Shrinking agriculture in the arid landscapes of the Cholistan Desert: a geospatial assessment of urban expansion and its implications for the sustainable future of Multan City, Pakistan

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Abstract. Pakistan is an agro-based country, and the majority of its population depends on agriculture for survival. Currently, sporadic urban expansion is a serious threat to urban agriculture, the environment, food security, and livelihood sustainability. This study aims to explore the dynamics of urban expansion patterns and their intricate interplay with agricultural land, focusing on their ramifications and future urban land-use predictions. For this purpose, remotely sensed data spanning 30 years from 1990 to 2020 and secondary data from the DCR and the Pakistan Bureau of Statistics are used. The collected data were analyzed through advanced geospatial techniques, CAM, and statistical techniques. The built-up area was observed 75 km^2 in 1990 to 299 km^2 in 2020. Furthermore, the annual increase is 9.5%. This haphazard growth converts approximately 31% (100 km2) of Multan city's fertile agricultural lands into a built-up environment, and the CA Markov model predicts that the built-up area will further increase by 54% in 2030 and 67% in 2040. The correlation between built-up and agricultural areas is strongly positive. The study provides nuanced insights for policymakers, land managers, and urban planners to formulate better policies for regulating sustainable urban expansion and fostering resilient urban development.

Keywords: Urban Agriculture, Urban Expansion, Urbanization, Markov model, Multan.

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1. Introduction

Worldwide, urban agriculture (UA) stands as an enduring, age-old and vital economic activity (Ackerman et al., 2014; Gunapala et al., 2025). It provides countless benefits and multifunctional services to the urban community (Horst et al., 2024; Sadian & Shafizadeh-

Moghadam, 2025). UA plays a pivotal role in providing healthy foods, nutrition security, livelihood sustainability, and eradication of urban poverty (Vieira & Panagopoulos, 2024; Ahmad et al., 2025a). Around, 25% of the world's food is produced in urban areas, with contributions of more than 70% in some urban regions around the globe (Houessou et al., 2020; Schuster-Olbrich et al., 2024). Additionally, UA offers green open spaces, enriches the sociocultural fabric of communities, mitigates the urban heat island effect, contributes to community economic development and environmental sustainability (Akbari, 2002; Moisa & Gemeda, 2021; Humaida et al., 2023) and reconnects the agriculture sector with urban population (Dittmann & Nüsser, 2002; Santo et al., 2016). It also promotes the recycling and reuse of urban wastes and wastewater, supports urban stormwater management, and serves as a strategy for disaster risk reduction (Picton, 2016; Gandharum et al., 2022). Currently, urban agriculture is shrinking rapidly and facing several threats due to population growth, urban expansion, water scarcity, and exacerbated by climate change (Hussain, 2024).

Rapid urban expansion is one of the major catalysts of the conversion of agricultural land into built-up areas. According Bapari et al. (2016), global urban expansion is projected to lead to a 1.8–2.4% reduction of the global agricultural area by 2030, with approximately 80% of this cropland loss attributed to urban expansion occurring in Asia. Currently, unplanned and parodic urban expressions are becoming a problem worldwide leading to severe global socioeconomic and environmental consequences, including soil erosion, loss of biodiversity, and agricultural land degradation. However, this situation has become more acute in Pakistan due to the underestimated importance of urban agricultural lands and the incomplete or ineffective legislation protecting agricultural lands (Ahmad et al., 2021; Ahmad et al, 2025b; Hussain & Shaikh, 2025). Consequently, agricultural land degradation in Pakistan affects the delivery of ecosystem multi-functionality/services and threatens the livelihood sustainability and food security of people and ecological prudence (Ahmad et al., 2020; Ahmad et al., 2023; Nasar-u-Minallah et al., 2021).

Urban expansion is one of the major developments that has occurred in the last few decades. The expansion of the cities is dominantly influenced by economic growth, urban facilities, and institutional development (Li et al., 2018; Ouyang et al., 2022). Rapid urbanization creates so many problems including social, economic, political, and environment (Pijanowski et al., 2009; Cao & Wang, 2025). The scenario of urban development in developing countries is ultimately connected with rapid population growth and a high fertility rate. The population of urban areas has increased rapidly, and as a result, the city size and density has changed haphazardly (Nor et al., 2017; Zhang et al., 2025). Globally, the major proportion of urban expansion is rural-to-urban migration (Zhang & Su, 2016). According to the United Nations reports, the urban population of the world was 0.75 billion in 1950 and 2.86 billion in 2000 and it is projected to increase 6.67 billion in 2050 (Ritchie & Roser, 2018).

The process of urban growth mainly occurred in developing countries due to changes in lifestyle, economy, and industrialization. At the start of the 20th century, only 16 cities were in the list of 1 million population category. But unfortunately, today almost 400 cities exist, and 70 to 75% are present in these developing countries (Carpio & Fath, 2011). The rate of increasing urban population is very common in developing countries, especially in Pakistan and the annual urbanization rate is the fastest in South Asia. People move from rural to urban areas for better facilities of health, education, recreation, and economic opportunities (Shuaib et al., 2018). The urban population of Pakistan was 6.57 million in 1950, and 45.68 million in 2000 and it is projected to be 160 million in 2050 (Ritchie & Roser, 2018).

Remote sensing provides one of the consistent and frequent analyses of large geographic data and GIS is one of the finest ways to analyze the spatial variation that occurs on earth surface (Wu et al., 2015; Islam et al., 2022; Haq et al., 2022; Ali et al., 2023; Shinwari et al., 2025a, b). Remote sensing and geospatial techniques are now quite useful for urban studies, analysis, and modeling of land cover change (Carpio & Fath, 2011; Zhang et al., 2025). With the help of these geospatial techniques, we can analyze the urban expansion spatially and temporally as well as the future prediction of Multan City. Simulations and predictions are commonly used in urban expansion phenomena. Several models are used for simulations nowadays, but the most common model is a cellular automata model (Cherigui et al., 2025; Mirzakhani et al., 2025).

The uncontrolled and unplanned growth of urban areas and the important land covers including water, vegetation, and agriculture are rapidly converted into concrete and asphalt material. These issues become a serious threat to natural ecosystems, agricultural land, human health, and the sustainable environment (Balçik, 2014; Yasin et al., 2025). Urban expansion needs more attention than other problems, especially in developing regions (Alsharif & Pradhan, 2014).

This study is an attempt to explore and analyze the spatio-temporal expansion pattern of Multan City and its impact on agricultural land, food security and livelihood sustainability. Additionally, it highlights future urban land use prediction using CAM model. Multan is the regional headquarter of south Punjab and the economic, political, and social hub for peripheral areas. It is also the most populated city in the south Punjab. Due to these factors, the urban expansion in Multan has increased and the land use land cover has changed rapidly in the last few decades. The land of this region is fertile and highly suitable for agricultural purposes.

2. Material and Methods

2.1. Profile of the Study Area: Multan City

The focus of this study is Multan city, southern Punjab, Pakistan. It is one of the oldest cities of the Indus civilization and it was founded around 5000 BC (Nadeem et al., 2022). It is the cultural, religious and economic hub of southern Punjab. It is dubbed as the city of Sufi, Saints (*Peers*) and Shrines. Geographically, Multan city is located between 29° 47’ 31’’ to 30° 27’ 25’’ N latitudes and 71°15’ 54’’ to 71° 50’ 6’’ E longitudes (Fig. 1). It is situated at an altitude of 122 meters (400 feet) above sea level and almost in the geographical center of Pakistan. Multan city covers an area of 585 km^2. Administratively, it is divided into three administrative units including Multan Municipal Corporation, Multan Cantonment, and Multan Revenue Estates.

The climate of the study area is typically continental with long hot summers and short cool winters. Generally, temperature exceed 45°C in summer and below 10°C during winter seasons. Additionally, heat waves generally hit the study area from April to June. Climatically, it is an arid region, and the annual rainfall is less than 200 mm (Haider et al., 2025).

Multan is the 7th largest city of Pakistan and the 3rd largest city the Punjab province in terms of Population. The population of Multan city is growing at an alarming rate during the last four decades. The population of Multan city was 1177014 souls in 1990 and has increased to 2815386 in 2020, resulting in the expansion of the urban area, leading to serious challenges for agricultural land and food security (Hussain & Shaikh, 2025).

The soil of Multan city is very fertile and alluvial soils. Agriculture is the lynchpin of the economy of inhabitants of the study area and more than 60% of people are engaged in agriculture. This region is very famous for mangoes and cotton throughout the world and is dubbed as the ‘Cotton Capital of Pakistan’.

