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Proceeding Paper

Spatio-Temporal Assessment of Land Use Land Cover Changes and Population Dynamics Using Geoinformatics: A Case Study of Mardan, Khyber Pakhtunkhwa, Pakistan †

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Abstract: Over the last three decades, Tehsil Mardan has gone through an incredible expansion of its built-up layer. This study explored the land use land cover changes in Tehsil Mardan from 1990 to 2021 along with population dynamics by applying geographic information systems and remote sensing techniques. Landsat satellite images for the years 1990, 1995, 2000, 2010, 2015, and 2021 were used for land use land cover classification. A maximum likelihood supervised algorithm and confusion matrix were applied for classification and accuracy assessment, respectively. The classification results outlined that there has been a substantial increase in the built-up layer from 37 km^2 to 188 km^2 and a significant decrease in bare land class from 437 km^2 to 252 km^2 from 1990 to 2021. The classification proces's overall accuracy ranged from 87.42% to 98.30%, and the Kappa Coefficient ranged from 0.82 to 0.97. Population dynamics were also studied in the present study, and it was found that the total population of Tehsil Mardan was 502,435, 864,017, and 1,403,002 in 1981, 1998, and 2017, respectively, and its population was further forecasted based on historical trends until 2027. Statistical analysis revealed a strong positive correlation (0.98) between the built-up layer and population and a significant negative correlation (−0.91) between population and bare land. Based on the findings of this study, policymakers should be able to better plan future land use and account for associated factors while keeping environmental threats and opportunities in mind.

Keywords: LULC classification; GIS and RS; change detection; Mardan

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1. Introduction

Global land use has changed by one-third over the last few decades once or multiple times [1]. The dynamic conditions of land use land cover (LULC) changes have given rise to various socio and environmental issues like the degradation of ecosystems, food security, and water resources and the exacerbation of climatic variation [1–3]. According to [4], in 1950, only 30% of the global population resided in urban areas, which increased to 55% in 2018 and is projected to increase further to 68% by 2050. About 90% of the projected increase will occur in developing countries. Urban growth is attributed to population flare-ups and rural–urban migration. Pakistan, a developing country, is urbanizing, with an annual growth rate of 3%, which is the highest in South Asia [5]. This growing population will require natural resources such as energy and water for survival [6]. Urbanization has become a widely known reality [7] and poses serious threats to environmental resources such as water (with respect to quality and quantity), vegetation (deforestation), and agriculture [8]. Urbanization creates negative impacts on socioeconomic conditions and biophysical factors [9]; for example, a high rate of urbanization will result in a larger impervious cover layer and eventually reduce infiltration capacity [10]. It was recently revealed that uncontrolled urban sprawl can limit water availability in terms of its intensity, duration, and frequency [11]. The speedy conversion of permeable earth surface to impervious cover due to land use and land cover changes has triggered regional as well as local environmental impacts [12,13]. According to the Pakistan Bureau of Statistics and the World Bank report for 2017, Pakistan ranked sixth in the list of most populous countries in the world. Since its inception, urbanization has been identified as a key factor in land use and land cover changes [14,15]. Globally, these changes have modified two thirds of the earth's surface over the last thousand years [16,17]. Expertise in LULC changes would improve the current land use policies and practices based on scientific data for sustainable environmental development [18]. An area's land use represents its natural and anthropogenic environmental characteristics [19–21]. An increasing built-up layer triggers the appearance of impervious cover, which ultimately results in a high amount of runoff and a decline in groundwater recharge [22–24]. Remote Sensing (RS) and Geographic Information Systems (GIS) are largely applied and recognized as a leading procedure for assessing and examining land use dynamics. Satellite imagery data have been successfully used in LULC change analysis for the last 30 years [25–27]. Population increase along with a lack of policy for land use have resulted in an alarming situation [28], as the built-up layer has been increased at the cost of cultivable land [29] in Tehsil Mardan. Therefore, the assessment and quantification of the current and historic land use land cover changes over spatio-temporal scales along with population dynamics are necessary for all types of policy making in order to comprehend the associated environmental issues on both regional and local scales.

2. Study Area

Tehsil Mardan was chosen because of its rapid urban and population growth over the last three decades (Figure 1). Mardan is the 2nd largest city in Pakistan after the provincial capital Peshawar in Khyber Pakhtunkhwa and is 23rd on the list of the biggest cities in the country. The climatic conditions of Mardan range from hot to semi-arid. The average annual temperature is 22 °C, with June being the hottest month, and total annual rainfall was 560 mm, with August having the highest rainfall volume, equal to 122 mm. Since 1990, Mardan has witnessed a shift in population growth and spatial change [30], and it has been acknowledged as a commercial hub serving the neighboring districts of Khyber Pakhtunkhwa.

