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Spatio-temporal analysis and trend prediction of land cover changes using markov chain model in Islamabad, Pakistan

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ABSTRACT

Rapid urbanization is changing the landscapes of urban areas and affecting the quality of life and environment. One of the most dynamic components of urban environment is land cover, which have been changing remarkably since after the industrial revolution at various scales and population growth. Frequent monitoring and land cover change detection provides a better understanding of functions and health of urban environment. Remote sensing and Geographical Information System (GIS) are advanced techniques to visualize these dynamics in the digital map. Therefore, this study aims to analyze the existing spatial extent of different land cover classes and predict the future trend in Islamabad; Capital city of Pakistan, by applying Cellular Automata (CA)-Markov model. For this aim, three consecutive-year Landsat imagery (i.e. 200, 2010, 2020) were classified using the Maximum Likelihood Classifier. From the classification, three LULC maps with four class (Barren Land, Vegetation, Water Body, built up were generated, and then change-detection analysis was executed. Using remote sensing data, we simulated Spatio-temporal dynamics of land use and land cover changes Simulation results reveal that the landscape of Islamabad city has changed considerably during the study period and the change trend is predicted to continue into 2030. The study observed a significant increase in built-up area from 2000 (9.53%) to 2020 (28.2%), followed by an increase in the cover of bare ground. On the contrary, vegetation cover declined drastically 2000 (28.61%) to 2020 (25.08%). Rapid population growth triggered by rural urban migration coupled with hasty socio-economic development post democracy are the main drivers of these changes. Under the business as usual scenario, prediction analysis for the year 2025 and 2030 show that built up area will consume almost all of the city area (47.04%) to (57.25%) with vegetation significantly reduced to patches making up only about (17.23%) to (14.4%) of the city. These findings demand for an urgent and effective planning strategies to protect the existing vegetation covers, agricultural land, and limit the growth of built-up land. The study has also potential in planning sustainable cities.

1. Introduction

Globally, the structure and function of ecosystem have been altered by different human land uses (Mishra et al., 2022). In terms of geography and economics, the main human uses of land are crop cultivation, building construction, infrastructure development, protecting natural areas, and logging (Shah et al., 2022). The spatial pattern of changes in land cover provides an insight into the factors leading to these changes (Shafiq & Mahmood, 2022). Land cover changes are mostly caused by urban expansion, particularly in emerging nations (Mohammad 2021). The primary driver of urban growth and the conversion of green space and undeveloped land into built-up land is urban population growth (Zhang et al., 2022). The The increased global urbanization is one of the biggest concerns facing the entire planet because around 55% of the world's population is urban and by 2050, this percentage is anticipated to increase to 68% (UN, 2018). Additionally, this will result in growth in the urban population, urban communities and frequency of disasters (Marando et al., 2022). There are several issues plaguing major cities as a result of the rapid urbanization of developing nations, including urban flooding, air and noise pollution, socioeconomic inequality, and political instability (Cheng et al., 2022). Rapid urban growth also jeopardises the local government's ability to give residents access to facilities like clean water, infrastructure, housing, and sewage systems (Magidi & Ahmed, 2019).

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The development of human settlements has also altered the ecosystem's composition and functionality. Additionally, the natural cover of the ground has been affected (Stalker, 2000). Cities put a pressure on resources and surrounding lands because of their fast growth (Leao et al., 2004). The use of Geographic Information System (GIS) and Remote Sensing (RS) in modeling land use land cover (LULC) is a suitable approach to understand the future pattern. Different Land cover are freely available particularly probabilistic models and multi regression approaches which includes the Cellular Automata (CA) Markov Synergy Models use to find out that how different scenarios can affect landscape changes, forecast changes and their consequences (Karimi et al., 2018). Land use change models, on the other hand, analyze the dynamics of land use in order to understand the outcomes and causes of land use changes. These models help with land use planning and policy making (Harish et al., 2017). High-quality understanding of the urban growth factors, past trends and previous studies is vital. As a typical model, the CA Automata Markov chain can determine the ratio of conversion of diverse land uses and anticipate their future development. The study of LULC changes is important in providing critical input for decision makers to manage future ecological and environmental changes (Kennedy et al. 2009).

In Pakistan urbanization tendencies have experienced rapid expansion over the past few decades, with a current rate of 3% that is the highest in South Asia. Compared to 36.4% in the 2017 census, the country's urbanization is predicted to reach 50% by 2025 (PBS, 2017).

The rapid urbanization with significant challenges particularly pressure on land, services and infrastructure (Zaman, 2012). Islamabad as Pakistan's capital attracts people from all over the country in search of job, education and better way of life. As a result, the city's population has increased dramatically in recent years and caused urban sprawl (Hassan et al., 2016). This urban sprawl has led to many urban issues like traffic congestions, land demand, water supply and sanitation, deforestation, loss of barren lands, increased street crimes etc. High levels of urbanization have been caused by the country's industrial boom, increasing economic activity, and inflow of foreign remittances from Pakistanis living abroad. Therefore, urban sustainability study is required for better urban planning, policy development for eradicating poverty, infrastructure planning, disaster management & prevention, environmental sustainability. The purpose of this study is to assess the spatio-temporal land use/land cover change detection and prediction in Islamabad, Pakistan by using CA-Markov Chain Modal.

