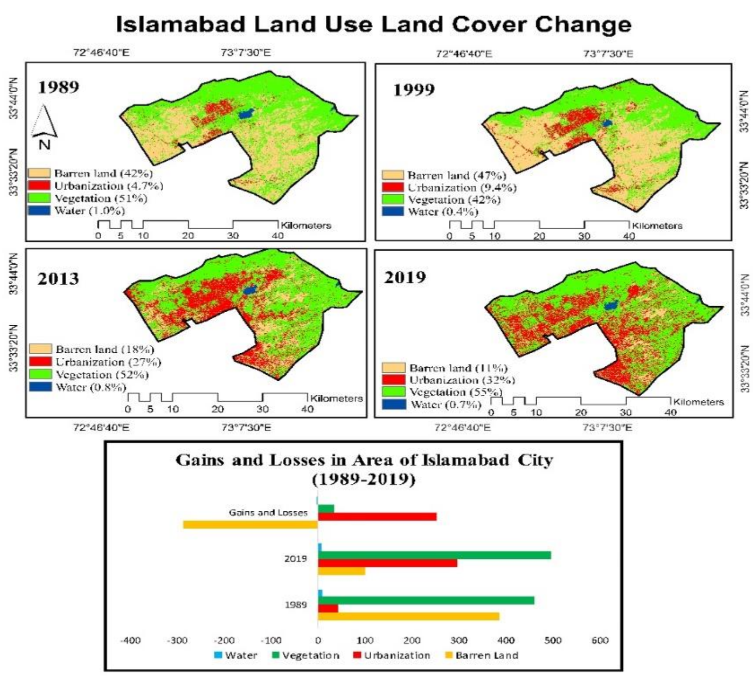

Fig 6: The classified images of Islamabad city for 1989, 1999, 2009 and 2019

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3.5 LULC Changes in Karachi

The aggregate changes over three decades show the city's rapid urbanization and expansion. Urban growth, which encroaches on previously barren land, indicates more infrastructure, housing, and economic activity. Population growth, rural-to-urban migration, and economic opportunities in cities have contributed to urbanization. Declining barren land may imply metropolitan growth, which affects natural resource availability and ecosystem services. The trend emphasizes the need for effective urban planning, sustainable land use, and environmental conservation to balance development and ecological preservation.

Karachi has evolved in urbanization dramatically over the period from 1989-2019 (Fig 7). The overall trend for Karachi city showed an increase in urbanization and decease in vegetation and barren land. The population growth is directly linked with the increase in urbanization, as more housing societies need to be developed [45].

Between 1989 and 1999, the city lost 108.54 sq. kilometer of barren land (3.12%) decrease. Urban development increased by 127.45 sq. kilometer, (28.09%). During the 1990-2013 timespan, vegetation increased because The Sindh Forest Department made efforts to restore and plant endangered mangrove species [46]. Also the 2010 floods caused the increase in cultivated land [38]. The results showed that 710 km2 of barren land was converted to vegetation in this time period. Another major shift was the conversion of approximately 195 km2 of barren land to urbanization [47]. Then from 2013-2019, Karachi showed a slight decrease in vegetation. Urbanization kept on increasing during this phase also. Approximately146 km2 area was shifted from vegetation to urbanization, 88 km2 and 274 km2 of barren land was converted to urbanization and vegetation respectively.

Urbanization is reducing barren land by 952.05 sq. kilometers (26.20%) by 2019 (Fig 7). The reduction in barren land indicates how rapid development and expansion have invaded nature. Urbanization is driven by population growth, rural-to-urban migration, and economic opportunities [48]. Karachi's urbanization has expanded built environments by 343.01 km2 or 9.36% by 2019 from 1989 (Fig 7). Minor growth indicates urbanization and infrastructure improvements in the city. The 17.46% increase in vegetation coverage of 638.43 sq. kilometers in 2019 highlights urban green spaces. Green spaces lower urban heat islands, improve air quality and add beauty and enjoyment [49]. City life reduces water bodies by 22.15 sq. kilometers (0.61% of the total) (Fig 7). The fast urbanization and infrastructural development in Karachi could endanger rivers. Hydrological trends, pollution, and water supply constraints may impact natural and human systems [50]. Kappa and classification accuracy demonstrate Karachi land cover categorization's trustworthiness. The high Overall Kappa value of 0.7358 and overall classification accuracy of 84.81% suggest that the classification technique is resilient, even in complicated metropolitan landscapes. This study confirms land use and cover change. The land use and cover trends in Karachi are influenced by various variables. Ecologically sustainable urban development can boost green spaces and vegetation. Encroachment,

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pollution, and hydrological changes have reduced water bodies and increased urbanization [51] (Fig 7).