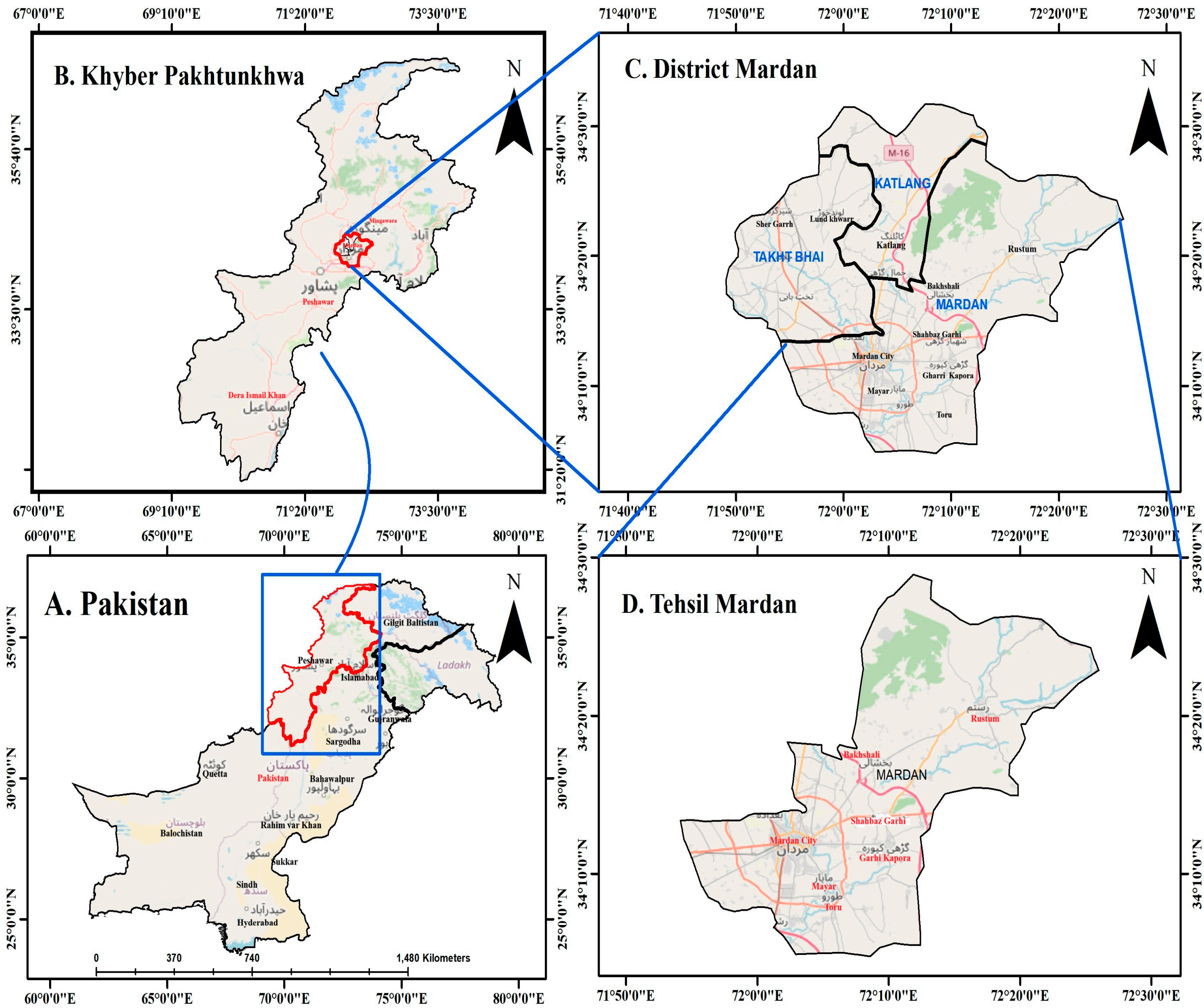

Figure 1. Location map of the study area (**A**) country, (**B**) province, (**C**) district, and (**D**) Tehsil Mardan.

