RESEARCH PAPER

SPATIO-TEMPORAL ANALYSIS OF URBAN EXPANSION AND FUTURE GROWTH PATTERNS OF LAHORE, PAKISTAN

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ABSTRACT. Lahore, a metropolis and 2nd largest city of Pakistan, has been experiencing rapid urban expansion over the past five decades. The socio-economic development and growth of the urban population have caused the rapid increase of urban expansion. The increase in the built-up area of Lahore has seen remarkable growth during the past five decades. This study is aimed at detecting the Spatio-temporal changes in land use land cover and evaluating the urban expansion of Lahore since 1973. The conversion of land to other uses is primarily because of growth in urban population, whereas the increase in economic activities is the central reason for the land-use changes. In this study, temporal Landsat imageries were integrated with demographic data in the GIS environment to quantify the spatial and temporal dynamics of land use land cover (LULC) changes and urban expansion of Lahore city. The supervised image classification of maximum likelihood algorithm was applied on Landsat MSS (1973 and 1980), TM (1990), ETM+ (2000), TM (2010), and OLI/TIRs (2020) images, whereas a post-classification comparison technique was employed to detect changes over time. The spatial and temporal analysis revealed that during the past five decades, the built-up area of Lahore city has expanded by ~ 532 km^2. It was found from the analysis that in Lahore city the urban expansion was primarily at the cost of loss of fertile agricultural land, vegetation, and other cultivable land use. The analysis further revealed that the structure and growth pattern of Lahore has mainly followed road network and linear expansion. The results indicate that this accretive urban expansion is attributed to socio-economic, demography, conversion of farmland, rural-urban migration, proximity to transportation routes, and commercial factors. This study envisions for decision-makers and urban planners to devise effective spatial urban planning strategies and check the growth trend of Lahore city.

KEYWORDS: Land use change, urban expansion, monitoring, growth pattern, Lahore

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INTRODUCTION

Cities are central places for socio-economic activities and human survival (Chen et al. 2021). In recent past decades, fast urbanization has been accompanied by momentous increases in the urban population in cities (García-Nieto et al. 2018; Yang et al. 2018). Expansion of cities has been continuous for several decades (Taubenbock et al. 2009). Expansion of towns and cities mostly observed in the developing countries is causing the loss of fertile agricultural, farmland, and urban green spaces (Mundia and Aniya 2006; Jat et al. 2008). According to the United Nations, the percentage of the urban population in cities during the period of 1950–2018, increased from 30% to 55% and projected that in 2050 urban population proportion will increase to 68% and 90% of the projected urban population increase would take place in developing countries (United Nations 2018). Today, most regions of the world are highly urbanized like 82% of Northern America, 81% of Latin America and the Caribbean, 74% of Europe, and 68% of Oceania. The urbanization level in Asia is now approaching 50%. In contrary to that, 43% of the African population is urban and 57% population is rural (United Nations 2018). Pakistan as a developing country is facing rapidly increasing urbanization and in Pakistan, the proportion of the urban population living in cities increased from 17.8% to 36.4%, from 1951 to 2017 (GoP 2000, 2017). According to the level of urbanization, within the Asia-Pacific region, Pakistan is experiencing a moderate level of urbanization. In comparison with other countries of South Asia, Pakistan has the maximum number of urban dwellers because 36.4% of its human population settled in towns and cities (GoP 2017). Pakistan is one of the fastest urbanizing countries in South Asia and the share of the urban population is increasing significantly. The other countries of South Asia are far behind Pakistan in terms of the urban population. It is projected that by the year 2030, the proportion of the urban population of Pakistan will increase to 50% (GoP 2015). Like other developing countries, the annual urbanization rate of Pakistan is 3% and is rapidly increasing in South Asian countries (Kugelman 2013).

Urbanization is the most powerful force that results in land-use change (LUC) around the world (Simwanda and Murayama 2018). By way of continuing development in urban areas, lands consist of the resources such as agriculture, farmland, woodland, and forest areas have been altered to built-up areas

(Son et al. 2017; Vasenev et al. 2019). Due to the increase of urban population, the fertile land use for agriculture is being encroached by industrial areas, infrastructural development, educational purposes, housing, and commercial usages (Quasem 2011). According to the report of UNFPA (2007), the recent developments of the urban expansion emphasize peripheral areas and most of the urban areas are located at the prime agricultural lands (Arif and Hamid 2007). Agarwal et al., (2002), reports that globally and over a longer period, nearly 1.2 million km2 of forest and woodland and 5.6 million km2 of grassland and pasture have been converted to other land uses during the last three centuries. However, urban land covers only 3% of the Earth's land-living surface and expansion of urban areas has important influences on ecosystems and climate change (Liu et al. 2014; Zang et al. 2017) in urban areas due to urban expansion (Kim et al. 2016). Perhaps, the alteration of natural land to urban built-up uses is one of the greatest irreversible anthropological effects and all over the world it is detected that urban land had enlarged of 58,000 sq. km during the period of 1970 to 2000 (Seto et al. 2011). Several studies (Chen 2007; Bagan and Yamagata 2014; Ahmad et al. 2016) show that high rates of urban expansion are occurring during the last three decades all around the world with the example from China, Egypt, United States, Turkey, India, Pakistan, and other Asian and African countries. Internationally, future urban expansion is projected to alter 27 to 35 million hectares of croplands during the period between 2000 and 2030 from which about 80% of worldwide loss of cropland due to urban expansion will take place in Africa and Asia (Bren d'Amour et al. 2017).

One of the characteristics of urbanization urban expansion has been getting significant consideration in different disciplines, such as urban planning and geography (Liu et al. 2005; Li et al. 2014; Song and Deng 2015). There is no doubt that the constant expansion of urban surfaces has caused a massive burden on sustainable urban development. Due to the significance of urban expansion and its everlasting effects, it has become an alarming issue in integrated socio-economic and ecological research (Kaza 2013; Li et al. 2018). Therefore, it is worth evaluating the spatial and temporal urban expansion dynamics, which can help in decision-making and urban planning efforts associated with sustainable development. Urban population growth and socio-economic development cause urban expansion (Wilson et al. 2003; Epstein et al. 2006). Computing the temporal and spatial urban expansion patterns is significant for understanding its effects on ecological processes. To get a detailed understanding of processes of urban expansion, current issues interrelated to urban expansion have been highlighted. Most studies have been accompanied to analyze and monitor the status of rapid expansion of urban areas in developed nations (Seto et al. 2002) as well as developing nations, which include India and particularly Pakistan (Sudhira et al. 2004; Ghaffar 2006; Anwar and Bhalli 2012; Shirazi and kazmi 2014; Bhalli and Ghaffar 2015), China (Weng 2002; Seto and Kaufmann 2003; Xiao et al. 2006), and Mexico (Muñoz-Villers and López-Blanco 2008). Several studies have been devoted to revealing how the expansion of urban areas modifies the spatial configuration of cities' landscape patterns (Estoque and Murayama 2013; Benza et al. 2016; Kirillov et al. 2019).