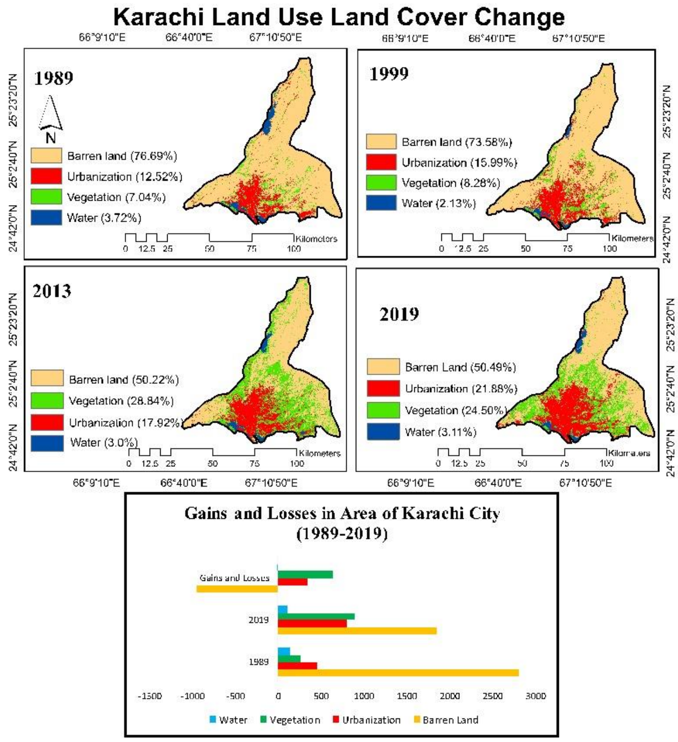

Fig 7: The classified images of Karachi city for 1989,1999, 2009 and 2019

3.6 LULC Changes in Lahore

The land cover changes in Lahore over the time period show a major shift in urbanization, vegetation, and water regions. Lahore city showed an increase in the built up area from 1989-1999. Approximately, 178 km2 of vegetation land was converted to urbanization [52,53]. From the years 1999 to 2013, there was increase in the built up area. The results showed that there is an increase in vegetation during 1999-2013 due to the efforts of provincial government for increasing the green areas. In this scenario, Lahore Development Authority (LDA) also played a key role. The total shift of 95 km2 was observed from barren land to vegetation [54]. From the year 2013 to 2019, Lahore city showed increase in overall urban sprawl. In the year 2018, urban land was increased due to establishment of housing schemes in Lahore and other cities [55]. From 1989 until 2019, Lahore's urban environment changed, including urbanization, vegetation, and water bodies. This study examines the intricate link between these changes, land cover categorization accuracy, and the variables that cause the observed patterns (Fig 8). The research period saw Lahore urbanization develop by 538.53 sq. kilometers (31.13%) in 2019 (Fig 8). The expansion shows the city's importance as a hub for economic and demographic growth, attracting residents and businesses [56,57]. Urban expansion reduced barren land by 134.24 sq. kilometers or 7.76% from 1989-2019 (Fig 8). The

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decline in barren land symbolizes the urban area's trend toward built environments, driven by industries, infrastructure, and residential needs.

Lahore's vegetation decreased by 403.89 sq. kilometers (23.35%) from 1989 to 2019 (Fig 8), reflecting the global trend of urbanization and its effects on green spaces. The reduction of vegetation is concerning since it improves the urban environment. The loss of greenery emphasizes the need for comprehensive urban planning that balances urban growth and ecological conservation [58,59].

The water bodies in Lahore decreased by 0.37 sq. kilometers or 0.02% for the respective time. Urbanization near waterways has been shown to harm hydrological patterns and water quality [60]. The reduction highlights the importance of sustainable urban development methods that prioritize aquatic habitat preservation and rehabilitation. Land cover categorization of Lahore's changing landscape is dependable, as shown by its Overall Kappa value of 0.8185 and classification accuracy of 87.58%.

The changes in land use and cover in Lahore have many causes such as rapid population growth, migration to cities, economic activity, and infrastructure development. Urbanization, deforestation, pollution, and land use changes have reduced vegetation and aquatic habitats [15,51] (Fig 8).