3. Methodology and Dataset

3.1. Land Use Land Cover Classification and Change Detection

Both primary and secondary data sets (literature and published reports) were accessed and analyzed during the current study. To determine the extent and space of urbanization, Landsat satellite images were downloaded from the USGS website (https://earthexplorer.usgs.gov/ accessed on 1 May 2022). A detailed methodological approach applied for the assessment of LULC changes and change detection is displayed in Figure 2. Landsat imagery has been used in various studies for the assessment of land use land cover (LULC) changes on a spatiotemporal scale [31–33]. In these studies, the temporal interval was 5 years; however, 2005 images were not included in this list due to the unavailability of imagery data from 2003 to 2007 for the study area. Images for the years 1990, 1995, 2005, 2010, 2015, and 2021 were downloaded as per the given details in (Table 1). The downloaded images were subjected to a radiometric and geometric correction process [34]. Radiometric calibration and atmospheric correction techniques are required for spatial change assessment [35,36]. Four land use land cover classes were selected based on the intended objective and maximum representation of the study area (Table 2). ENVI 5.3 software was used for land use land cover assessment and change detection analysis. Sufficient and accurate training samples of each class were collected [37] for the classification process by using various band combinations, Google Earth historical preview, local knowledge, and ground truth points [37]. Supervised classification technique based on maximum likelihood algorithm was used [38,39] for classification of LULC in Tehsil Mardan from 1990 to 2021. The accuracy assessment technique was used for the quantitative calculation of classification accuracy [36,40–42], while the change detection technique was employed for the quantification and assessment [42] of land cover changes during the study period [43,44].

