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Projections of Future Land Use in Bangladesh under the Background of Baseline, Ecological Protection and Economic Development

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Abstract: Land is one of the important input resources in a highly populous and land-scarce country such as Bangladesh. When different factors change (such as, geophysical, proximity, socioeconomic and climatic), there are dramatic changes in the spatial pattern of land uses. Thus, shedding light on the dynamics of land use and land cover changes has great importance for finding the changing pattern of land use in Bangladesh. In the present study, we predicted the land use and land cover changes from 2010 to 2030 under baseline, ecological protection priority and economic growth scenarios in Bangladesh. On this basis, we applied a previously developed Dynamics of Land Systems (DLS) model to simulate the changes in land uses according to the driving mechanisms. The findings indicate that cultivated land declines and built-up area expansion is common under all three scenarios. However, the future land use demand shows differences under different scenarios. The results under the ecological protection priority scenario shows that forest area and grassland will increase more, while under economic growth scenario, built-up area will expand dramatically in the future. The present research results furnish meaningful decision-making information for planners to conserve and/or exploit land resources in Bangladesh in a more sustainable manner.

Keywords: land use change; projection; ecological protection; economic development; dynamics of land system (DLS) model; Bangladesh

1. Introduction

Bangladesh is one of the least developed countries of the world [1], and is mostly rural and agricultural [2]. Bangladesh has a large population (144.1 million) and high population density (964/km^2) [3]. Bangladesh has faced many factors in recent years that driving land use and land cover changes (LUCC) such as population dynamics; rapid changes in economic growth; climate change; construction of roads and highways; electrification; more advanced agriculture, technology and irrigation facilities; extended education; improved health services; new residential infrastructure; etc. [4]. Rapid land use and land cover change (LUCC) induced land degradation, together with climate change and human activities, is thought to be a threat worldwide [5–7]. Asia has also experienced impressive land cover changes, yielding land degradation, and ecosystem service and economic loss [8,9].

Land use is conceived as a manmade adjustment of the land surface, and has a crucial role in shaping ecosystem functions [10]. Land use change is the modification system of land into the cultivated land, grassland, forest, and urban land and land use and land cover change (LUCC) is one of the key factors for quantifying the natural environmental and human activity related changes [11]. In general, LUCC is termed as the modification of several land types by human beings [12,13].

In Bangladesh, few studies have been conducted thus far on LUCC. Utilizing the Remote Sensing technique during the period of 2001 to 2008, Shapla et al. classified land use types of Gazipur district and detected the increasing trend of built-up and urban areas [14]. In another study, Kumar and Ghosh utilized Remote Sensing (RS) technique to detect the land cover change on Hatya island from 1977 to 1999 and noticed that cultivated land and forestlands were increasing while grassland was decreasing [15]. Through Advance Land Observing Satellite (ALOS) technique, Zaman and Katoh identified that population pressure and overexploitation of resources helped to reduce the forest cover in Takurgaon district [16]. In another study, Rahman and Begum, through RS technique, identified, in the Sudarbans area, shrinkage of grassland and forest cover by the transformation of unused land [17]. Islam and Hassan used remotely sensed data in Rajshahi district and acknowledged that built-up area was increased by the loss of agricultural land from 1977 to 2010 [18]. Mamun et al., utilizing GIS and RS technique on Dhaka City, revealed that built-up area expanded by the transformation of agricultural lands, water areas and unused lands [19]. Roy et al. monitored and predicted land use changes in the Chittagong Hill Tracts by utilizing remote sensing technique and Markov-chain cellular automata model. They simulated the land cover change of the study area from 2014 to 2042. Although their study exhibited a variation of the land use types of the study area, they did not consider important factors such as physical, socioeconomic and policy that might affect the land use change. They recommended further studies incorporating relevant factors [20]. Ahmad et al. utilized Conversion of Land Use and its Effect (CLUE-s) model to identify the key driving factors influencing urban growth of Dhaka City [21]. They simulated urbanization for the periods 1988–1999 and 1999–2005. Islam and Ahmed utilized Markov Chain Modeling technique to detect the future land cover map of Dhaka City in 2020 and 2050 based on past trend from 1991 to 2008. Their findings suggested that built-up area would increase in the future after the conversion of cultivated lands and vegetation [22]. Through a similar study utilizing the Markov Chain Cellular Automata model, Corner et al. suggested that cultivated land and built-up area will decrease in Dhaka City during 2022–2033 [23].

The World Bank [24] defines sustainable land management as practices and technologies that target incorporating the overall management of land, water, biodiversity and other environmental resources which can fulfill the human requirements for ensuring the long-term sustainability of ecosystem services and livelihoods. Global environmental change results in soil erosion, shortage of water, drought, loss of biodiversity and ecosystem damage [25]. Xie et al. conclude that ecological land is perceived as an important natural resource and necessary for preserving environmental security [26], an essential factor to attain economic development and protection [27]. Any form of alteration of ecological land can start different types of environmental problems [26]. Furthermore, ecological land also needs to include both cities and rural areas. Yao and Xie in China recognized and explored the multiple functions of the countryside, including agricultural production, ecological services, aesthetic and environmental values. Their findings also exhibited that the government's scientific planning and controlling of rural land resources could ensure the most economical land use, ecological welfare and food security [28]. Therefore, it is important to note that LUCC is considered a crucial factor affecting global environmental change and environmental protection [29–31]. Hence, sustainable land management is essential in a land-scarce country such as Bangladesh.

It is common that cultivated lands are converted into nonagricultural purposes in most countries, and the situation is more severe in Bangladesh due to huge population pressure. Due to this cultivated land lost, agricultural production has been hampered in Bangladesh. Thus, LUCC research is a good topic for scientists of Bangladesh. In Bangladesh, very few studies have been conducted so far on future land use change. Most of the conducted studies utilized the remote sensing technique to show LUCC in different regions of Bangladesh. Thus, we can assume that the use of different land use models for future land change prediction in Bangladesh is rare. Therefore, it is crucial to simulate the dynamics of land systems, which ultimately helps in land management decision-making and land use planning [32]. However, land change processes are a complex issue resulting nonlinear developments [33] and human decisions directly or indirectly affect land change process [34]. For the last 20 years, various land use models have been adopted throughout the world [35], and most are used to predict future land cover changes [36].

In this context, we deployed the Dynamics of Land System (DLS) model to simulate the dynamics of the land system by integrating multiple data sources. The DLS model is a widely practiced model of simulation of the land system [32,37–41]. DLS model has two special features: firstly, it provides scenario analysis of land demand at regional level and spatial integration of land uses at pixel level. Secondly, it can consider the interactions among influencing factors of land use and neighboring pixels for those influencing factors. In this study, we will examine the future land use pattern in Bangladesh and will forecast the future land use under baseline, ecological protection priority, and economic growth scenarios so Bangladesh can develop a sustainable land use pattern.