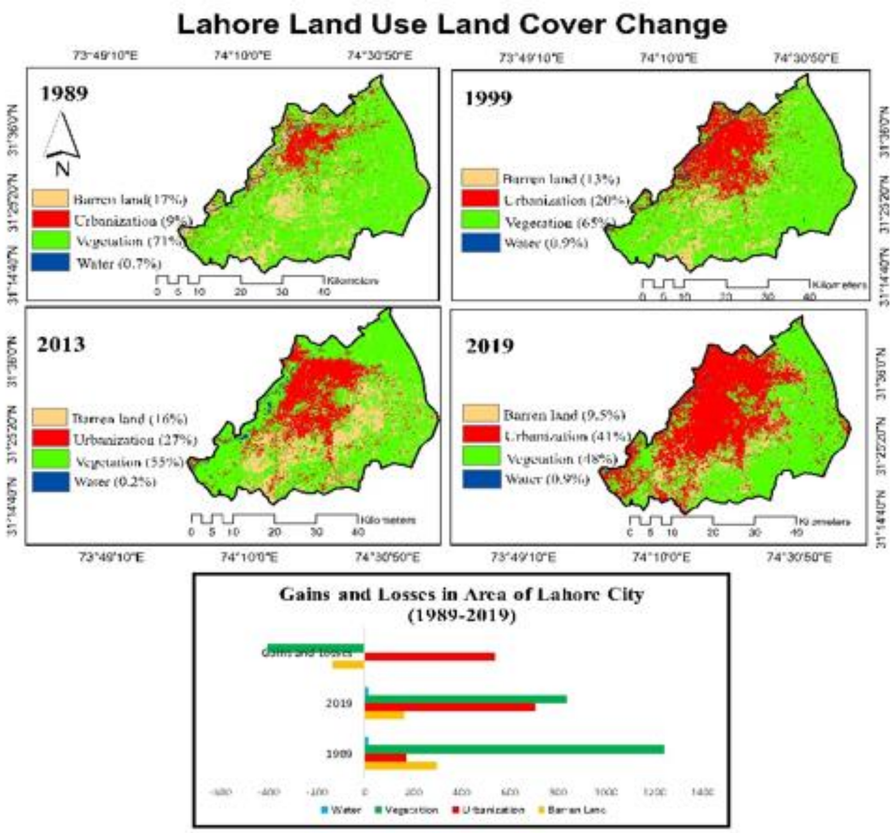

Fig 8: The classified images of Lahore city for 1989,1999, 2009 and 2019

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3.7 LULC Changes in Multan

The medieval city of Multan has had major land use and cover changes during the past 30 years (Fig 9). These changes reflect the city's urban environment and ecological developments. Post classification change detection of Multan showed that, during the years 1989-1999, Multan underwent urban expansion.

The barren land was decreased. It can be seen that about 95 km2 of barren land was converted to urban land. in addition to this, 167 km2 of vegetation was also converted to urbanized area [62]. During 1999-2013, again in Multan, urbanization showed an increasing trend [63]. A decrease in vegetation cover was seen, corresponding to approximately 191 km2 of vegetation converted to urban land during this time period.

It was also noticed that 74 km2 of barren land was also converted to concrete buildings. Multan showed an increase in urbanized land and a decrease in vegetation and barren land respectively. A total of 95 km2 of vegetative area was shifted to urban area. In addition to this, 47 km2 of barren land also showed a conversion to urban land. Water bodies also showed a decreasing trend, but during 1989-2019 overall water bodies showed an increasing trend from 2000-2005, then decreased till 2010, then showed an increasing trend till 2015 and again decrease till 2019. This unusual pattern occurred due to flash floods in Upper Chenab River during the last two decades [64].

Urbanization in Multan increased by 289.89 sq. kilometers, or 14.91%, over 30 years (Fig 9). The expansion is comparable with global urbanization and sprawl due to population growth and economic growth [65]. The 7.32% drop in barren land, or 142.38 sq. kilometers until 2019, implies that previously empty places are becoming urban and developed. The vegetation cover in Multan has dropped 8.12% to 157.85 sq. kilometers from 1989 to 2019 (Fig 9). This decline may have far-reaching ecological effects. Vegetation is crucial to improving air quality and moderating climate [58,59]. The decline is due to urban development, agricultural conversion, and deforestation.

The hydrological dynamics of Multan have changed significantly due to the 10.33 sq. kilometers increase in water body surface area, a percentage shift of 0.53%. The percentage increase may seem minor, but it could affect regional water resources, flood dynamics, and aquatic ecosystems [66].

Urbanization can alter surface runoff patterns, affecting water body health. The Overall Kappa value of 0.7214 and the classification accuracy of 86.92%. Multan's land use and cover changes are driven by population growth, economic development, infrastructural projects, and land use rules. The structure of urban areas and how land is used are profoundly changed by urbanization [67,68] (Fig 9).

