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Research article

Exploring the nexus between land use land cover (LULC) changes and population growth in a planned city of islamabad and unplanned city of Rawalpindi, Pakistan

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A R T I C L E I N F O

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A B S T R A C T

For the last three decades, Islamabad - a planned city, and Rawalpindi - an unplanned city, have experienced massive land use and land cover changes. The main objective of this study was a comparative assessment and quantification of LULC changes in relation to population growth and urbanization from 1990 to 2021 with the help of satellite imagery and population data in planned and unplanned cities. For classification four land-use land cover classes: built-up, vegetation, bare land, and water were selected. Maximum likelihood algorithm and confusion matrix were employed for classification and accuracy assessment. Results revealed that built-up increased from 5.7% (52 km^2) to 25.7% (233 km^2) and 3.7% (60 km^2) to 14.1% (228 km^2) from 1990 to 2021 for Islamabad and Rawalpindi, respectively. Wherein the bare land decreased from 42.2% (382 km^2) to 18.1% (164 km^2) in Islamabad and 65.5% (1058 km^2) to 32.1% (518 km^2) in Rawalpindi. Vegetation showed an increment of 4.7% for Islamabad and 24.5% for Rawalpindi. Surface water bodies decreased in both study areas. Population growth showed a strong positive correlation with the built-up class and a strong negative correlation with the bare land class for both cities. The outcomes of this study may be helpful in policymaking for better planning and management of land use land cover and urban sprawl in the context of sustainable development goals.

1. Introduction

Land use and land cover (LULC) changes contribute to the alteration of the environment on local, regional, and global scales. LULC

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changes could be natural or anthropogenic in nature. Population growth, urban sprawl, changes in local and regional environmental characteristics, loss of agricultural land, and consumption of other environmental resources are major contributors to the urban growth trend [1]. In countries like Pakistan, people move from rural to urban cities for better amenities of life, which creates pressure on the available natural resources. The process of urbanization is unavoidable due to economic growth and results in a high urban population and demand for residential facilities [2]. The unprecedented population growth gives birth to numerous environmental and human problems, such as disturbance in economic development, poor livelihood, law and order situation, limiting the available water supply and deterioration of its quality, and climate change [3,4]. Global urbanization is becoming a source of concern as it could reach up to 70% by 2050 [5–7]. Thousands of people migrate daily from rural areas to urban centers for better living opportunities [8,9], resulting in huge pressure on the socioeconomic and environmental resources of cities [10–12]. Urbanization and population growth results in spatial/physical growth of cities [10], thus leading to an increase in impervious cover, abundant built-up, and transformed climatic and hydrological conditions of the cities [13,14]. The major problems associated with unplanned urbanization are improper housing facilities, traffic mobbing, provision of basic services to residents, health issues, unemployment, education [15–18], slums, crime, shortages of clean water and energy and environmental deterioration [19–22]. All these factors largely affect urban life in cities [23]. In developing countries, the major driver behind urban sprawl is unplanned housing projects which are taking place at the cost of agricultural lands conversion into urban centers [24,25]. The magnitude and extent of LULC changes in many parts of the world are influenced by socioeconomic and biophysical factors [26]. Land use and land cover changes are some of the key factors influencing the hydrological regime of any area [27]. The driving forces behind the land use land cover changes are uncontrolled population growth, high rate of urbanization, and agricultural expansion/contraction on spatial scales [28–31]. Land use and land cover changes are directly or indirectly linked with human activities [32,33], and could create an impact on the climatic condition. Land use changes e.g. urbanization, deforestation etc. could influence the hydrological patterns of infiltration, evaporation, and runoff [34–37]. As indicated by Ref. [38], built-up and agricultural land would increase but forest and water bodies will shrink in near future. In Pakistan [39] cities expanded in unplanned manner both in number and magnitude [40]. There are no such established rules for classifying cities into planned and unplanned, however, some guiding principles are available such as low to mild population density, planned pattern of development, and green space allocation [41]. On the other hand, unplanned cites are confronting with high population density, unplanned development pattern, paucity of green spaces and small building sizes. Planned cities are dispensed into regular towns, phases, and sectors while unplanned cities lack such allocations. Planned cities growth is managed and controlled on already set blueprint criteria (master plans).

Remote sensing has emerged as a useful tool for monitoring land use and land cover changes by providing high spatial resolution satellite images and for mapping LULC change assessment [42–44]. Remote sensing techniques are widely used to assess various dynamics of LULC, including but not limited to the rate and extent of land transformation over spatio-temporal scales. There are numerous LULC classification techniques [45] such as i) supervised classification ii) unsupervised classification and iii) non-parametric classification [46–48] and among them supervised classification technique is the most applied one [49–51].

1.1. Problem statement

Pakistan is urbanizing since its independence, however, historical surge was noted from 1971 [52,53]. According to the 6th national population census report, the urban population is 36.4% with a population density of 261 persons per km^2 [54] which may rise to 50% by 2025 [55]. According to (Pakistan Economic Survey 2019–20), Pakistan is the 5th most populous country in the world. Growing population and uncontrolled urbanization are driving up demand for housing and extending impervious cover in cities. The environment and its functions, including soil formation and protection, water regulation, agricultural output, energy consumption [56–59], water quality [60] and quantity [61] are ultimately deteriorating as a result of unprecedented growth in population and urbanization. Islamabad, the country's capital city, is constantly under pressure from urbanization, population growth, and rapid economic growth. An increase in impervious cover and decline of surface water bodies in Islamabad from 1992 to 2012 was reported [29]. Rawalpindi being the historic city, unplanned, and adjacent city to the capital also shows high population growth, high rate of urbanization, and unplanned land cover trends. Both study areas have shown urban expansion [62] and congestion of already built-up area over time. Few studies have examined LULC changes in the past [63–67], however, the nexus and comparative analysis of LULC changes and population dynamics is still unknown. Therefore, it is very important for a developing country like Pakistan where urban growth is taking place but with limited or no statistical data of LULC, to have proper/planed growth of its urban sector [68]. The current study directly and indirectly aligned with United Nations Sustainable Development Goals (SDGs) number 6 (clean water and sanitation), number 11-(sustainable cities and communities), and number 15 (life on land).

1.2. Research objective

The main objective of the study was to investigate the long-term trends in LULC changes and urbanization in a planned and unplanned city of Pakistan. Further emphasis was on to identify the dynamic contributing to observed land use land cover changes over the period of last few decades.

2. Study areas

2.1. Islamabad, a planned city

Islamabad is the capital city of the Islamic Republic of Pakistan and the country's ninth largest city. It was built as a planned city in 1960. The city is divided into 9 zones including administrative, diplomatic enclave, residential areas, educational, industrial sectors, commercial areas, as well as rural and green areas [69]. The city attracts people from all over the country and makes it one of the most cosmopolitan and urbanized cities of the country. Being the capital city, Islamabad has a diverse population outlook, with representation from all parts of the country. The city is a hub for government offices/officials, politicians, and corporate offices. Islamabad is located at latitude 33.738045^o N and longitude 73.084488^o E [70] and spread over an area of 906 km^2 with an altitude ranging between 457 and 1240 m above mean sea level (Fig. 1). The climate of the city is in the range of tropical to subtropical with four seasons. The mean annual temperature is 20.9 °C with a yearly precipitation record of 1323.4 mm [71].

