

## **PREDICTION OF LAND USE DYNAMICS IN DHAKA CITY USING REMOTE SENSING AND CA-ANN MODELING**

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### **ABSTRACT**

Land use and land cover (LULC) change analysis is a crucial tool for evaluating environmental degradation and guiding sustainable urban development. Understanding historical LULC transitions and projecting future trends help shape effective land use policies. Dhaka City, the capital of Bangladesh, has experienced rapid urban expansion in recent years due to population growth, migration, and infrastructural development. These pressures have led to significant changes in LULC, driven by both natural and anthropogenic factors. This study analyzes the LULC dynamics of Dhaka City between 2017 and 2023 and predicts future LULC patterns for the years 2026 and 2030 using the Cellular Automata–Artificial Neural Network (CA-ANN) model. Sentinel-2 satellite imagery was used, and the data were pre-processed and reclassified. Accuracy assessment of the reclassified maps was performed through visual validation using Google Earth Pro. The findings reveal notable LULC changes between 2017 and 2023. Water bodies and forest cover decreased by 50.08% and 58.60%, respectively, while agricultural land and built-up areas increased by 8.33% and 9.76%. Bare land declined significantly by 52.93%, primarily due to urban expansion and conversion to agricultural or built-up uses. Based on the CA-ANN model, projections for 2026 and 2030 indicate continued trends: by 2030, forest cover may decrease by 81.69%, agricultural land by 20.95%, and bare land by 85.39% compared to 2023. Conversely, built-up areas are projected to grow by 4.25%, with a marginal increase in water bodies by 0.26%. These results suggest accelerating urbanization and the ongoing loss of ecological and agricultural spaces in Dhaka City. If current trends persist, the city's land use structure may become increasingly dominated by built-up areas, leading to challenges in environmental sustainability, urban livability, and resource management. The study emphasizes the urgent need for integrated land use planning and evidence-based policy interventions to ensure balanced and resilient urban growth.

**Keywords:** *Land Use Change; Dhaka City; Cellular Automata–Artificial Neural Network (CA-ANN); Urban Expansion; Sentinel-2 Imagery;*

## **1. INTRODUCTION**

Land use refers to the various ways in which humans utilize land, such as for agriculture, housing, industry, and infrastructure development, whereas land cover describes the physical features on Earth's surface, including vegetation, water bodies, and bare soil (Ahmad et al., 2023). The alterations of land use and land cover (LULC) have become a major environmental concern on the planet, as they can have far-reaching effects on ecological soundness, environmentally sustainable development, and socio-economic growth (Das et al., 2025). Increased urbanization due to population increase and economic development has radically changed the LULC patterns around the globe (Halmy et al., 2015; Zheng et al., 2015).

The effective land management and spatial planning at the regional and national levels require understanding of LULC change processes and their drivers (Gaur and Singh, 2023). Both biophysical (topography, soil properties, and climate) and anthropogenic forces determine these dynamics (Bajocco et al., 2016). Urbanization in Bangladesh has been more dramatic in Dhaka the administrative and economic centre of the country. The consequences of fast population growth and rural-urban migration in the last several decades have led to a large portion of urban development being unplanned and, thus causing agricultural fields and wetlands to be converted into urban centers. This change has led to the degradation of the environment, green cover, and fragmentation of habitats (Morshed et al., 2017; Kocur-Bera and Pszenny, 2020; Mao et al., 2018).

Therefore, detecting and monitoring changes in LULC require advanced techniques that involve the use of remote sensing and image classification. Over the past few years, the use of machine learning as classifiers has become more prominent as they are more accurate and capable of working with complex features on the land surface (Talukdar et al., 2020). Such strategies combine a vast variety of both supervised and unsupervised algorithms and have been gradually combined with predictive models to model future LULC conditions and assist in informed decision-making and sustainable land management (Myint et al., 2024).

Many researchers used various models such as Markov Chain Analysis (MCA), Cellular Automata (CA), CA-Markov, Artificial Neural Networks (ANNs), the SLEUTH model, binary logistic regression, and fractal models for predicting LULC (Land Use and Land Cover) changes (Hossein et al., 2023; Islam & Ahmed, 2011; Kafy et al., 2021; Nteranya et al., 2024; Rahman & Rahman, 2023). Past research on Dhaka City mainly used medium-resolution Landsat satellite data, which has limited the ability to record the fine spatial heterogeneity of dense and fast changing urban settings. Conversely, Sentinel-2 imagery, which has a higher spatial resolution (10 m) and also better spectral information permits a more accurate apprehension of complicated urban landscapes. In addition, the CA-ANN model addresses non-linear changes in land use and neighbourhood effects well.