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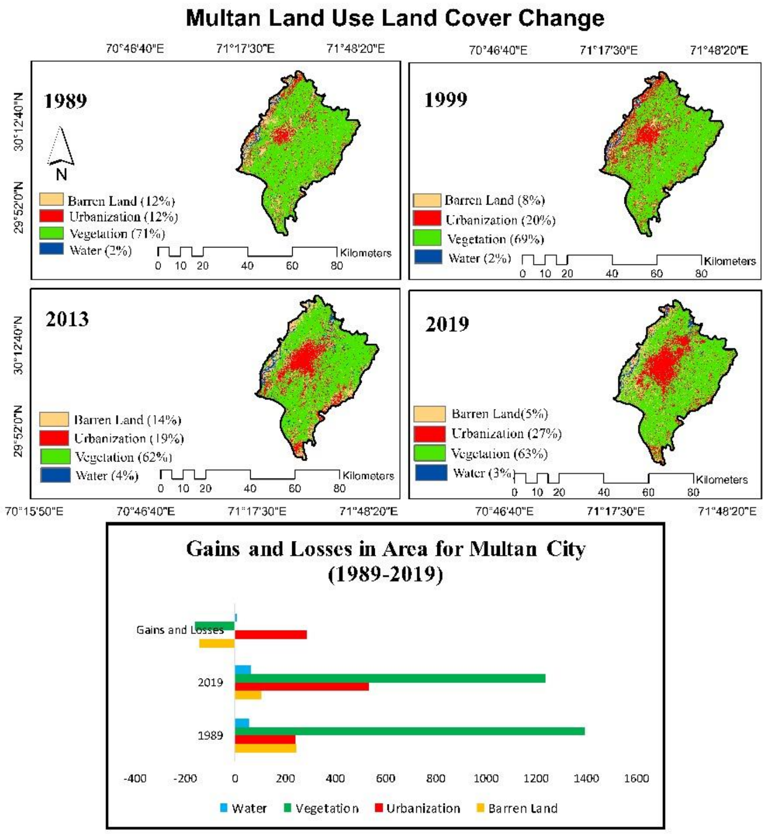

Fig 9: The classified images of Multan city for 1989,1999, 2009 and 2019

3.8 LULC Changes in Murree

Murree, a picturesque town in the Himalayan foothills, changed its land use over 30 years (Fig 10). The post classification change detection of Murree during 1989-1999 showed that there is 18 km2 shift of vegetative land to urbanization, 14 km2 of barren land was also converted to urbanization. Further moving to the next time span, from 1999-2013, Murree showed a considerable increase in urban land and decrease of vegetation cover [69]. 42 km2 of vegetation was converted to urbanization during this phase. During 2013-2019, Murree showed an exponential growth in the urbanized land. Murree is one of the largest tourist spots of Pakistan, to meet the requirements of increasing tourists and commercial activities, major portion of Murree city is being converted to urban area. The hotels, buildings and infrastructure has posed a burden on the vegetation and other resources of the city. Urban areas in Murree have grown by 34.02 sq. kilometers, an 8.86% increase throughout the study period (Fig 10). The phenomenon follows the global trend of urban expansion driven by population and tourism [67]. The 5.77% decline in vegetation spanning 22.19 sq. kilometers from 1989 to 2019 raises concerns about its effects on adjacent ecosystems and biodiversity [70].

The 11.40 sq. kilometers (2.97%) (Fig 10), decrease in barren land area may reflect land reclamation or afforestation as a reaction to environmental difficulties [71]. These efforts

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improve soil stability, erosion, and environmental quality, so they must be acknowledged. The Murree aquatic bodies have shrunk 0.46 sq. kilometers (0.12%). The size of water bodies can affect local water supplies, especially in places that depend on snowmelt and mountain springs [44]. The study's Overall Kappa value of 0.7214 and classification accuracy of 86.92% show that land cover classifications are reliable. The results' precision lends credibility and significance to land use management and conservation considerations. Tourism, urbanization, land management policy, and natural resource extraction have caused land use and cover changes in Murree. The dynamic land use in Murree requires a comprehensive policy that balances urban expansion and ecological conservation. Urban sprawl, vegetation degradation, and aquatic ecosystem changes demonstrate the need for sustainable land management and conservation. An accurate land cover classification from this study helps Murree residents make informed decisions and plan sustainable development [69].