This article proceeds by a brief introduction of the study area in Bangladesh. Then, we discuss the research methodology, including variables and parameters used in the scenario analysis. This section also includes a detailed description of the three scenarios. Next, we explain the DLS model methods for predicting future condition for each of the three scenarios. Finally, we conclude through the presentation of crucial results and discussing their significance.

2. Data and Methodology

2.1. Study Area

The study area encompasses the entire Bangladesh. The country is located between the latitudes 20°34′ and 26°38′ north and the longitudes 88°01′ and 92°41′ east. Bangladesh covers lowlands of the Indo-Gangetic Plain, which is terminated by the two main rivers (the Ganges and the Brahmaputra) with alluvial plain. Tertiary hill regions are found as a part of the Himalayan range. Two hill regions are seen, Chittagong hills in the southeast and low hills in the northeast and modest-elevation highlands in the north and northwest. Southwestern Bangladesh is occupied by the Sundarbans, which is characterized by marshes and swamps. North and west Bangladesh is boarded by India, while the Bay of Bengal is in the south of Bangladesh. Both India and Myanmar are east of Bangladesh. Total area of the country is 147,570 km^2. The territorial water area is 200 nautical miles. Administratively, there are seven divisions (as of 31 December 2015, there are eight) in the country: Dhaka, Chittagong, Khulna, Rajshahi, Barisal, Sylhet and Rangpur. The newly added division is Mymensingh. There are 64 Districts (Figure 1), which are key administrative units of the country. Total number of Upazilla (the lowest administrative unit) is 489. The total population of Bangladesh is 144.1 million, of which the urban population is 33.5 million and rural population is 110.6 million [3]. Annual growth rate of population is 1.37%. Bangladesh is one of the most densely populated countries in the world and her population density is 1062.5 per km^2 [42].

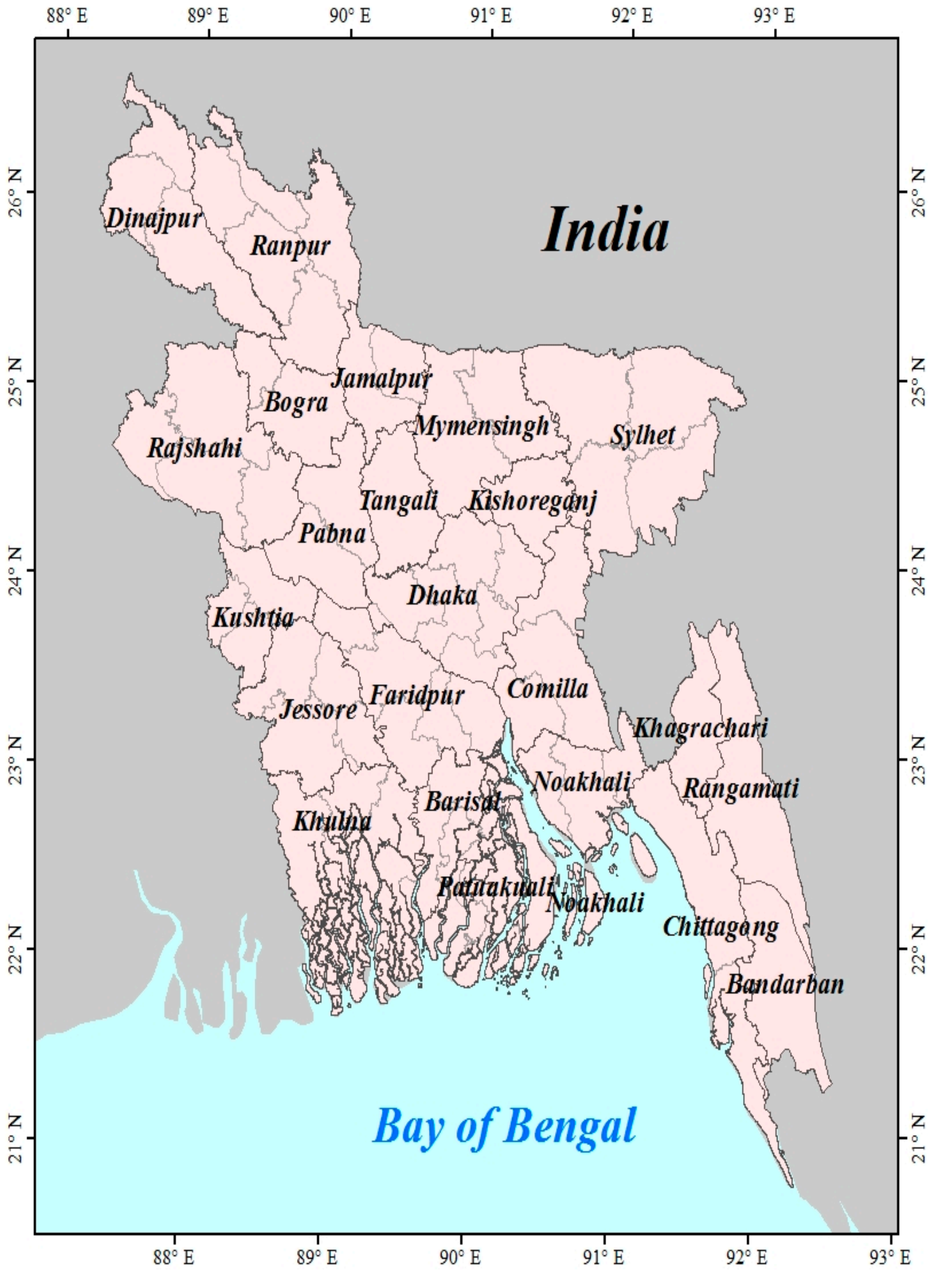


Figure 1. Boundary map and surrounding areas of Bangladesh.

2.2. Data

2.2.1. Land Use Data

Land use data from 2000 and 2010 for Bangladesh, with a resolution of 1km, were used in this study. The original land use maps (map of 2000 and 2010) were derived from www.globallandcover.com [43]. These are 30m fine resolution global land cover maps developed by China Globe Cover [44]. Primarily from the global land cover map, four tiles contain the Bangladesh land cover map for each year: for 2010, N45_20_2010LC030, N45_25_2010LC030, N46_20_2010LC030, and N46_25_2010LC030; and, for 2000, N45_20_2000LC030, N45_25_2000LC030, N46_20_2000LC030, and N46_25_2000LC030. After downloading the tiles from the website, they were processed through mosaicking using the software ArcGIS 10.1. Then, the whole Bangladesh land cover maps are derived by clipping through ArcGIS 10.1 software (ESRI, Redlands, CA, USA).

According to the requirements of the DLS model, it is necessary to prepare all the data with unified projection and spatial registration. Moreover, most of the driving factor data were premade in 1 km × 1 km resolution grid data. Thus, after extracting the land use data, we transformed 30 m resolution to a grid format with spatial resolution of 1 km × 1 km in the same projection coordinates [37,45]. Then, the land uses are reclassified into six types [32,40,41,46,47] with different coding according to Table 1 and are generalized through a distinct representation scheme. Meanwhile, the land use data from2010 were adopted to assess the accuracy of the simulation with the DLS model.