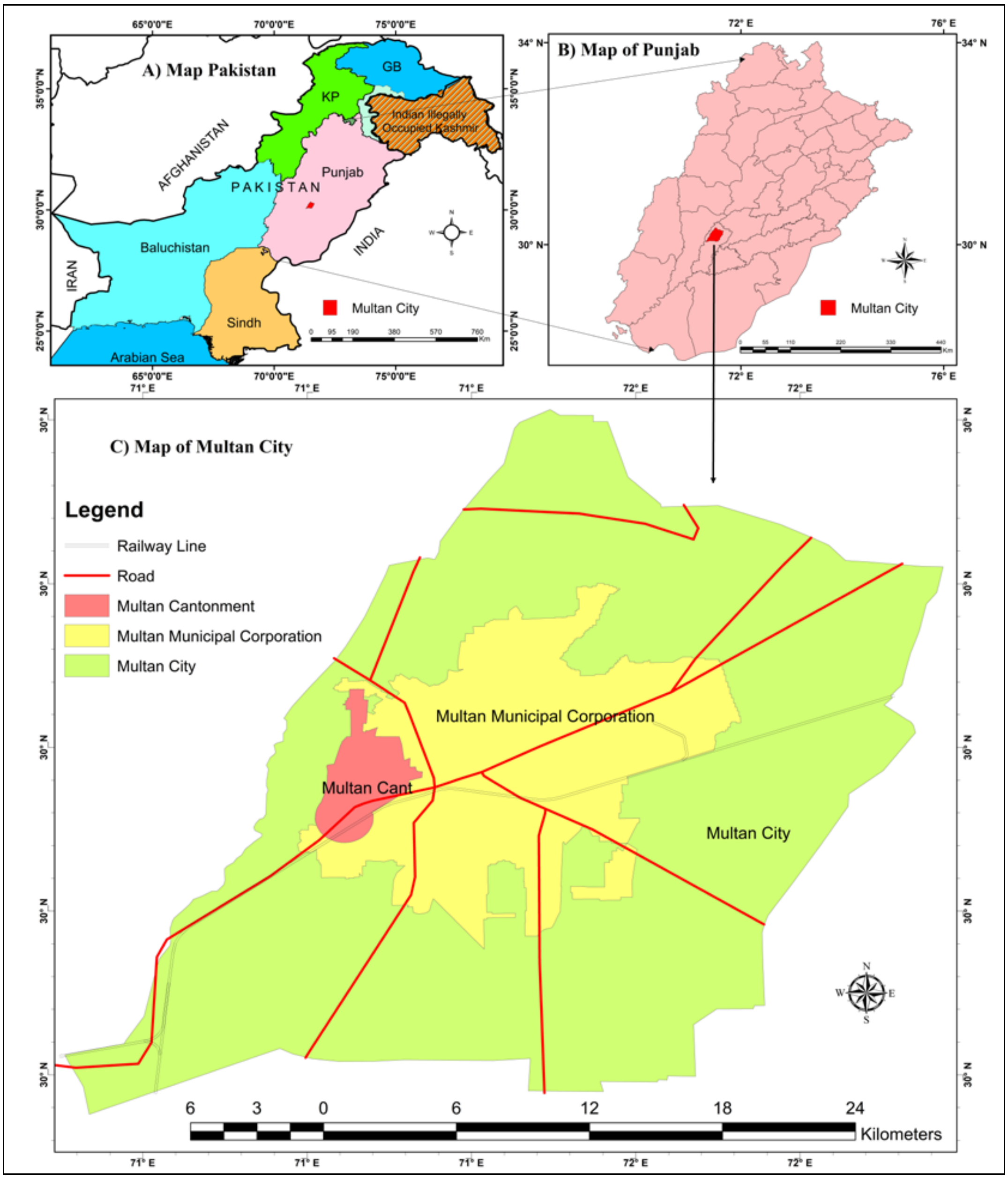

Figure 1. Location Map of Multan City, Southern Punjab, Pakistan

2.2. Data Collection and Acquisition

To achieve the objectives, this research utilizes time-series remotely sensed Landsat satellite data spanning thirty years from 1990 to 2020. The remotely sensed data, multi-spectral temporal Landsat images with less than 10% cloud cover for the years 1990, 2000, and 2010 from TM Landsat 5, and for the year 2020 from OLI Landsat 8, were downloaded from the USGS official website (Table 1). For the temporal trend analysis of urban expansion of Multan city, the entire study span was divided into three decadal intervals: 1990 to 2000 is taken as period-1 (P_1), 2000 to 2010 as period-2 (P_2), and 2010 to 2020 as period-3 (P_3). This temporal division provides a comparative assessment of urbanization dynamics including the magnitude, rate, the spatial extent and directional patterns of urban expansion over time. In addition, primary data were also collected from questionnaire survey, focus group discussion, interview and field observation through a stratified random sampling technique.

Relevant secondary data were explored from the District Census Report of Multan (GOP, 1984; GOP, 2000; GOP, 2021), Gazetteer of Multan, Punjab Development Statistics Reports (2013-2018), Pakistan Bureau of Statistics Report, and UN-Habitat Reports. To cross-check and validate the remotely sensed data, necessary data were acquired from the Multan Master Plan (1987-2007), Integrated Master Plan of Multan (2008-2028), Settlement Assessment Report, and open sources as well.

Table 1. Detail of Satellite data and its characteristics

Year	Sensor	Date of Acquisition	ID		Spatial Resolution	Cloud Cover	No of Band
			Row	Path			
1990	TM 5	1990-01-11	O39	151	30-m	< 10 %	7
2000	TM 5	2000-01-23	O39	151	30-m	< 10 %	7
2010	TM 5	2010-02-03	O39	151	30-m	< 10 %	7
2020	OLI 8	2020-01-14	O39	151	30-m	< 10 %	9

2.3. Data Analysis

2.3.1. Remotely Sensed Data Processing and Image Classification

All the Landsat images were preprocessed for geo-referencing, layer stacking, and mosaicking in ArcGIS 10.5 software. Color composites of 6 bands of 1990, 2000 and 2010, and the first seven bands of 2020 were generated. All scenes of each image of Multan City were mosaicked, and the study area was extracted using a shape file of Multan City. Subsequently, the pen sharpening/standard deviation technique was applied for image enhancements. Moreover, atmospheric and radiometric correction of all images were carried out. The images were classified through supervised classification using a maximum likelihood algorithm. Five different land use/cover classes, i.e., five categories namely built-up, agriculture, fallow land, barren land, and water were developed for 1990, 2000, 2010 and 2020 classified images (Table 2).

Table 2. Description of Urban Land Use/Cover Classes of Multan City

LULC Category	Description
Built-Up Area	Commercial area, building, road
Agriculture/ Vegetation	Cultivated land, garden, trees
Fallow Land	Agricultural land left uncultivated for at least one growing season to enhance soil fertility
Barren Land	Bare ground
Water	River, stream, canal, lake

2.3.2. NDVI (Normalized difference vegetation index)

The normalized difference vegetation index is broadly used in remote sensing studies to identify the vegetation. The research is primarily related to agriculture, and this index will give an accurate scenario of the vegetation. This index is more accurate and quite easy to elaborate on the scenario of vegetation. The values of NDVI exist between -1 and 1. According to the values of NDVI, if the result is shown in negative value that means the area is covered with snow, clouds, or water. If the result value is close to zero that means it's rocks or barren land. If the values are 0.1 or less that means this is the empty area of rocks sand and snow. The moderate values are 0.2 to 0.3 representing the meadows and shrubs etc. while the value of 0.6 to 0.8 shows agricultural areas mostly. This index is extracted from the satellite image according to the formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad \text{Eq (1)}$$

NIR: Light reflected in the near-infrared spectrum

Red: Light reflected in the red range of the spectrum.

2.3.3. NDBI (Normalized difference Built up index)

The normalized difference index was used to find out the built-up areas precisely as compared to other analyses. Urbanization or urban expansion is a structure of a built-up area whether it is residential, commercial, or industrial. The primary objective of this research is related to urban expansion, so NDBI is more suitable for this research. The values of the NDBI also lie between -1 and 1. Negative values mean the other land covers and positive values mean the higher built-up area. This index is extracted from the satellite image according to the formula:

$$NDBI = \frac{(SWIR - NIR)}{(SWIR + NIR)} \quad \text{Eq (2)}$$

SWIR- light reflected in the Short-wave infrared spectrum

NIR- light reflected in the near-infrared spectrum.

In addition, periodic and annual urban expension rates during each of the periods were calculated in percentages with help of the following Equation (3) and (4).

$$\text{Percentage Change in Urban Expension } (\%\Delta\acute{U}) = \left(\frac{\grave{U}\alpha_f - \acute{U}\alpha_i}{\acute{U}\alpha_i}\right) \text{ X } 100 \qquad \text{Eq (3)}$$

$$\text{Percentage Change in Urban Expension per Annun } (\%A) = \left(\left(\frac{\grave{U}\alpha_f - \acute{U}\alpha_i}{\acute{U}\alpha_i}\right) 100\right) Y_n \qquad \text{Eq (4)}$$

where:

$\acute{U}\alpha_i$ = Urban area in the initial year, i.e. 1990 for Period 1

$\grave{U}\alpha_f$ = Urban area in the end year, i.e. 2000 for period 1

Y_n = No of year in a period.

2.3.4. Urban Land Use/Cover Change Detection Analysis

For Urban land use/cover change analysis, a post-classification change detection technique was employed. For this purpose, initially, the change detection map for P_1(1990-2000) was prepared using the classified images of 1990 and 2000 to identify changes in urban land use classes that occurred during 1990-2000, represented as transitions from one class to another. During the comparison process, Landsat images were resampled and geo-rectified with a root mean square error (RMSE) of less than 0.5 pixels and changes in Urban Land use/cover classes were identified. Moreover, to generate a dataset for qualitative and quantitative changes, the classified images were compared using the cross-tabulation technique.

The method of supervised classification in urban studies is widely used because this method is more authentic than other types of analysis. Supervised classification is a very important tool that is used for acquiring quantitative figures from satellite-based data. The classes or land covers are obtained from the Anderson classification 1972 of the land covers which is widely used for multi-spectral data. According to Anderson's classification, the classes are divided into five categories namely built-up, agriculture, fallow land, bare land, and Water. The classification is performed on three decadal data (1990, 2000, 2010, and 2020) using a maximum likelihood classifier (MLC). The change detection method is used to find out the change that has occurred in the last 30 years and to know which land cover is converted into another land cover in that specific period.

2.3.5. Future Urban Expansion Prediction Using Cellular Automata Model

To understand the complexity of urban areas, the Cellular automata model (CA) is widely used to predict and understand the future scenario of any area of the world over a time period. The integration of geographic information systems and the Cellular automata model create the simulations of urban development. The working concept of the CA model in urban studies starts after the result of supervised classification. The classified images of the initial year and final years were used as input as well as some variables like the digital elevation model of the study area, slope, Aspect, Distance from the road and distance from the river, etc. The system processes this information with the help of MOLUSCE Plugin which is worked in Q GIS software. The initial and final land cover maps were used for predicting future urban expansion for 2030, 2040. The CA-Markov model was applied through the following formula with modification:

$$U_{Mn}(t+1) = P_{ij} \cdot U_{Mn}(t) \qquad \text{Eq (5)}$$

where:

U_{Mn} (t+1): It represents the urban expansion rate of Multan at time t+1

U_{Mn} (t) : It denotes the urban expansion status at time t

and

P_{ij} : It represents the transition probability matrix CA-Markov model which is used for predicting urban expansion of Multan City for the years 2030 and 2040.