In recent decades, there has been an increasing trend in the use of GIS, photogrammetric, and satellite remote sensing (SRS) data retrieval procedures for mapping, intelligent navigation, as well as simulation modeling of urban expansion and future patterns of urban growth. These methods have been used extensively in the identification of variations in land use as well as the growth of cities (Batisani and Yarnal 2009; Bhatta 2010). Most of the conventional methods of field surveys were time taking; the procedure of Remote Sensing and GIS have facilitated scientists to do broad spatial and temporal investigation in a comparatively short period (Lo and Yang 2002). The applications of RS and GIS techniques confirm the accuracy, flexibility, authenticity, and easiness of data collection, storing, and study of important digital data for revealing, and timely observing of spatial features at local to global level (Wu et al. 2006). Lahore is the second biggest metropolitan city after Karachi in Pakistan and haphazard urban expansion creates several issues related to the conversion of agricultural land into a built-up area, water quality deteriorating, air pollution, urban heat islands, and others. In this study, an attempt has been made to apply multi-temporal images while analyzing the urban expansion and its impact on land use and for monitoring the future growth patterns of Lahore.

Study Area

The study area of Lahore extends between 31°15′ N to 31°42′ N and between 74°01′ E to 74°-39′ E, (Nasar-u-Minallah 2020) spread over an area of 1772 sq. km. (Fig. 1). The average elevation of Lahore is 150 to 200 m above sea level with the annual mean temperature varies from 18°C to 38.8°C and the average annual rainfall is about 628.7mm (Nasar-u-Minallah and Ghaffar 2020).

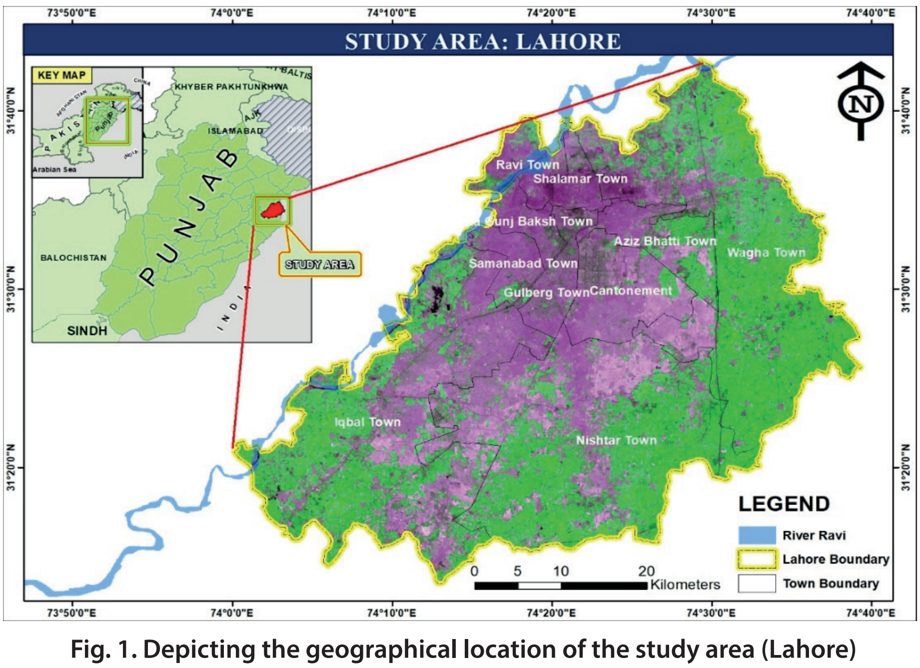

Fig. 1. Depicting the geographical location of the study area (Lahore)

Land use profile within Lahore is unevenly distributed into a built-up area, agricultural land, vacant land, and water bodies. However, much of the agricultural land, vegetation cover, and green spaces have been removed as a result of land-use change due to urban expansion. The urban population of Lahore has grown considerably, according to the population census reports it increased from 1.12 million in 1951 (GoP 2000) to 11.12 million in 2017 (GoP 2017). The population density of Lahore estimated in the 2017 census is 6275 persons/sq. km (GoP 2017).

MATERIALS AND METHODS

Data acquisition and preparation

This study is based on Spatio-temporal satellite data along with non-spatial data accessible from different sources for different periods. Urbanization has led to the expansion of the city landscape of Lahore, leading to land-use variations. The present study precisely emphasizes understanding the patterns of land-use change and dynamics of expansion based on demographic and satellite data. Satellite digital data is used to extract the land use statistics of Lahore comprising of six Landsat images. The Landsat 4, 5, 7, and 8 data sets were created by the USGS and acquired in GeoTIFF format. The Landsat satellite images were acquired as standard products, i.e. geometrically and radio-metrically rectified (Ifatimehin 2008; Bhatta 2009). In order to achieve the desired objectives of the study, the earliest available Landsat image was acquired on 23 March 1973, and the rest of the images with the interval of ten years were acquired on 04 March 1980, 16 March 1990, and 19 March 2000 while the up-to-date two images were acquired on 07 March 2010 and 18 March 2020. The data specification of Landsat images is shown in Table 1. The optical bands of Landsat images have been used to extract land use information. It is worth mentioning that the thermal bands of satellite images were not considered for the analysis. High-resolution Google earth image was used as reference data for land use classification and geographic data (GPS points) were also collected for all the various land-use types to assess classification accuracy. Other reference data includes topographical maps and aerial photographs, district and town boundary of the study area which was obtained from the office of the urban unit, Lahore. The data collected from the Survey of Pakistan (SOP) includes topo-sheets (scale, 1:50,000) of Lahore. Socio-economic data consist of primarily statistical information regarding the population of city and land use data as well as road infrastructure also used in this study was acquired from population census organization and Punjab development statistics respectively. The data manipulation and image processing were accompanied using procedures provided by ERDAS, which also integrates GIS functions. ArcGIS is utilized for overlay analysis. ArcGIS and ERDAS Imagine are used as GIS and satellite remote sensing software to analyze the digital data and acquire the final output during the entire study.