Table 1. Reclassification of land uses of Bangladesh.

Code	Land use	Description
0	Cultivated land	Original data include both rice and non-irrigated uplands.
1	Forest area	Natural or planted forests with canopy covers greater than 30%; land covered by trees less than 2 m high, with a canopy cover greater than 40%; land covered by trees with canopy cover between 10% and 30%; and land used for teagardens, orchards and nurseries.
2	Grassland	Lands covered by herbaceous plants with coverage greater than 5% and land mixed rangeland with the coverage of shrub canopies less than 10%.
3	Water area	Land covered by natural water bodies or land with facilities for irrigation and water reservation, including rivers, canals, lakes, beaches and shorelines, and bottomland.
4	Built-up area	Land used for urban and rural settlements, industry and transportation.
5	Unused land	All other lands.

2.2.2. Different Influencing Factors Data of Land Use Changes in Bangladesh

Different factors influenced land use pattern [41,48]. We utilized four categories of influencing factors during this study: geophysical, climatic, proximity and socioeconomic factors. These variable and factors are explained in Table 2.

Table 2. List of influencing factors for considered during land use change study in Bangladesh.

Factor Type	Influencing Factor	Definition
Geophysical variables	Soil pH	pH value of the soil
	Elevation	Digital Elevation Model (m) (DEM)
Climatic variables	Air temperature	Mean annual temperature (°C)
	Hours of sunshine	Hours of sunshine rectified to account for the spatial variability of solar radiation (mean annual) (i.e., topographic effects)
	Average rainfall	Mean annual rainfall (mm)
Proximity variables	Distance to divisional head quarter	Geometric distance to the nearest divisional head quarter (km)
	Distance to nearest highways	Distance to the nearest highway (km)
	Distance to nearest secondary highways	Distance to the second nearest highway (km)
Socioeconomic variables	Population density	Interpolated population density (persons/km^2) based on the population distribution model [32,49]
	GDP	Interpolated values of gross domestic product (GDP; million USD/km based on spatially explicit analyses of the relationship between economic growth and factors that might affect economic growth [50]
	Urban population density	Interpolated urban population density (persons/km^2) based on the population distribution model

The land use types and factors influencing land use are used for simulating the land use scenarios in this study. Then, we identified, measured and considered the relationships between the binary variable for each land use and their influencing factors through regression analysis.

First, we collected all of the factors and processed at 1 km × 1 km pixel level resolution [37]. Out of these factors, the climatic data were collected from the Bangladesh Agricultural Research Council (BARC). There are 35 weather stations present in Bangladesh. Monthly average climatic baseline data for all 35 weather stations were collected for this study. Then, the climate data were interpolated by means of kriging method of ArcGIS 10.1 [32,41,51]. We collected geophysical data from the International Soil Reference and Information Center (ISRIC) World Soil Information Service [52,53], and Ministry of Agriculture (MoA), Bangladesh. The data were pre-made at 1 km × 1 km grid level [32]. The estimation of proximity data was done using the national highway and divisional data with the ArcGIS software. The socioeconomic dataset was derived from the Statistical Year Book of Bangladesh [54], and the population data were collected from The World Population Organization [55]. Finally, logistic regression analysis was employed to find the statistical relationship between the quantitative changes and spatial dynamics of land use changes, their driving factors, and the weight coefficient matrix of the land use change driving factors [56,57]. We carried out the logistic regression by means of SPSS software. The logistic regression formula was as flows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \quad (1)$$

where, y is the probability of existence of one specific land type in the cells under given driving factors; $X_1, X_2, \ldots, X_n$ indicate the driving factors of different categories such as location, climate, population, GDP etc.; and $\beta_1, \beta_2, \ldots, \beta_n$ are coefficients of regression analysis of driving factors. β_0 is constant.

2.3. Methodology

2.3.1. Land Use Scenarios

There exists a convenient relationship between scenario analysis and land use projections for each year of the simulation period. We developed scenarios for the land use and land cover changes in Bangladesh for the present study based on a literature review related to future Bangladeshi plans and expert judgments. Before developing scenarios, we reviewed several literature documents, including the Prospective Plan of Bangladesh 2010–2021: Making a vision 2021 a reality [58]; 6th Five Year Plan (FY2011–FY2015) of Bangladesh [59]; 7th Five Year Plan (FY2016–FY2020) of Bangladesh [60]; Statistical Year Book of Bangladesh [42]; and the World Bank Data [61]. We also consulted experts in developing the scenarios, both the Chinese and Bangladeshi parts. Based on literature review, expert opinion, and the characteristics of land use and regional development of Bangladesh, we embodied three scenarios, baseline, ecological protection priority, and economic growth, which were used in the Dynamics of Land Systems Model (DLS) to simulate the changes of land systems of Bangladesh.

In this study, taking the land use data of the year 2010 as baseline, we simulated the land use in 2030 under the three scenarios.

Baseline Scenario

The Baseline scenario is a reference case scenario delineating a future condition of society and environment where no new economic and environment policies are implemented, and the same population growth and economic growth trend continue. The baseline scenario is constructed according to the previous statistical data (e.g., 2000 and 2010 for the current study) and current socioeconomic development of Bangladesh that can reflect the pattern succession of land use change following the previous development trend and explore the future land use structure.

The previously identified factors of land use changes acknowledge that these affect the land use changes of Bangladesh in 2010. According to the linear interpolation within the two time periods, the land uses for each year from 2010 to 2020 and 2010 to 2030 are then calculated.

Ecological Protection Priority

In ecological protection priority scenario, a number of useful measures would be implemented to protect the environment, while, at the same time, the growth of both population and GDP would be maintained at a lower rate. Under this scenario, forest areas would be reforested and grasslands would be re-cultivated with plants to reduce environmental degradation and protect the environment. Furthermore, built-up area expansion would be maintained at a lower rate.

Economic Growth

Under the economic growth scenario, the national average economic growth in the form of industrial structure; technology innovation; and adoption of policies to advocate expansions of urbanization, population and economy would be given preference. Under this projection, the built-up area will increase at a relatively higher speed; both the population growth rate and GDP growth rate will be higher than they are in baseline scenario; and more cultivated land will be converted to built-up area over time.

Spatial Allocation and Transition Probability of Land Use Change

The spatial allocation of land use change is the distribution of location specific quantitative land use change according to weight coefficients of driving factors and the scenarios. The decision rule of structural land use change is required in the spatial allocation of land use change. The value of decision rule is between 0 and 1. Bigger values indicate it is more difficult for one certain land use type to change to another land use type, and vice versa (e.g., urban land that is unlikely be converted again back into agricultural land). It is important to use a time set that is different from the original period for future projection. Mas et al. [62] exhibits that, in IDRISI (CA_MARKOV and LCM), transition probability matrices are used to calculate the quantity of each land use for a desired date for land use projection. The transition probability matrix is calculated using a simple powering when the projected date is a multiple of the calibration period. For example, we used the calibration period of 10 years (2000 to 2010) so the base matrix is squared to change probabilities for 2020, and raised to the power of three for 2030.