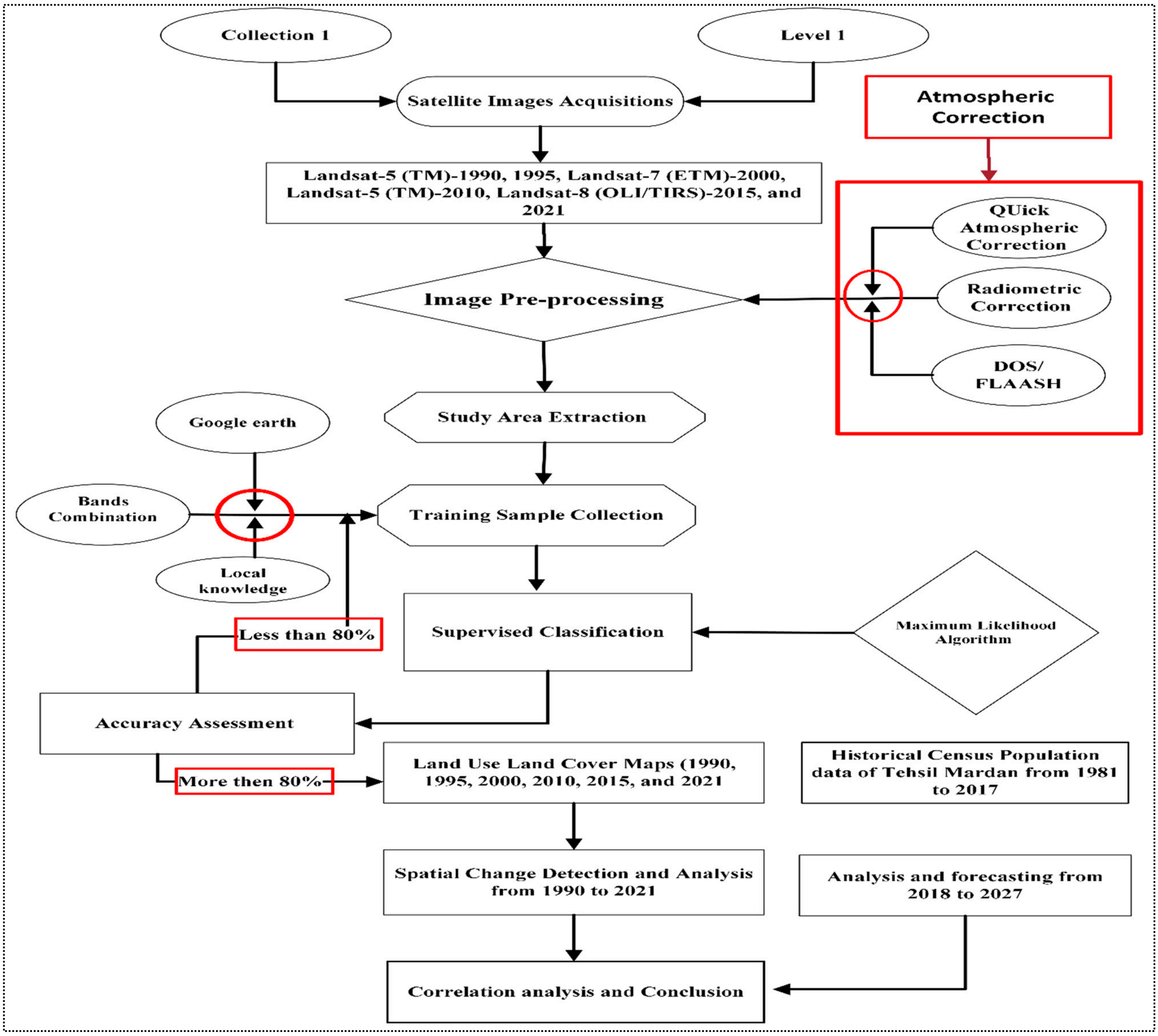

Figure 2. Methodological flow chart.

Table 1. Landsat satellite imagery data for detection of LULC changes.

S.No.	Year	Satellite	Sensor	Acquisition Date	Cloud Cover (%)	Remarks
1	1990	Landsat 5	TM	14th March 1990	2	-Targeted Months -Minimum Cloud Coverage -Clear Study Area -Free from Scan-Line Error -Resolution = 30 × 30 m
2	1995	Landsat 5	TM	13th April 1995	1	
3	2000	Landsat 7	ETM+	18th April 2000	3	
4	2010	Landsat 5	TM	6th April 2010	1	
5	2015	Landsat 8	OLI/TIRS	19th March 2015	1.7	
6	2021	Landsat 8	OLI/TIRS	19th March 2021	2.4	

Table 2. Description of land use classes.

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

3.2. Population Data

Population data were obtained from the Pakistan Bureau of Statistics population censuses for 1981, 1998, and 2017. Using the inter-census annual growth rate (ICGR) formula, the inter-census annual population was calculated using Equation (1). The Exponential Smoothing Forecast function in Microsoft Excel was used to project/forecast population statistics from 2017 to 2021 and onward till 2027. Using time series of historical population data, this technique can be used to forecast future populations, as shown in Equation (2) [45]

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

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

$$\text{Forecast} = \text{FORECAST.ETS (target year, values, timeline, [seasonality], [data completion], [aggregation])} \tag{2}$$

4. Results and Discussion

4.1. Land Use Land Cover Dynamics and Accuracy Assessment

The overall results of the LULC assessment showed that the built-up class remained in a state of continuous increase from 1990 to 2021 [46]; however, the bare land class showed a decreasing pattern of change (Figures 3 and 4). The LULC assessment results of Tehsil Mardan for the years 1990, 1995, 2000, 2010, 2015, and 2021 are displayed in Figure 4. The LULC data for 1990 showed that the built-up class accounted for 37 km^2 (4%), vegetation was recorded as accounting for 441 km^2 (47%), surface water bodies covered 21 km^2 (2%), and Bare land was spread over 437 km^2 (47%). Bare land and vegetation land cover were equal in 1990 [46]. In 1995, the LULC of Tehsil Mardan comprised 61 km^2 of built-up land, 527 km^2 of land corresponding to the vegetation class, 12 km^2 of surface water bodies, and 399 km^2 of bare land. After 10 years, in 2000, the land cover pattern results showed an increase in built-up land (83 km^2) and vegetation (527 km^2); however, water bodies were found to account for 18 km^2, and bare land decreased to 308 km^2. In 2010, the LULC composition showed expansion in the built-up layer (101 km^2) and a slight decrease in the vegetation class (516 km^2) as compared to the 2000 LULC results. In 2021, the LULC composition corresponded to 52% vegetation, 20% built-up layer, and 27% bare land. The net change in LULC from 1990 to 2021 in Tehsil Mardan was observed to correspond to a 408% increase in the built-up class and a 10% increase in the vegetation sector, while bare land and water bodies decreased by 52% and 42%, respectively. The overall classification accuracy for the years under study was more than 90%, except for 2010. Furthermore, the Kappa Coefficient was above 0.80 for all the images (Table 3).