In this background, the current study will utilize Sentinel-2 images to predict the LULC of Dhaka city using a CA-ANN model. This study analyzes the Land Use and Land Cover (LULC) dynamics of Dhaka City between 2017 and 2023 and predicts future LULC trends for the years 2026 and 2030 using the Cellular Automata–Artificial Neural Network (CA-ANN) model.

## **2. METHODOLOGY**

### **2.1 Study area**

Dhaka is the capital of the People's Republic of Bangladesh, Several official and diplomatic institutions are located in Dhaka, which serves as the hub for all of the nation's development initiatives. The watershed region taken into consideration in this study includes the city of Dhaka and its environs, and is located between latitude 23°45'34.56" North and longitude 90°22'44.40" East (<https://wiki.openstreetmap.org/wiki/Dhaka>). The Buriganga river on the southwest, the Turag river on the northwest, the Balu river on the northeast, and the Shitalakshya river on the south all

encircle the larger city of Dhaka. The districts of Gazipur, Tangail, Munshiganj, Rajbari, Narayanganj, and Manikganj surround the Dhaka area. Dhaka has 34,000 citizens per square kilometer(<https://en.wikipedia.org/wiki/Dhaka>), making it one of the world's most densely populated megacities.

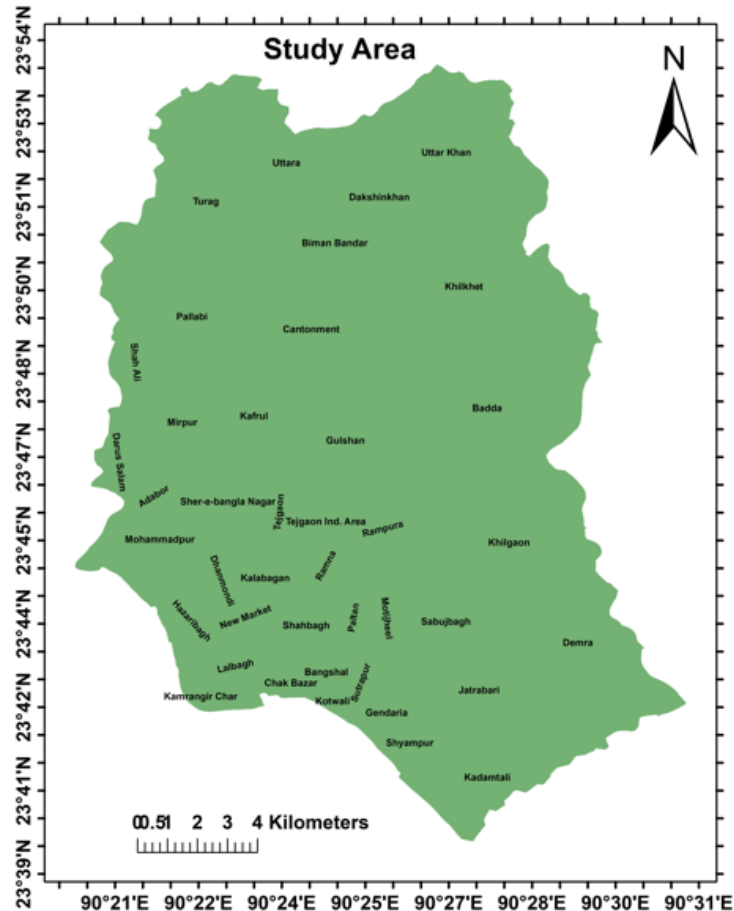


Figure 1: Study Area(Dhaka City)

## 2.2 Data Collection

This study employed Sentinel-2 Global Land Use/Land Cover (LULC) data from Esri, covering the period from 2017 to 2023, to examine land cover dynamics across Bangladesh. Topographic parameters, including slope and aspect, were derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) at a 30 m resolution, acquired from the United States Geological Survey (USGS).