The transition probability is depicted in Table 3, which exhibits the transfer direction of land use types from 2000 to 2010. Out of six land use types, built-up area, water area and forest area are the most stable classes, with 0.83, 0.70 and 0.63 probabilities, respectively, while, the most dynamic classes are unused land, cultivated land and grassland with transition probabilities of 0.24, 0.29, and 0.64, respectively. In these classes, the cultivated lands were mainly transformed into built-up area and grassland also converted into built-up area.

Table 3. Transition probability of land use types in Bangladesh from 2000 to 2010.

	Cultivated Land	Forest Area	Grassland	Water Area	Built-Up Area	Unused Land
Cultivated land	0.97	0.02	0.04	0.15	0.12	0.04
Forest area	0.02	0.93	0.08	0.02	0.01	0.00
Grassland	0.00	0.02	0.82	0.03	0.00	0.35
Water area	0.00	0.00	0.02	0.77	0.01	0.06
Built-up area	0.00	0.01	0.01	0.02	0.85	0.00
Unused land	0.00	0.00	0.01	0.00	0.00	0.54

2.3.2. DLS Model

For simulating the land use changes of Bangladesh in our scenarios, we selected and used the dynamics of land systems (DLS) model developed by Deng et al., 2008 [32]. The DLS model incorporates two special features: scenario analysis for future land demand (primarily setting up parameters value) and a spatial econometric regression between the explained and explanatory variables. The DLS considers that land use changes occur under land demand directed by socioeconomic developments in a region. Land use changes as pixel-specific changes are dominated by various factors according to Figure 2 (e.g., geophysical, socioeconomic, proximity or climatic factors). The results were utilized for simulating land use changes at any region. By executing the scenario analysis based on the hypothesis for key explanatory variables, the DLS model can improve the robustness of the simulation results [37]. During the present study, land use data from 2000 and 2010 were used to simulate the land use change of 2020 and 2030.

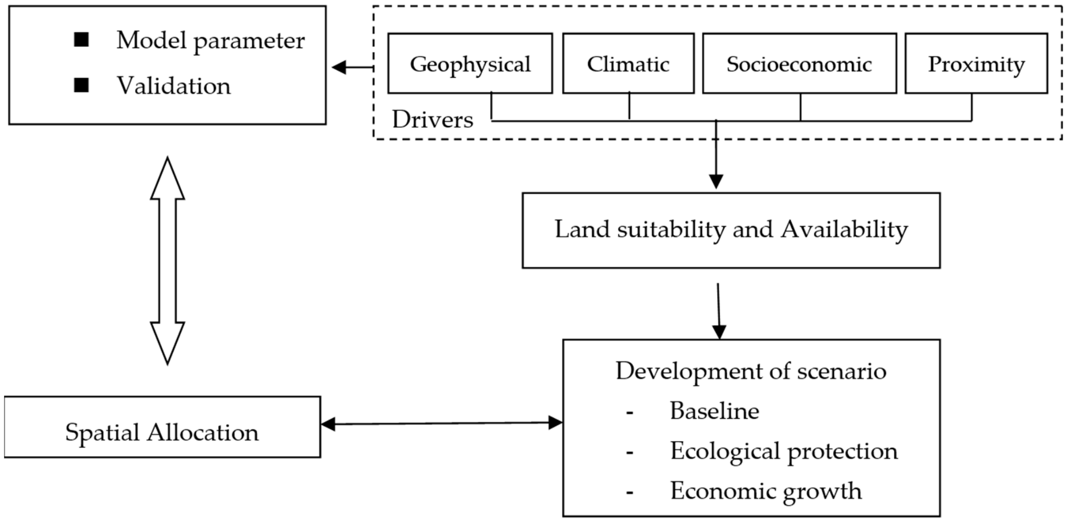


Figure 2. Frame work of the Dynamics of Land System (DLS) Model.

There exist three main modules in the DLS model. Firstly, a spatial regression module that analyzes the driving forces of land distribution for identifying the relationships between different land uses and influencing factors. Secondly, the scenario analysis module, which provides the changes in demand for different land use types at regional level during a given period. Thirdly, a spatial explicit allocation module, which is based mainly on a spatial regression analysis that can allocate land use changes from a regional level to the disaggregated grid cells [32]. Accordingly, for the current study, three processes occur in the simulation of spatial–temporal pattern changes of different land use types of Bangladesh: spatial regression analysis, analysis of the demand for different land use types and spatial allocation of different land use type changes. The spatial regression analysis, or the driving factor analysis, determines the statistical relationship between different land uses and their influencing/driving factors, which ultimately decides the weight coefficient matrix of driving factors of different land use changes [56]. Moreover, the driving factors may change over time due to the effect of conversion rules of original land use types as well as the changes in demand. For this study, we selected 11 driving factors for conducting the logistic regression analysis (Equation (1)) to obtain the relationships between the driving factors and the frequency of each land use type (results are shown in Table 4). The Logistic regression was utilized for estimating the probabilities of the existence of certain land use types in the cells. According to the regression results, the 11 driving factors can logically explain the spatial pattern of the six land use types. The relationship between the different factors affecting land use changes and their interaction between adjacent pixels with land uses can be incorporated by collinear diagnostic in the spatial lag terms (Equation (2)).

$$\pi = \frac{\exp\left(b_0 + \sum_{j=1}^{n} b_j X_j + \sum_{j=1}^{n} \rho W_{mn} X_j\right)}{1 + \exp\left(b_0 + \sum_{j=1}^{n} b_j X_j + \sum_{j=1}^{n} \rho W_{mn} X_j\right)} \tag{2}$$

where, X is the vector of land use influencing factors, and π identifies the existence probability of a grid cell for the considered land use type j. W_{mn} is the spatial weight identifying the neighborhood between m and n. ρ is the estimated coefficient of spatial lag term of X_j. The increment of one unit of influencing factors is related to the increase of a unit increase of the influencing factors is associated with an increase in the exp(b_j) plus exp(W_{mn}) of the probability of occurrence probability of the respective land use type. b_j is the estimated coefficient of X_j, the residual constant of the equation.

The demand analysis or the scenario design furnishes one of the essential inputs in the DLS model. It determines the land use demand and calculates the dynamic demand changes of different land use types. The spatial allocation of land use change is an indispensable input parameter of the DLS model. The spatial allocation aims of determining the conversions that are allowed for a specific land use by a number of grid cells. It explains the temporal behavior of land use types or the status of grid cells [32]. For the current study, the spatial allocation and transition probability of land use change are shown in Table 3. For the simulating purpose, the whole land use structure was applied as input data and the development restricted areas were used as the restricted region.