2.2. Rawalpindi, an unplanned city

Rawalpindi is the 4th largest city of the country. The city has a centuries-old history and is located on the Pothohar Plateau. District Rawalpindi consists of seven tehsils (*an administrative subdivision of a district*) including Taxila, Rawalpindi, Murree, Kotli Sattian, Kallar Syedan, Kahuta, and Gujjar Khan (Fig. 2). This study will focus only on tehsil Rawalpindi. The urban locality of the city includes the Rawalpindi Municipal Corporation, Rawalpindi Cantonment Board, Chaklala Cantonment Board. According to Köppen–Geiger climate classification system [72,73] the climate of the city is humid sub-tropical. The average annual rainfall is 1254.8 mm and annual mean temperature is 21.3 °C.

3. Data set and methodology

3.1. Data set

Numerous studies used Landsat satellite imageries to assess land use land cover changes at various geographical locations and at different spatial and temporal scales [28,74,75]. Landsat satellite imageries were acquired from the United States Geological Survey website (https://earthexplorer.usgs.gov/) as per details given in Table 1, from 1990 to 2021 with 5 years interval to measure long term LULC trend in the selected study areas. However, due to technical issues (scan line error) with satellite data from 2003 to 2007 over the study areas, 2008 imageries were used instead of 2005 for LULC changes assessment. March and April were chosen as targeted months because of less atmospheric haze, fewer ground reflectance changes, the rabi crops and prevailing vegetation in the study areas [76]. The satellite imageries were used to study and analyze the spatial pattern of land use land cover changes over the past 3 decades in Rawalpindi and Islamabad. It was taken care that the downloaded imageries met the minimum criteria requirements i.e., minimum cloud coverage, targeted months, and free from scan line error, clear study area, and good quality. The sensor specifications were

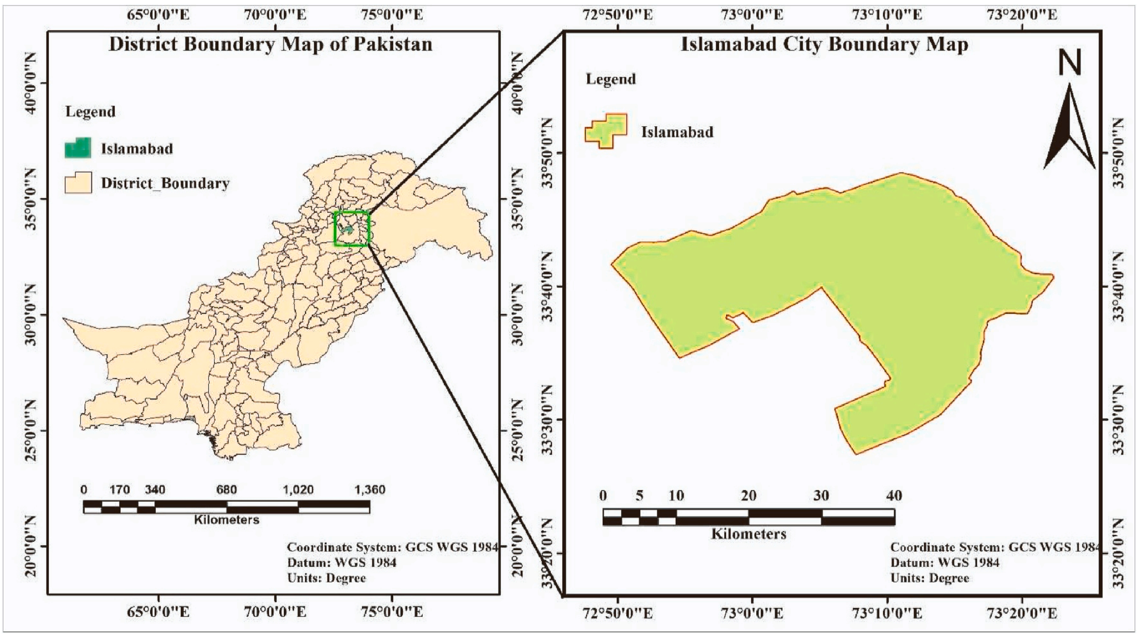

Fig. 1. Location map of Islamabad city in Pakistan.

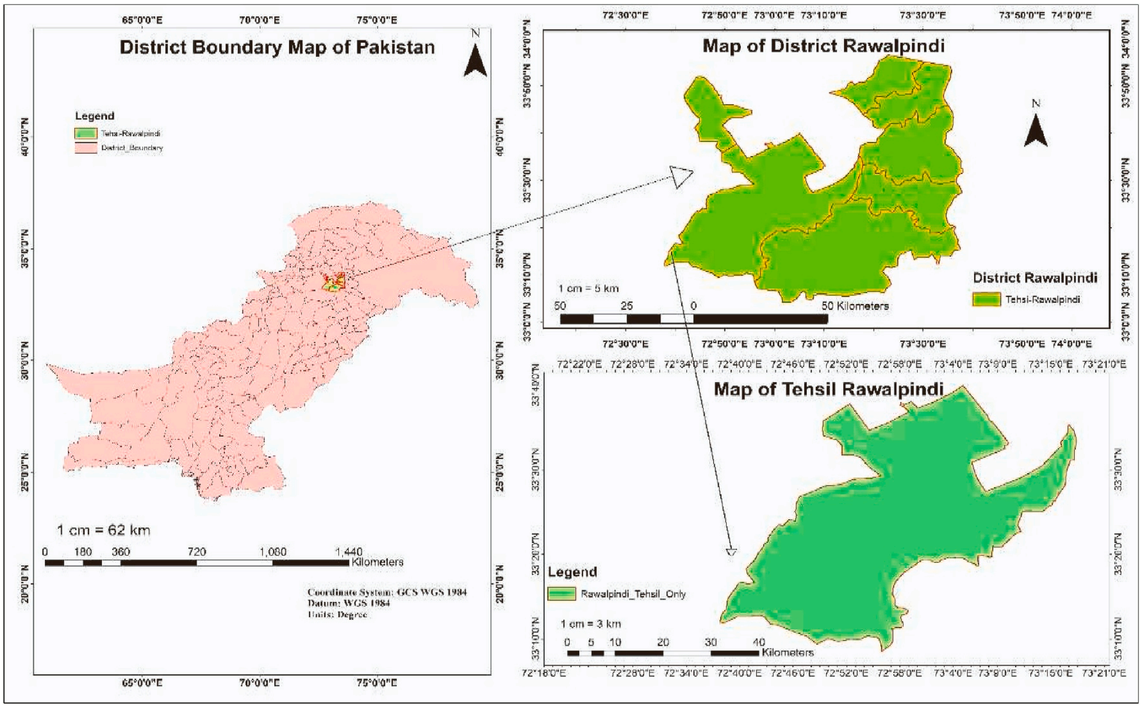

Fig. 2. Location map Rawalpindi city in Pakistan.

Table-1
Landsat satellite images used for land cover classification.

S.#	Year	Satellite	Sensor	Acquisition date	Cloud Cover (%)	Remarks
1	1990	Landsat 5	TM	March 7, 1990	0	-Targeted Months
2	1995	Landsat 5	TM	March 21, 1995	27	-Minimum Cloud Coverage
3	2000	Landsat 7	ETM+	April 11, 2000	0	-Clear Study Area
4	2008	Landsat 5	TM	April 25, 2008	4	-Free from Scan-Line Error
5	2010	Landsat 5	TM	March 14, 2010	8	Resolution = 30 × 30 m
6	2015	Landsat 8	OLI/TIRS	April 13, 2015	0.14	Path/Row = 150/37
7	2019	Landsat 8	OLI/TIRS	April 8, 2019	0.10	
8	2021	Landsat 8	OLI/TIRS	March 28, 2021	1.73	

Thematic Mapper, Enhanced Thematic Mapper (ETM+), Operational Land Imager (OLI). The spatial resolution of all imageries was 30 m. Fig. 3 depicts an overll methdology opted in this study to attain the set research objectives.