## 2.3 CA-ANN Model Framework

The CA-ANN model was applied to the MOLUSCE in QGIS to simulate and predict LULC dynamics. The transition probabilities were obtained based on the observed changes in LULC in 2017-2020 and 2020-2023. ANN component estimated transition potential maps relying on determinant factors, such as DEM, slope, aspect, and distance to roads. The Cellular Automata (CA) component was used to enforce spatial transition rules and took into consideration the influence of the neighborhood factors and considered the importance of land-use contiguity. Training was done on the

model by using randomly chosen sample pixels of the change and persistence classes. The simulation LULC map 2023 was further taken and compared with the real map and then a prediction of future LULC patterns in 2026 and 2030 was performed. The overall methodology is shown in Figure 2.

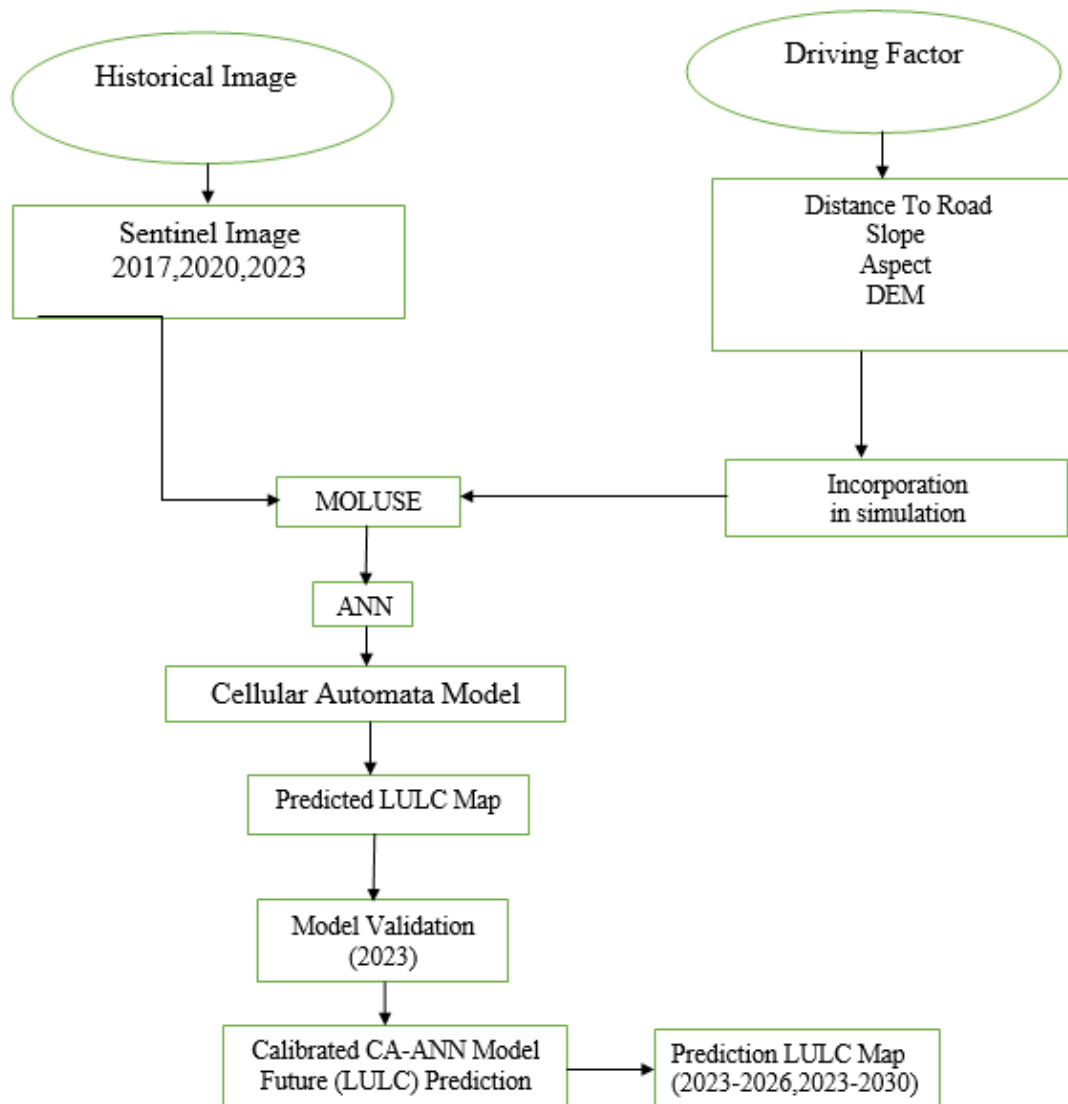


Figure 2: General flowchart of LULC change monitoring and prediction using the CA-ANN transition probability model.