2. Materials and Methods

2.1. The study area

Islamabad is the capital of the Islamic Republic of Pakistan, which was developed in the early 1960s when it was decided to shift the capital of the country from Karachi to Islamabad, by Field Marshal Muhammad Ayub Khan; president at that time. Islamabad is regarded as one the example of modern planning (Sohail et al., 2019). According to the 2017 census, its population was about 1.7million and it has spread over an area of 906km2 with population density is 1876 persons/km2. The topography of the study areas is Potohar Plateau ranges, with elevation range from 457 to 610 m above mean sea level (Shah et al., 2022). The Specified Green Area covers an additional 3626 km2, with the Margalla Hills to the north and northeast. According to the United Nations World Urbanization Prospects (2018), the population was 1.095million in 2018 and projected population 1.67million by 2030. The Capital Territory comprises of urban and rural areas. The rural consists of 23 union councils (UC: smallest electoral unit), 133 villages while urban has 27 UCs (Figure 1). The city is characterized by a grid pattern which divides the city into eight basic zones viz., administrative, diplomatic enclave, residential areas, educational sectors, industrial sectors, commercial areas, rural and green areas, along with protected green belts (Ali et al., 2014).

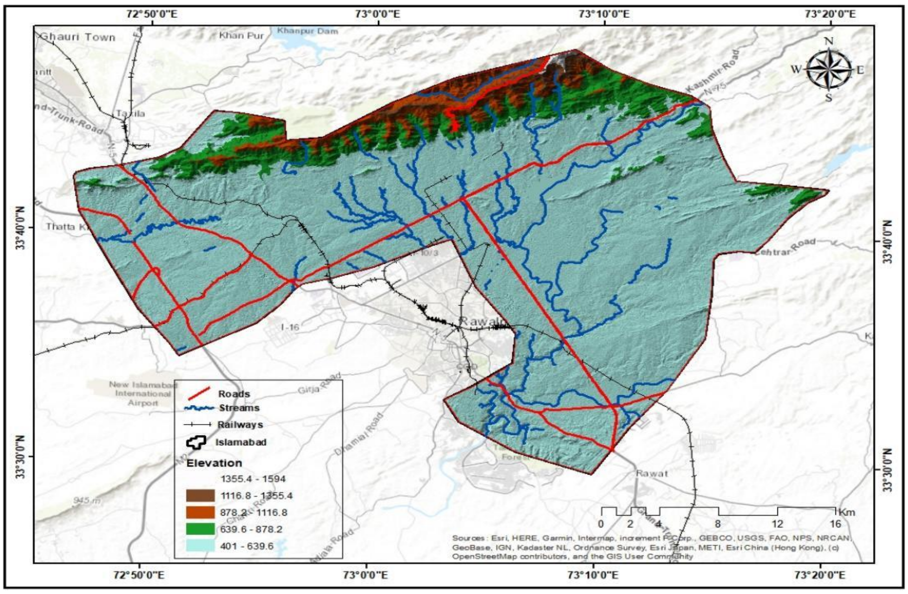

Figure 1. Location of the study area

2.2. Research methodology

The study is based on secondary data. Landsat satellite images for the years 2000, 2010 and 2020, and ASTER Global Digital elevation model (GDEM) bothhaving 30m spatial resolution were downloaded from United States Geological Survey (USGS) open source geo-database (Figure 2).

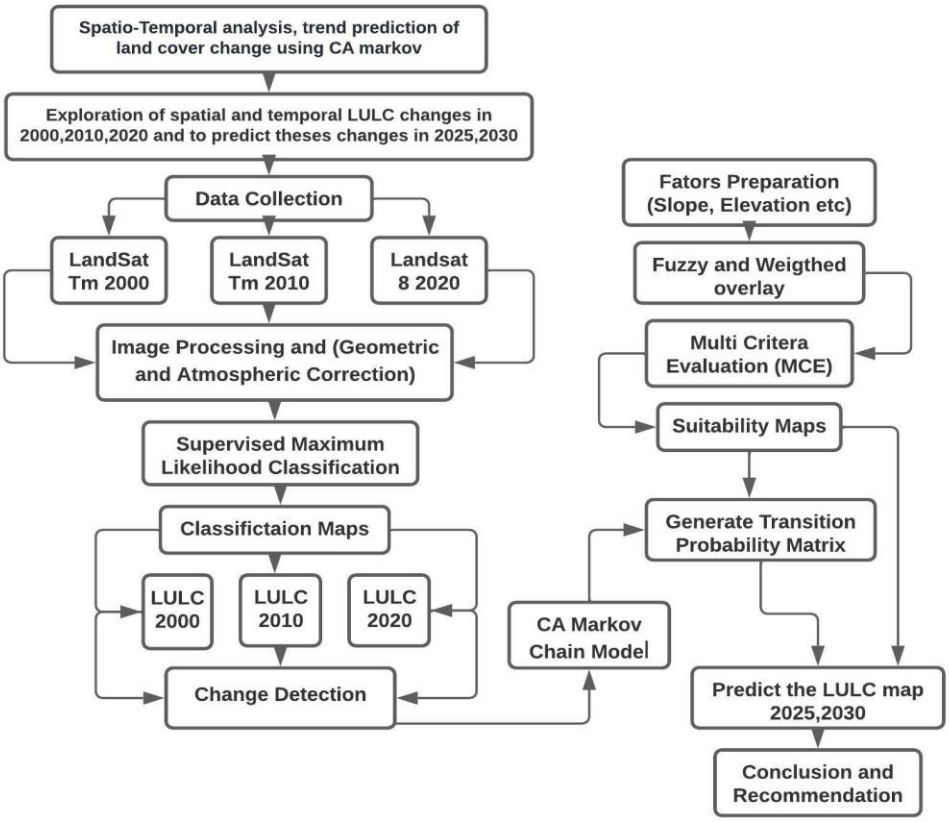

Figure 2. Research process

2.3. Data acquisition and pre processing

Pre-processing is a crucial step in determining a direct link between the collected data and biophysical phenomena. The remotely sensed data is subject to brightness, geometric, and atmospheric aberrations. When optical sensor data is processed then one of the main functions of pre-processing is removal of aberrations. Atmospheric correction involves removal of haze primarily originating from water vapor, fog, dust, smoke, or other particles in the atmosphere. The satellite images were then imported into ArcGIS environment to classify image