2.3.3. Validation of DLS Model

Different land use models have been extensively utilized to judge possible land use dynamics and help future land management and policy. For validating the results of these models, it is common to check a comparison of actual and simulated land use pattern. We utilized Kappa coefficient to validate the DLS model. Kappa coefficient of the agreement is widely practiced method [63,64] for agreement assessment. Although we acknowledge that the Kappa coefficient has some bottlenecks, such as, Kappa value can be affected by skewed distributions of categories and the bias problem [65], and the kappa value for three or more categories is considered un-interpretable [66]. Despite the difficulties, it is the most extensively used coefficient for summarizing inter-rater agreement [67–71].

The land use datasets are categorical and we utilized Kappa for validating the accuracy of the DLS model [72]. For the current study, the land use data from 2000 and other factors data were employed as the base data for simulating the 2010 land use data. We then applied the Kappa to assess the agreement between actual and simulated land use change of 2010 through the following expression:

$$Kappa = (P_0 - P_c)/(P_p - P_c) \tag{3}$$

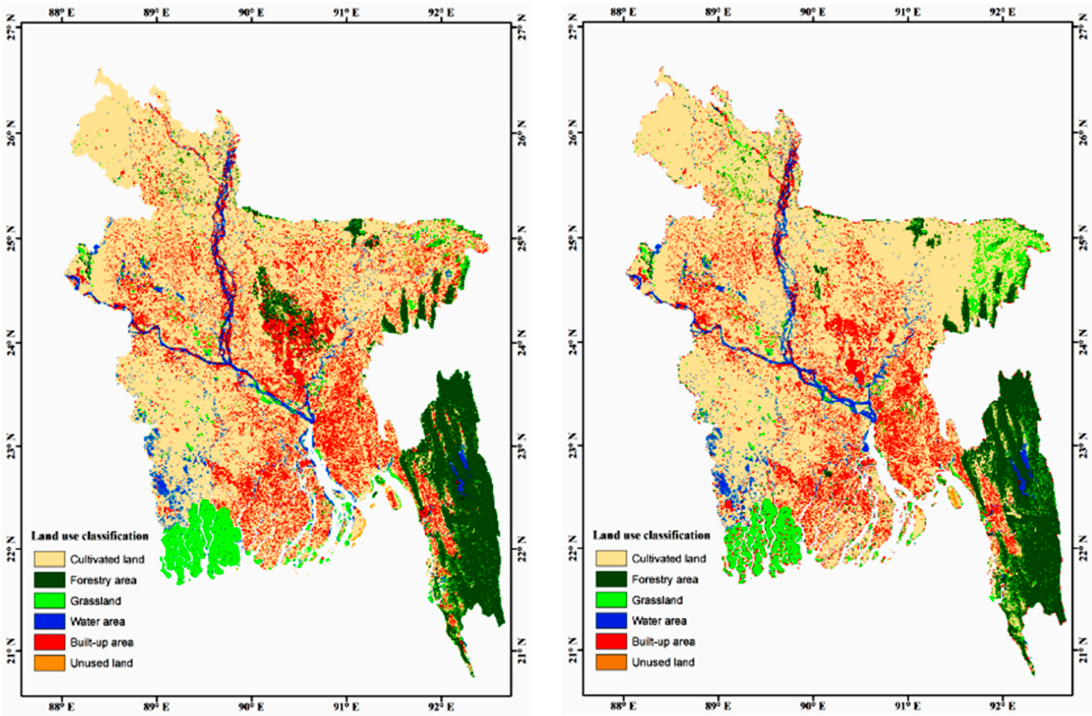
where, P_0 is the percent correct for the output, P_c is the expected percent correct as by chance and P_p is the percent correct for perfect classification.

3. Results and Discussion

3.1. Performance of the DLS Model

The Kappa was employed to assess the agreement between the actual and simulated land use patterns in 2010 (Figure 3).

The value of Kappa statistic is 0.667. Based on the Kappa coefficient, Kappa value above 0.6 is considered a substantial [73–75] and/or good [76–78] assessment between actual and simulated results. Thereby, it shows that the applied DLS model in this study was appropriate to simulate the land use pattern of Bangladesh. Figure 3 shows the simulated and actual map of land use in 2010 are similar but still exhibit certain biases. Cultivated land, grassland, water area and unused land are similar to the actual map of 2010, while forest area and built-up area are poorly simulated and under-predicted by the DLS model.



(**a**) (**b**)

Figure 3. Comparison of: actual (**a**); and simulated (**b**) land use situation in Bangladesh, 2010.

3.2. Analysis of the Driving Factors for the Dynamics of Land Use Changes

The relationship of land use and different factors affecting changes of land is explored based on spatial regression analyses [32,37,40,41,45]. Table 4 summarizes the regression coefficients of the effect of influencing factors on different land use changes such as cultivated land, forest area, grassland, water area, built-up area and the unused land of Bangladesh in 2010. The standard errors inside the parentheses indicate that the influencing factors fluctuate on their effect on the dynamics of land use. Smaller standard error simply stronger factor effects on the land use dynamics. For example, population density and GDP affect strongly the change of cultivated land, water area, and built-up area. On the other hand, average rainfall strongly affects the grassland change.

Table 4. Regression coefficients of the influencing factors of land uses in Bangladesh. Standard errors are included in parentheses.

Driving Factors	Cultivated Land	Forest Area	Grassland	Water Area	Built-Up Area	Unused Land
Soil pH	0.020 (0.001)	−0.014 (0.001)	0.000 (0.001)	−0.015 (0.001)	−0.001 (0.001)	−0.006 (0.013)
DEM	−0.015 (0.000)	0.001 (0.000)	−0.008 (0.001)	−0.003 (0.001)	−0.017 (0.001)	−0.033 (0.047)
Average temperature	−0.179 (0.018)	−3.256 (0.053)	2.718 (0.053)	0.044 (0.045)	−0.004 (0.027)	3.194 (2.026)
Average sunshine hours	−1.779 (0.096)	14.676 (0.181)	2.255 (0.261)	−1.501 (0.257)	−6.494 (0.173)	4.305 (8.622)
Average rainfall	−0.012 (0.000)	0.004 (0.000)	0.012 (0.000)	−0.015 (0.001)	−0.001 (0.000)	0.063 (0.016)
Distance to divisional HQ	0.003 (0.000)	0.002 (0.000)	−0.003 (0.001)	−0.009 (0.001)	−0.007 (0.000)	−0.028 (0.030)