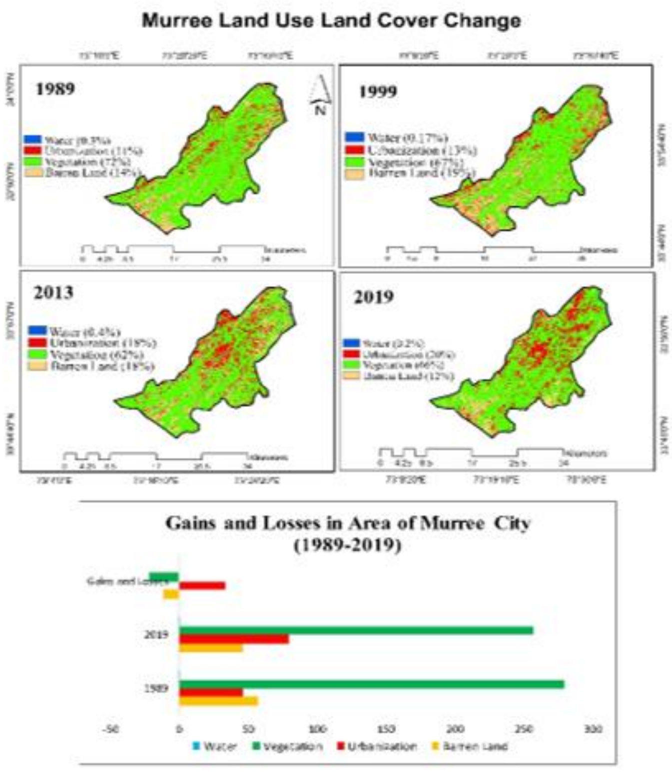

Fig 10: The classified images of Murree city for 1989,1999, 2009 and 2019

3.9 LULC Changes in Peshawar

The global trend of faster urbanization due to population growth and economic growth is consistent with the increase in urbanization seen in Peshawar from 1989 to 2019 (Fig 11). Peshawar showed an increase in urbanization during 1989-1999, but the vegetation also increased. During 2013-2019-time span, the scenario changed. Barren land was shifted to vegetation due to the Billion tree project [72] and urbanization increased due to the

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migration of people from Afghanistan towards KPK [73]. Water and barren land doesn't show any major change Urbanization in Peshawar has increased by 18.88% up to 2019 (Fig 11). This involved 243.22 sq. kilometers of extension. The decrease in barren land by 31.76 sq. kilometers (2.12%) reflects urban sprawl and land use changes, which are often connected with urbanization [67]. Due to its ecological implications, the reported vegetation cover reduction of 206.07 sq. kilometers by 2019 (15.73% of the total area) is concerning (Fig 11). Vegetation loss can worsen soil erosion, change microclimates, and hinder biodiversity conservation [72]. The Overall Kappa value of 0.8021 and classification accuracy of 85.85% show that land cover classifications are reliable. The changes in land use patterns in Peshawar are due to population growth, urbanization, agricultural expansion, and infrastructure development. Urbanization and land use changes are often driven by population movements and development strategies, resulting in changes to urban areas' physical structure [74].

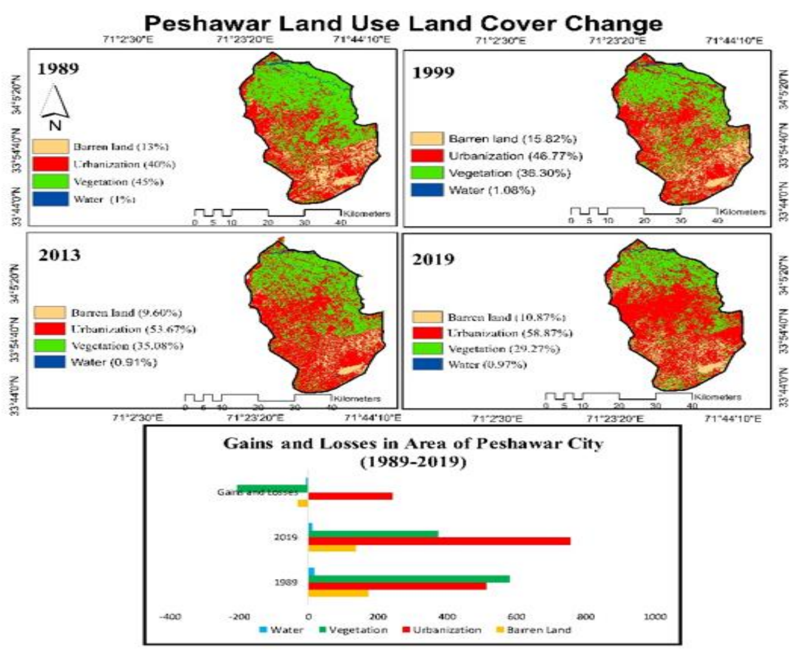

Fig 11: The classified images of Peshawar city for 1989,1999, 2009 and 2019

3.10 LULC Changes in Quetta

The changes over three decades show Quetta's fast urbanization and its effects on land cover (Fig 12). The loss in bare land and vegetation cover appears to be caused by urban expansion. Economic growth, population growth, and infrastructure projects may influence this trend. However, urbanization and its changes raise concerns about ecological impacts and the need for sustainable urban development [75]. The land cover transition in Quetta underlines urbanization's ongoing difficulties and the necessity for a balanced development approach. The observed patterns demonstrate the importance of integrated urban planning, green infrastructure, and environmental conservation in managing urban growth and maintaining the region's natural resources and ecosystems. Quetta's land use shift from 1989 to 2019, over the past three decades has changed