3.2. Satellite imageries pre-processing and classification

The downloaded imageries were preprocessed with atmospheric and radiometric correction, and dark object subtraction using *ENVI version 5.5*. Pre-processing was necessary for establishing direct contact of biophysical characteristics and the acquired data [69,77]. Atmospheric correction and radiometric calibration was required for the assessment of spatial change detection [78,79]. Atmospheric correction was applied to remove the effect of atmosphere on the spectral values of satellite imageries. The study areas of both cities were extracted using *ArcMap 10.7* software. For LULC classification, training samples were collected based on the existing knowledge of the study areas, various bands combinations along with the historical view of *Google Earth*. Based on the intended objectives of the study four land-use land cover classes; built-up, vegetation, water bodies, and bare land were selected for supervised classification (Table 2). Sufficient number of samples were collected for each class throughout the imageries so maximum possible representation should be obtained [80]. Imageries were enhanced by applying different band combinations to select each class with maximum accuracy [81]. Samples were collected by drawing polygons of each class. The area enclosed by each of these polygons was used to represent the spectral signature of the respective class. Supervised classification technique based on maximum likelihood algorithm was applied using *ENVI 5.5 software* [82,83].

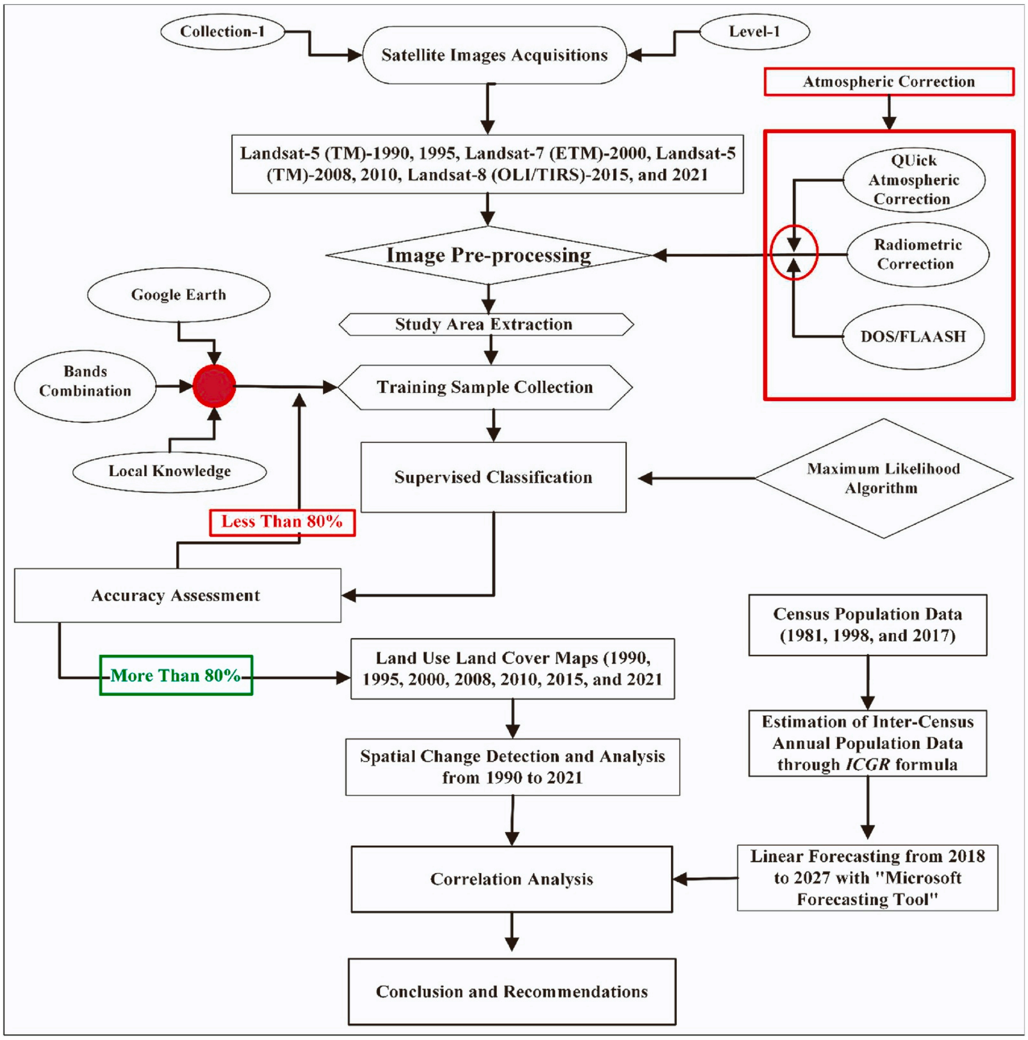

Fig. 3. Methodological flow chart.

Table 2
Description of land use classification.

S.No.	LULC Type	Description
1	Built-up	This class includes buildings, roads, concrete, and asphalt structures which are covered with impervious surfaces and anthropogenic.
2	Vegetation	This class includes forest, grasslands, green-belts, and cropland
3	Water bodies	This class include lakes, reservoirs and streams, and inundated area
4	Bare land	This class includes areas where no permanent built-up, vegetation, or water bodies exist.

3.3. Post-processing and spatial change detection

Accuracy assessment and spatial change detection were performed during the post-supervised classification stage. Accuracy assessment was necessary to recognize the level of agreement between classified images with a set of reference data [84–86] and to gather valuable information for spatial change detection and further analysis [87]. Accuracy assessment was carried out by collecting ground truth samples for 1990, 1995, 2000, 2008, 2010, 2015, 2019, and 2021 imageries based on the visualization of the imageries, indigenous information, and *Google Earth*'s archived imageries. To assess the overall classification accuracy non-parametric Kappa Test was applied [88,89]. Numerous studies applied spatial change detection in the post-classification stage [90–92]. Change detection technique was used to quantify and assess land use changes that occurred during the study period (1990–2021) [93], as well as how much one class in 1990 has been converted to another over the course of study period [94].

3.4. Population change analysis

Population census data comprising of the urban population, rural population, and total population for the years 1981, 1998, and 2017, was obtained from the Pakistan Bureau of Statistics. The inter-census annual population was estimated through inter-census annual growth rate (ICGR) formula (See Eq. (1)). Population data from 2017 till 2021 was projected/forecasted with the help of *Microsoft Excel*'s Exponential Smoothing Forecast tool. This tool could project future population using the time series historical population data (See Eq. 2). Exponential Smoothing - is a commonly used statistical algorithm for time-series forecasting. Exponential smoothing forecasting in Excel is based on the AAA version (additive error, additive trend, and additive seasonality) of the Exponential Triple Smoothing (ETS) algorithm, which smooth out minor deviations in past data trends by detecting seasonality patterns and confidence intervals

$$\text{ICGR} = \text{X} + \text{XR} \tag{1}$$

whereas X is the population of the previous year and R is the census reported growth rate factor.

Forecast = FORECAST.ETS (target year, values, timeline, [seasonality], [data completion], [aggregation]) Eq (2)

4. Results and discussion

4.1. Accuracy assessment

4.1.1. Islamabad

Accuracy assessment results of land us land cover classification process are shown in Table 3. Results of overall accuracies were 90.9%, 95.9%, 89.4%, 94.1%, 92.3%, 98.1%, 90.6% and 97.9% with Kappa Coefficient values 0.86, 0.93, 0.84, 0.91, 0.82, 0.97, 0.84, 0.97 for the year 1990, 1995, 2000, 2008, 2010, 2015, 2019 and 2021, respectively. The producer accuracy for all images classes was above 80% except built-up (71%) in 2000 [86].