Methodology

The whole procedure of the present study has been illustrated in a flowchart as shown in Fig. 2. The image processing procedures comprised of pre-processing of the image, classification of the image, scheme of classification and design, overall accuracy assessment, and dynamics of urban expansion and exploration of land-use changes (LUC). To achieve the objective of the existing research, satellite images of the Landsat system of MSS, ETM+, and OLI/TIRs modes were acquired in GeoTIFF format from the USGS website free of cost. At first, different optical bands of Landsat images were stacked by the procedure of layer staking to develop false-color composite imagery (Jensen 1996; 2009). The satellite Landsat imageries were geo-referenced to a common coordinate system of UTM43 and datum WGS84 (Almas 2005). The vector layer of Lahore was utilized to subset each image for clipping the study area from the complete scene. All the subset images were enhanced by the histogram equalization technique to raise the volume of visible information and to increase a higher level contrast in the peaks of the original histogram (Shalaby and Tateishi 2007). This procedure is important for helping the identification of GCPs and the rectification process (Weng 2001).

Image classification is a process whereby all pixels in the image are categorized into a theme or different land-use class (Lillesand and Kiefer 2004). Supervised image classification technique has been extensively utilized in remote sensing satellite applications. A supervised image classification procedure by maximum likelihood algorithm (MLA) is subsequently applied for mapping of land-use changes on the six Landsat satellite imagery. Training sites for supervised image classification were defined with the help of field acquired data (Almas 2005). After the scheme of land use organization has been selected, training areas are wisely chosen inadequate homogeneity to increase the image classification accuracy assessment. This phase is perhaps the vital part of supervised image classification, to extract the spectral signature from the training sample to

Table 1. Detail of Landsat satellite imagery

<table>
<tr><td>Date of Acquisition</td><td>Sensor</td><td>Spectral Band</td><td>Spatial Resolution</td><td>Path/Row</td></tr>
<tr><td>23-03-1973</td><td>MMS</td><td>1-4</td><td>60m</td><td>160/38</td></tr>
<tr><td>04-03-1980</td><td>MMS</td><td>1-4</td><td>60m</td><td>160/38</td></tr>
<tr><td>16-03-1990</td><td>TM</td><td>1-5 & 7</td><td>30m</td><td>149/38</td></tr>
<tr><td rowspan="2">19-03-2000</td><td rowspan="2">ETM+</td><td>1-5 & 7</td><td>30m</td><td rowspan="2">149/38</td></tr>
<tr><td>Pan (8)</td><td>15m</td></tr>
<tr><td>07-03-2010</td><td>TM</td><td>1-5 & 7</td><td>30 m</td><td>149/38</td></tr>
<tr><td rowspan="2">18-03-2020</td><td rowspan="2">OLI</td><td>1-8</td><td>30m</td><td rowspan="2">149/38</td></tr>
<tr><td>Pan (9)</td><td>15m</td></tr>
</table>

Source: http://landsat.usgs.gov/

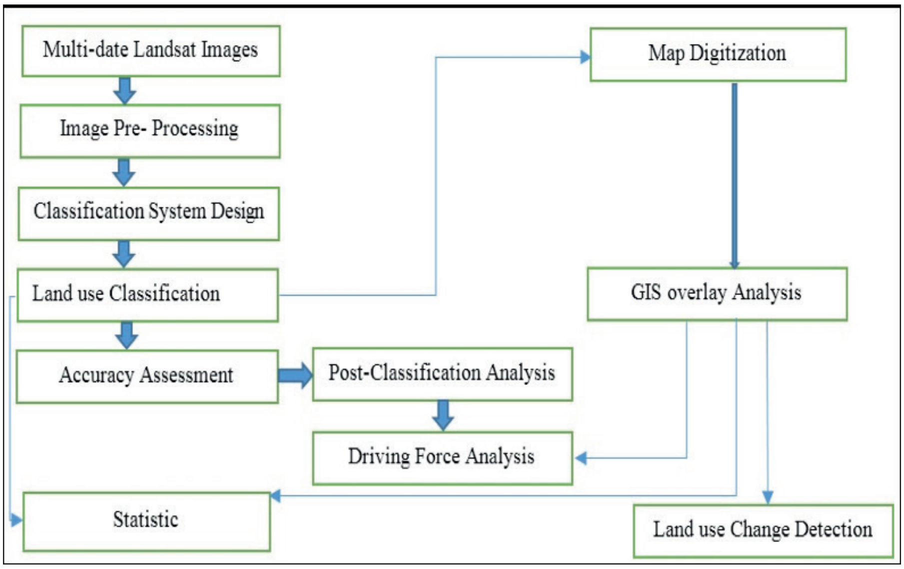

Fig. 2. Flowchart depicting the outline of the general methodology

determine the overall classification accuracy, and thus the utility of the creation of the thematic map. An altered form of the Anderson classification scheme of land use (Anderson et al. 1976) is utilized to classify the different types of land use. Although the Anderson land use classification scheme was formerly designed for the USA land-use type, after that it is frequently utilized to classify the land use all over the world (Dewan and Yamaguchi 2008). The Anderson land-use system determined that the classification of land use of level I and II classes can be mapped over large areas from Landsat data. So, Anderson's land use classification scheme of levels I and II is taken and referred to as the land use scheme in the present study. Land use types and schemes of classification are given in Table 2.

To detect the land-use change, there are two basic approaches for the analysis of multi-temporal data i.e.; post-classification comparisons and simultaneous analysis (Singh 1989). Both above-mentioned approaches have their own benefits and drawbacks (Mundia and Aniya 2007). In the present study, the first approach post-classification comparisons were selected, because the post-classification approach is very helpful when available data is acquired in different sensors and spectral and spatial resolutions are not the same (Alboody et al. 2008). Moreover, it is a common method for comparing land-use dynamics (Congalton 1991). It is used for change detection of different types of land use, by associating individually produced classified land use maps (Mundia and Aniya 2007). The major benefit of this approach is its ability to offer descriptive land information on the nature of changes that occur during the study span (Alboody et al. 2008). It is significant to note that this procedure depends on the outcomes of the classification of all classified images and digital data stored in the GIS catalog. The GIS functional abilities permitted the comparison of post-classification and helped qualitative calculation of the factors inducing urban expansion. Accuracy assessment of classification determines the value of the information derived from satellite remotely sensed (SRS) data. The accuracy assessment of the classification of six land use maps of Lahore is determined using the techniques of random sampling. Stratified random sampling techniques, where the points were stratified according to the distribution of land use classes were accepted (Mundia and Aniya 2006). By permitting the reference pixels to be selected at random, the probability of business is reduced. For satellite images of MSS, ETM+, and OLI a total of 500 points were selected. The overall accuracies of the classified images were 85%, 89%, and 90% for MSS, ETM+, and OLI, respectively.