Table 4. *Cont.*

Driving Factors	Cultivated Land	Forest Area	Grassland	Water Area	Built-Up Area	Unused Land
Distance to highways	0.032 (0.002)	−0.070 (0.004)	0.099 (0.005)	0.006 (0.005)	−0.056 (0.003)	0.077 (0.157)
Distance to secondary ways	−0.002 (0.001)	−0.089 (0.002)	0.128 (0.003)	0.024 (0.003)	−0.051 (0.002)	−0.013 (0.126)
Population density	0.003 (0.000)	0.047 (0.002)	0.048 (0.000)	0.002 (0.000)	0.001 (0.000)	−0.107 (0.072)
Urban population density	0.010 (0.000)	0.000 (0.001)	0.009 (0.001)	−0.008 (0.001)	0.004 (0.000)	−0.019 (0.084)
GDP	0.041 (0.004)	0.030 (0.008)	0.131 (0.006)	0.019 (0.007)	0.005 (0.000)	0.003 (0.000)
Constant	−1.213	−6.672	−1.423	−3.165	−2.412	−6.502
Observation numbers	165573	165573	165573	165573	165573	165573
Pseudo R^2	0.175	0.432	0.239	0.141	0.110	0.315

The geophysical variables are important factors affecting LUCC in Bangladesh. The estimation illustrates that soil pH and DEM exerts an obvious influence on the LUCC, which means that higher soil pH and elevation lead to more grassland and forest area change. The climatic variables have little influence on LUCC in Bangladesh. Only average rainfall is found to have an influence on the LUCC. The variables measuring the effects of distances to divisional headquarters, the nearest highways, and the nearest secondary roads cannot be ignored. These variables have an effect on the cultivated land and forest area change. Socioeconomic variables are one of the major factors affecting LUCC in Bangladesh. Population density, urban population density, and GDP have influence on different LUCC. In highly populated areas, damage of cultivated land, forest, grassland and water areas is more dramatic. Meanwhile built-up area increases more in more populous areas. The estimation result under urban population density and GDP indicate the same results, such as regarding population density.

3.3. Dynamic Simulation of Land Changes

Cultivated land, forest area and built-up area are the major land use types in Bangladesh. Under the three scenarios, the changing trends of land uses in Bangladesh are shown in Figure 4 and Table 5. We observed that competition exists among the six land use types in different scenarios (baseline, ecological protection priority and economic growth scenarios). It mainly shows a decrease of cultivated land and increase of built-up areas. Meanwhile, when the ecological condition is considered, forest area and grassland area show a positive relationship with ecological protection. However, when economic growth is considered, a dramatic increase of built-up area is seen. These changes might be due to the effect of different influencing factors on different land use pattern (Table 5 and Figure 5).

Under the baseline scenario, every land use type would primarily expand or decrease according to their previous existing areas. By 2020, both forest area (13.35%) and grassland (12.89%) would be expanded from the other lands, i.e., water areas, unused lands, and cultivated lands. The main expanded grass land areas are located mainly in the northeast (Sylhet Division), and in forestry areas in the Chittagong hill tracts area. During baseline period, water areas are reduced (35%) as the water areas are affected by the annual change of rainfall, increased temperature, and population growth. By 2030, under baseline scenario, both forest area (13%) and built-up area (5%) would be increased, mainly due to the shrinkages of grassland (14%), and water area (34%). Under the baseline scenario, an increase of built-up area and decline of cultivated land is common feature due to the pressure of huge population. The dramatic change in land use types, including the reduction of water area by 35% and 34% in 2020 and 2030, respectively, will lead to shortage of water resources in Bangladesh.

Under the ecological protection priority scenario, the study assumes a land use that is under strict environmental protection policy from 2010 to 2030. Under the ecological protection priority scenario in 2020, both forest area (18%) and grassland (12%) would be expanded. The shrinkage of water areas (35%), cultivated land (2%) and unused area (45%) would be mostly responsible for this expansion. By 2030, under ecological protection priority scenario, forest area and grassland would be increased by 35% and 30%, respectively. On an average, water areas and cultivated land decrease by 6% and 35%, respectively, which indicates that the regulation has significant effect on checking the huge expansion of built-up land. Under the economic growth scenario, the expansion of built-up area is strikingly clear when compared to the other scenarios for 2020 and 2030, and with the actual map for 2010. This expansion of built-up area by 46% (2020) and 51% (2030) would be due to the shrinkage of cultivated area (8.24% and 7.78%, respectively), and the conversion of forest area (3.53% and 6.48%), and grassland (11.06% and 24.33%). In total, unused area is very small in Bangladesh but it was also converted to built-up area.

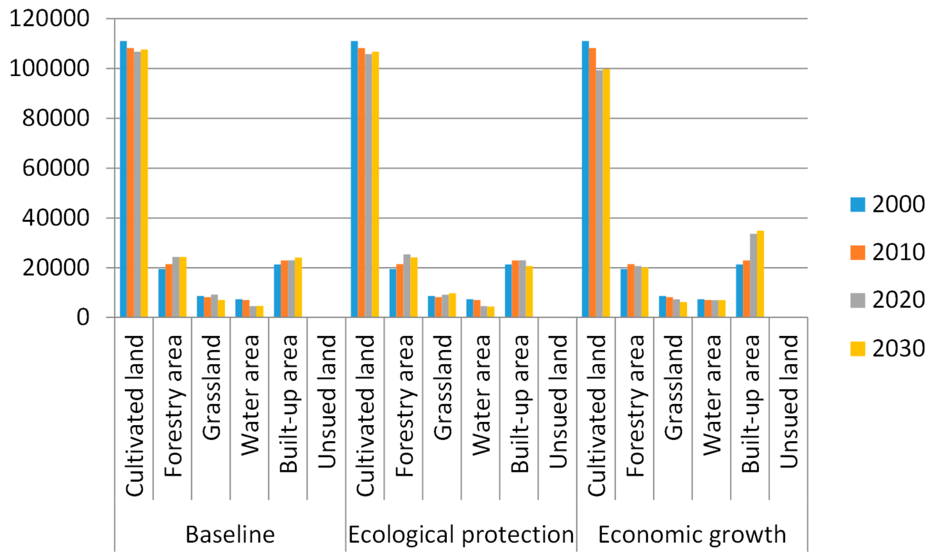


Figure 4. Land use structure changes under baseline, ecological protection and economic growth scenarios.

Table 5. Simulated areas of land use types under different scenarios (Unit: km^2).

Scenario	Year	Cultivated Land		Forest Area		Grassland		Water Area		Built-Up Area		Unused Land	
		Area	% Change	Area	% Change	Area	% Change	Area	% Change	Area	% Change	Area	% Change
Base year	2010	108,223	0	21,513	0	8079	0	6911	0	22,964	0	170	0
Baseline scenario	2020	106,777	−1.33	24,387	13.35	9121	12.89	4475	−35.24	23,007	0.19	93	−45.29
	2030	107,662	−0.51	24,390	13.37	6962	−13.82	4557	−34.06	24,092	4.91	197	15.88
Ecological protection priority	2020	105,769	−2.26	25,397	18.05	9071	12.28	4475	−35.24	23,055	0.39	93	−45.29
	2030	99,023	−8.50	29,185	35.66	10,531	30.35	4437	−35.79	24,643	7.31	41	−75.88
Economic growth	2020	99,298	−8.24	20,752	−3.53	7189	−11.06	6890	−0.30	33,710	46.79	21	−87.64
	2030	99,795	−7.78	20,118	−6.48	6113	−24.33	6897	−0.20	34,892	51.94	45	−73.53