The transition probability matrix (P_{ij}) can be calculated using the following Equation (6) and (7).

$$|P_{ij}| = \begin{vmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,N} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,N} \\ \vdots & \vdots & & \vdots \\ P_{N,1} & P_{N,2} & & P_{N,N} \end{vmatrix} \qquad \text{Eq (6)}$$

$$0 \leq P_{ij} \leq 1 \qquad \text{Eq (7)}$$

In the above Equation (6), P_{ij} represents the probability of transitioning from the current state i to another state j in the subsequent time period. P is the transition probability, and P_N denotes the state probability at any given time. The value of P_{ij} ranges from 0 to 1, wherein 0 indicates no probability of transition while 1 shows a certain transition from one urban land-use state to urban expansion.

2.3.6. Population growth and statistical analysis

Demography and demographic factors play a very important role in economic, social, and environmental planning and decision-making. The relationship between population growth and urban expansion is very strong. The main force behind the phenomena of urban expansion is population growth. Population-wise, Multan City is 3rd largest city in Punjab province, and the population of Multan has increased rapidly in the last few decades. The population data is derived from the census reports of the Pakistan Bureau of Statistics department. The relevant census according to this study is 1998 and 2017 and other relevant years were extracted with the help of growth rate. The least square regression analysis is used to find out the relationship between the different dependent and independent variables.

3. Results

3.1. Temporal Dynamics of Urban Expansion from 1990-2020

Over the last three/four decades, Multan City has experienced accelerated urban expansion and rapid urbanization. The results of NDBI indicate that a persistent increase in urban expansion in all directions has been observed in Multan city from 1990 to 2020 (Fig. 2). The statistical outcome reveals that significant changes and transformation have occurred in the urban area during the last 30 years. The built-up area increased by 54%, from 75 km^2 in 1990 to 115 km^2 in 2000. From the result, it is inferred that urban areas were increased consistently with an annual expansion rate of 5.3% from 1990-2000 (P_1). During P_2, the urban area expanded from 115 km^2 in 2000 to 180 km^2 in 2010. During P_2, the urban area increased by 56.6%, with an annual urban growth rate of 5.6%. During P_3, the urban area of Multan City increased by 58.4%, expanding 180 km^2 in 2010 to 285 km^2 in 2020 with an annual urban growth rate of 5.84%. The overall urban expansion indicates that the urban area of Multan has been expanded about fourfold, growing from 75 km^2 in 1990 to 285 km^2 in 2020. Furthermore, the overall annual urban growth rate in Multan was quite high at 9.5% increase per annum. On average, the urban area of Multan has increased by 9.5 km per year, which is indicative of a rapid urbanization (Fig. 2). The urban area of the Multan city has increased from 13% in 1990 to 48% in 2020, more than three times during the last 30 years (Fig. 3). Initially (1990-2010), the city was growing at a slow pace and it took two decades to be double. However, 2010 to 2020, it takes only a decade to be double. This abrupt urban expansion during this period is driven by multitudes of factors such as population growth, development of colonies, economic development and rural-urban migration. However, it is primarily attributed to the development of new colonies. During 2010-2020, hundreds of developmental projects were started. According to Figure 4, more than 50 new housing colonies were launched in Multan city with most of them to be developed in the agricultural land. Besides this, economic and health and educational facilities within the Multan city have been improved and increased during this period. Due to these facilities, people migrated from the surrounding rural areas to Multan city.