RESULTS AND DISCUSSION

Dynamics of urban expansion and analysis of Land use changes

The history of development and land use planning in Lahore city has been reported in several studies in the previous decades (Rana and Bhatti 2018). This study, however, highlights the existing as well as the projected state of the urban built-up area of Lahore in future decades. Urban built-up area measured as being reflective of urban expansion. Urban expansion is a difficult process determined by a range of spatial and temporal constituents (Deng et al. 2009). The rapid increase in urban expansion of Lahore city is largely attributed to natural increase, migration, area annexation in urban boundary,

Table 2. Description of satellite-derived Land use classes modified after Anderson, 1976

Level I	Level II	Explanation
Key land use	Sub-land use	
Urban	Built-up land	Residential, industrial, transportation, commercial and services, communications and utilities, and mixed-use of land.
NON-Urban	Vacant Land	Open space, fallow land, construction sites, excavation sites, bare soils, and exposed areas.
	Vegetation/ Agriculture	Trees, natural vegetation, forest, grassland, gardens, parks and play areas, agricultural land, and crop fields.
Water Body	Water	River, streams and canals, open water, ponds, lakes, reservoirs.

reclassification, and merging of villages in urban territory. Urbanization is the main cause of land conversions and land-use changes. It creates unpredictable and long-term modifications to the city landscape. A significant aspect of change detection is to determine what is changing to what i.e. which land-use class is changing to the other (Weng 2002; Xiao et al. 2006). Exploring the spatial and temporal changes in land use is one of the most effective methods to recognize the existing ecological status of an area and to monitor land variations (Yuan et al. 2005). The present study examined urban expansion and future growth patterns of Lahore through the built-up area employing Landsat satellite data for the period from 1973 to 2020.

The results of the study indicated that there is a rise in the urban built-up area in the direction of the south and east of Lahore. The increase in urban population intensified the pressure on the residential and commercial sector which caused the expansion of new, and extensions of existing residential colonies in these areas of Lahore. The built-up area increased from 223 sq. km to 756 sq. km during the study period primarily at the cost of vegetation, agricultural and vacant areas. The areas recognized as built-up in 2020, but not developed in 1973 had a vegetation cover in the 1973 satellite image and thus had no built-up areas in the 1973 time period. Remarkably, the rise in the built-up area from 1973 to 2020 in the fringes of the city was considerably higher than that in the core regions. About 80% increase in the urban built-up area is observed in the outskirts region as contrasting 20% of that change is observed in the central region indicates rapid urban expansion in the peripheries of the city. There is a prediction that in the future the possibility of urban expansion will be in the direction south and east of the city by 2025 and predominantly at the cost of vegetation, agricultural and vacant land; On the other hand, some extensions in the urban built-up area is also projected to the west by 2035. The overall trends in all land-use change types are presented in Table 3.

Urban expansion of Lahore from 1973 to 2020

The spatial and temporal land-use dynamics from 1973 to 2020 were derived from the examination of multi-spectral satellite imageries. Prompt increase in the population of towns and cities and constant urbanization is the leading factor of massive growth in the change of land use in Lahore. From 1973 to 2020, the overall changes that took place in land use are shown in Table 3 and Fig. 3a-f. The urban built-up area of Lahore that has enlarged significantly during the period between 1973 and 2020 has been illustrated in Fig. 5. The analysis revealed that the urban built-up area of the city was estimated to increase from about 223.96 sq. km in 1973 which enlarged to 445.12 sq. km in 2000 and further expanded to 756.44 sq. km by the year 2020 (Table 3). In addition to this, it is also revealed that the agricultural land of the city, however, reduced from 1213.23 sq. km in 1973 to 825.23 sq. km in 2020 (Table 3), whereas the vacant land also reduced from 320.02 sq. km in 1973 to 175.10 sq. km in 2020 (Fig. 3). This expansion of built-up area had engulfed the surrounding agricultural and vacant land. With the rapid growth of the urban population, the demand for new houses scheme and commercial purposes also increased and the neighboring cropped and farmland was transformed into a built-up environment. The spatial distribution of land use profile for the three most significant classes includes built-up area, agricultural and vacant land are illustrated in Fig. 3a-f.

The study revealed that in Lahore urban population growth over the period has affected great changes in existing land use. The comparison of land use maps revealed in Fig. 3a-f and Table 3 shows that the built-up area of Lahore has extended by 532.48 sq. km during the period of 1973 to 2020. From 1973 to 2000, the built-up area grew about 221.16 sq. km while the vacant land decreased 77.79 sq. km, whereas, agricultural land also reduced 150.98 sq. km (Table 3). The important aspect of rapid expansion in cities is the increase in the urban population. According to the census report of 1972, the city population was 2.58 million

Table 3. Lahore city: Land use change, 1973 to 2020

Year		Land-use Type				Total Area
		Built-up Area	Vacant Land	Agricultural Land	Water Bodies	(in sq. km)
1973	Area sq. km	223.96	320.02	1213.23	14.79	1772
	Percentage	12.64	18.06	68.47	0.83	100
1980	Area sq. km	273.29	305.44	1170.57	22.70	1772
	Percentage	15.42	17.24	66.06	1.28	100
1990	Area sq. km	352.75	277.74	1117.82	24.17	1772
	Percentage	19.91	15.67	63.08	1.36	100
2000	Area sq. km	445.12	242.23	1062.25	22.40	1772
	Percentage	25.12	13.67	59.95	1.26	100
2010	Area sq. km	517.43	230.69	1004.99	18.89	1772
	Percentage	29.20	13.02	56.72	1.07	100
2020	Area sq. km	756.44	175.10	825.23	15.23	1772
	Percentage	43%	10%	46%	0.86%	100