4.1.2. Rawalpindi

Accuracy results of the classification process for Rawalpindi are displayed in Table 3. Overall accuracy results were 95.2%, 90.4%, 96.7%, 96.9%, 85.1%, 90.8%, 98% with Kappa Coefficient results 0.91, 0.86, 0.94, 0.95, 0.80, 0.87 and 0.97 respectively. The producer accuracy for all classified image classes were above 80% except for bare land (67%) in 2015.

4.2. Spatial pattern of change dynamics and comparison of both cities

4.2.1. Land use land cover classification of islamabad

The classified land use maps of Islamabad city for the years 1990, 1995, 2000, 2008, 2010, 2015, 2019, and 2021 are shown in Fig. 4. The results of the 1990 LULC showed that vegetation was spread over 50.2% (455 km^2) area and the built-up class covered 5.7% (52 km^2) of the city. Similarly, bare land and surface water bodies were recorded 42.2% (382 km^2) and 1.9% (17 km^2), respectively. In 1995, built-up increased up to 8.6% (78 km^2) and vegetation reduced to 45.6% (413 km^2) as compared to 1990. Bare land and surface water bodies covered 43% (390 km^2) and 2.8% (25 km^2) of the total land area. The current study results for the year 1995 differ from Ref. [29], wherein the LULC in 1992 recorded 18.09% as built-up, however for comparison purpose, the real time imageries of the study area are shown in the Annex A as supplementary material of the paper. In 2000, vegetation cover remains constant at 45.6% (413 km^2) and the built-up raised to 11.6% (105 km^2), while bare land was reduced to 39.7% (360 km^2) and water bodies covered 3.1% (28 km^2) of the city land use. In 2008, the built-up, vegetation cover, bare land and water bodies were recorded as 13.6% (123 km^2), 40.6% (368 km^2), 43.5% (394 km^2) and 2.3% (21 km^2), respectively. In 2010, built-up was increased up to 14.2% (129 km^2), vegetation cover 46.2% (419 km^2), bare land reduced to 36.3% (329 km^2), and water bodies cover was 3.2% (29 km^2). In 2015 the LULC classification results showed that built-up was increased up to 17.3% (157 km^2), vegetation cover increased to 53.8% (487 km^2), bare land reduced to 27% (245 km^2), and water bodies 1.9% (17 km^2). In 2019, the built-up class covered 23.4% (212 km^2), vegetation cover increased up to 51.2% (464 km^2), water bodies covered 1.7% (15 km^2) and bare land was decreased to 23.7 (215 km^2). Our results for the year 2019 are different from Ref. [95], wherein the LULC represented with 52.2% as built-up, 0.7% water bodies and 17.1% as barren land. In 2021 LULC resulted in the vegetation cover, water bodies, built-up and bare land covered 54.9% (497 km^2),

Table 3
Accuracy results of LULC classification.

Cities	Year/Accuracy	1990	1995	2000	2008	2010	2015	2019	2021
Islamabad	Overall Accuracy (%)	90.94	96	89.41	94.08	92.32	98.13	90.67	97.97
	Kappa Coefficient	0.86	0.93	0.84	0.91	0.83	0.97	0.84	0.97
Rawalpindi	Overall Accuracy (%)	95.25	90.45	96.72	–	96.97	85.17	90.86	98.04
	Kappa Coefficient	0.91	0.87	0.95	–	0.96	0.8	0.87	0.97

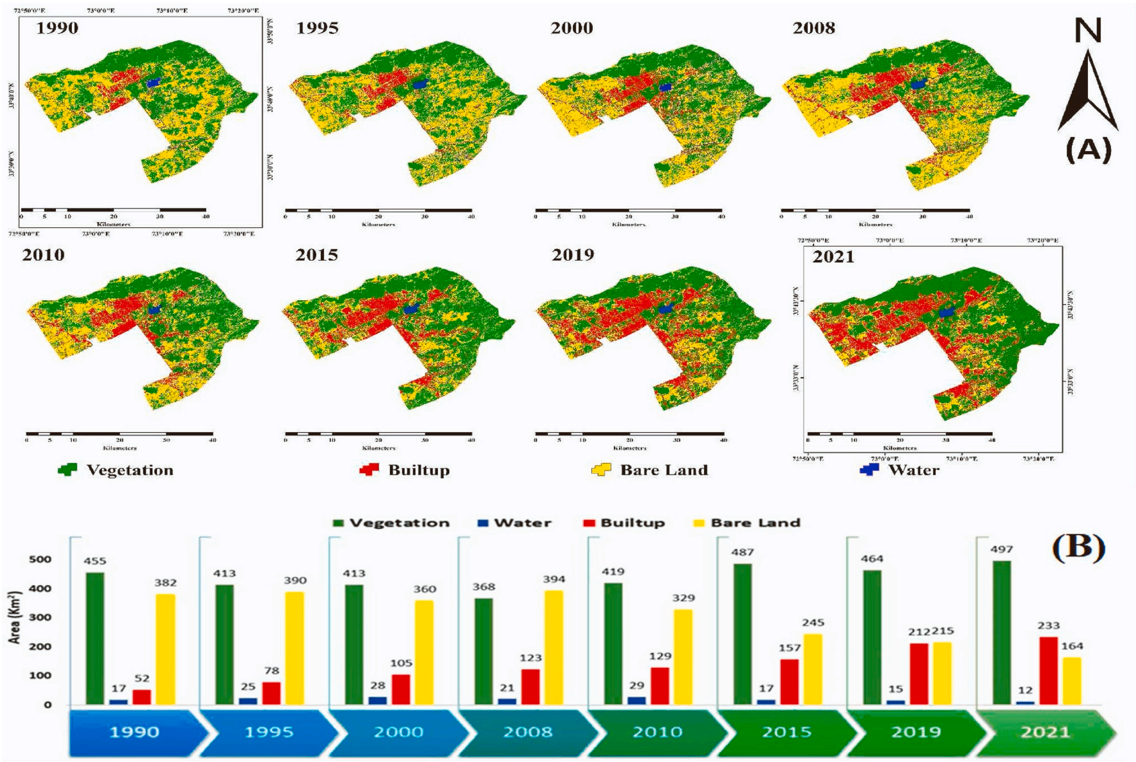

Fig. 4. LULC classification maps of Islamabad (A) Spatio-temporal change (B) Quantitative temporal change assessment.

1.3% (12 km^2), 25.7% (233 km^2) and 18.1% (164 km^2), respectively. The overall quantitative results are depicted in Table 4 and land cover trend over the last 3 decades is shown in Fig. 4. The vegetation cover showed a decreasing trend from 1990 till 2008, however, after 2008 the vegetation cover showed an increasing trend with $R^2 = 0.30$. Vegetation class shown a positive increment from 50.2% (1990) to 54.9% (2021), according to Ref. [96] grass land was increased by from 2010 to 2018. The increase in vegetation cover is due to the afforestation practices by both public and private communities. As per Millennium Development Goals, Pakistan committed to having forest cover of 5.2% and 6% by 2011 and 2015, respectively. Some of the public lead programs includes spring and monsoon mass afforestation programs and tree plantation drives, National Vision 2030, National Forest Policy (2010) etc. Furthermore, 18th August was declared as National Plantation Day, in 2009 massive plantation was carried out throughout the country. Five years afforestation program "President Mass Afforestation Program (2008–2013)" was launched to enhance the vegetation. Capital Administration Department (CDA) Islamabad planted hundreds of thousands trees in Islamabad during the last 20 years [97,98]97. The built-up class showed a continuously increasing trend over time from 1990 till 2021. The continuous rise in built-up class of the city was attributed to the growth/expansion of residential spaces, development of new housing societies/colonies, construction of industrial units, road and street pavement network, and business hub for commercial activities [29,95]. The development of built-up class put pressure mainly on bare land and vegetation classes, similar trend was reported by other studies [96,99,100]. The Built-up class showed a continuous positive increase from 5.7% (1990) to 25.7% (2021).The driving factors identified for increase in built-up class are population growth, migration, better economic opportunities and new housing societies (both public and private) [97] and industrial development. Similarly, the bare land showed an overall decreasing trend over the span of study period with $R^2 = 0.83$ (Fig. 4) and decrease was from 42.2% (1990) to 18.1% (2021).