2.4. Supervised image classification

Satellite images were classified using the Maximum Likelihood Classifier (MLC) technique. The MLC classifier was employed since it is a reliable and widely used algorithm for LULC mapping. The probability density distribution functions for each particular land use class are prepared using a parametric statistical technique in the MLC procedure. MLC is considered to be more accurate than other methods because it calculates the total amount of variance and the correlation of the spectral values of different bands according to the specimen and uses this property for the association of pixels classified into one of the groups based on the pixels' most similarity. LULC maps were identified on the basis of four classes in Table 1.

Table 1. LULC Classes

No	LULC Class	Description
1	Built-Up Area	Residential, commercial, industrial, transportation, roads
2	Green Cover	Mixed forest lands, Crop fields and fallow lands
3	Barren Land	Land use exposed to soil
4	Water Body	River, open water, lakes, ponds, and reservoirs

2.5. Land cover trend prediction

For simulating and forecasting LULC, CA-Markov is a robust model that has outperformed previous techniques. As a result, the CA-Markov model was chosen for simulating and forecasting. This approach entailed Markovian chain analysis in order to construct transition area matrices and producing LULC transitional area maps. Each LULC class's transition appropriateness maps were created utilizing four input parameters namely elevation, slope, distance from streams and distance from roads. GDEM with 30m spatial resolution was used to extract elevation, slope and drainage input spatial layers. The distances from roads and streams are significant. The Euclidean Distance Technique was used to compute the distances from roadways and drainage.

The road network (2000-2020) was geo-visualized using heads-up digitizing from time-series Landsat imagery (Figure 10).

2.6. Markov chain analysis

The possibility of the proper positions (pixels) of the four factors having an effect on the LULC classes was evaluated using a fuzzy set function. Visual analysis was used to analyze the effect of each element by overlaying the urban cover and each factor separately, and once satisfied, the values of each factor were changed based on the present condition of urban expansion. The MCE technique was used on the factors that were chosen. MCE combines a number of criteria (factors) to determine the most appropriate locations (pixels) for each land cover type. The four parameters (elevation, slope, distance from roads, and distance from streams) were examined to construct the suitability map for the urban class. In order to anticipate future change, the Markov model simulated changes in LULC from one time to the next. The Markov chain model analyses and summarizes changes in land use over time by transitioning areas from one status to another using a set of probabilities. Furthermore, the probabilities transition areas may be utilized to anticipate and uncover possible future scenarios of land use change and urban growth patterns. The prediction of future land use changes can be calculated based on conditional probability formula by using Eq.1

$$S(t+1) = P_{ij} * S(t) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

Where $S(t)$ is the state of the system at time $t, S(t+1)$ is the state of the system at time$(t+1)$; P_{ij} is the matrix of transition probability in a state Low transition will have a probability near (0) and high transition probability near. The 2000 LULC image of the Islamabad city was used as the base (t1) image while 2020 LULC map as the later (t2) image in this model to obtain the transition matrix between 2000 and 2020. In this study, ArcGIS was used to generate transitional area matrices by multiplying each column in the transition probability matrix by the number of pixels of corresponding class in the later image.

2.7. Accuracy Assessment

Classification accuracy assessment is critical to obtain reliable results and its impacts. Hence, a total of 929 systematic points is generated at a fixed distance of 1 × 1 km throughout the study area, as given in Figure 1. Among them, approximately 10 10 points were checked in the image Vegetation, build-up, water bodies, barren land etc. using the global positioning system (Stonex S-7), while the remote locations are validated from high-resolution satellite images. User accuracy and producer accuracy are calculated for each land-cover class; the overall accuracy of classification exceeds (i.e., those for 2000, 2010 are 93.19% and 94.87% and 2020 are 92.17% with Kappa coefficients of 0.89 and 0.91 and 0.87 respectively), which meet the requirement of the study (Table 2).

Table 2. Accuracy assessment

LULC Class	2000%	2010%	2020%
Barren Land	87.3	88.5	88.9
Green Cover	89.3	90.2	88.3
Built-Up Area	92.3	93.1	90.1
Water Body	95.8	97.1	98.2
Overall accuracy (%)	93.19	94.87	92.17
Kappa coefficient	0.89	0.91	0.87

3. Results and Discussion

3.1. Land Cover (2000)

A classified image of Islamabad taken in the year 2000 figure 3. It depicts that Barrens cover a large region. Barren Land covers 519.8 land area, which is the most among the other groups. Vegetation covers 241.9 sq. km, built-up area is 80.5 sq. km, and water bodies cover only 2.94 sq. km of the land area figure 6.