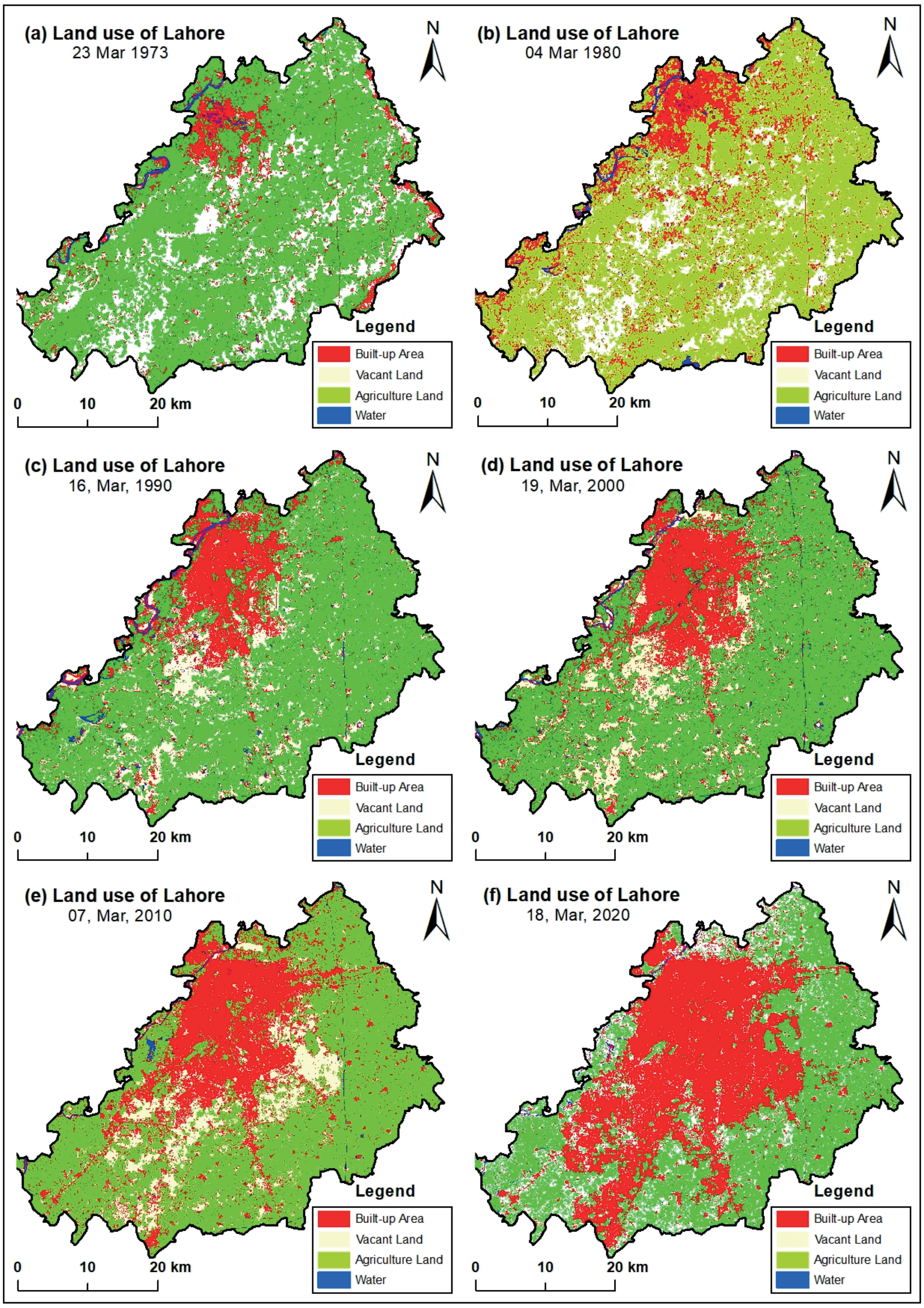

Fig. 3. Land use map of Lahore from 1973 to 2020

which increased rapidly and reached up to 3.54 million in 1981. Within the one decade, about 1 million population was increased. There is a great demand for new residential areas due to the increase in the urban population and its growing income. The population of the cities has been increasing rapidly due to two main reasons; one is rural to urban migration and the other one is a natural increase of population. Population from the countryside has moved to Lahore in search of better health, educational facilities, and employment opportunities.

From 2000 to 2020, remarkable growth in the urban expansion of Lahore was observed. According to the population census statistics of 1998, from the total population of the city which is 6.3 million in 1998 around one million of the population includes migrated people. The statistics also reveal that the bulk of the migrated population inhabited the urban regions of Lahore city (GoP 2000). From 2000 to 2020, the built-up area increased about 311.32 sq. km while agricultural land reduced 237.02 sq. km whereas, the vacant land also decreased 67.13 sq. km (Table 3 and Fig. 4). That is the time when the government decided to consider the whole of Lahore as the city district and in the provisional population census statistics of 2017, the whole of Lahore has been declared as an urbanized area (GoP 2017). The settlements which are located nearby the limits of Lahore are also considered urban areas. Due to the conversion of land, the land values inside the city boundaries have accelerated several times.

The rate of expansion of urban/built-up areas and land conversion on other land uses has increased rapidly, with fragmented patches of urban development distinguishing urban sprawl. This type of urban sprawl, with its irregular spatial directions, could have been encouraged by not conforming to the rules and guidelines of the local

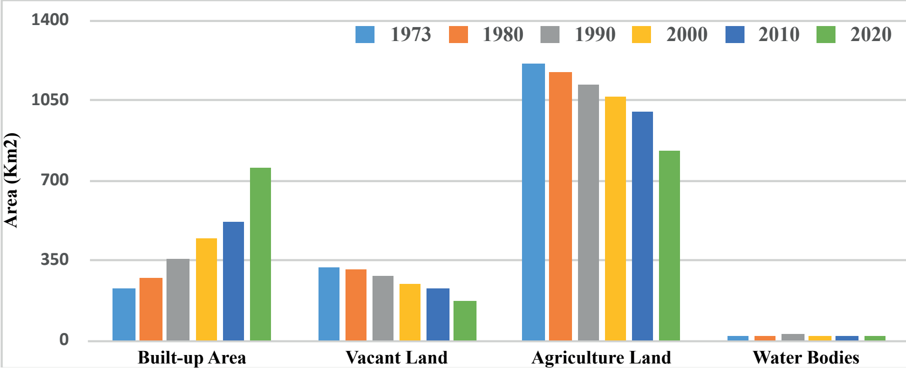

Fig. 4. Trends of urban/built-up area, agriculture, and vacant land-use change

government. The urban growth of Lahore does not follow the classical models of urban spatial structure views, for example, multiple-nuclei by Harris and Ulman (1945), sector model by Hoyt (1939), and concentric zone model by Burgess (1925). Since ancient times, the growth of Lahore had been haphazard and does not follow the regular pattern as mentioned above in many development western models. However, after British Raj, many sections of Lahore were developed and do follow some patterns of radial growth. The growth has not occurred equally everywhere and in all directions but rather it has occurred rapidly and further along with specific directions in a haphazard manner. The expansion of Lahore has taken gradual growth around the periphery where new developmental activities have occurred along with increasing the density of the built-up area in the city center.