4.2.2. Land use land cover classification of Rawalpindi

LULC maps of Rawalpindi for the years 1990, 1995, 2000, 2010, 2015, 2019, and 2021 are shown in Fig. 5. Classified map of Rawalpindi for the year 1990 shows that built-up and vegetation classes covered 3.7% (60 km^2) and 27% (437 km^2), while the bare land and water bodies covered an area of 65.5% (1058 km^2) and 3.8% (61 km^2) respectively. In 1995, the LULC resulted in 37.3% (603 km^2) vegetation cover, 2.8% (45 km^2) water bodies, 5.2% (84 km^2) built-up and 54.7% (884 km^2) bare land respectively. In 2000, built-up, vegetation, bare land, and water bodies comprised on 5.6% (91 km^2), 29.9% (483 km^2), 60.6% (980 km^2), and 3.8% (62 km^2) of the total area. In 2010 the built-up increased up to 9.3% (150 km^2) and vegetation cover was reduced to 25.4% (410 km^2), water bodies remained 5% (80 km^2) and bare land decreased to 60.4% (976 km^2). In 2015, the percentages of vegetation cover, water bodies, built-up and bare land were 58.8% (951 km^2), 2.1% (34 km^2), 10.4% (168 km^2), and 28.7% (463 km^2), respectively. In 2019, LULC resulted in 53.9% (871 km^2) vegetation cover, 2.4% (39 km^2) water bodies, 11% (178 km^2) built-up and 32.7% (528 km^2) bare land. In 2021, the classified map showed that vegetation cover is the leading land-use class with 51.5% (832 km^2) area, followed by bare land

Table 4
Land use and land cover classification statistics of Islamabad.

Land Use	1990		1995		2000		2008		2010		2015		2019		2021	
Classes	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetation	455	50.2	413	45.6	413	45.6	368	40.6	419	46.2	487	53.8	464	51.2	497	54.9
Water	17	1.9	25	2.8	28	3.1	21	2.3	29	3.2	17	1.9	15	1.7	12	1.3
Built-up	52	5.7	78	8.6	105	11.6	123	13.6	129	14.2	157	17.3	212	23.4	233	25.7
Bare Land	382	42.2	390	43	360	39.7	394	43.5	329	36.3	245	27	215	23.7	164	18.1
Total	906	100	906	100	906	100	906	100	906	100	906	100	906	100	906	100

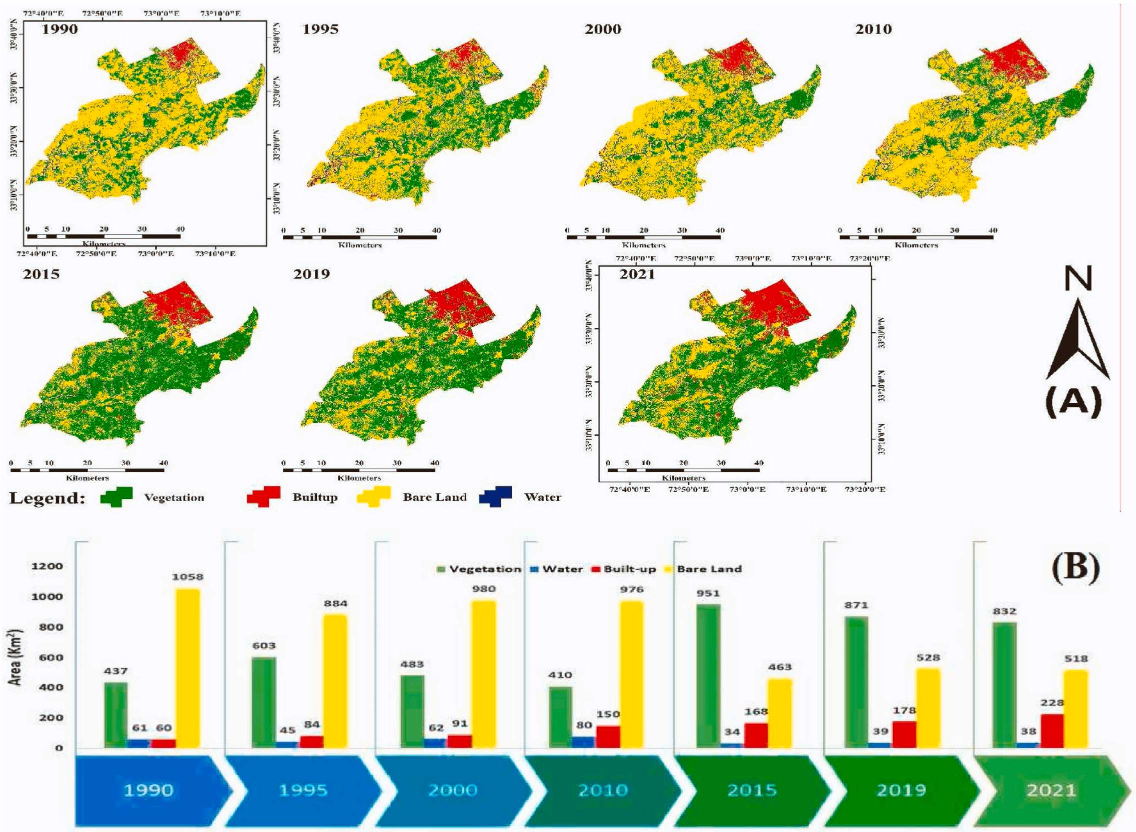

Fig. 5. LULC classification maps of Rawalpindi (A) Spatio-temporal change (B) Quantitative temporal change assessment.

32.1% (518 km^2), built-up 14.1% (228 km^2), and water being the least with 2.4% (38 km^2). The overall quantitative results are depicted in Table 5.

4.3. Spatial change detection

4.3.1. Islamabad

Spatial change detection was carried out to quantify and visualize the transition of one land-use class to other classes from 1990 to 2021. The major transformation among the land use classes is shown in Figs. 6 and 7 both visually and quantitatively. The results showed that 119.8 km^2 of bare land has been converted to built-up class and about 164.8 km^2 of bare land has been converted to vegetation class. Vegetation to bare land transformation was noticed for 47.1 km^2 and vegetation to built-up showed 71.1 km^2 area. Zero-point interchange (lat 33.693793; lon 73.065202) is considered to be the center point to analyze the built-up dimensions of the city. The hotspot areas in eastern parts of the city where built-up had been substantially increased include Bhara Kahu, Bani Gala, Kot Hatyal, Nurpur Shahan, Diplomatic Enclave, Phulgran, Athal, Mair Begwal, and along the bank of river Korang. In eastern parts of the city, the major contributor to built-up includes the Bahria Enclave, Jagiot, Chatta Bakhtawar, Nilor, Thanda Pani, Jhang Sayedan, Frash Town, Royal City, Panjgran, Alipur, Khadrapur, Taramri, Kirpa, Chirah, Tarlai Kalan, Sudran Kalan, Al-Huda Town, Kiyan Town, Kashmir Town, Partal Town, Arsalan Town, Gulberg Greens and Dhok Jabi. The Southern part of the city was covered with a built-up

Table 5
Land use and land cover classification statistics of Rawalpindi.