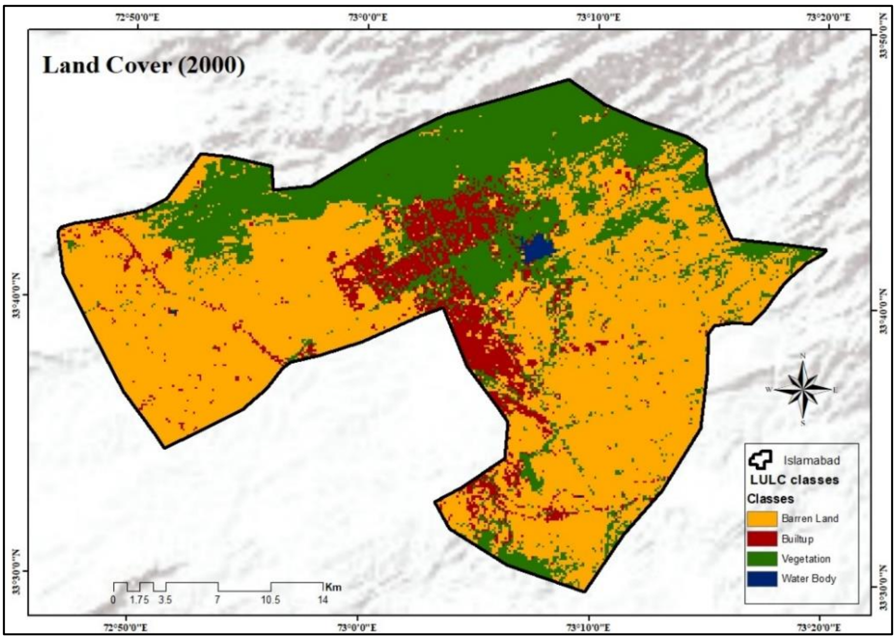

Figure 3. Land Cover 2000

3.2. Land Cover (2010)

The categorized map of Islamabad for the year 2010 is shown in Figure 4. The graph depicts a massive increase in built-up area. The year 2010 can be remembered as a year in which the urban city's growth caught up with the rest of the world. According to the image classification results, the area covered by barren land was 478.1 sq. km, the largest among the other classes, such as green cover, which covered about 202.5 sq. km of area. The built-up area was 19% covered an area 162.29 sq. km, while the water body covered the bare requirement of 0.58% and area of about 2.38 sq. km. The data in the pie chart Figure 6 provides a visual representation of the area of LULC in each class in 2010.

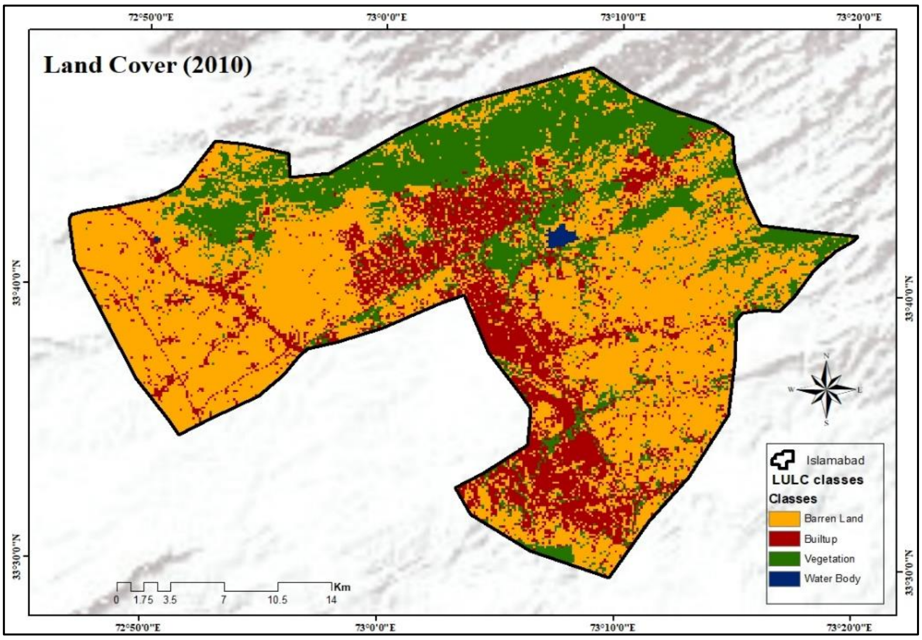

Figure 4. Land Cover 2010

3.3. Land Cover (2020)

The result depicts a classified map of Islamabad in the year 2020 figure 5, clearly demonstrating the largest change in the built-up area. The results of image classification show that the area covered by built up is 238.4 sq. km, which is the greatest among the other classes, such as green covered at 212.02 sq. km, barren land area 389.1 sq. km, and water body covered 5.82 sq. km of area figure 5.