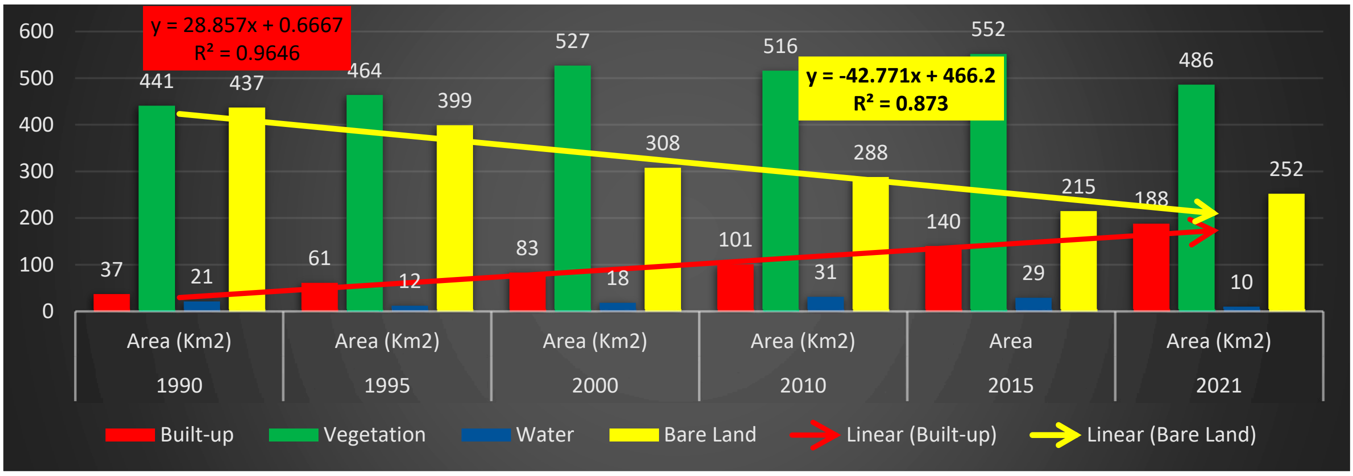

Figure 3. LULC composition of Tehsil Mardan from 1990 to 2021.

Table 3. Accuracy assessment.

Year/Parameter	1990	1995	2000	2010	2015	2021
Overall Accuracy (%)	97.25	96.69	94.15	87.42	94.71	98.30
Kappa Coefficient	0.95	0.95	0.91	0.82	0.88	0.97

4.2. Spatio-Temporal Change Detection from 1990 to 2021

The change detection technique was applied to evaluate and measure various transitions from one land use class to another. The present study focused on an already-set temporal range spanning from 1990 as the base map (LULC) and 2021 as the final land use land cover map. The transition between these targeted years was visualized and quantified using Arc Map (Figure 5). Significant transitions were observed among the land use classes, wherein bare land changed to the vegetation class (173.4 Km^2), vegetation changed to built-up layer (86.1 km^2), bare land changed to built-up layer (65.4 km^2), and vegetation changed to bare land (49.3) during the last three decades. The major contributors to the spatial change were divided into three factors (Figure 6): Contributing Factor (A), where 238.8 km^2 of bare land changed to vegetation and built-up land; Factor (B), where 135.4 km^2 of vegetation class changed to built-up and bare land; and Factor (C), where 16.1 km^2 of water class area changed to built-up and vegetation. Spatially, the vegetation improved in the north-eastern and south-eastern parts of Tehsil Mardan due to the Billion Tree afforestation project [47,48], the implementation of Khyber Pakhtunkhwa Forest Ordinance 2002, and he enactment of The Khyber Pakhtunkhwa wildlife and Biodiversity plan (Protection, preservation, conservation, and management act, 2015) and the Forestry Sector Master Plan (FSMP). The conversion of vegetation to bare land was observed in the southwestern parts of the study area near the vicinity of the city. It is anticipated that this bare land will be transformed into built-up land in the near future.