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significantly (Fig 12). This debate addresses the size of these shifts, the categorization's precision, and possible reasons. The urban landscape of Quetta has changed significantly, with 154.8 sq. kilometers of expansion in urbanization up to 2019 (Fig 12). The increase in urbanization and decrease in the barren land can be thought of as a rapid growth of population in Quetta. The reason behind the increase in population can be the Afghan migrants and the migration of people from nearby villages to the city for better opportunities [76].

From 1999-2013, Quetta showed significant changes in three LULC classes. A significant increase in urbanization was seen during this era, and a considerable reduction was observed in both green spaces and barren land respectively. The overall reduction of vegetation by 189.28 sq. kilometers suggests that urbanization may be accompanied by land reclamation and repurposing, supporting previous research on urban land dynamics [77]. Quetta's water bodies expanded by 0.95 sq. kilometers remarkably. The high Overall Kappa value of 0.8236 and classification accuracy of 87.28% show solid land cover classifications. This study's precision increases the credibility of its conclusions, making them more applicable to land use planning and decision-making (Fig 12).

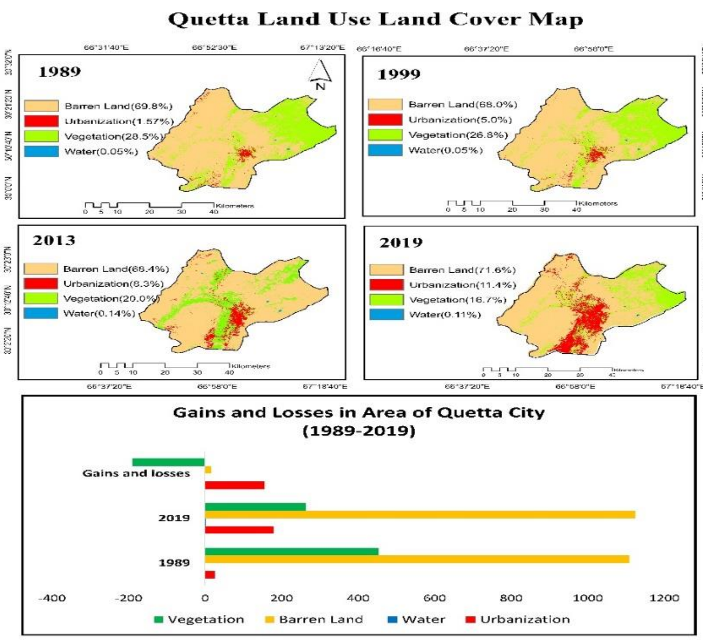

Fig 12: The classified images of Quetta city for 1989,1999, 2009 and 2019

3.11 LULC Changes in Rawalpindi

A comprehensive analysis of the land use transformations according to LULC maps in Rawalpindi between the years 1989 and 2019 demonstrated significant alterations (Fig 13). Rawalpindi is one of the major cities of Pakistan. Due to the high population growth, the need for housing societies and infrastructure increases. From 1989-1999, Rawalpindi showed a decrease in barren land and an increase in urbanization. During 1999-2013, urbanization increased significantly, causing a reduction in barren land. Approximately,

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52 km2 of barren land was converted to urbanization during this period. Vegetation increased during this time period [78]. During 2013-2019, maximum change in the class of urbanization was seen. A total of 28 km2 of barren land and 17 km2 of vegetation was converted to urbanization. Most significant change in vegetation was seen during this time period, the green cover almost expanded to double from 1999-2019 [21]. The area of barren land experienced a reduction of 245.00 sq. km (equivalent to 23.82% of its initial size) over the period from 1989 to 1999 (Fig 13).

In contrast, urbanization increased by 124.46 sq. km (representing a growth of 7.61%). The vegetation, on the other hand, exhibited major variations, with a decline of 113.61 sq. km (equivalent to a fall of 20.27%) between 1989 and 1999 (Fig 13). However, it subsequently recovered with a substantial gain of 413.46 sq. km (representing a growth of 65.73%) from 1999 to 2019 (Fig 13).

The water bodies exhibited a rather consistent state, with a marginal change of 10.16 square kilometers, which accounts for approximately 61.85% of the total duration. These modifications serve to underscore the dynamic nature of Rawalpindi's urban environment and its progressive development throughout several decades. Urbanization is an inevitable outcome of economic development, leading to a substantial increase in urban population and a corresponding surge in the need for residential infrastructure.