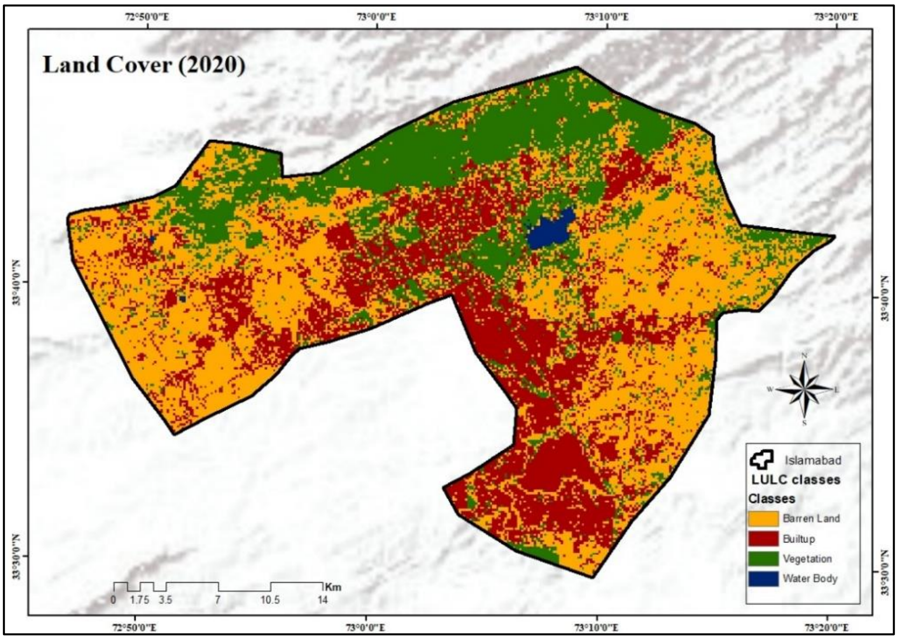

Figure 5. Land Cover 2020

Comparative Analysis (Change Detection)

The LC in Islamabad was compared using a change detection map, which consisted of categorized photos of the city and was used to extract information about dynamic changes in the city from 2000 to 2010 and from 2010 to 2020, as shown in Figure 6. A comparison of three years (2000, 2010 and 2020) (figure 6) revealed dramatic changes in built-up area, which expanded due to newly constructed housing.

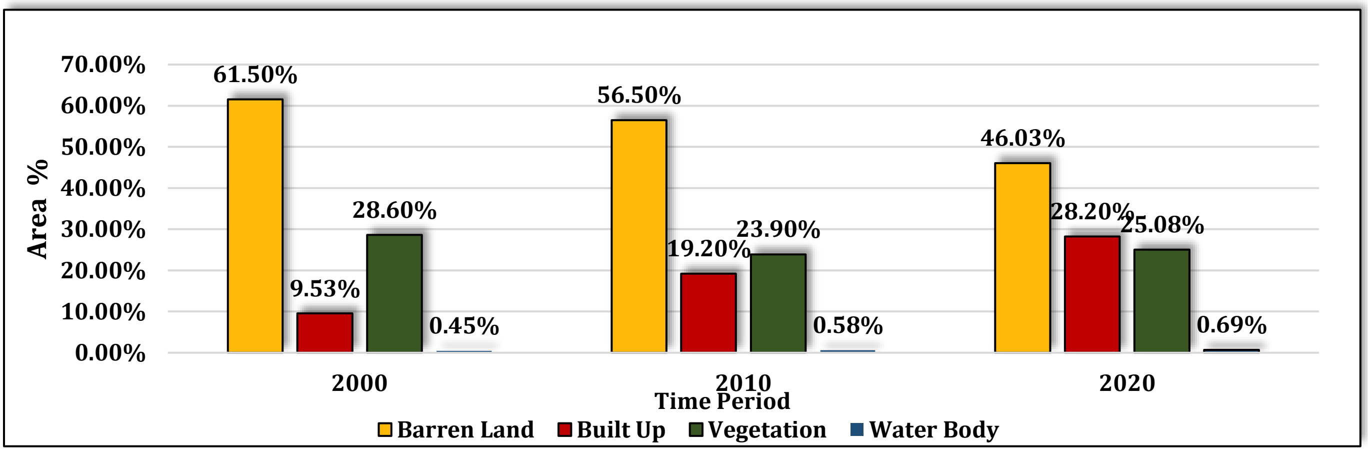

Figure 6. LULC Change detection (2000-2020)

Due to enhanced chances and facilities, as well as increased population density, infrastructure is being created in the center and western parts of Islamabad. Barren land has declined by around 36% in 10 years, primarily from 2010 to 2020, with the most significant shift being the transition of most barren ground into built-up regions, which has continued to increase. Vegetation cover was reduced in this study, it has decreased by 25% in the last 10 years, from 2000 to 2020, according to this study (Table 3).

Table 3. Analysis of LULC change

No	Classes	Year 2000		Year 2010		Year 2020	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
1	Barren Land	519.8	61.5%	478.11	56.5%	389.1	46.03%
2	Green Cover	80.59	9.53%	162.29	19.2%	238.4	28.2%
3	Built-Up Area	241.9	28.6%	202.55	23.9%	212.02	25.08%
4	Water Body	2.94	0.45%	2.38	0.58%	5.82	0.69%

3.4. Transition Suitability Maps (Factor Maps)

Each LC class's transition appropriateness maps were created utilizing four variables or parameters. Elevation, slope, distance from streams, distance from roadways was all considered Below Figure 7 (a, b, c, d) showing the factor maps.