Land Use	1990		1995		2000		2010		2015		2019		2021	
Classes	Area \(km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetation	437	27	603	37	483	30	410	25	951	59	871	54	832	52
Water	61	3.8	45	2.8	62	3.8	80	5	34	2.1	39	2.4	38	2.4
Built-up	60	3.7	84	5.2	91	5.6	150	9.3	168	10	178	11	228	14
Bare Land	1058	66	884	55	980	61	976	60	463	29	528	33	518	32
Total	1616	100	1616	100	1616	100	1616	100	1616	100	1616	100	1616	100

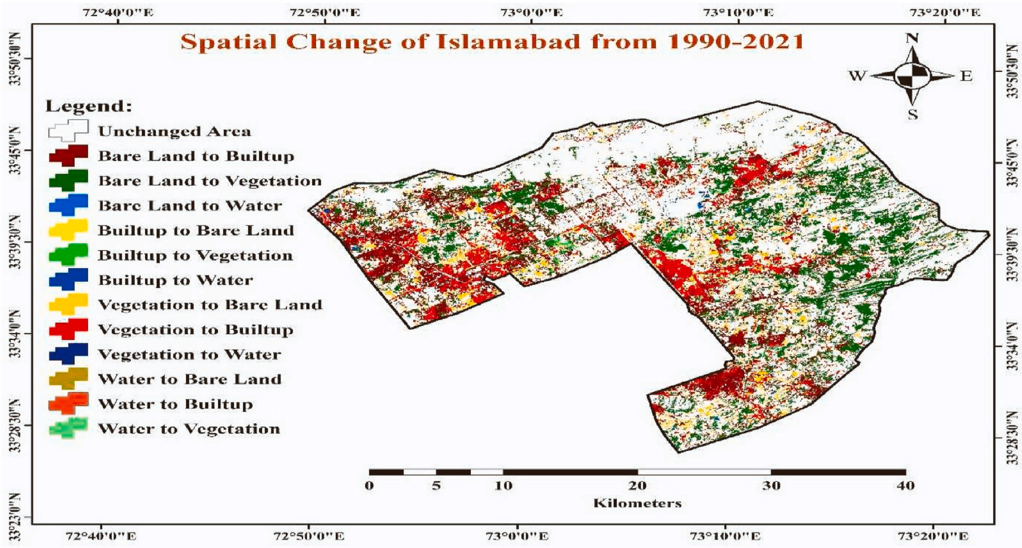

Fig. 6. Spatial change detection of Islamabad from 1990 to 2021.

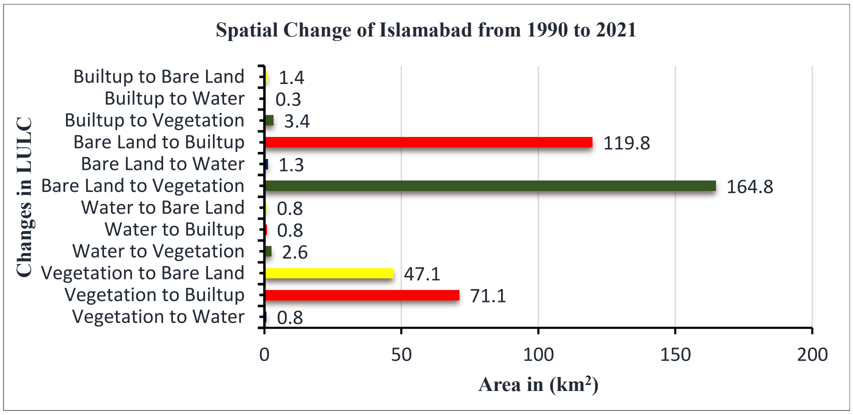

Fig. 7. Spatial change statistics of Islamabad from 1990 to 2021.

layer made by Sohan, Iqbal Town, Awan Town, Burma Town, Bilal Town, Garden Green, Khana, Ghauri Town (all phases), Koral Town, Lohi Bhair, Jinnah Garden, DHA (Phase I &II) and Rawat. Built-up contributor in the western dimension includes Sectors F-11, G-11 to G-15, I-14, H-13, Jhangi Syedan Awan Town, Naseer Abad, Qasim Abad, British Homes, Islamabad View Colony. On north-west side Sector E−11, D-12, Chautra & Ghea villages, and Shah Allah Dita mainly contributed to impervious cover. On the north side of the city sectors E−7, E−8, E−9 are a prominent built-up contributor. On western side along the GT road to Peshawar side F-15 Jammu & Kashmir Housing Scheme, Tarnol, Dhoke Paracha, Multi Garden B-17 and D-17 showed an increase in the built-up layer.

4.3.2. Rawalpindi

The spatial change detection map of Rawalpindi and land cover statistics from 1990 to 2021 are shown in Figs. 8 and 9. Vegetation and bare land classes were remained a major part of change detection. Bare land was changed to vegetation class by 534.4 km^2 and about 124.3 km^2 area has been changed from bare land to built-up class. Vegetation to bare land transformation was recorded 70.4 km^2 and vegetation to built-up conversion was noted 46.5 km^2. Initially (1990) the built-up layer was recorded in upper northwestern part of the study area, however, later (2021) the built-up was noticed in areas of Dhoke Gujran, Bakra Mandi, Chakra, Razzaq Town, Misrial. In south-eastern part of the study area the hotspots include Fazal Town, Gharibabad, Chaklala Scheme-3, Gulbahar Scheme, Soan Gardens, Gulrez housing scheme, and some part of DHA and Bahria Town.

4.4. Population dynamics of both cities

4.4.1. Islamabad

Population census data was obtained from the Pakistan Bureau of Statistics. The recorded census data showed that the population

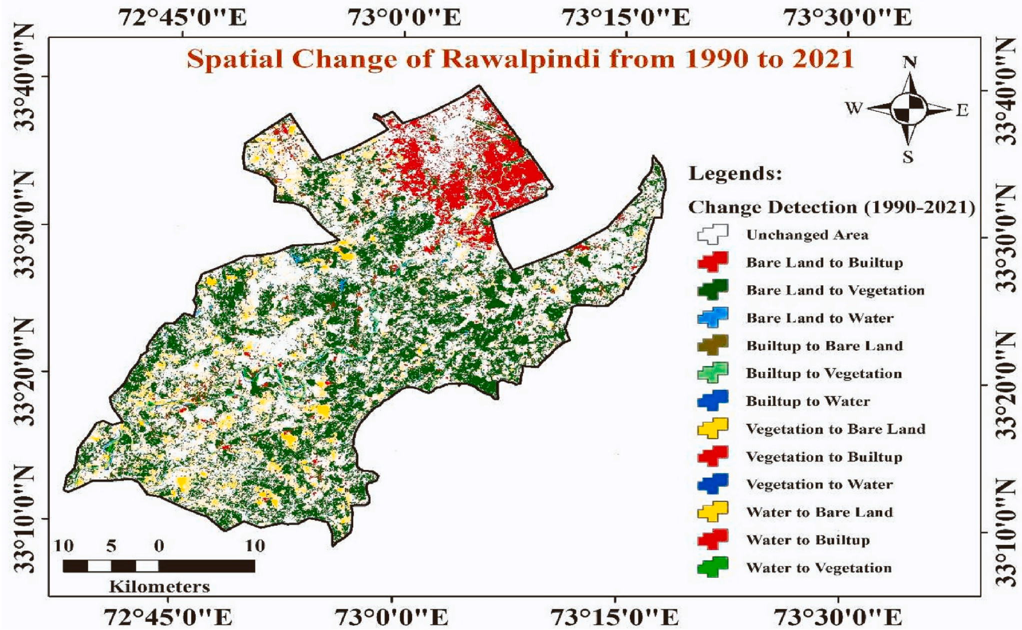

Fig. 8. Spatial change detection of Tehsil Rawalpindi from 1990 to 2021.