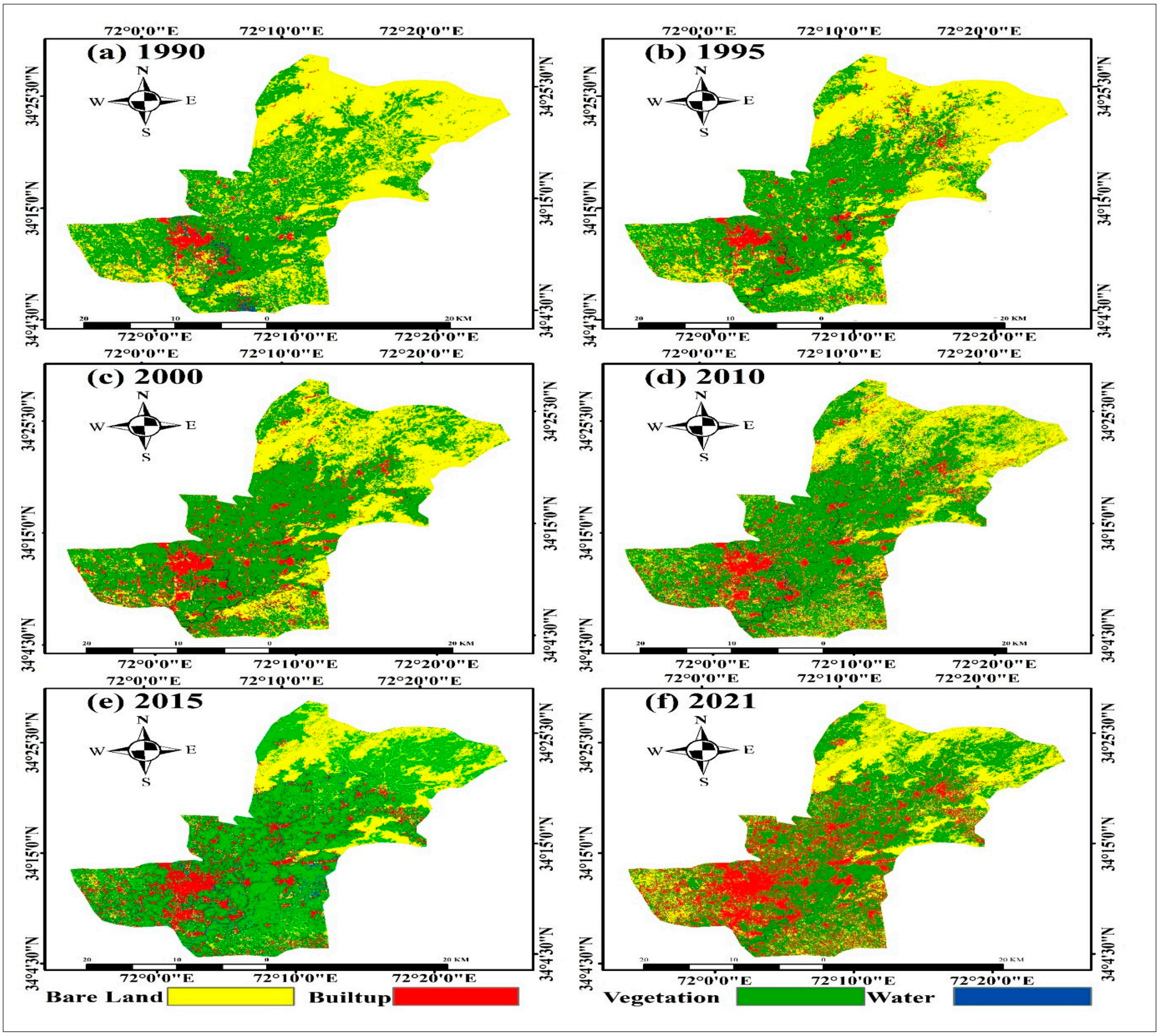

Figure 4. Land use land cover maps of Tehsil Mardan.

4.3. Population Change Dynamics of Tehsil Mardan

According to the sixth population census in 2017, the total population of Tehsil Mardan was 1,403,002, in which the urban population share was 359,024 and the rural population numbered 1,043,978. Similarly, in 1998, the total population was 864,017 and the urban population was 245,926. For 1981, the population data of the district of Mardan was proportionally divided based on the current boundaries of tehsils. The forecasted populations of Tehsil Mardan for the years 2021 and 2027 were recorded as 1,580,539 and 1,759,485, respectively Figure 7.