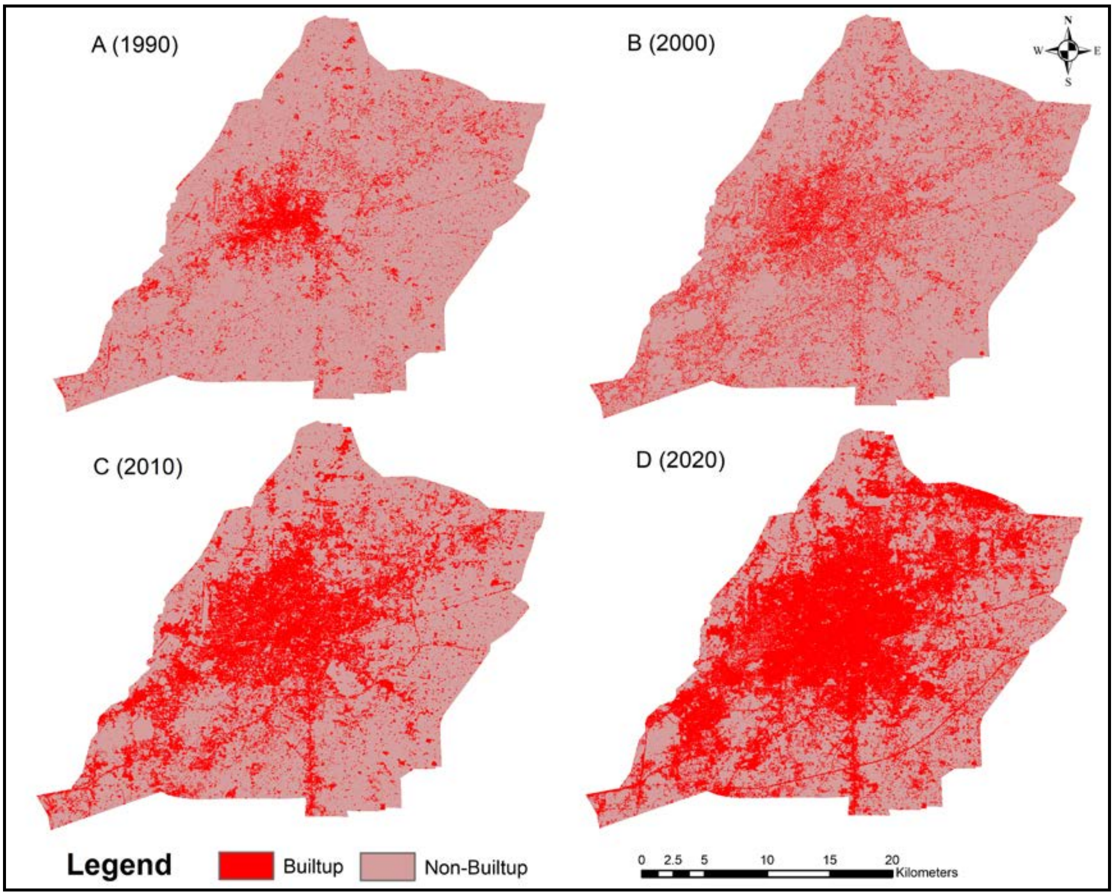

Figure 2. Spatiotemporal Urban Expansion of Multan City using NDBI, 1990-2020

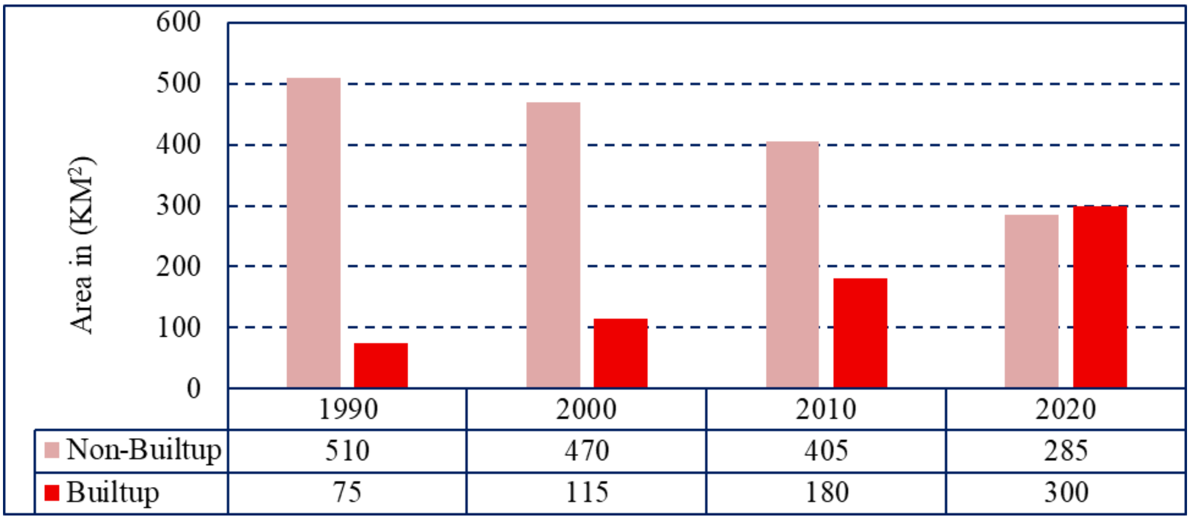

Figure 3. Statistics of the Urban Expansion of Multan City using NDBI, 1990-2020

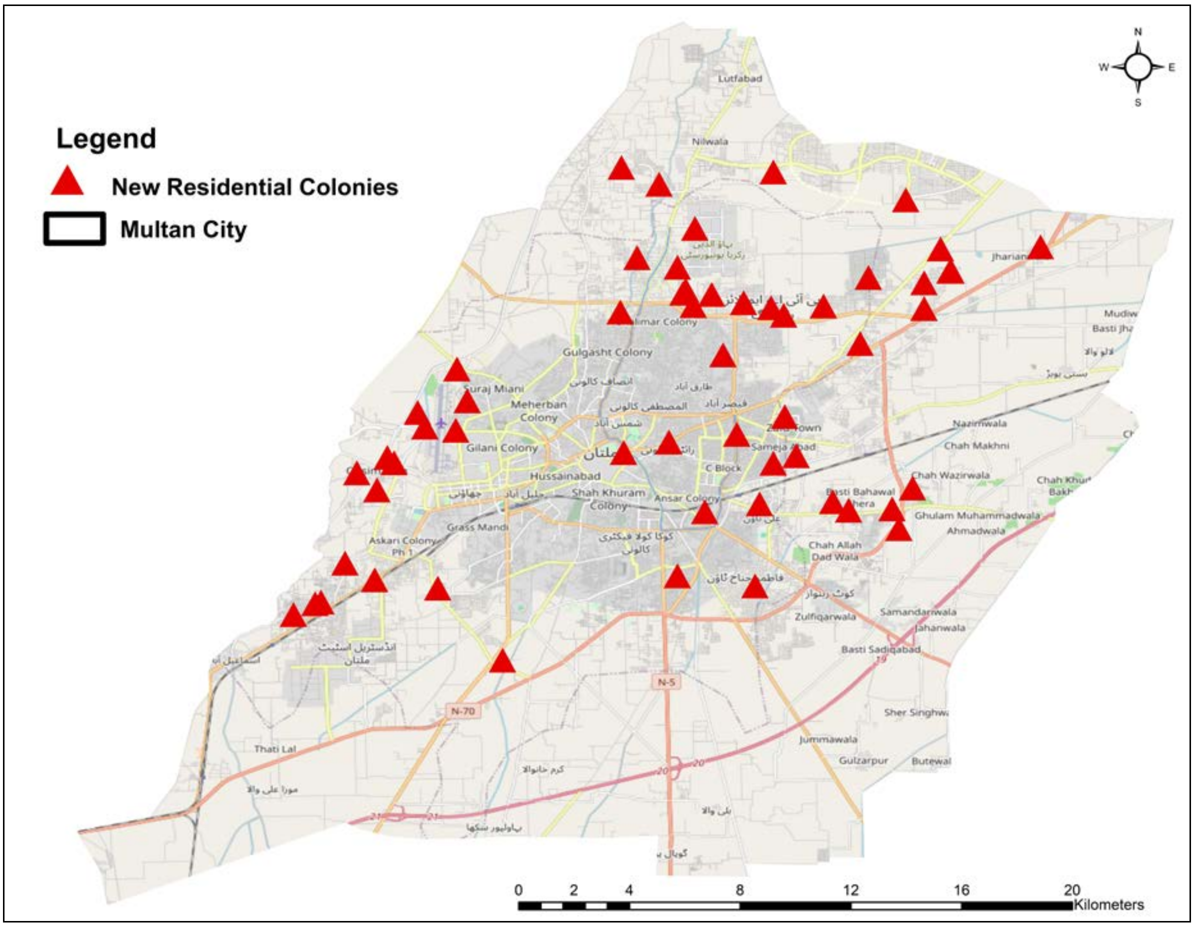

Figure 4. Development of new Residential Colonies in Multan City from 2005 to 2020

3.2. Urban Land Use/Cover Changes and Future Prediction Using CA Markov Model

Land use/cover changes are an essential aspect of the urban growth, development and urban sprawl of Multan city. The built-up environment of the Multan city is increasing rapidly resulting in obvious socioeconomic and environmental challenges. To validate and cross-check, the result of NDBI, multi-spectral satellite imaginaries were analyzed through MLT. The images were categorized into five land use/cover classes including built-up, agriculture, water, barren land and fellow land. Supervised classification was employed for the multi-spectral temporal images (1990, 2000, 2010, 2020), and the Markov model was conducted for future prediction and simulations for 2030 and 2040.

The spatial distribution of urban land use/cover of the Multan City has been mapped in Figure 5. The result reveals that significant changes and transformations have been experienced in various land cover classes between 1990 and 2020. The statistical results indicate that the built-up area of Multan city covered 80 km^2, agriculture spanned 319 km^2, barren land covered 55 km^2, fallow land encompassed 103 km^2 and water bodies accounted for 28 km^2 of the total area of Multan city in 1990. During 1990-2000 (P_1), the built-up area increased significantly by 38%, from 13.6% in 1990 to 19% in 2000 of the total area of Multan city, while agricultural land decreased by 3.4%, from 54.5% to 52.6% during the same period. Built-up/urban areas have increased from 19% to 32%, while agricultural areas declined from 52.6% to 50.9% during P_2. Therefore, it is inferred that the urban area of Multan City was expanded by more than three times, from 80 km^2 in 1990 to 299 km^2 in 2020. It can be attributed to the shrinkage of agricultural land, barren areas and fallow land. The barren areas decreased steadily from 55 km^2 in 1990, 53 km^2 in 2000, 38 km^2 in 2010 and 8 km^2 in 2020. The barren land of the study area which serves as rangeland and grazing ground for livestock has been contracted by more than six times resulting in obvious consequences such as a decrease in animal husbandry, and a shortage of meat, milk and dairy production. Similarly, fallow land decreased by 62%, from 103 km^2 in 1990 to 39 km^2 in 2020. Furthermore, water bodies have also shrunk by 57% between 1990 and 2020.

The Markov model was applied for the LULC prediction for the years 2030 and 2040. The CA–Markov model projected that the urban/built-up area of Multan city will be increased by 54%, from 299 km^2 in 2020 to 319 km^2 in 2030. In 2040, the built-up area will be increased by approximately 397 km^2 (67%), projected to increase by 435 km^2 in 2050. Similarly, the agricultural land will be converted to other land use due to uncontrolled horizontal urban development. Consequently, the agricultural land will be reduced from 226 km^2 in 2020 to 222 km^2 in 2030. In 2040, it will be decreased to 130 km^2 (22%) (Figs 5, 6).

From the result of future land use land cover change prediction, it is inferred that the fast and haphazard urban growth will lead to even more significant environmental and socioeconomic challenges.