The urban expansion of Lahore has grown around the node of the major transportation routes originating from the center of the city (Fig. 5). Transportation and accessibility are perhaps significant factors in the process of urbanization in Lahore. In the same fashion, as other Asian urban centers expand, Lahore's rate of land-use change has been quite rapid, primarily because of the huge number of migrants (1 million) from the countryside (GoP 2000, 2017). Lahore's urban built-up area expanded by 171.83 km2 from 1980 to 2000 compared to the 311.32 km2 during the period between 2000 and 2020. According to the predictions, urban expansion can occur mostly at the coast of land covered by agriculture and urban green spaces towards the south and east of Lahore by 2025; a certain increase in the urban built-up area is also predictable to grow in 2035 by the west.

Factors Influencing Urban Expansion

The land-use changes shown for Lahore occurred as a consequence of the relationship of many demographic as well as socio-economic and environmental factors. The process of urbanization of Lahore has been quite rapid as compared to other big cities of Asian counties. Some of the key aspects that have caused the urban expansion of the city are as follows.

Population growth: Lahore's urban population has increased significantly during the past five decades. The population census reports state that it has increased from 1.12 million to 11 million during the years 1951 and 2017 respectively (GoP 2000, 2017). Population estimate of 2016 shows that most of the population that live in an urban area is 82% (GoP 2016), which has remarkably grown to 100% in 2017 as shown in the provisional population census report when the district

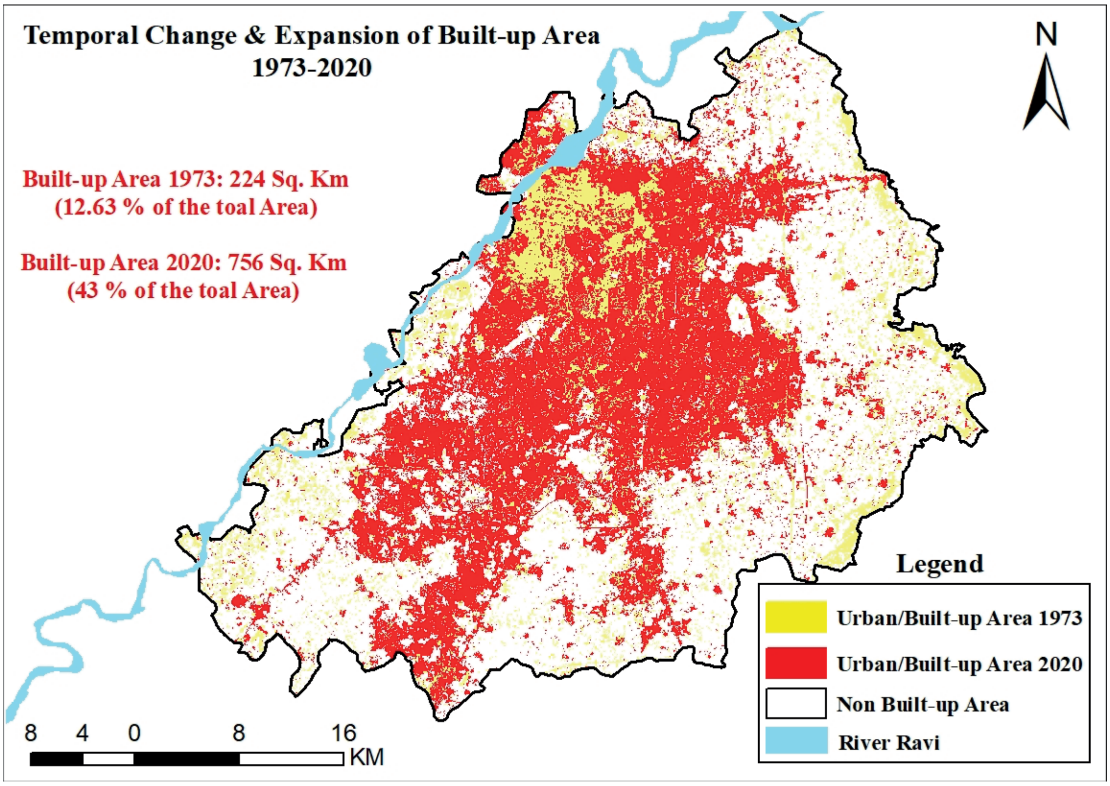

Fig. 5. Temporal change and expansion of the built-up area of Lahore between 1973 and 2020

Lahore has been stated as an urbanized area (Table 4) (GoP 2017). The population density of Lahore is 6300 people/sq. km. in 2017, while in 1951, the population density was 641 persons/sq. km (GoP 1951, 2017). The average household size of Lahore is about 6.1, which is relatively high related to the other cities of the same size. Although the average annual growth rate of the population of Lahore reflects a declining trend. As revealed in Fig. 6, the growth rate of Lahore declined from 4.1% between 1961 and 1972 (GoP 1972) to 3% between 1998 and 2017 (GoP 2000; 2017). A decreasing growth rate of population states that it is not the only main cause for urban expansion but rural to urban migration is a leading cause of urban population growth (GoP 2000; Shirazi and Kazmi 2014; Nasar-u-Minallah 2017; Rana and Bhatti 2018). According to the 1998 population census statistics, about 16.4% (1 million) of the total population of Lahore (a total of 6.3 million in 1998) consists of migrated people (GoP 2000; Rana and Bhatti 2018). The data of migrated people also revealed that migrated people majority which is 86% (GoP 2000), reside in the urban areas, which indicates that they increased the burden on the infrastructure of the city (Rana and Bhatti 2018). The significant population growth in Lahore during the last 5 decades is responsible for the conversion and changes of land use patterns. This growing population demands increased residential and commercial areas and has caused an increase in land-use change and development of the city. The growing population at a rate of 3% annually and the high rate of incoming migrants, have contributed to the urban sprawl, which caused an increasing number of mushrooming slums and settlements in a squatter manner (Rana and Bhatti 2018). This population growth combined with lack of planning are interrelated with each other and has caused the worsening of already prevailing socio-economic, physical, and environmental complications. Additionally, with the observing of infrastructural development and growth of the built-up area, it is also essential to obtain and examine the