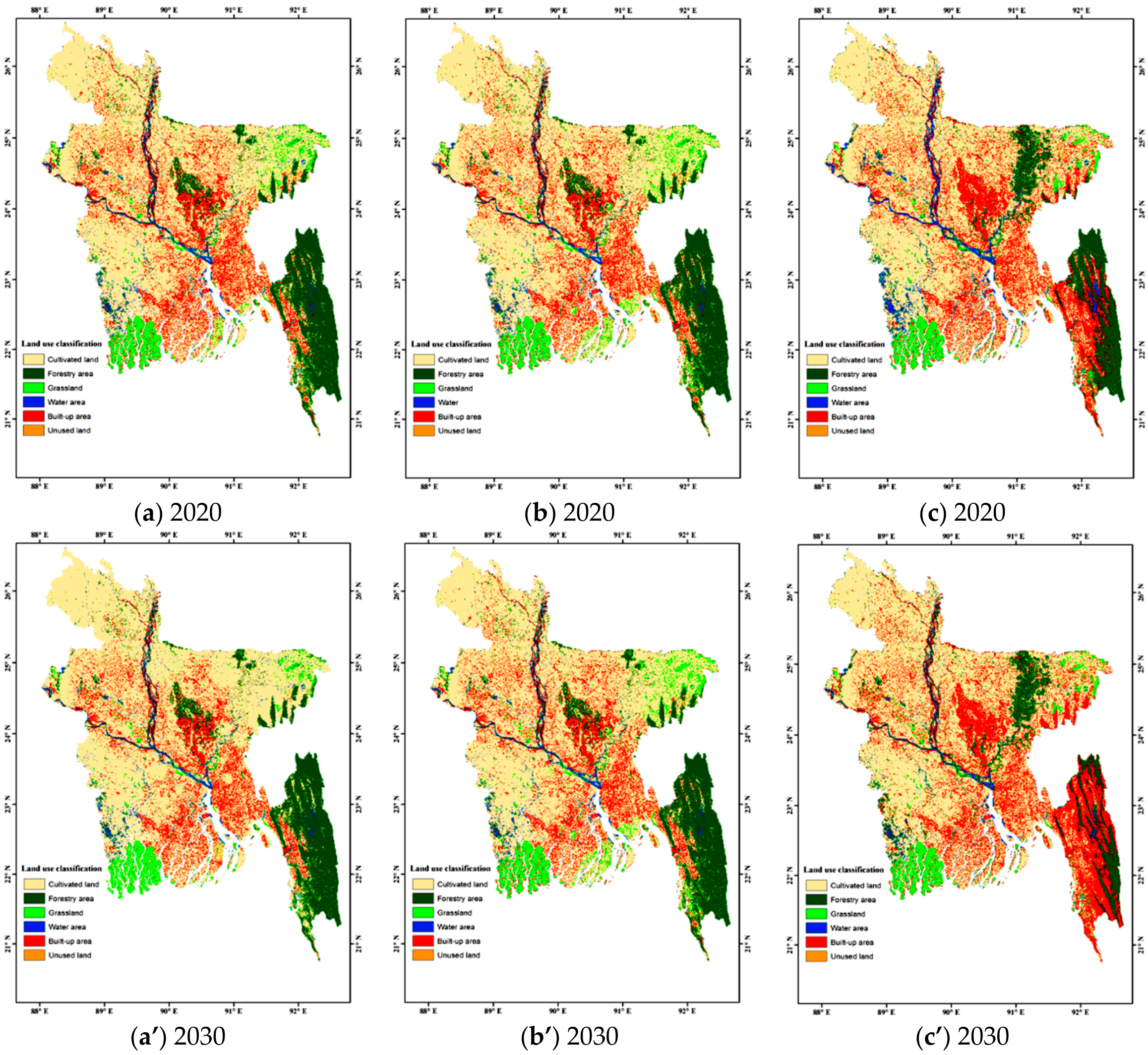


Figure 5. Projected land use situation under: (**a**,**a′**) the baseline scenario; (**b**,**b′**) the ecological protection priority scenario; and (**c**,**c′**) economic growth scenario of Bangladesh.

Figure 5 exhibits the land use pattern of Bangladesh under three scenarios for 2010–2030. The simulation results showed that LUCC during 2010–2030 under ecological protection priority scenario was driven by the substantial expansion of forest area and grassland areas and the decrease of cultivated land, water areas, and unused lands, which would have a significant impact on the environmental protection. This expansion trend for forest area and grassland occurs mainly in the northeast (Sylhet region), the Chittagong hill tracts and the southwest (the Sundarbans). Similarly, the results under the economic growth scenario indicated a steep increase in built-up areas with the loss of cultivated land, grassland, water areas and forest areas. Although overall in the whole country, forest areas and grassland would generally decrease, an increase would be observed in the northeast (Sylhet division). The forest areas in Sylhet region have been found to be unutilized for a long time. However, the government also plans to plant 5000 ha of forests in the Sylhet region according to the 7th Five Year Plan [60]. Social forestry programs in Bangladesh are beginning to become a social movement. Currently, the government is strongly considering extending this social forestry program, and an estimated 20,000 km of strip plantation might be planted. The country also plans to deploy the local government bodies and NGOs to coordinate afforestation programs at the grass root level.

4. Discussion

Compared with the baseline scenario, land use changes under ecological protection priority scenario would be marked by the expansion of forest area and grassland area. A noticeable amount of forest area and grassland areas would present in the northeast, southeast and southwest of Bangladesh in 2020 and 2030. According to the Prospective Plan of Bangladesh: Vision 2021 [58], Bangladesh Government wants to raise the forest area and grassland cover to 15% from the current 13%. Within this time frame, the government set a target of upgrading the tree coverage of 2.84 million hectares in forest area and grassland areas with the diversification of tree species for ecological balance as well as increasing forestry employment under the social and agro-forestry program. Currently, forest area and grassland are gaining importance in government policy h yielding more budgetary allocation for accomplishing forestry programs. For supporting forestry sector in climate change perspective, the government opens new programs, such as "Bangladesh Climate Change Trust Fund" and "Bangladesh Climate Change Resilient Fund". The government also plans to conserve and protect forest and grassland ecosystems for environmental stability, improve biodiversity and increasing employment opportunity and alleviating poverty for forest-dependent people through people oriented afforestation programs. Moreover, the government plans to improve quality and density of existing forests and older plants through "enrichment planting" and "assisted natural regeneration". According to the 7th Five-Year Plan (2016–2020), Bangladesh government plans to plant and/or replant an estimated 50,000 ha of hill forest, 5000 ha of plain forest and 30,000 ha of coastal area forest [60]. All these activities are helpful to increase the forest and grassland areas in the country. The findings from Hasan et al. stated that forest area declined 0.129% during 1976–2000 but increased 0.081% during 2000–2010 in Bangladesh [79]. The expansion of forest area and grassland area is found in the northeast, Chittagong hill tracts area and the southwest, while the grassland cover increased 0.009% (1976–2000) and then decreased 0.032% (2000–2010).