#### 2.4 Accuracy assessment of Sentinel-2 image

The Land Use and Land Cover (LULC) maps, generated from pre-processed Sentinel-2 imagery using Google Earth Engine, exhibited high temporal reliability. Five major land cover classes—Water, Forest, Agriculture Area, Built-up Area, Bare Ground—were accurately mapped. The Overall Classification Accuracy was 92% in 2017, 86% in 2020, and 88% in 2023, with corresponding Kappa Statistics of 0.88, 0.78, and 0.82, respectively, indicating a precise representation of land surface dynamics over time.

### 3. RESULTS

The validation shows a very good agreement between the predicted and reference data. The predicted map achieved overall classification accuracy 89.88%. The overall Kappa coefficient was 0.697. Class-specific agreement was strong, with Kappa (state) = 0.953, while Kappa (location) = 0.728 indicates good spatial agreement in class allocation.

Table 1: Summary of LULC Change Trends

Period	Water Area	Forest	Agricultural	Built-Up Area	Bare Land
2017–2020	-28.90%	-45.33%	+14.65%	+5.32%	-59.00%
2020–2023	-30.00%	-24.00%	-5.31%	+4.36%	-16.45%
2023–2026*	-20.71%	-52.81%	+5.97%	+1.46%	-5.00%
2023–2030*	+0.27%	-81.69%	-20.95%	+4.25%	-85.39%

The analysis has shown that the changes in land use and land cover (LULC) in Dhaka City were significant and sustained within the 2017-2023 range (Figure 3; Table 1). In the period between 2017 and 2020, the natural land cover decreased significantly. The water bodies decreased by 28.90% and the forest cover decreased by 45.33%. On the other hand, there was an agricultural land growth of 14.65%, which implies short run land changes in land use. Another growth that was noted in the urban area was of 5.32% in the built-up areas. It was too high in bare land loss at 59.00%. The trends carried on into the period 2020-2023. Water bodies and the quantity of forests also decreased by 30.00% and 24.00% respectively. The agricultural lands reduced by 5.31% as compared to the previous years implying that there was urbanization pressure on the agricultural lands. The increase in the built-up areas was preceded by 4.36% and the decrease in bare land by 16.45%.