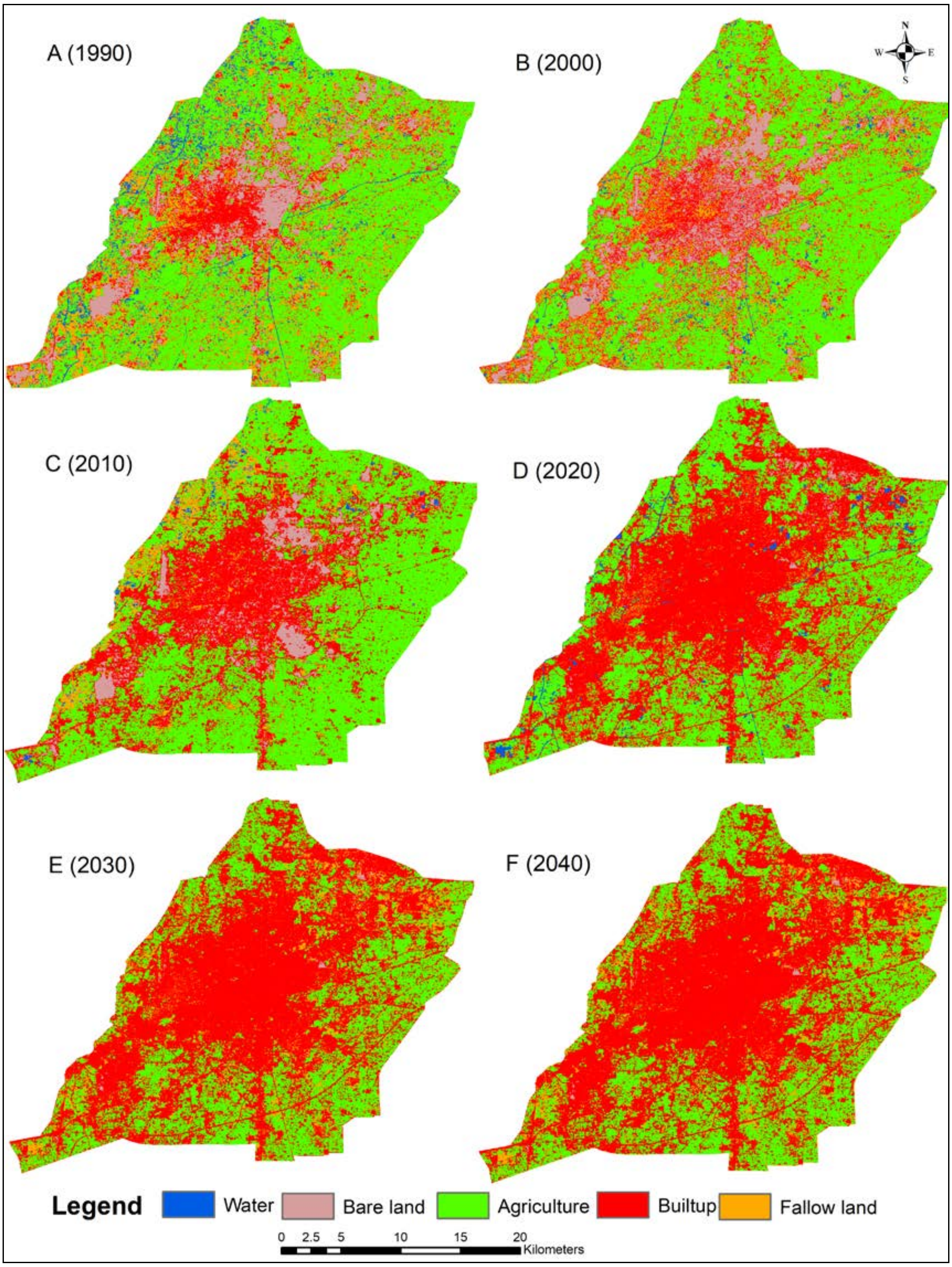

Figure 5. Urban Land Use Transformation and Prediction in Multan City, 1990-2040

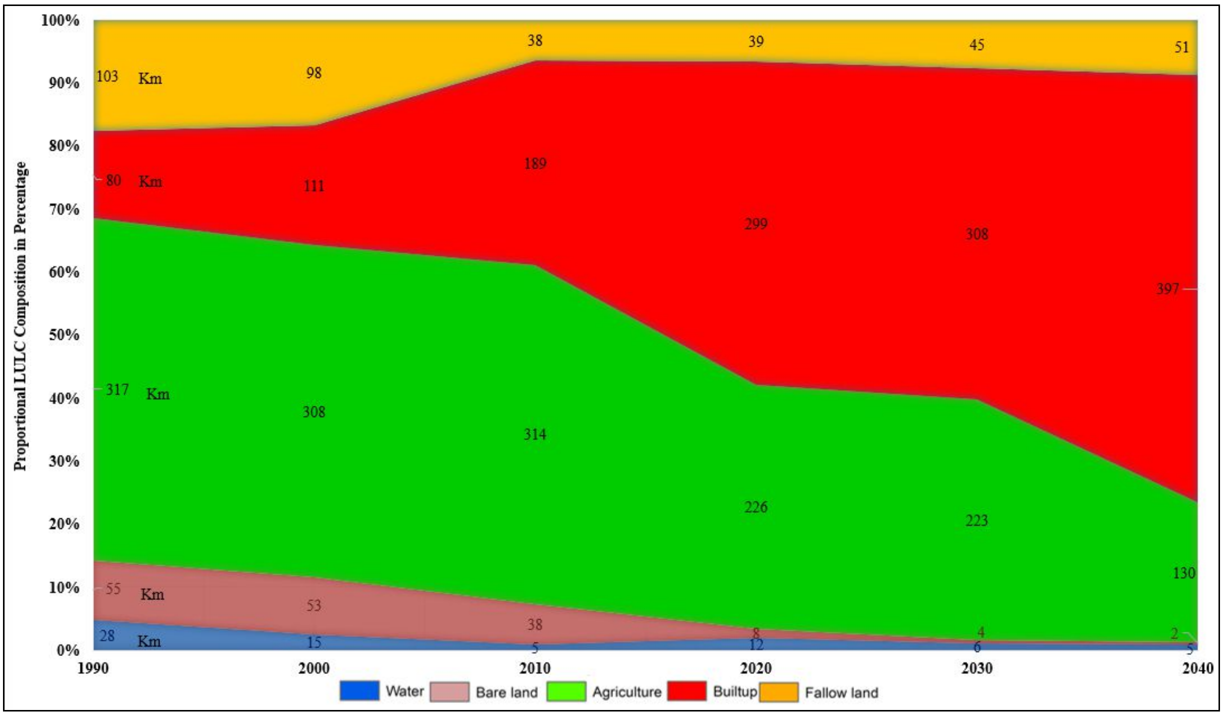

Figure 6. Analysis of Urban Land Use and Future Prediction, 1990-2040

3.3. Population Growth and Urbanization

Population growth is the most important trigging factor behind the increasing of built-up areas in the study region. Generally, rural-to-urban migration and population increase within the urban area are the two main reasons for population growth in urban areas. Multan City is a major and important city in this region playing the role of regional headquarters of different sectors including the commercial, agriculture, health education etc.

The urban area is divided into three categories including Multan corporation, Multan cantonment and Multan revenue estates (Mouzas). According to the census of 1998, the total population was 1,613,917 (Multan Corporation 1,078,245, Multan cantonment 19,139, Multan revenue estates 516,533) and in the census of 2017 the total population was 2,651,549 (Multan Corporation 1,826,546, Multan cantonment 45,297, Multan revenue estates 779,706). The total increase in the population in 19 years is 1,036,632 (Fig. 7).

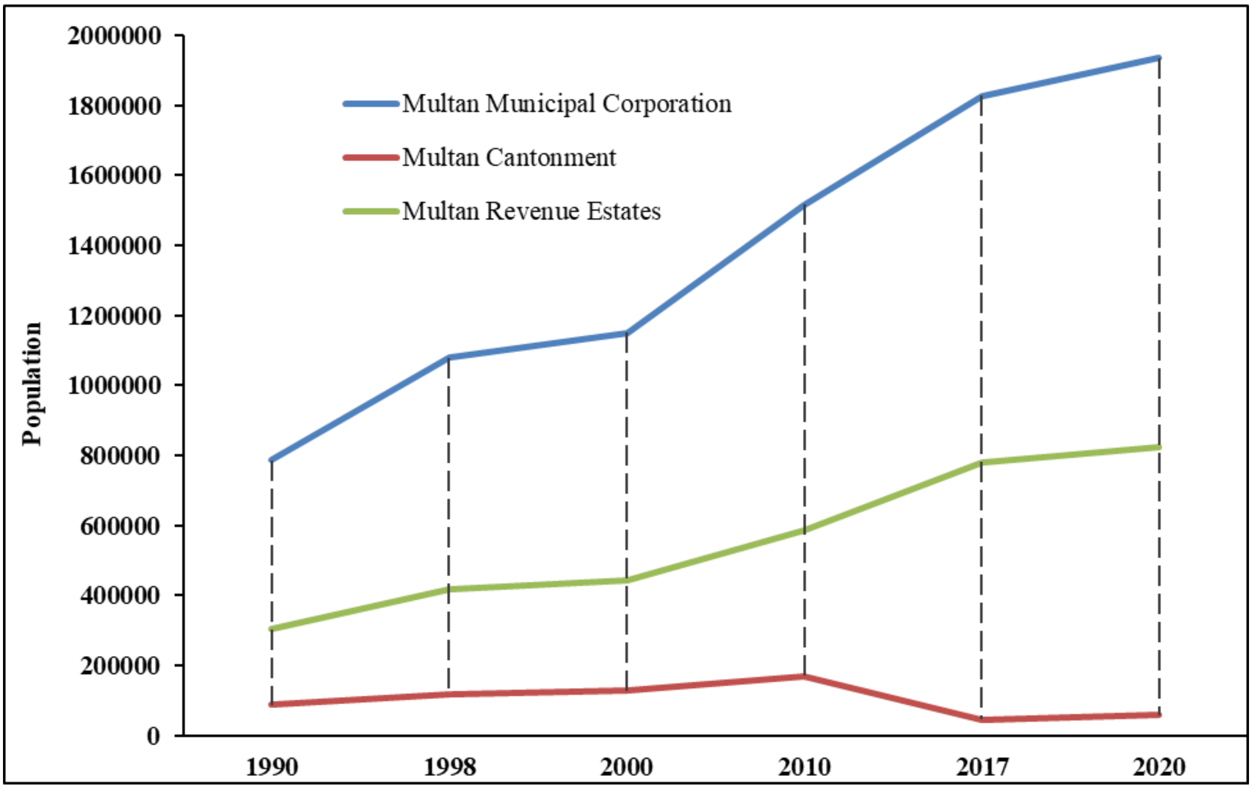

Figure 7. Population Growth in Multan City, 1990-2020

3.4. The Shrinking and Contraction of Agricultural Land

Urban expansion in Multan city is an unavoidable phenomenon that ultimately converts the fertile and most productive agricultural land into urban land which may negatively impact the food and livelihood security of the local inhabitants. The results of NDVI indicate that the agricultural area has experienced a significant decline since 1990. The area covered by agricultural land was 320 km^2 in 1990, which decreased to 305 km^2 in 2000. From 1990-2000, agricultural land decreased by 4.6%, with an annual decline rate of 1.5 km^2. During 2000-2010, agricultural land has been contracted by 5%, reflecting a decrease of 1.5 km^2 per year. From 2010-2020, agricultural land has further shrunk by 24%, from 290 km^2 in 2010 to 220 km^2 in 2020. The conversion of agricultural land into non-agricultural land is going on at an alarming rate of 7 km^2 per year. The overall change result of NDVI indicates that about 31.3% of agricultural land area has been transformed to an urban area. From the result it is inferred that about 100 km^2 of fertilized agricultural land which was very famous for Mangoes production was lost during 1990-2020 (Figs 8, 9). This loss of agricultural land can be attributed to urban expansion encroaching upon agricultural areas.