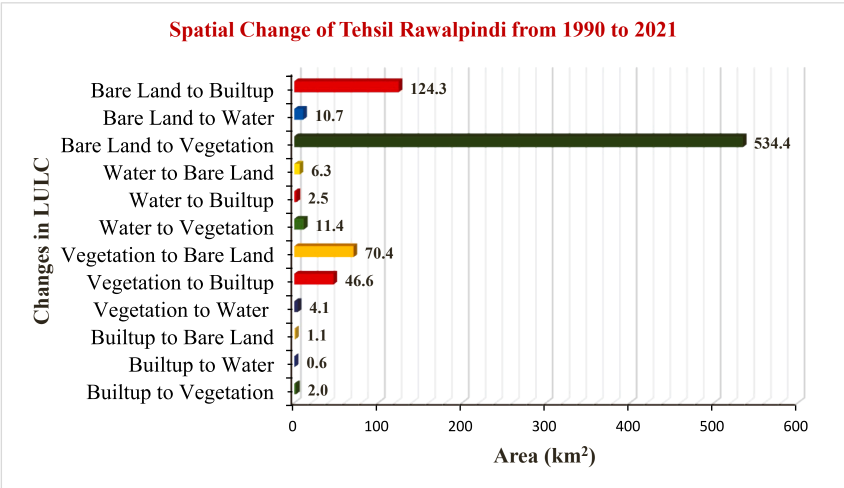

Fig. 9. Spatial change statistics of Tehsil Rawalpindi from 1990 to 2021.

has been steadily increasing since the first national census (1951). Total population of Islamabad was 340290, 805235, and 2001579 in 1981, 1998, and 2017, respectively (Fig. 10). Similarly, the urban population was 204364, 529180, and 1009832 in the years 1981, 1998, and 2017, respectively. In 1972 urban population was lesser than the rural population, however, with the passage of time the urban population got higher than the rural population. The annual population data was estimated from the growth rate given by the recorded population census. Population forecasting for the year 2018–2027 was done with Microsoft Excel forecasting tool (Fig. 11). Future population estimation was required for further correlation analysis with land use land cover changes occurred after 2017. By 2027 it is projected based on historical trend, that Islamabad's population would be between 2.8 million and 3.1 million. Statistical analysis shows that there is a strong positive correlation ($r=0.98$) between built-up and total population. Similarly, there is storge negative correlation ($r=-0.93$) between bare land and population. Correlation matrix at level 0.01 (two tailed) and 0.05 (two tailed) was computed to examine relationship among different land use classes and total population (Table 6). Significant negative correlation ($r= -0.60$) was found between total population and surface water bodies.

4.4.2. Rawalpindi

Rawalpindi population data from 1981 to 2017 (national census) was plotted and projected till 2027 based on the previous 37

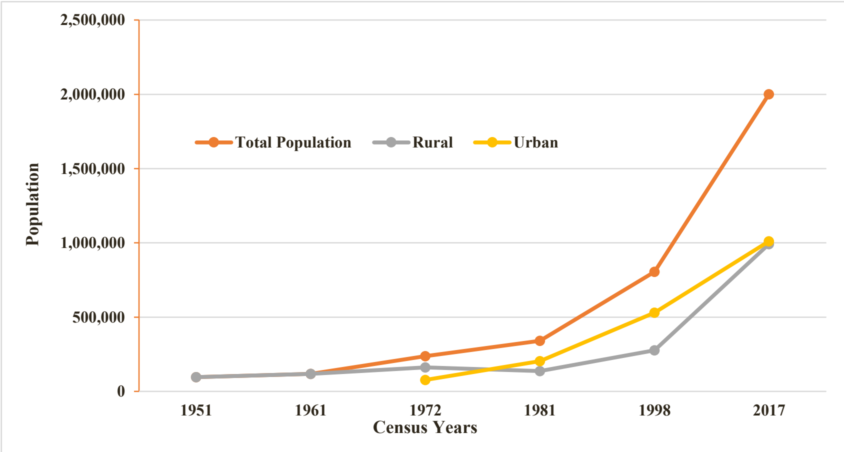

Fig. 10. Historical population growth of Islamabad from (1951–2017).

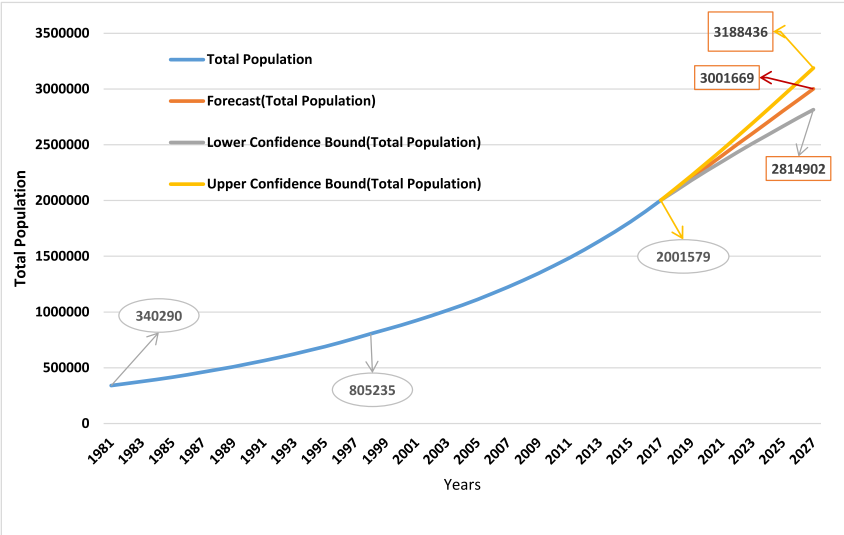

Fig. 11. Population projection of Islamabad from 2017 to 2027.

Table 6
Correlation matrix of land use classes and population for Islamabad.

Correlation Matrix-Islamabad						
		Total Population	Built-up	Bare Land	Vegetation	Water
Total Population	Pearson Correlation	1				
	Sig. (2-tailed)					
Built-up	Pearson Correlation	.987[a]	1			
	Sig. (2-tailed)	0				
Bare Land	Pearson Correlation	−.931[a]	−.927[a]	1		
	Sig. (2-tailed)	0.001	0.001			
Vegetation	Pearson Correlation	0.586	0.554	−.824[b]	1	
	Sig. (2-tailed)	0.127	0.154	0.012		
Water	Pearson Correlation	−0.604	−0.577	0.681	−.715[b]	1
	Sig. (2-tailed)	0.113	0.134	0.063	0.046	

[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

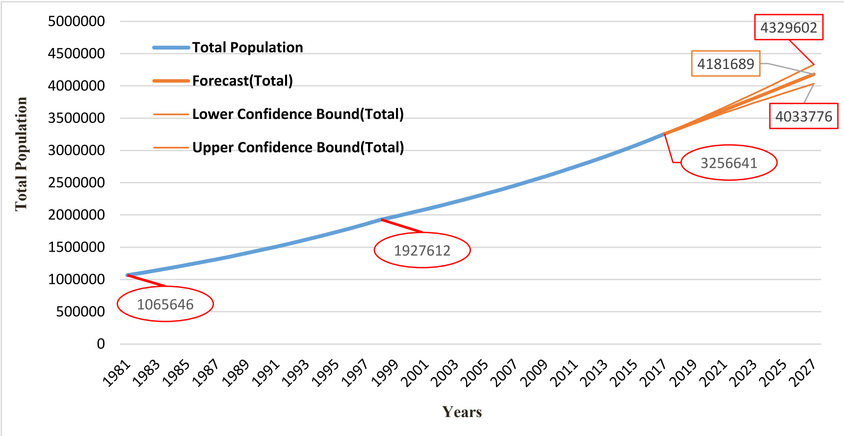

Fig. 12. Population projection of Rawalpindi from 2017 to 2027.

years' records (Fig. 12). The projected population in 2027 will remain in the range of 4.0–4.3 million, and consequently will cover the land with built-up class from 277 to 295 km^2. However, due to the development of Rawalpindi Ring Road Project the situation may vary in future. Rawalpindi population in 1981, 1998, and 2017 was recorded 1,065,646, 1,927,612 and 3,256,641, respectively. Strong positive correlation ($r = 0.98$) was observed between population and built-up and strong negative correlation ($r = -0.86$) was found between population and bare land. Correlation matrix of different land uses classes and total population is given in Table 7.