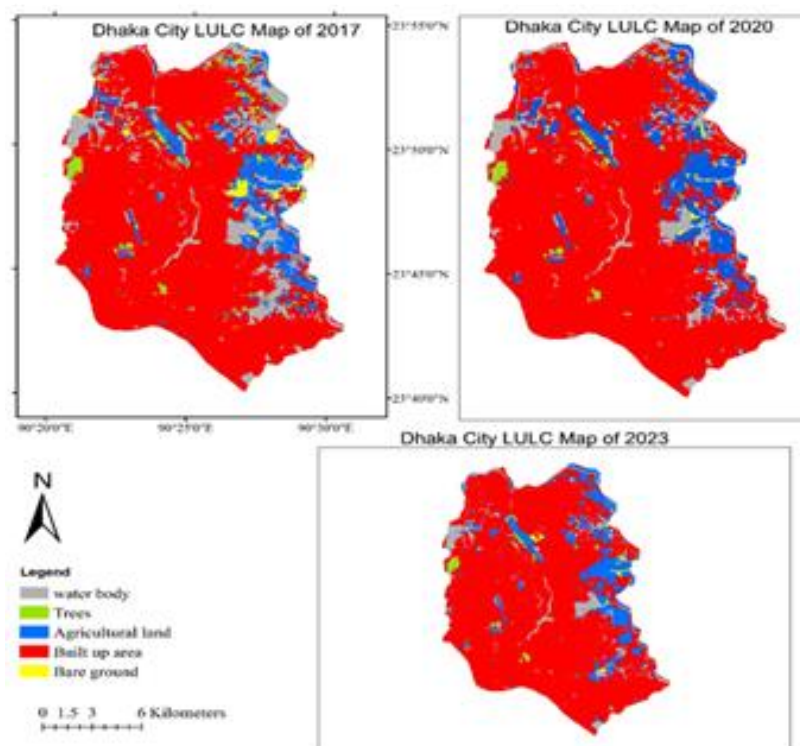


Figure 3: Historical Observations LULC map for the years 2017, 2020 and 2023

The predicted changes in land use and land cover (LULC) based on the Cellular Automata-Artificial Neural Network (CA-ANN) simulation of the timeframes 2023-2026 and 2023-2030 are presented in Figure 4 and Table 1. For the period 2023-2026, the water bodies will decline by 20.71%, and, on the other hand, the forest cover will decline considerably by 52.81%. Land under agriculture is expected to grow by 5.97% and land under built-up area is expected to grow by 1.46%. It is projected that bare land will reduce by 5.00 percent within this period. In the longer-term forecast (2023-2030), greater changes will be expected. The forest cover will experience a significant reduction of 81.69%, which is the highest change of all the land cover classes. The agricultural land and bare land are projected to decrease by 20.95% and 85.39%, respectively. On the contrary, the growth in built-up areas will be 4.25% with a slight growth of 0.27% in water bodies.