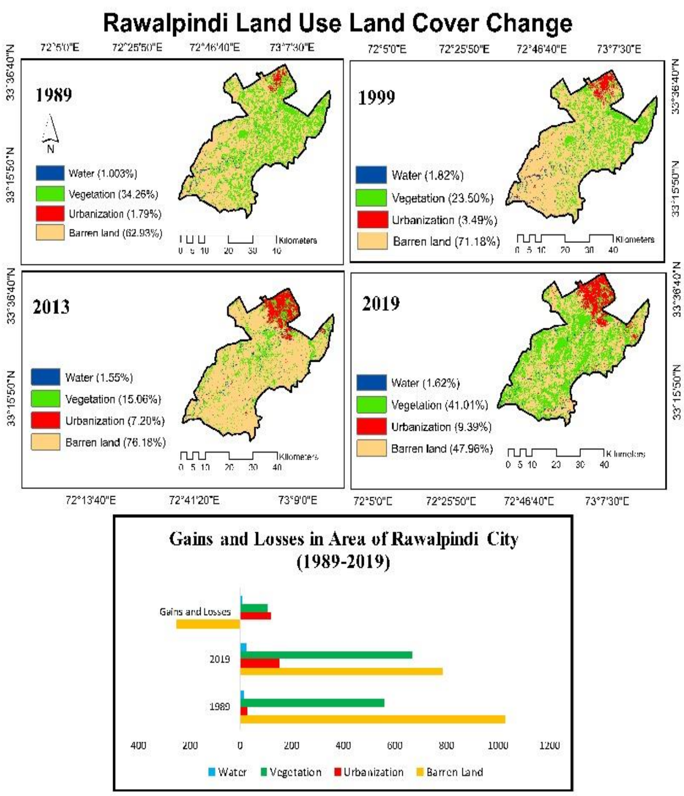

Fig 13: The classified images of Rawalpindi city for 1989,1999, 2009 and 2019

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Table 3: Showing Kappa's accuracy assessment through the years (1989-2019)

City	1989	1999	2013	2019	Overall Kappa	Overall Clarification Accuracy
Peshawar	85%	87.50%	87.27%	83.64%	0.80	85.85%
Gujranwala	85%	87.50%	87.27%	83.64%	0.80	85.85%
Hyderabad	91.46%	90.00%	80.60%	81.54%	0.78	85.40%
Islamabad	84.38%	90.00%	90.48%	83.33%	0.80	87.55%
Karachi	84.21%	87.50%	85.71%	81.82%	0.74	84.81%
Lahore	88.00%	88.89%	82.93%	91.49%	0.82	87.58%
Multan	90.70%	90.00%	90.00%	90.38%	0.84	90.27%
Murree	89.19%	86.11%	84.38%	85.00%	0.72	86.92%
Quetta	86.49%	85.71%	88.10%	87.80%	0.82	87.28%
Rawalpindi	82.61%	84.31%	81.48%	86.05%	0.75	83.36%
Faisalabad	85%	87.50%	87.27%	83.64%	0.80	85.85%

4. CORRELATION BETWEEN POPULATION AND URBAN SPRAWL

Pakistan has observed a large rate of rural-to-urban migration for the last three decades. In this study, population statistics were created through Census data, and Urban sprawl was calculated through LULC image classification. The results of the Pearson correlation coefficients (r) provide insight into the relationship between census data from the years 1998 and 2017, as well as urban area characteristics for the years 1999 and 2017 presented in the proximity matrix (Table 3). The correlation coefficient ranges from -1 to 1, where -1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no correlation between the variables, quantifying the degree of linear association between the respective variables.

Table 4: Correlation Coefficient values for Urban Sprawl vs. Census Data

Proximity matrix (Pearson correlation coefficient)				
	Census 1998	**Urban 1999**	**Census 2017**	**Urban 2019**
Census 1998	1.0000	0.6260	0.9470	0.6970
Urban 1999	0.6260	1.0000	0.6970	0.8750
Census 2017	0.9470	0.6970	1.0000	0.7080
Urban 2019	0.6970	0.8750	0.7080	1.0000

Comparing the census data with urban area characteristics for each specific year, such as 1998 census data with 1999 urban area, a correlation coefficient of 0.626 and R2 of 0.392 (Fig 14). This implies a moderate positive correlation between these variables. It suggests that there is some degree of alignment between the demographic insights captured by the census in 1998 and the characteristics of the urban areas in 1999. Similarly, a correlation of 0.697 (R2= 0.50) (Fig 14) between 2017 census data and 2019 urban area characteristics implies a recognizable relationship between the demographic composition of the population in 2017 and the corresponding urban attributes in 2019. The results are found consistent with previous studies on Tokyo metropolitan having a significant positive correlation [79].