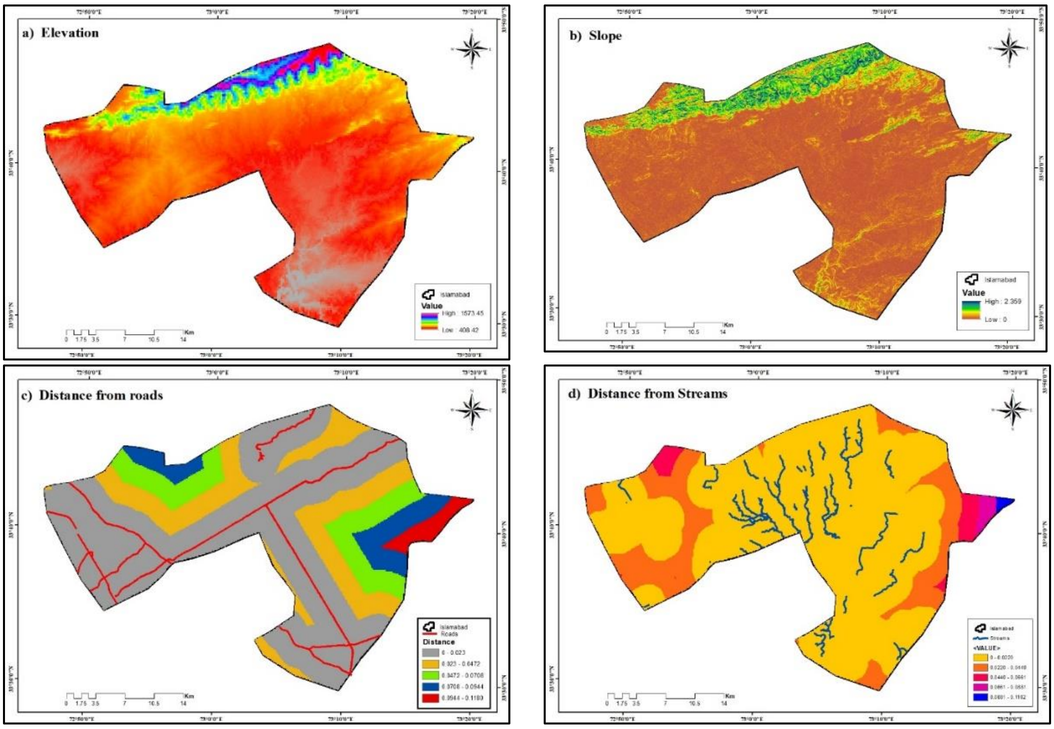

Figure 7. Suitability Maps

3.5. Prediction of land cover change (2025 and 2030)

Results of LC prediction using CA-Markov analysis are shown in Table 4 and comparison between the base years (2000, 2010, and 2020) and predicted years has been shown in Figure 8.

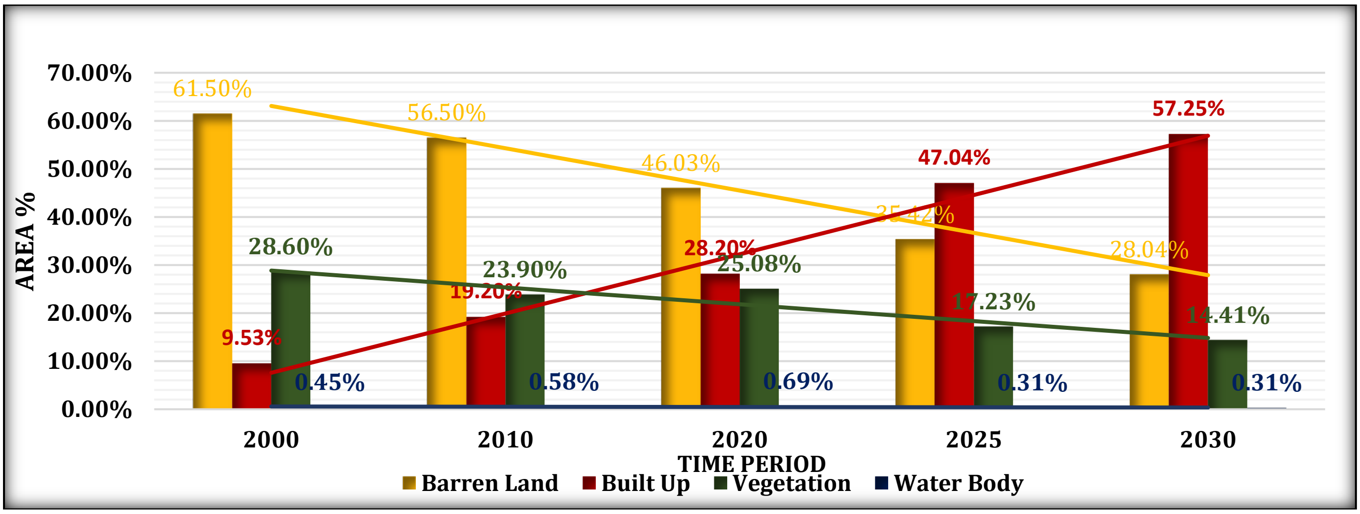

Figure 8. Predicted analysis comparisons

Figure 9 predicted figure for 2025 and 2030 is showing further decrease in the vegetation cover (17.23%) and (14.41%) water body (0.31%) land use types which compared to 2000, 2010, 2020 figures represent a loss of vegetation respectively (Table 4). These losses are gained by built-up area 2025 of (47.04%) and of 2030 (57.25%) bare ground (35.42%) and (28.04%) taking their total coverage to (298.48) and (236.59) area sq km respectively.