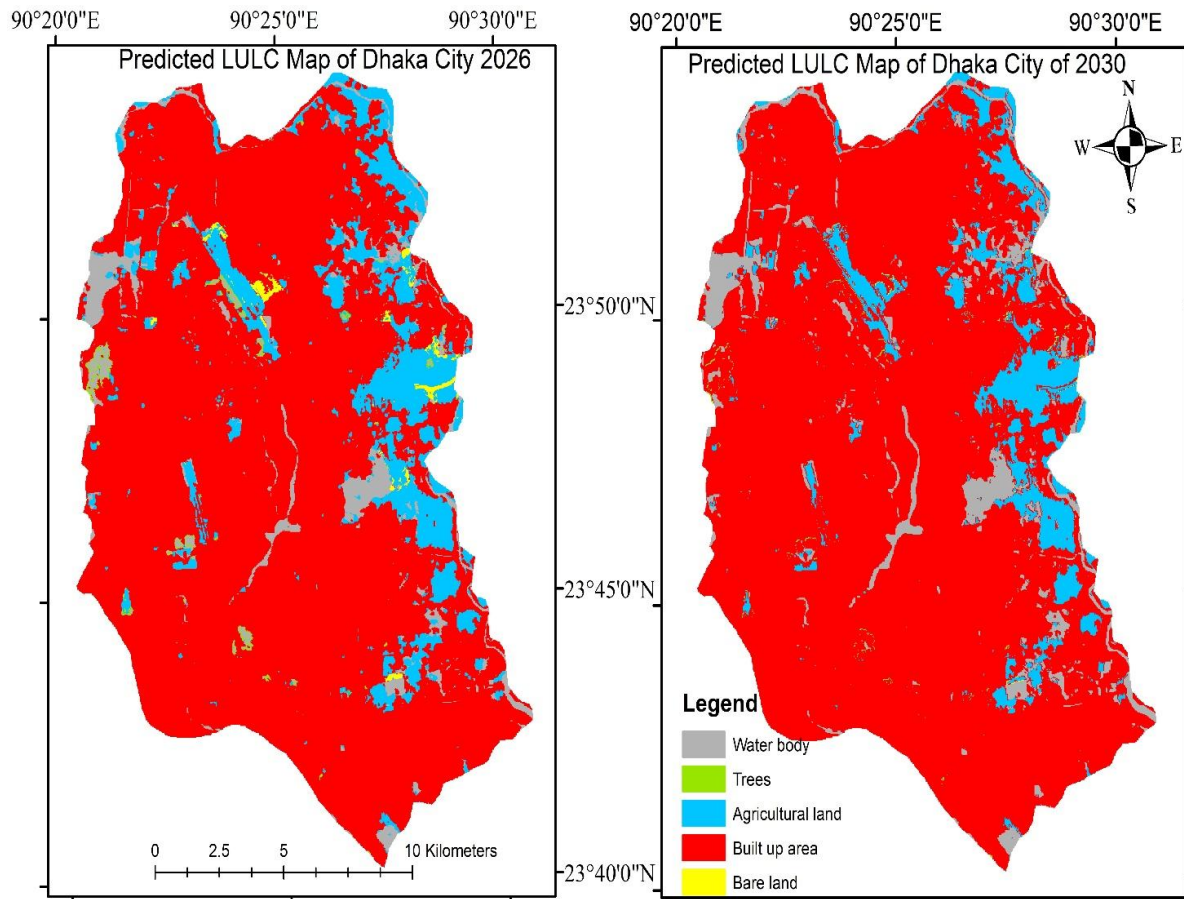


Figure 4: Predicted LULC from CA-ANN simulation for the years 2026 and 2030

### 3.1 DISCUSSION

The accuracy of the predicted LULC results is verified by the fact that the CA-ANN model has high performance and reached the overall classification accuracy of 89.88, which is much higher than the generally accepted minimum threshold of 70% (Osman et al., 2023). Despite the model being a good reflection of long-term spatial trends, there are uncertainties associated with the possibility of classification errors and possible future policy interventions.

The analysis of Land Use and Land Cover (LULC) in Dhaka City reveals that the urban environment has experienced a very quick and mostly unsustainable change in the last several decades. The observed period (2017-2023) and the predicted period (2023-2030) are highlighted by a high burden of natural land and open spaces under the influence of the increase in population, economic growth, and the development of infrastructures. This has led to the unplanned urban sprawl and significant

alterations in land use patterns in the city. The identified and predicted trends indicate that the main determinant of urban transformation is the growing pressure on the natural environment, poor land management, and the lack of effective enforcement of urban planning regulations, which align with the findings of other studies (Hosseini et al., 2023; Rahman, 2022; Rahman and Szabo, 2021). There is a clear difference between the two periods of history. Dhaka had experienced a rapid urban growth between 2017 and 2020, with huge losses of forest cover, water bodies and bare land, leading to gains in agricultural land and built-up area. Conversely, 2020-2023 period reflects the tendency toward urban consolidation, with the further growth of built-up areas, additional decay of agricultural lands, and the decline of the availability of vacant land, according to (Moniruzzaman et al., 2020) indicate that the increased rate of urban densification and land use change in recent years. Comparison of the actual (2017- 2023) and projected (2023-2030) changes in LULC reveals that the current trends are still persisting and growing. In the short term (2023-2026) indicate that significant losses in forest cover and water bodies, whereas in the long-term (2023-2030) show that forests and bare land will be practically completely lost and the built-up areas will continue their growth. These developments are manifestations of the shift of horizontal urban sprawl to intensive urban densification.

From a policy and sustainable development perspective, these trends have been an extreme challenge to the long term urban sustainability of Dhaka City. Further loss of forests and wetlands enhances the risk of flooding, intensifies the urban heat island effect and leads to additional environmental degradation. It is important to highlight that the planned preponderance of naturally built-up areas in 2030 is the reason why integrated land-use planning, rigid adherence to zoning laws, and conservation of the remaining natural resources are much-needed, in line with Sustainable Development Goal(SDG) 17.

Overall, the monitored and estimated transitions in the LULC demonstrate the fact that Dhaka is shifting to intensive urbanization with high densities of population and great deterioration of the environment. These trends can be expected to increase the pressure on the environment and make urban life considerably more uncomfortable unless timely and adequate land management policies are in place to address them, which is especially worrying given the fact that Dhaka is one of the fastest growing megacities in the world.

#### **4. CONCLUSIONS**

This paper compared the observed (2017-2023) and the projected (2023-2030) land use and land cover (LULC) changes in Dhaka City. The results show that the natural land cover, including forests, water bodies and bare land, is continuously declining with the continued growth of built-up lands. These processes suggest that Dhaka is moving out of horizontal proliferation towards intensive urbanization, where the extent of environmental degradation is very high. Although the CA-ANN model has a predictive accuracy of 89.88, there are several limitations. These include uncertainties in classification, sensitivity to input data and assumptions concealed in future scenario projections, which should all be carefully examined during the interpretation of the findings. The connection between the lulc changes, climate risks, flood exposure, and socio-economic effects should be studied in the future to inform the sustainable urban planning process and minimize the environmental and infrastructural strains in dhaka.

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