In summary, the correlation outcomes indicate numerous degrees of association between census data and urban area characteristics across varying years. The robust correlations

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within the same time frame suggest consistency and persistence in trends over time, while the inter-temporal correlations hint at the complex interplay between population dynamics and urban development. These insights could be valuable for urban planning strategies, policymakers, and researchers investigating how changes in population demographics relate to shifts in urban attributes over time (Fig 14).

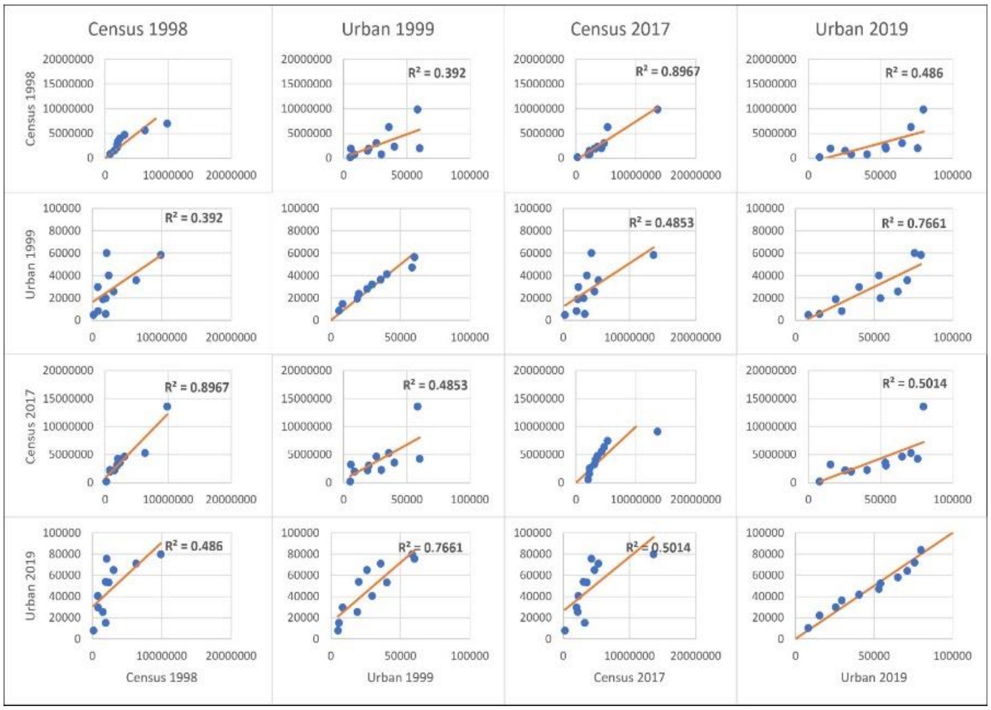

Fig 14: Urban Sprawl VS Census Data Scatter plots

5. CONCLUSION AND RECOMMENDATIONS

The study of urban developments is critical in landscape studies, land development, and conservation planning. It entails an in-depth study of how humans use and modify the land. This includes identifying different types of development, assessing their spatial distribution, and comprehending their relationship with population dispersion. Combining remote sensing, spatial analysis, and census data to acquire full insights into this complicated process is a new technique for analyzing urban development. The study uses the Landsat Data of the years 1989,1999,2013 and 2019 for eleven cities of Pakistan, known for rapid urbanization. By integrating census data from 1998 and 2017 with Landsat imagery, we were able to discern important trends and correlations. The study utilized a systematic approach, starting with the creation of land use and land cover maps for each year. In addition, change detection analysis was conducted both decade-wise and throughout the entire three decades studied. The results indicate a significant increase in urban land cover across all the cities examined and allowed us to discern subtle shifts in urbanization patterns over time. The use of Pearson correlation analysis to contrast census data with urban areas, as outlined by the land use maps, provided crucial insights. The calculated R-values (0.392 and 0.697) for specific variables demonstrate the close relationship between population growth and urban expansion. This affirms that cities have been required to extend their urban boundaries to accommodate this demographic shift. This level of urbanization creates immense pressures on key resources, with water resource management, a decrease in agricultural lands, and the shortage of basic services in the future, becoming a major priority. Likewise, the substantial loss of vegetation indicates potential ecological consequences that should be carefully considered. Furthermore, this study establishes an adequate foundation for future research into the numerous dimensions of urbanization, including socioeconomic, environmental, and infrastructure. Continuous monitoring and analysis of urban expansion in these areas is necessary to inform decision-makers and enable policy formulation to establish a harmonious balance between urban development and environmental preservation to promote long-term sustainability.

Conflicts of Interest

The authors declare no conflict of interest.

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