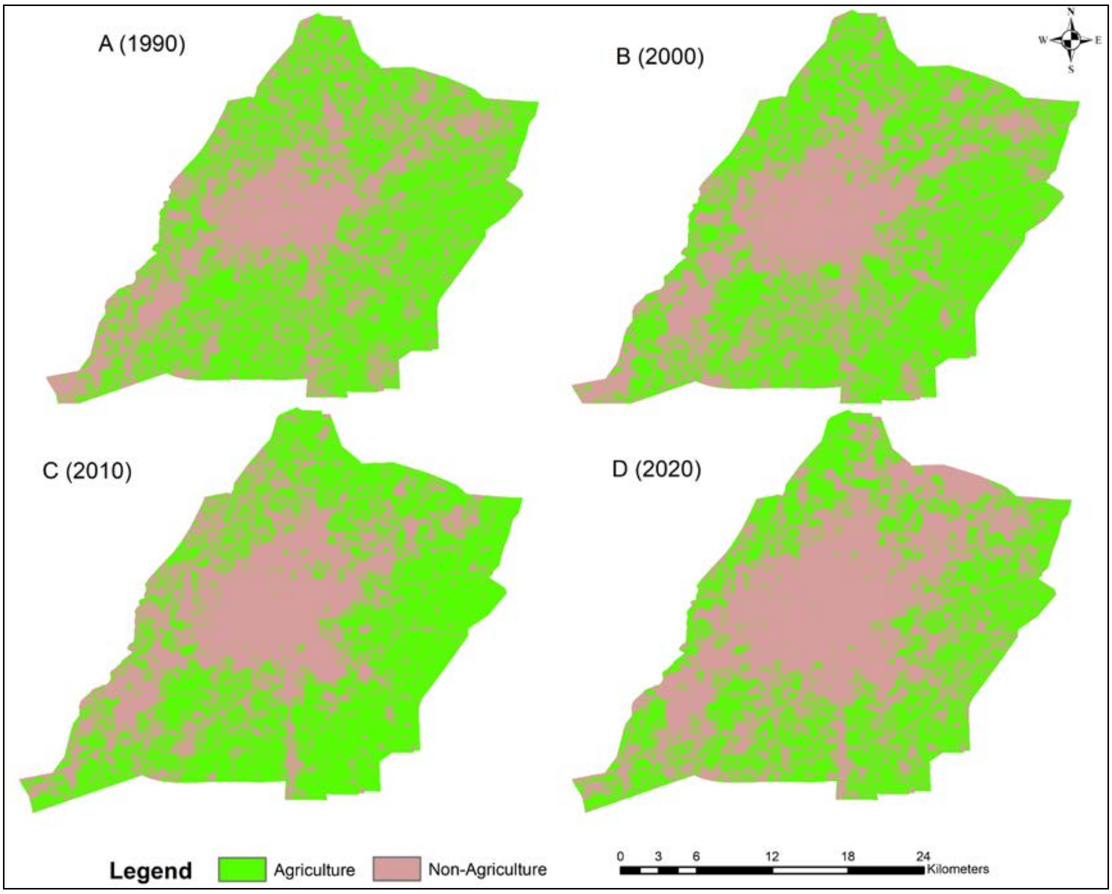

Figure 8. Temporal Analysis of Agricultural Land Using NDVI, 1990-2020

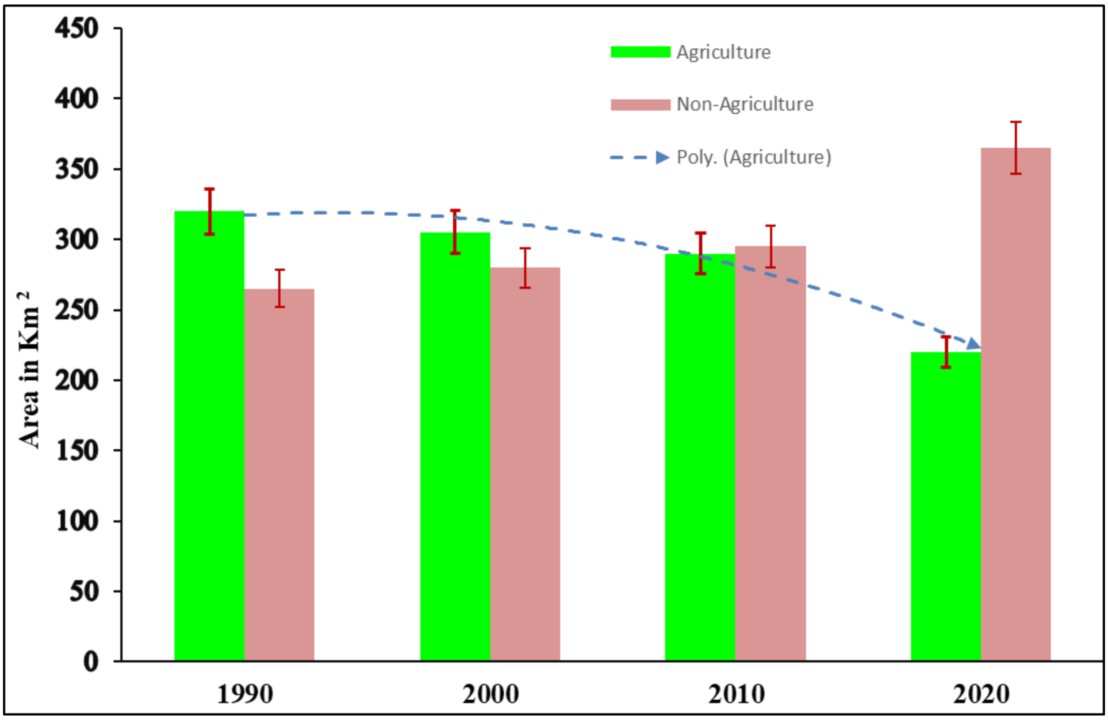

Figure 9. Agricultural Land Dynamic in Multan City, 1990-2020

3.5. Intricate Interplay between Buil-up area (NDVI) and Agricultural land (NDBI)

Over the last three decades, the abrupt urbanization and the haphazard expansion in the built-up area posed significant challenges and major threats to agricultural land in Multan city. They are the major driver and catalysts of the conversion of agricultural land into built-up areas in Multan city. Therefore, the relationship between built-up areas (quantified by NDBI) and agricultural land (measured by NDVI) was developed for the year 1990, 2000, 2010, and 2020, indicating that there is a strong inverse association between urban expansion and agricultural land for all the study periods. In 1990, a strong negative relationship between NDBI and NDVI was reported, with a statistical value of $r > -0.75$. During 1990-2000, the strength of the negative correlation between NDBI and NDVI increased slightly, with the R^2 value of -0.75 in 1990 to -0.83 in 2000. Therefore, it is evident that a consistent trend of urban expansion negatively impacts the fertile and productive agricultural land of the Multan city. In 2010, the inverse correlation between NDVI and NDBI persisted, the strength of the negative relationship increased from r value of -0.83 in 2000 to -0.91 in 2010. During 2010-2020, the intensity of negative correlation between NDVI and NDBI increased significantly, as indicated by the r value of -0.96 in 2020. Consequently, the accelerated and intensified urban expansion has increasingly exerted a negative impact on the agricultural land of Multan city during 1990-2020 (Fig. 10).

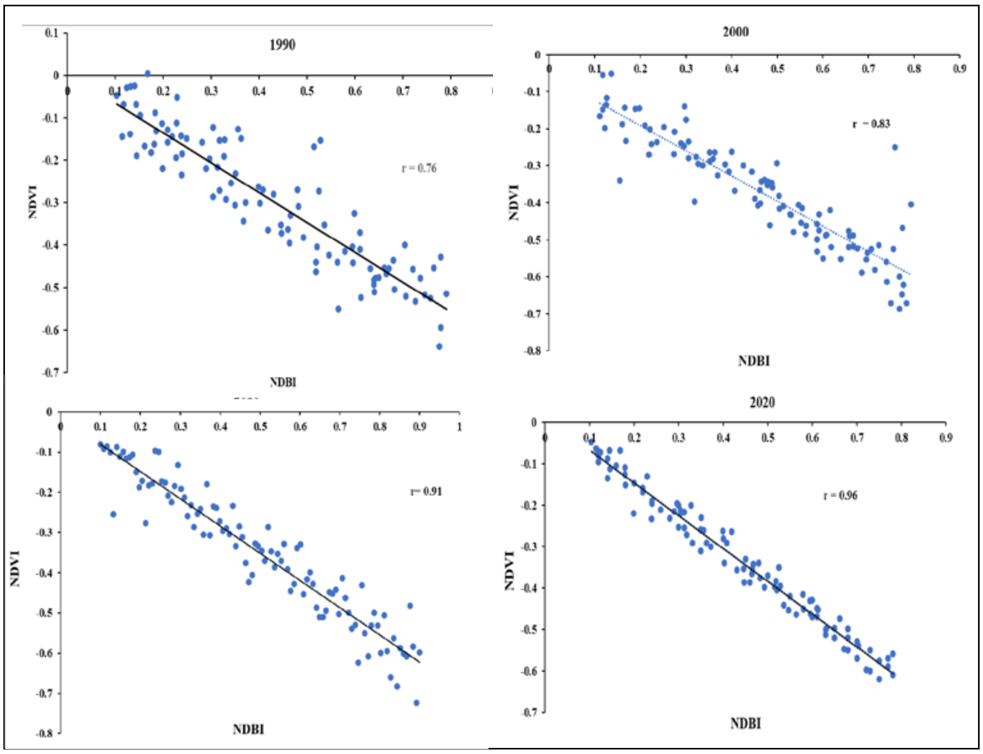

Figure 10. Built-up Area (NDBI) Vs Agricultural land (NDVI) Relationship, 1990-2020

3.6. Spatiotemporal Transformation and Change Detection in Urban Area

Change detection analysis for the specified three time periods was conducted and the statistics are shown in Figure 11. The findings of the change detection map of urban expansion and other LULC indicate that approximately 45.3% of the total area of Multan city has experienced significant change and transformation, while the remaining 54.7% of the area remained unchanged during P_1 (1990-2000). During P_1, the highest positive change has been observed in the built-up area which increased by 16.2%. This abrupt increase is attributed to the conversion of agricultural land (7.5%), fellow land (4.7%), barren (3.6%), and water (0.3%), respectively (Table 3). Hence, it is apparent that a high percentage of the agricultural area has been converted into a built-up area, during P_1. The change detection map of P_2 shows that about 49.3% of the total area has been changed, while the 50.7% of the total area Multan City remained unchanged during the decade 2000-2010. During this period, major negative changes have occurred in agricultural land, barren land, water bodies and fellow land, which mostly converted into built-up areas. However, a major positive change has occurred in the built-up area which increased by 30.6% during 200-2010.

During 2010-2020, the rate of LULC has increased and approximately 55.6% of the area of Multan city has witnessed significant transformation. The urban area has increased by 40.5%. The statistics of the built-up area for the years 2010-2020 show that the change from agriculture to build-up was 21.8% and the other land covers 18.64%. During 2010-2020, more than 18% of fertile agricultural land was converted into built-up area. Additionally, agricultural area was also converted to barren land, and fallow land due to desertification processes. However, during the same period, some of the area of fallow land (3.5%) was converted back to agricultural land (Table 3).