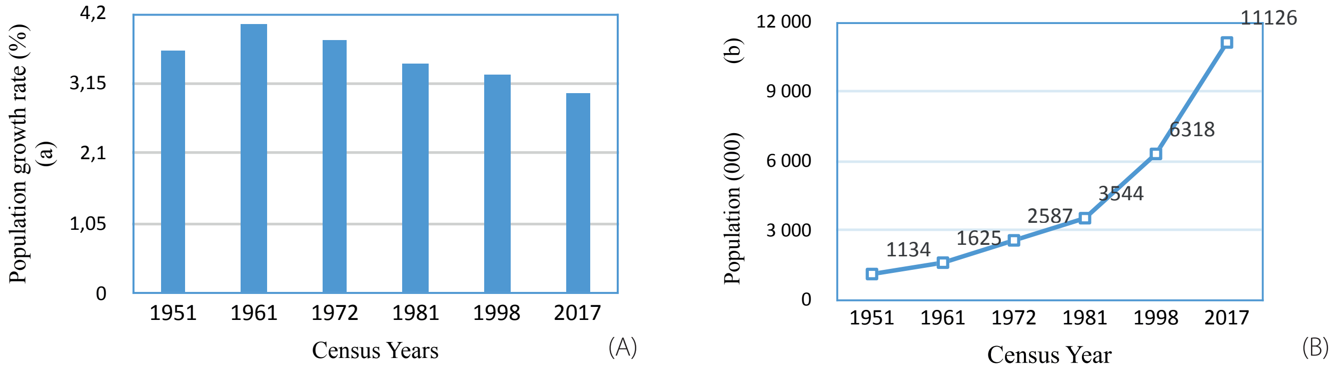

Fig. 6. (a) Average annual growth rate and (b) Population growth from 1951 to 2017

Table 4. Proportion of urban population of Lahore from 1951–2017

Census Year	Population		The proportion of Urban Population (%)
	Urban Population	Total Population	
1951	861,279	1,134,757	75.90
1961	1,312,495	1,625,810	80.73
1972	2,189,530	2,587,621	84.62
1981	2,988,486	3,544,942	84.30
1998	5,209,088	6,318,745	82.44
2017	11,126,285	11,126,285	100

Source: GoP 1951; 2000; 2017

Table 5. Lahore district and urban migration trends 1981–98

	1981		1998	
	District (%)	Urban (%)	District (%)	Urban (%)
Same province	49	50	52	53
Different province	7	7	6	6
AJK/NA	1	*	1	1
International	38	38	20	21
Not reported	5	5	21	19

Source: GoP 1981, 2000

population authentic data with the help of a census survey from the recent population census 2017 which will significantly assist in this regard.

Road infrastructure: The urban built-up area's spatial pattern has a geometry that has primarily been molded by the road network. The provincial highway department appraisals that there are about 1265 km roads in Lahore city (GoP 2015) and Lahore city is connected by a thick road network in terms of approachability. Due to ease of access, people migrate to Lahore and settle there. Major roads that connect Lahore with other cities are Multan road, G.T. road, Ferozepur road, Raiwind road, Jaranwala road, and Sheikhupura road. While the main railway line of Lahore connects it to many settlements along northern and southern routes and also to the bordering country-India, through Wagha in the east. Lahore is also connected with other parts of the country particularly in the north through a network of Motorways (M-2, M-3, M-1, M-4). It has developed the historic route which links central Asia with the sub-continent. The high number of transportation routes has encouraged the urban sprawl, which results in linear growth along the major roads of Lahore. The recent infrastructure development of Lahore i.e. metro bus system (27 km) and orange line train system (27.1 km) would probably affect the future patterns of urbanization, and it is significant to observe and comprehend the local dynamics of urban growth from time to time so that more informed decision can be made accordingly.

Commercial and trade Centre: Lahore being a higher-order commercial and trade Centre, has customers across the country. This sector of the urban economy has provided the city of Lahore with a concrete stimulant to the energetic activities of the metropolis. Currently, a unified commerce and trade nucleus is established in and around the Walled City of Lahore and adjacent to the urban and sub-urban areas of Lahore mostly in the south and southeast direction. As the pressures on the infrastructure continue to increase, prospects of commercial and trade activities in the central business district will be at stake. Lahore's gross domestic product (GDP) due to the purchasing power parity (PPP) was assessed at $40 billion in 2008, and the estimated GDP growth rate is at 5.6% by the year 2025 (Rana and Bhatti 2018). Lahore contributes to the provincial economy of Punjab at an estimate of 19% and 11.5% to the national economy has extraordinarily expanded in both human population growth and process of industrialization and spatial extent owing to the economic development. The creation of some prospects of employment in several sectors of the economy such as business, commercial, transport, and industrial growth gave rise to the growth of an urban population of Lahore. This urban population explosion played a significant role in the change of land use patterns and expansion of the built-up area of the city. This tremendous growth influenced the urban area of Lahore and captured the hinterland of the city. It is also stated that the city has experienced noteworthy industrial growth over the past few decades and Punjab development statistics reveal that about 2233 factories are government registered (GoP 2015a; Rana et al. 2017).

Professional and educational Centre: Lahore is an extraordinary seat of learning and scholarly people in Pakistan. As a specialized, professional, scientific, technical, and educational Centre, the city makes a noteworthy influence on the academic circle of the country. According to the most recent statistics, the city of Lahore has 657 primary, 219 middle, and 327 government high schools as well as several private schools (GoP 2015a). In addition to these, there are 47 government colleges and 28 public and private universities that offer higher education respectively. Better educational and professional facilities are also causing the population growth and expansion of Lahore city.

Constraints to the Expansion of Lahore

It is apparent from the analysis of urban expansion, there are many considerable directions for the expansion of the city, for which there are favorable factors. Contrary to that, there are unfavorable factors that would discourage the future expansion of the city. The development and growth of a city are usually affected by certain constraints and Lahore is no exception to this. River Ravi is one of the main physical constraints and manipulating factors in the expansion of Lahore. However, the presence of the Ravi River together with the risk of flood plain possibly threatens built-up area extension by the directions of north and north-west. Other major physical constraints to the built-up area expansion of Lahore comprise the closeness of the Indian border (Wagha) in the East direction which facilities the city expansion only in the direction of the South and Southwest (Fig. 5). Furthermore, there are several imperceptible constraints, which are not easy to measure but can be observed which include traffic problems, solid waste management, exhausted housing environments, and city congestion within the heart of the city that dynamism forces people to travel to the peripheries of Lahore. The city area and its vicinity comprise of flat land that slopes gently towards south and south-west. So we can say that there is no physical difficulty in the expansion of these areas of the city. As a result of these physical constraints, city development has been generally limited towards a southerly direction (Fig. 7). Growth strategies for Lahore are also being constrained by these physical barriers in the east, north, and north-west and the future growth trends towards the south will have to be accepted.