Table 4. Land Cover Prediction

No	Classes	Year 2025		Year 2030	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)
1	Barren Land	298.48	35.42%	236.59	28.04%
2	Green Cover	396.38	47.04%	483.06	57.25%
3	Built-Up Area	145.22	17.23%	121.55	14.41%
4	Water Body	2.61	0.31%	2.6	0.31%

Figure 9 shows the predicted spatial destruction of LC in 2025 and 2030. Overall, Vegetation cover is fragmented with smaller patches remaining mainly in the north of the city along the Margalla hills. Small and narrow patches of forests are also seen scattered across the city figure 9 also reconfirm the findings that most of what is covered by forest in 2000, 2010, 2020 will transition into built-up and bare ground. The presence of bare ground indicates soil excavations probably. These findings are reflective of the current urbanization trend and government policy. If Islamabad city is to avoid irreversible problems that are plaguing many global cities, the city must shift form present business model to urgently adopt ecosystem based approach to urban development.

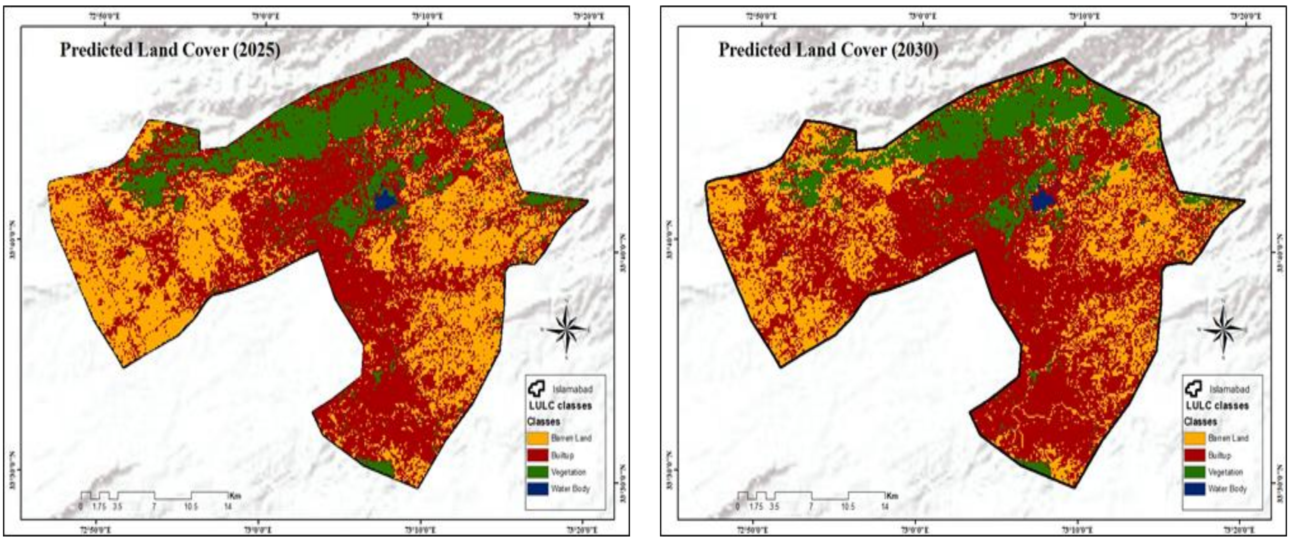

Figure 9. Predicted Land Cover 2025 and 2030

4. Discussion

The increase in population growth further augment the rate LULC changes especially in the metropolitan cities of the world that are threatening the sustainability of these cities. Islamabad is planned as a linear metropolis with straight sections and crossing roadways, according to the master plan. Each residential sector is characterized by an alphabet letter and a number and spans an area of around 906.50 km. It indicates that the city is designed for the present while also considering the future development.