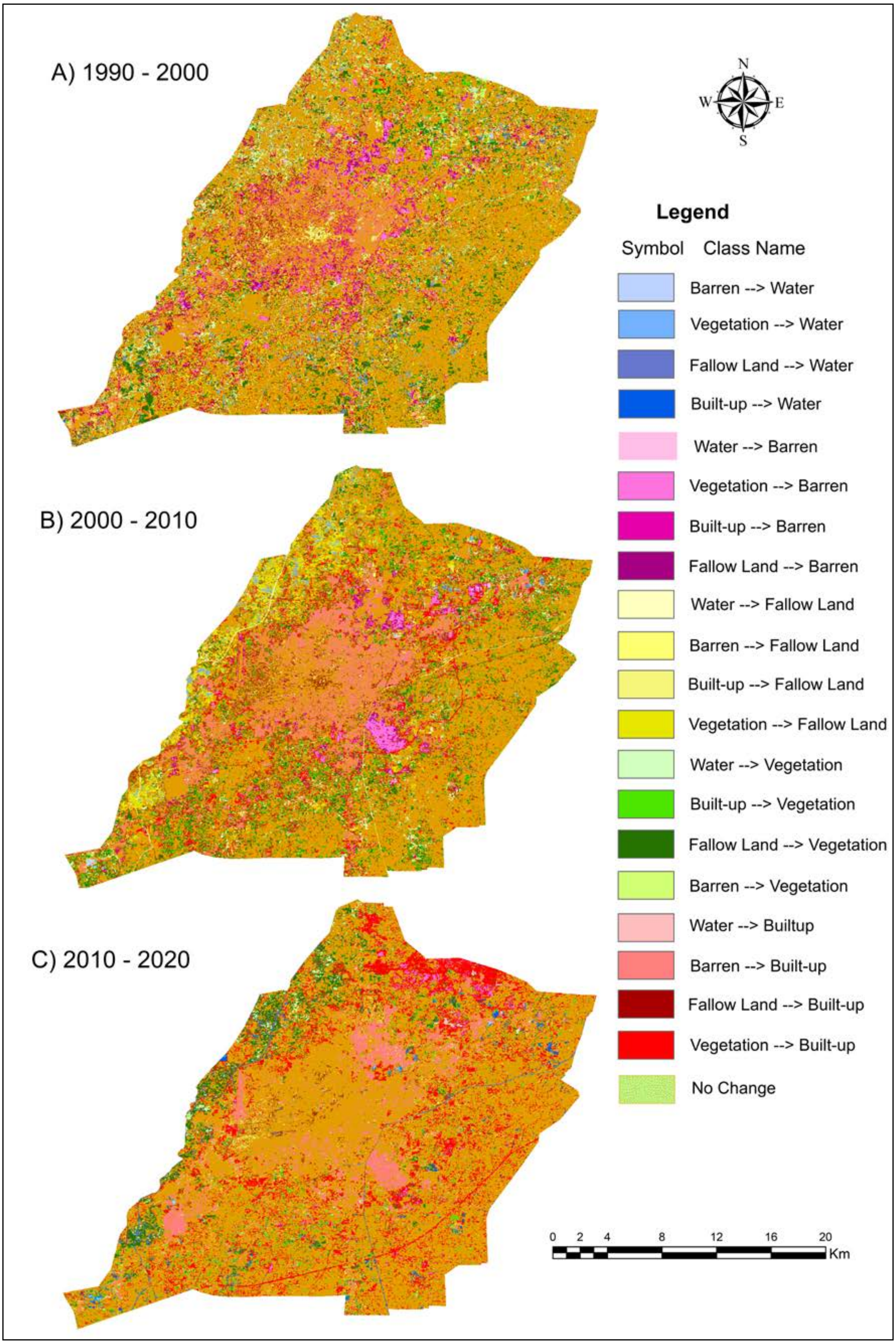

Figure 11. Change Detection in Urban Area and other LULC from 1990-2020

Table 3. Change Detection in Urban Area and other LULC from 1990-2020

Land covers		1990-2000	2000-2010	2010-2020
From	**To**	Area (%)	Area (%)	Area (%)
Water	Barren	0.14	0.1	0.01
	Vegetation	3.21	1.65	0.61
	Built-up	0.36	0.48	0.12
	Fallow Land	0.86	0.61	0.01
Barren	Water	0.1	0.07	0.04
	Vegetation	0.55	0.36	0.06
	Built-up	2.6	7.9	6.3
	Fallow Land	0.81	0.15	0.19
Vegetation	Water	1.37	0.7	0.93
	Barren	1.83	1.52	0.85
	Built-up	4.58	6.3	14.9
	Fallow Land	7.07	4.26	3.38
Built-up	Water	0.19	0.04	0.33
	Barren	2.94	1.06	0.37
	Vegetation	2.35	4.22	2.41
	Fallow Land	2.92	0.67	2.38
Fallow land	Water	0.66	0.06	0.84
	Barren	1.25	0.8	0.05
	Vegetation	7.69	7.35	3.59
	Built-up	3.72	7.01	2.22
No Change		54.79	54.69	60.42

4. Discussion and Conclusions

Since 1990, significant changes and palpable transformations have been witnessed in the urban environment of Multan city. The major change has been experienced in the urban built-up environment of Multan city which increased significantly over the last three decades. The findings of this study reveal that persistent increase, haphazard and horizontal urban expansion in all directions have been observed in Multan City from 1990 to 2020. Over the past three decades, the urban area of Multan City has increased more than four times, and currently, the city is expanding at a rapid rate of 9.5 km per year corresponding to rapid urbanization. The rate of urban expansion is very high compared to other cities of Pakistan. The increase in the built-up area was more pronounced between 2010 to 2020 due to rural-urban migration from the surroundings and the development of new housing colonies. This rapid urban expansion is driven by a multitude of factors, including population growth, geopolitical and policy changes, the development of colonies, economic development, and rural-urban migration. The abrupt urban expansion is an indicator of economic development;

however, it triggers numerous socio-ecological and economic challenges, including loss of agricultural land, food and livelihood insecurity, environmental and biodiversity degradation, reduced ecosystem services, increased greenhouse gas emissions, urban heat island effect, heightened pollution (i.e., noise, light, soil, and water), increased municipal costs, and spatial segregation of natural habitats, and different environmental hazards (e.g., heat waves and increasing land surface temperature) (Dupras & Alam, 2015; Khan et al., 2021; Zhou et al., 2015; Arshad et al., 2020; Haider et al., 2025). Overall, it is inferred that the surge in the built-up area has affected agricultural land, fallow land and barren land of the study area.

The peripheral and suburban area of Multan city is highly fertile agricultural land renowned for producing top-quality agricultural products, particularly mangoes. However, our findings reveal that the unplanned new development of colonies and horizontal urban expansion has encroached upon this valuable agricultural land of Multan City. About 31% of the agricultural land has been converted into built-up environments within a short span of time from 1990 to 2020. Furthermore, this trend of agricultural land conversion/urbanization is ongoing at an alarming rate. The LULC prediction result indicates that the built-up area will increase by about 67%, and 60% of the agricultural land will be lost by 2040. This poses significant threats and jeopardizes food and livelihood security, as well as environmental degradation in Multan City.

From the analysis, it is revealed that there is a strong negative association between urban expansion and agricultural land. Similar to other urban cases (Arshad et al., 2020), the increase in the built-up area has resulted in a decrease in the proportion of agricultural land. According to the validation data, it is inferred that a consistent trend of urban expansion negatively impacts the fertile and productive agricultural land of the Multan city. Moreover, the accelerated and intensified urban expansion has increasingly exerted a negative impact on the agricultural land of Multan city during 1990-2020. This change not only threatens the livelihoods and food security of local inhabitants but also undermines the resilience of agriculture, livelihood sustenance and economic stability at regional and national levels. This research emphasizes the imperative of policy formulation to mitigate uncontrolled horizontal urban expansion encroaching upon fertile agricultural land. The findings of this study provide manced insight to urban/town planners, decision-makers, and relevant authorities for the formulation of strategies for sustainable future of urban areas and agriculture.

Conflict of Interest

The authors declare no conflict of interest.

References

Ackerman, K., Conard, M., Culligan, P., Plunz, R., Sutto, M.-P., & Whittinghill, L., 2014, Sustainable food systems for future cities: the potential of urban agriculture. The Economic and Social Review 45: 189–206.

Ahmad, Z., Fazlur-Rahman, Dittmann, A., Hussain, K., & Ihsanullah, I., 2020, Water crisis in the Eastern Hindu Kush: a micro-level study of community-based irrigation water management in the mountain village Kushum, Pakistan. Erdkude 74(1): 59–79. https://doi.org/10.3112/erdkunde.2020.01.04

Ahmad, Z., Postigo, J.C., Rehman, F., & Dittmann, A., 2021, Mountain Pastoralism in the Eastern Hindu Kush: The Case of Lotkuh Valley, Pakistan. Mountain Research and Development 41(4): 16–28. https://doi.org/10.1659/MRD-JOURNAL-D-21-00007.1

Ahmad, Z., Malik, S.M., Mehran, Hussain, K., & Altaf, F., 2023, Resilience and Innovation in Mountain Agriculture: Exploring the Drivers of Agricultural Transformation in the Eastern Hindu Kush, Lotkuh, Pakistan. Journal of Asian Development Studies 12(4): 158–177. https://doi.org/10.62345/jads.2023.12.4.11

Ahmad, Z., Postigo, J.C., Rahman F., & Altaf, F., 2025a, Changing Mountain Pastoralism and its Impacts in the Hindu Kush-Karakorum-Himalaya: The Case of Kushum, Pakistan. Nomadic Peoples 29(1): 70–100**.** https://doi.org/10.3828/whpnp.63837646691066

Ahmad, Z., Altaf, F., Kamp, U., Rahman, F., & Malik, S.M., 2025b, Glacier Recession and Climate Change in Chitral, Eastern Hindu Kush Mountains of Pakistan, Between 1992 and 2022. Geosciences 15(5), 167. https://doi.org/10.3390/geosciences15050167

Akbari, H., 2002, Shade trees reduce building energy use and CO_2 emissions from power plants. Environmental Pollution 116: 119–126.

Ali, L., Ali, S., Khattak, S.A., Janjuhah, H.T., Kontakiotis, G., Hussain, R., Rukh, S., Shah, M.T., Bathrellos, G.D., & Skilodimou, H.D., 2023, Distribution, Risk Assessment and Source Identification of Potentially Toxic Elements in Coal Mining Contaminated Soils of Makarwal, Pakistan: Environmental and Human Health Outcomes. Land 12, 821. https://doi.org/10.3390/land12040821

Alsharif, A.A, & Pradhan, B., 2014, Urban sprawl analysis of Tripoli Metropolitan city (Libya) using remote sensing data and multivariate logistic regression model. Journal of the Indian Society of Remote Sensing 42: 149–163. https://doi.org/10.1007/s12524-013-0309-0

Arshad, A., Ashraf, M., Sundari, R.S., Qamar, H., Wajid, M., & Hasan, M.-U., 2020, Vulnerability assessment of urban expansion and modelling green spaces to build heat waves risk resiliency in Karachi. International Journal of Disaster Risk Reduction 46**,** 101468. https://doi.org/10.1016/j.ijdrr.2020.101468

Bapari, M.Y., Haque, M.E., Chowdhury, M., & Islam, M.J., 2016, Impacts of unplanned urbanization on the socio-economic conditions and environment of Pabna Municipality, Bangladesh. Journal of Environment and Earth Science 6(9): 105–113.