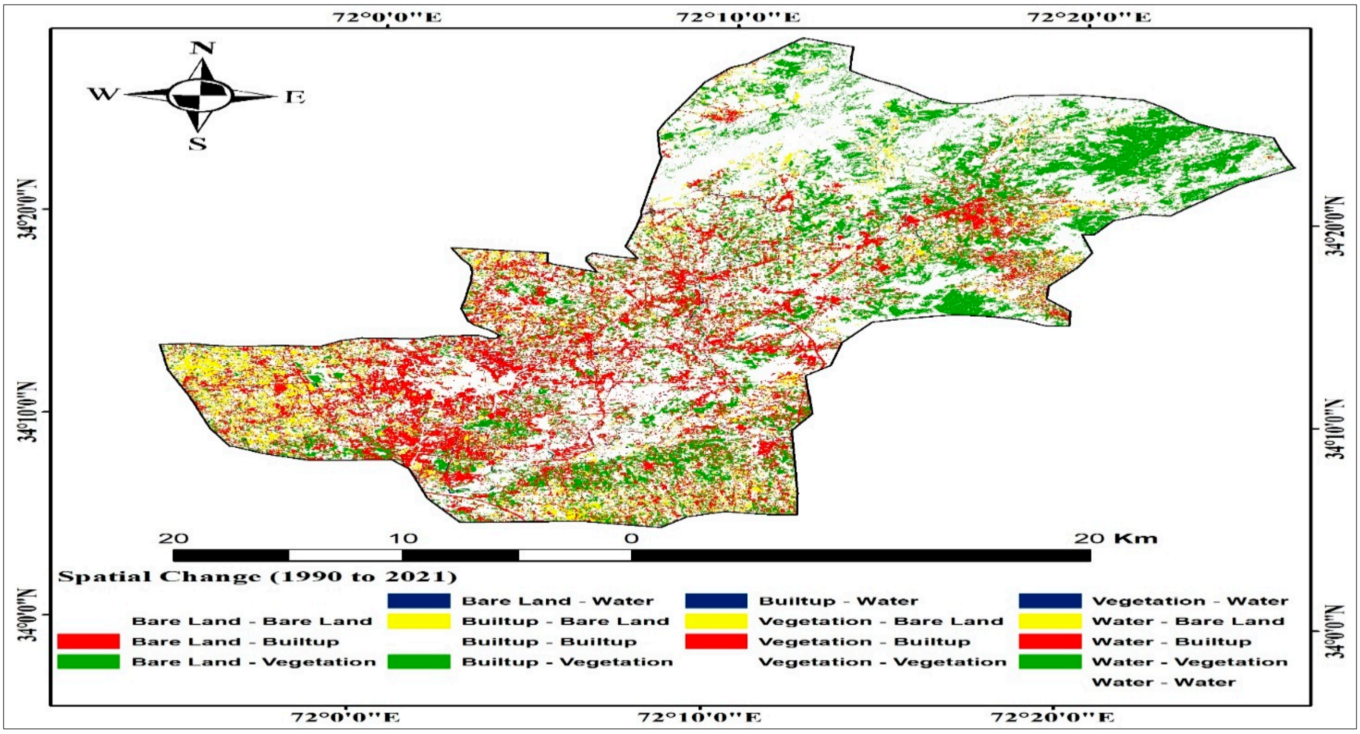

Figure 5. Spatial change detection results from 1990 to 2021.

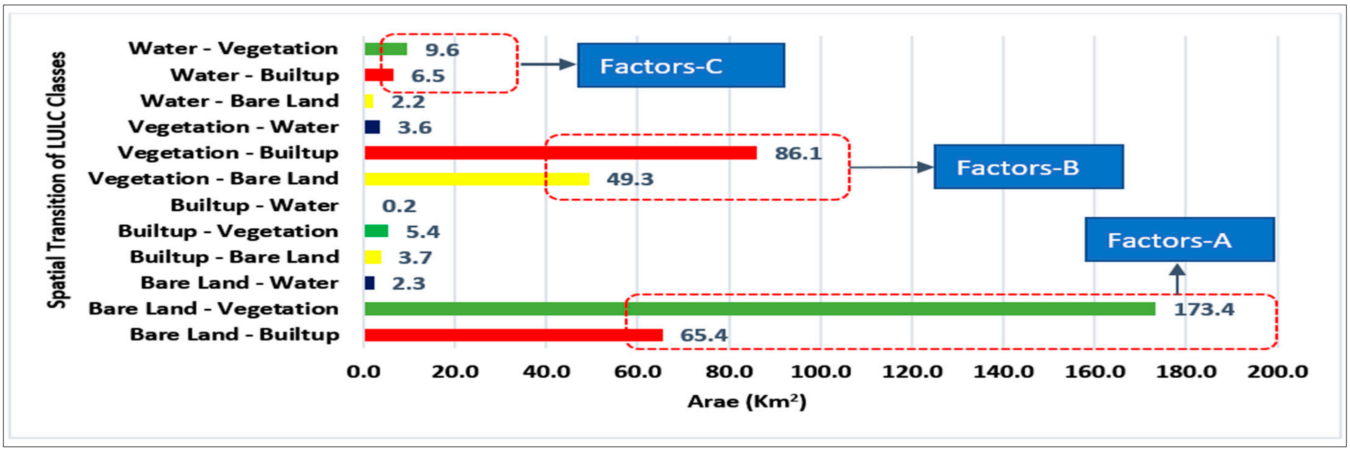

Figure 6. Change detection results from 1990 to 2021.