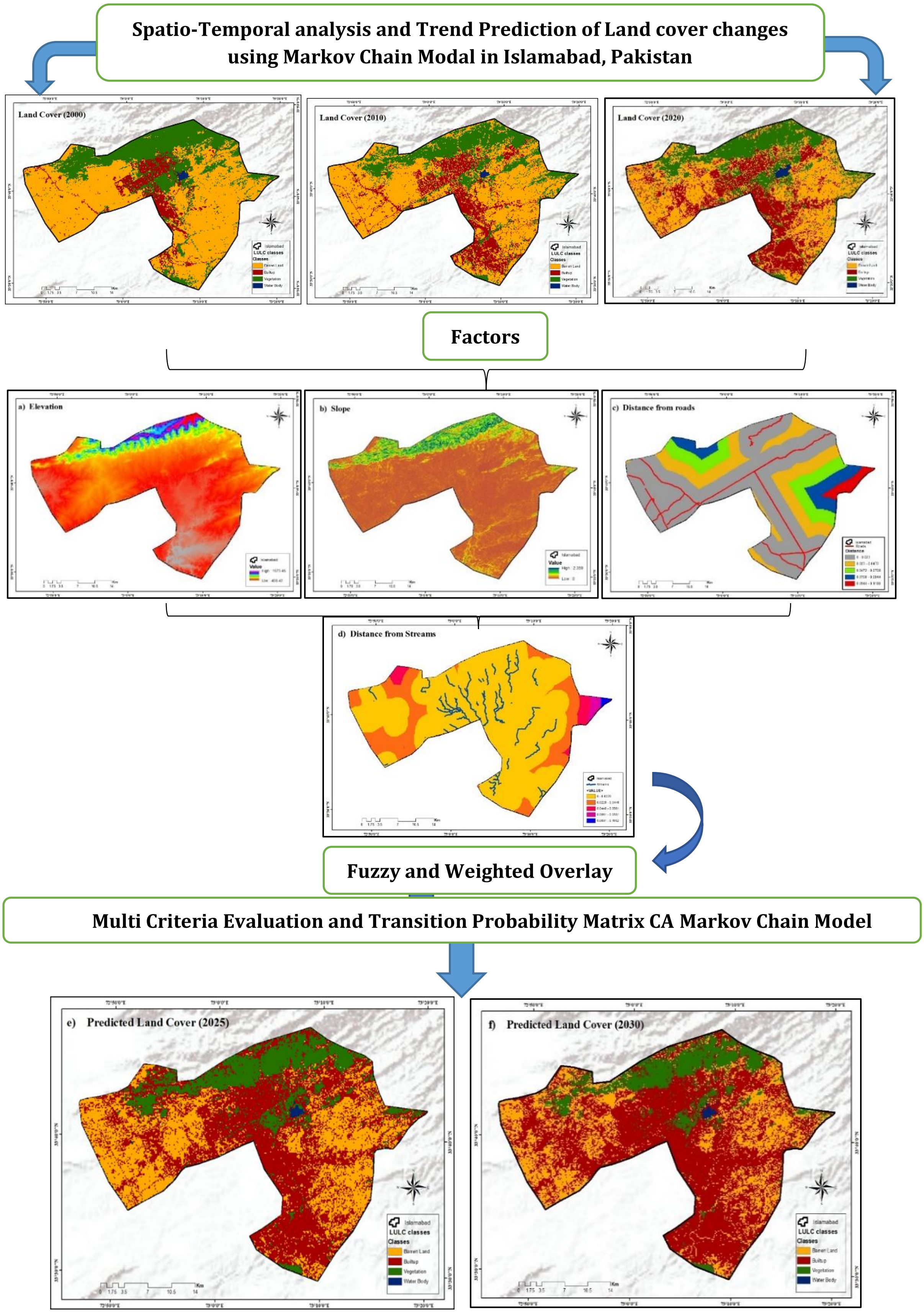

Figure 10. The method used in trend prediction of land cover changes

However, above results of LU analysis, the city landscape has altered with LULC changes, affecting the city thermal climate from 2000 to 2020. The study emphasizes on the Land cover change and its future behavior by showing the increase in built up areas by 9.53% to 51.8% annually, the expansion of built up mainly occurred in central part of the city, whereas the vegetation decreased by 28.6% to 25.08% from the years 2000-2020. Based on results derived from the LULC change map, the vegetation cover is replaced by grass land, Such LULC changes bring differences in surface energy impervious surfaces has increased the surface temperature due to the transformation of high to low evaporative surfaces.

Comparing the above mentioned graphical results it is evidenced that the agricultural land is converting into barren land and residential land in the city. This barren land is transforming into commercial or industrial land. The technology is being used. Remote Sensing and Geographic Information System are playing their vital roles in the detection and assessment of the land use land cover changes. In the previous studies Chim (2021) applied the Multi-layer perceptron neural Network-Markov chain (MLPNN-MC) to assess the land use and climate change on hydrology of the upper Siem Reap River. Kundu et al. (2017) assessed the LU change impact on sub-watersheds prioritization by analytical hierarchy process (AHP). Logistic regression model (LRM) has been applied by Muhammad Salem in 2020 to assess the Land use/land cover change detection and urban sprawl in the peri-urban area of greater Cairo since the Egyptian revolution of 2011. This study has predicted Land cover changes in 2025 and 2030 showing the shrink in vegetation 17.23% to 14.41% and water areas by 0.31% which is devastating for the environmental behavior of the city. The built up showed is increasing about 47.04% to 57.25%. It is observed that urban growth is very fast and eating up not only barren lands but also very fertile agricultural lands. In addition these land cover maps and predicted results which are produced by remote sensing techniques and CA Markov model of class definition, meet the growing need of legend standardization.

The output of this study is invaluable for Government, environmental scientists, conservation biologists, nature-related NGOs, decision-makers, and urban planners to protect the existing vegetation covers, agricultural land, and limit the growth of built-up land. The prediction has potential to assist the local management authorities and planners to control the urban expansion in built up environment because the question arises, Are the residents and authorities prepared to face the consequences of urban growth? The predicted space of urban growth is precisely engulfing the natural vegetation that is posing risk on natural environment. These future analysis studies can help to use more detailed socio-environmental variables to improve the understanding of the causes, locations, and trends of land cover changes in such regions. Understanding how the changes in the landscape and climate change might influence the distribution of the important species will help guide conservation planning in the area. The study can serve as guidelines for other studies attempt to project LC change in arid lands areas experiencing similar land use changes. Urbanization in Pakistan is increasing at 3% annually, the highest in South Asia. 50% of the population is expected to urbanize by 2025. The capital city of Pakistan, Islamabad has experienced phenomenal increase in the urban population and extent in the last four decades (Shah et al., 2022).

5. Conclusion

Existing land cover trend and predicting future trend is very important for sustainable land use planning and management. In the last two decades significant change in LULC has been occurred. The built-up land is continuously increasing by engulfing the green cover. The results shown of the 2025 and 2030 estimate vegetation cove will further decreased by 17.23% in 2025 and 14.4% in 2030. The loss of forest cover will weaken essential ecological functions and make the city more vulnerable to gulley erosion, drying water supplies, increase in temperature, exacerbated air pollution, and loss of biodiversity.

It is highly recommended to bane construction on agriculture land and forest cover. Second vertical development must be encouraged and horizontal expansion should be discouraged.

Author Contributions

The contributions of the Authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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