Balçik, B.F., 2014, Determining the impact of urban components on land surface temperature of Istanbul by using remote sensing indices. Environmental Monitoring Assessment 186: 859–872. https://doi.org/10.1007/s10661-013-3427-5

Cao, C., & Wang, J., 2025, The impact of urban expansion on food production: a bibliometric study of development, hotspots, and future prospects. Frontiers in Sustainable Food Systems 9, 1550373. https://doi.org/10.3389/fsufs.2025.1550373

Carpio, O., & Fath, B.D., 2011, Assessing the environmental impacts of urban growth using land use/land cover, water quality and health indicators: A case study of Arequipa,

Peru. American Journal of Environmental Sciences 7(2): 90–101. https://doi.org/10.3844/ajessp.2011.90.101
Cherigui, A., Talia, A., Benstaali, I., Blissag, B., Zerouali, B., & Meddi, M., 2025, Urban expansion and its environmental impacts in northwestern Algeria using cellular automata-Markov-chain modeling. Modeling Earth Systems and Environment 11(3), 159. 10.1007/s40808-025-02309-y
Dittmann, A. & Nüsser, M., 2002, Siedlungsentwick-lung im östlichen Hindukusch: Das Beispiel Chitral Town (North-West Frontier Province, Pakistan). Erdkunde 56(1): 60–72. https://doi.org/10.3112/erd-kunde.2002.01.04
Dupras, J., & Alam, M., 2015, Urban sprawl and ecosystem services: A half century perspective in the Montreal area (Quebec, Canada). Journal of Environmental Policy and Planning 17: 180–200. https://doi.org/10.1080/1523908X.2014.927755
Gandharum, L., Hartono, D.M., Karsidi, A., & Ahmad, M., 2022, Monitoring urban expansion and loss of agriculture on the north coast of west java province, Indonesia, using Google Earth engine and intensity analysis. The Scientific World Journal 20(1), 3123788. https://doi.org/10.1155/2022/3123788
GOP, 1984, District Census Report of Multan, 1981. Population Census Organization of Pakistan, Lahore.
GOP, 2000, District Census Report of Multan, 1998. Population Census Organization of Pakistan, Lahore.
GOP, 2021, District Census Report of Multan, 2017. Population Census Organization of Pakistan, Lahore.
Gunapala, R., Gangahagedara, R., Wanasinghe, W.C.S., Samaraweera, A.U., Gamage, A., Rathnayaka, C., ... & Merah, O., 2025, Urban agriculture: A strategic pathway to building resilience and ensuring sustainable food security in cities. Farming System 3(2), 100150. https://doi.org/10.1016/j.farsys.2025.100150
Haider, S., Haq, F., Kontakiotis, G., Ahmad, Z., Besiou, E., Malik, S.M., Antonarakou, A., & Altaf, F., 2025, Spatiotemporal analysis of temperature variability and trends in the cholistan desert, Pakistan: Implications for water management and sustainable development. Environmental Earth Sciences 84, 665. https://doi.org/10.1007/s12665-025-12665-8
Haq, N.U., Kontakiotis, G., Janjuhah, H.T., Rahman, F., Tabassum, I., Khan, U., Khan, J., Ahmad, Z., & Jamal, N., 2022, Environmental Risk Assessment in the Hindu Kush Himalayan Mountains of Northern Pakistan: Palas Valley, Kohistan. Sustainability, 14, 16679. https://doi.org/10.3390/su142416679
Horst, M., McClintock, N., & Hoey, L., 2024, The intersection of planning, urban agriculture, and food justice: A review of the literature. In book: Planning for Equitable Urban Agriculture in the United States, p. 89–104. https://doi.org/10.1007/978-3-031-32076-7_6
Houessou, M.D., Van, D.E., Louw, M., & Sonneveld, B.G., 2020, What constraints the expansion of urban agriculture in Benin? Sustainability 12, 5774. https://doi.org/10.3390/su12145774
Humaida, N., Saputra, M., & Hadiyan, Y., 2023, Urban gardening for mitigating heat island effect. IOP Conference Series: Earth and Environmental Science 1133, 012001. https://doi.org/10.1088/1755-1315/1133/1/012001
Hussain, M., 2024, Impact of population growth on urban expansion, and future prediction modeling: a comparative study of Multan, Bahawalpur and Bahawalnagar using Geospatial technique. [Unpublished PhD thesis], University of Karachi, Pakistan.
Hussain, M., & Shaikh, S., 2025, Nexus of Urban Expansion and Socio-economic Transformation of Bahawalnagar, Pakistan: A Geospatial Perspective. Journal of

Asian Development Studies. 14(1): 751–763. https://doi.org/10.62345/jads.2025.14.1.58
Islam, F., Ahmad, M.N., Janjuhah, H.T., Ullah, M., Islam, I.U., Kontakiotis, G., Skilodimou, H.D., & Bathrellos, G.D., 2022, Modelling and Mapping of Soil Erosion Susceptibility of Murree, Sub-Himalayas Using GIS and RS-Based Models. Applied Sciences 12, 12211. https://doi.org/10.3390/app122312211
Khan, U., Janjuhah, HT., Kontakiotis, G., Rehman, A., & Zarkogiannis, S.D., 2021, Natural processes and anthropogenic activity in the Indus River sedimentary environment in Pakistan: A critical review. Journal of Marine Science and Engineering 9, 1109. https://doi.org/10.3390/jmse9101109
Li, G., Sun, S., & Fang, C., 2018, The varying driving forces of urban expansion in China: Insights from a spatial-temporal analysis. Landscape and Urban Planning 174: 63–77. https://doi.org/10.1016/j.landurbplan.2018.03.003
Mirzakhani, A., Behzadfar, M., & Azizi Habashi, S., 2025, Simulating urban expansion dynamics in Tehran through satellite imagery and cellular automata Markov chain modelling. Modeling Earth Systems and Environment 11(2), 145. DOI:10.1007/s40808-025-02325-y
Moisa, M.B., & Gemeda, D.O., 2021, Analysis of urban expansion and land use/land cover changes using geospatial techniques: a case of Addis Ababa City, Ethiopia. Applied Geomatics, 13(4): 853–861. https://doi.org/10.1007/s12518-021-00397-w
Nadeem, M., Khaliq, N., Akhtar, N., Al-Rashid. M.A., Asim, M., Codur, M.K., & Baig, F., 2022, Exploring the urban form and compactness: A case study of Multan, Pakistan. Sustainability 14, 16066. https://doi.org/10.3390/su142316066
Nasar-u-Minallah, M., Zia, S., Rahman, A-U., & Riaz, O., 2021, Spatio-temporal analysis of urban expansion and future growth patterns of Lahore, Pakistan. Geography, Environment, Sustainability 14: 41–50. https://doi.org/10.24057/2071-9388-2020-163
Nor, A.N.M., Corstanje, R., Harris, JA., & Brewer, T., 2017, Impact of rapid urban expansion on green space structure. Ecological Indicators 81: 274–284. https://doi.org/10.1016/j.ecolind.2017.05.031
Ouyang, X., Xu, J., Li, J., Wei, X., & Li, Y., 2022, Land space optimization of urban-agriculture-ecological functions in the Changsha-Zhuzhou-Xiangtan Urban Agglomeration, China. Land Use Policy 117, 106112. DOI: 10.1016/j.landusepol.2022.106112
Picton, R.M., 2016, Back to Nature: New urban policy and environmental governance in Canada's capital. Local Environment 21: 1435–1450. https://doi.org/10.1080/13549839.2015.1136416
Pijanowski, B., Tayebi. A., Delavar, M., & Yazdanpanah, M., 2009, Urban expansion simulation using geospatial information system and artificial neural networks. International Journal of Environmental Research 3(4): 493–502.
Ritchie, H., & Roser, M., 2018, Urbanization across the world today. Our World in Data. https://ourworldindata.org/urbanization
Sadian, A., & Shafizadeh-Moghadam, H., 2025, The future of agricultural lands under the combined influence of shared socioeconomic pathways and urban expansion by 2050. Agricultural Systems 224, 104234. https://doi.org/10.1016/j.agsy.2024.104234
Santo, R., Palmer, A., & Kim, B., 2016, Vacant lots to vibrant plots: A review of the benefits and limitations of urban agriculture. Johns Hopkins Center for a Livable Future, Baltimore, MD, USA. DOI:10.13140/RG.2.2.25283.91682
Schuster-Olbrich, J.P., Marquet, O., Miralles-Guasch, C., & Arce, L.F., 2024, Spatial patterns and drivers of urban expansion: An exploratory spatial analysis of the

Metropolitan Region of Santiago, Chile, from 1997 to 2013. Cities 153, 105305. https://doi.org/10.1016/j.cities.2024.105305

Shinwari, F.U., Khan, M.A., Siyar, S.M., Liaquat, U., Kontakiotis, G., Zhran, M., Shahab, M., & Alshehri, F., 2025a, Evaluating the contamination susceptibility of groundwater resources through anthropogenic activities in Islamabad, Pakistan: a GIS-based DRASTIC approach. Applied Water Science 15, 81. https://doi.org/10.1007/s13201-025-02374-9

Shinwari, F.U., Liaquat, U., Khan, M.A., Kontakiotis, G., Makri, P., Lianou, V. & Antonarakou, A., 2025b, Hydrochemical zonation and depth-based vulnerability of groundwater in Islamabad using GIS and WQI techniques. Frontiers in Water **7**, 1581668. https://doi.org/10.3389/frwa.2025.1581668

Shuaib, M., Ali, K., Ahmed, S., Hussain, F., Ilyas, M., Hassan. N., & Hussain, F., 2018, Impact of rapid urbanization on the floral diversity and agricultural land of district Dir, Pakistan. Acta Ecologica Sinica 38: 394–400. https://doi.org/10.1016/j.chnaes.2018.03.002

Vieira, TA., & Panagopoulos, T., 2024, Urban agriculture in Brazil: Possibilities and challenges for Santarém, eastern Amazonia. Land Use Policy 139, 107082. https://doi.org/10.1016/j.landusepol.2024.107082

Wu, W., Zhao, S., Zhu, C., & Jiang, J., 2015, A comparative study of urban expansion in Beijing, Tianjin and Shijiazhuang over the past three decades. Landscape and Urban Planning 134: 93–106. https://doi.org/10.1016/j.landurbplan.2014.10.010

Yasin, K.H., Iguala, A.D., & Gelete, T.B., 2025, Spatiotemporal analysis of urban expansion and its impact on farmlands in the central Ethiopia metropolitan area. Discover Sustainability 6(1), 36. https://doi.org/10.1007/s43621-024- 00749-7

Zhang, A., Tariq, A., Quddoos, A., Naz, I., Aslam, R.W., Barboza, E., ... & Abdullah-Al-Wadud, M., 2025, Spatio-temporal analysis of urban expansion and land use dynamics using google earth engine and predictive models. Scientific Reports 15(1), 6993. https://doi.org/10.1038/s41598-025-92034-4

Zhang, Q., & Su, S., 2016, Determinants of urban expansion and their relative importance: A comparative analysis of 30 major metropolitans in China. Habitat International 58, 89–107. https://doi.org/10.1016/j.habitatint.2016.10.003

Zhou, D., Zhang, Z., & Shi, M., 2015, Where is the future for a growing metropolis in North China under water resource constraints? Sustainability Science 10: 113–122. https://doi.org/10.1007/s11625-014-0278-6