Future Patterns of Growth

In the light of the above-mentioned potentials and constraints, the future growth of Lahore in various forms is as follow follows:

Densification and vertical growth: The built-up area of Lahore which is presently being densified by sub-division of larger plots into smaller ones to fill the vacant pockets of land and by adding new rooms and stories to the existing housing units, this trend can be seen in the form of vertical growth in the city Centre (Shirazi and Kazmi 2014). This way of in-fill land along with financial affordability of the people, the process of densification will be affected by now allowing the congestion and strain the existing physical and social infrastructure (LDA and NESPAK 2004). Vertical growth is one of the forms of future growth of Lahore like elsewhere in the world.

Peripheral growth: Along with densification within the built-up area, peripheral growth is persistently growing informally and haphazardly in the form of the creation of new commercial and residential schemes. This trend can be detected in areas including south of

Khaire Distributary areas, Harbanspura, along both sides of Ferozepur Road, Shahdara, and riverbed across Bund road. Irrespective of the facilitation of basic amenities in these areas which are encroaching upon the fertile agricultural land, the natural vegetation of these areas can be protected by some legislation to protect the indigenous vegetation of Lahore.

Growth across Ravi: Before encouraging development along the River Ravi banks, a thorough study is needed by flood management because of the vast patches of vacant land across the river Ravi are available for commercial and residential purposes which are adjacent to the central core of Lahore (LDA and NESPAK 2004; Shirazi and Kazmi 2014).

Growth in the South-West: There are numerous housing schemes in the offing, in and around Lahore, which are consuming the large agricultural land. Cheap-land is the main reason behind the mushrooming of such housing schemes in the peripheral and suburban areas of the city. This can pave a way for the future expansion of the city. This growth corridor is more popular in the southwestern direction where the major housing schemes are flourishing in dispersed form. This sprawl wave further increases ribbon development along the major roads like Multan, Ferozepur, and GT road. These areas are getting centrifugal from present city Centre which is furthering chaos and congestion on the roads with every coming day. This situation demands decentralization and development of new commercial, trade, and institutional Centres in the area (LDA and NESPAK 2004).

Future Direction of Growth

Lahore has been experiencing quite a rapid population growth since 1951 and is now home to about 11 million people in 2017 (GoP 2017). The growth of the urban population constantly acts as an attribute to the development of Lahore. Future growth directions of the city of Lahore are towards the south-east and south-west, as displayed in Fig. 7, these two growth corridors are potentially more favorable for future development and expansion of the built-up area of the city as shown in Fig. 7. Although the city of Lahore has the prospective to grow all-around that comprises its sprawl in the direction of Wagha border (east) and towards River Ravi (north-west), from 2000 onwards, much of the development has been in the eastern and southern parts of the city and to some extent, in the north-western area across the river, Ravi has largely been in the form of approved new housing schemes (Shirazi and Kazmi 2014). It is apparent from the expansion analysis and identified that south-east and south-west directions as recognized future growth corridors for the city of Lahore and Gulberg Main Boulevard, Jail Road, MM Alam Road recommended as new CBD for the city of Lahore as shown in Fig. 7. This will not only reduce pressure on old business centers but also help in decreasing travel distance from far-flung areas of the city in the south to the core areas.

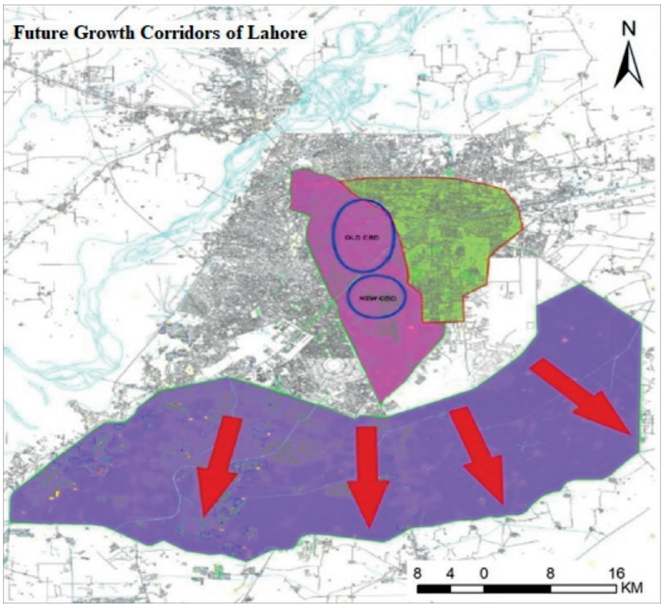

Fig. 7. Future Growth Corridors of Lahore

CONCLUSION

The study used post-classification techniques along with the GIS techniques to integrate multi-spectral data with socio-economic and demographic data to examine changes in land use and the Spatio-temporal dynamics of urban expansion. The present study has proven the effectiveness of GIS and remote sensing techniques in producing precise land use maps and detailed change statistics of Lahore, which provides a database for the site suitability for further urban expansion of the rapidly growing metropolis of the country. This valuable information is also crucial for the suitable provision of facilities and infrastructures for sustainable urban planning. The land-use profile of Lahore has changed over time considerably. Specifically, the built-up areas have enlarged by 532 sq. km, which is a major attribute to the rapid population increase due to the great influx of migration, signifying loss of agricultural land and green spaces by 702 km2 over the period from 1973–2020. Reduction of agricultural land, loss of vegetation, and the issue of urban sprawl have attuned the urban expansion. The network of roads has affected the structure of urban development, due to which the expansion has ribbon growth along the main roads of the city. This study helps a lot in the better understanding of spatial and temporal dynamics of urban expansion of Lahore and will facilitate in the better planning and effective spatial organization of urban infrastructural activities, which is essential for development in future leading to improve the environmental conditions, quality of life and living standards of the millions of people living in the city of Lahore. In the future, studies exploring the hidden patterns of urban growth and loss of vegetation, urban green spaces, and agricultural land can probe the future changes through high-resolution satellite imagery of Lahore.

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