4.5. Population densities of both cities

Population densities of both study areas were assessed and projected using census data and total area (Fig. 13). The comparison has shown that Islamabad's population density increased from Rawalpindi after 2012. In 1990 the population density of Rawalpindi was observed 902 persons per square kilometer while the Islamabad was 591, but due high rate of urbanization Islamabad crossed the Rawalpindi and reached to 2650 person per square kilometer in 2017. Based on the previous data the expected population density of Islamabad in 2027 may increase to 3313 persons per square kilometer as compared to Rawalpindi with projected population density of 2588 persons per square kilometer.

5. Conclusions and recommendations

Based on the comparison analysis, it was concluded that the built-up layer had greatly increased between 1990 and 2021 in both study regions. The observed increase in built up area for Islamabad was 348% and 248% for Rawalpindi. In case of Islamabad, significant transition to built-up class was found primarily from bare land (120 km^2) followed by vegetation (71 km^2). Similarly, bare land has been reduced by 51% in Rawalpindi and 57% in Islamabad in the last three decades. Surface water bodies in both study areas also showed a decreasing pattern and illustrating towards the stress on water resources in the study region. In Rawalpindi, the water bodies decreased by 38%, while in Islamabad it reached to 29%. Vegetation cover in Islamabad shows a clear decreasing trend from 1990 till 2008, however, after 2008 it shows improvement till 2021, and the overall increase was recorded at 9%. In Rawalpindi the vegetation cover became almost double from 1990 to 2021. Population of Islamabad and Rawalpindi increased considerably from 1990 till 2021.

Table 7
Correlation Matrix of land use classes and population for Rawalpindi.

Correlations						
		Total Population	Built up	Bare Land	Vegetation	Water
Total Population	Pearson Correlation	1				
	Sig. (2-tailed)					
Builtup	Pearson Correlation	.981[a]	1			
	Sig. (2-tailed)	0				
Bare Land	Pearson Correlation	−.864[b]	−.829[b]	1		
	Sig. (2-tailed)	0.012	0.021			
Vegetation	Pearson Correlation	.760[b]	0.713	−.983[a]	1	
	Sig. (2-tailed)	0.047	0.072	0		
Water	Pearson Correlation	−0.486	−0.456	.840[b]	−.913[a]	1
	Sig. (2-tailed)	0.269	0.304	0.018	0.004	

[a] Correlation is significant at the 0.01 level (2-tailed).
[b] Correlation is significant at the 0.05 level (2-tailed).

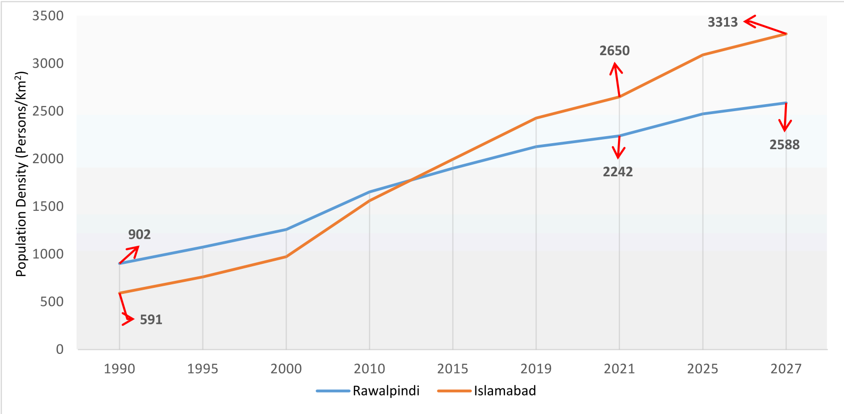

Fig. 13. Evolution of Population densities of both study areas.

Primarily it can be attributed to the uncontrolled birth rate in Pakistan. Although, during London Family Planning Summit in July 2012, Pakistan pledged to raise the contraceptive prevalence rate from 35% to 55% by 2020 and lower the fertility rate from 3.8 to 2.6 to manage the country's higher birth-rate [101]. However, the birth rate of 3.6 Pakistan's in 2022 demonstrates a significant failure of birth control strategies. Furthermore, rural to urban migration could be major source of increasing population in the study area. As the urban population proportion in Pakistan has bene increased from 28% in 1990 to 36% in 2017. Worldwide urban centers offer various opportunities for better livelihood by providing access to quality public services such as affordable housing, reliable water supply, and other public services. By providing such facilities in the rural areas can help in reducing the rural to urban migration. Although, the Government of Pakistan is trying to boost the industrial sector in far flung areas by providing numerous incentives to uplift the economic situation, employment and reduce rural to urban migration. However, the huge sprawl of housing colonies and schemes in both study areas reflect more concrete efforts are required on ground to avoid unprecedented urban sprawl. Recent figures from the Rawalpindi Development Authority (RDA) show that more than 200 unapproved housing societies and approximately 50% of housing projects within the Capital Development Authority (CDA) Islamabad's territorial limits are operating without NOC from the CDA. Other key factors that contributed to unplanned LULC changes include the country's poor governance structure, a lack of proper planning and monitoring, and the country's regional security situation. During the last decade, the Afghan war on terror and anti-terrorism operations in the country have also increased rural-urban migration. Lack of approved land use plan and management practices in cities haphazardly resulted in unplanned development with consequent enhanced emissiosn of carbon dioxide and other pollutants leading to environmental degredation [102,103]. Therefore, it is suggested that the government should formulate a sustainable and environmentally viable land use plan for cities by exploiting the remote sensing and GIS based information. Awareness campaign should be launched to raise the awareness among all stakeholders regarding negative implication of built-up layer and consequent ecosystem degradation.

Considering the increase in built-up layer and decrease in bare land of both cites, future research studies may be carried out on quantifying the loss of rainfall runoff, decreasing infiltration capacity of the cities and its impact on ground water recharge. It is further recommended that research should be carried out on the impact assessment of LULC changes on environmental parameters such as water quality and quantity, climatic parameters like temperature and precipitation.

6. Limitations and strategy adopted

Major limitations during this study were i) non-availability of Landsat satellite data for the year 2005 over the study area, and ii) annual population data. The first limitation was covered by using the nearest available Landsat satellite data of 2008. The second limitation was covered by applying the recorded census annual population growth rate factor to obtain annal population data.

Author contribution statement

Mr. KAMRAN, PhD Scholar: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Junaid Aziz Khan, PhD Scholar; Umer Khayyam, PhD: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Abdul Waheed, PhD: Performed the experiments; Wrote the paper.

Muhammad Fahim Khokhar, PhD: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no competing interests.

Declarations

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