4.4. Correlation Analysis

A correlation analysis was performed to assess the correlation between the land use classes and total population data. The total population showed a strong positive correlation (0.98) with built-up land and a strong negative correlation with bare land (−0.90). Built-up land showed a significant negative correlation with bare land (−0.86). The correlation results are depicted in the following Table 4.

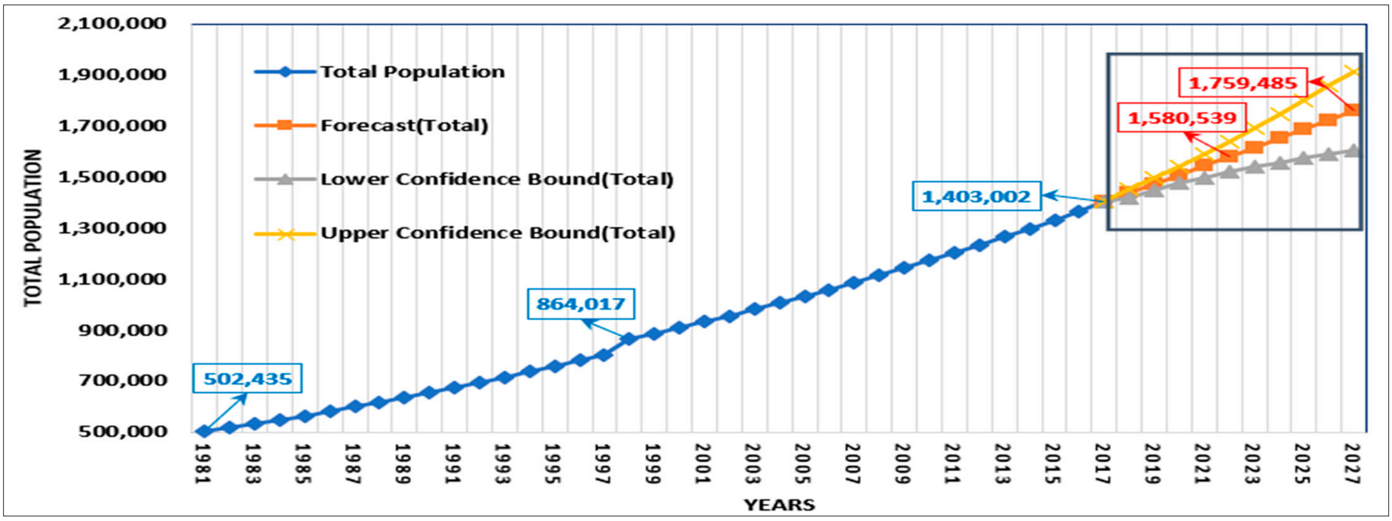

Figure 7. Population dynamics of Tehsil Mardan.

Table 4. Correlation matrix of LULC classes and population.

	Total Population	*Built-up*	*Vegetation*	*Water*	*Bare Land*
Total Population	1				
Built-up	0.982	1			
Vegetation	0.554	0.486	1		
Water	0.077	−0.096	0.537	1	
Bare Land	−0.907	−0.868	−0.851	−0.300	1

5. Conclusions and Recommendations

The current study demonstrated the LULC change dynamics by exploiting RS and GIS. This study showed that the built-up layer increased from 3.96% to 20% from 1990 to 2021. The built-up layer is increasing at the cost of bare land and vegetation cover. The main driver behind the increase in the built-up layer is population growth, infrastructure development, and the provision of the basic amenities of life in the city. Bare land decreased from 46.7% to 27%. The population of Tehsil Mardan increased from 502,435 in 1981 to 1,544,750 in 2021.

It is recommended that further research should be carried out on the impact assessment of LULC changes with respect to environmental parameters such as water quality and quantity and climatic parameters like temperature and precipitation.

The Pakistani government should formulate an approved and sustainable land use plan for current and future generations of Tehsil Mardan. An awareness campaign should be launched to raise awareness among all stakeholders regarding the negative implications of the built-up layer and consequent ecosystem degradation.

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