Comparing the baseline scenario with the economic growth scenario, the land cover change would be characterized by the dramatic expansion of built-up areas. Findings of the Prospective Plan of Bangladesh: Vision 2021 [58] suggests that Bangladesh wants to increase its GDP growth rate from 6.1% in 2010 to 10% by 2021. Similarly, the government wants to raise the GDP growth rate to 12% by 2030. According to the prospective plan, the industrial and manufacturing sectors will increase by double digits and account for about 37% of GDP by 2021. To become a middle-income country by 2021, industrial expansion must be accompanied by the agricultural sector. Hence, increasing pace of built-up area and industrialization will be an important feature in the future to address the incremental poor capacity of agricultural sector to absorb increasing labor force, cater the growing local demand for industrial goods and also taking advantage of emerging opportunities of the global market. Meanwhile, under economic growth scenario, expansion of built-up areas would be profound in the southeast of Bangladesh and the Chittagong hill tracts area, as the population of these areas is increasing. In 1972, the government announced about 50,000 ha forest area as reserve forest and 4000 ha was leased for rubber plantation [80]. This decision enticed migrating low land people into the Chittagong hill tracts. Moreover, it was a common perception of the government that the Chittagong hill tracts is a thinly populated area, which ultimately accelerated the government to emigrate lowland people into the Chittagong hill tracts [81] resulting in an estimated 200,000–450,000 people being resettled in the Chittagong hill tracts, increasing population density and population pressure [82].

The built-up area increase is also associated with increasing housing demand in urban areas that can stimulate the land use pattern change. On the contrary, if the high population density in cities of Bangladesh cannot be accommodated, then sprawl might occur. This rapid spatial expansion of cities will exert huge pressure on cultivated land conversion to built-up areas in the future. On the other hand, rapid and unplanned urban area development and management is a challenge for the government. The government set a target of maintaining balance distribution of urban centers throughout the country with the cleaner urban environment. It is estimated that, by 2021, nearly one-third of the total population in Bangladesh will live in urban areas. Moreover, the urbanization in Bangladesh is characterized by the predominance of few urban centers and uneven distribution of urban population. A large proportion of urban population is concentrated in Dhaka, Chittagong and Khulna Metropolitan areas, which comprise about 54% of the total urban population [58]. Seizing of land by the powerful, changing ownership through false statements by the corrupt officials, and the subdivision of lands into un-economical parcels by inheritance make land in Bangladesh a source of constant violence [83]. Moreover, national politicians and bureaucrats in Bangladesh have large land ownership and often rely on rich landholder farmers to gain political support [84]. Bangladesh government has changed its policy to redistribute fallow land to landless households since 1987, although the system is still controlled by local politicians and large landowners [85].

As cultivated land loss amounts to 1% annually [58], to ensure food security for the huge population, sustainable land management is essential. According to the Prospective Plan of Bangladesh (2010–2021), the government formulated a policy to promote sustainable urban land management, which should be environmentally sound ([58], p.76). Moreover, government plans to take effective measures for protecting Bangladesh from adverse climatic effects and global warming. At the same time, it targets protecting the environment from manmade threats such as deforestation, air pollution, over fishing, river encroachment, unplanned building construction, conversion of water areas into agricultural land and other purposes and population pressure on the land. Additionally, the government of Bangladesh also identified major policy thrust areas as the maximum utilization of available lands, capturing and reversing the degraded lands. In this context, to prepare an integrated action plan, simulation results of the current study of Bangladesh can provide decision making references spatial land management planning and control practices.

Due to high population growth rate, increasing income growth rate and increasing per capita income are important factors affecting intensive fixed land area competition in Bangladesh. The land use patterns are changing in complex and different ways in Bangladesh. Thus, meaningful land use policy is necessary to ensure the best possible use of land and water bodies, restrict their misuse, protect the gradual decreasing trend of agricultural land for feeding the growing population, ensure best utilization of fallow lands, and control unsubstantiated land business by the landowners [86]. As a result of a huge population density of the country, land is the scarcest production factor in Bangladesh. This situation enhances the skyrocketing prices of land all over the country, especially in metropolitan cities. Thus, Bangladesh government is strongly considering this when developing future growth strategies and trying to manage the land for the sustainable rapid growth of the country. Thus, sound land management is thought to have a direct effect on poverty reduction and social welfare [59]. For controlling the high conversion of agricultural land into nonagricultural purposes, determining the best land use, and enhancing the environmental sustainability of land use, the government formulated and adopted a National Land Use Policy in 2001 [59]. Moreover, the government is trying to develop a database of all land resources, and land-zoning information in some selected areas and other environmentally endangered area. Bangladesh has a great shortage of vacant land, which pushes land price even higher, developing a nontransparent land market throughout the country. This makes it impossible for most urban residents to buy land and build their own houses [60]. Thus, the current research findings will help planners and decision makers formulate future sustainable land use policy in Bangladesh.

Bangladesh formally joined China's "one belt, one road" initiative in October 2016 [87]. The "one belt, one road" initiative aims to maintain connectivity in five aspects: infrastructure, resources development, financial and industrial cooperation, and people to people bond [88]. The land based "one belt one road" will connect 14 stops including the port city Chittagong, Bangladesh. Thus, a huge opportunity exists for Bangladesh in terms of the development of many aspects, and future land use pattern development is important for Bangladesh to strengthen the "one belt, one road" initiative of China. The current research findings can be utilized as a guideline to develop future land use policy.

It is recognized that no single model can be sufficient enough to describe the different process of land use change pattern [89]. Assessment of the validity of recent studies has identified that most spatial models still have high uncertainty [90]. We selected several variables such as geophysical, socioeconomic, climatic and proximity variables, but there are still some other factors that are difficult to quantify. Selection of factors and indicators, to a certain extent, may cause differences in the simulation results; for example, housing size changes in built-up areas may have an influence on spatial land use pattern in respect of housing demand, and policy related issues (such as land use zoning, infrastructural policy) impact on the land use pattern change. However, in this study, we do not deal with policy related variables. A future study could employ the current study variables together with policy and other variables in the simulation of LUCC in Bangladesh, yielding more fruitful decision-making recommendations.

5. Conclusions

It is of great importance to explore the dynamics and spatial pattern of land use and land cover changes in a land-hungry country such as Bangladesh. The present case study of Bangladesh recognized related driving factors, including geophysical, climatic, proximity and socioeconomic variables, which were exploited using a dynamics of land systems (DLS) model for simulating land use demand over the next 20 years (2010–2030).

The scenario simulation offers a distinct picture of land use and land cover changes. The results suggest that, following the normal trend of land use change according to the previous years and areas under the baseline scenario, forest area would be augmented and water area as well as cultivated lands would be decreased. The water area shrinkage will have consequences for the water crisis in Bangladesh. Subsequently, when the ecological protection priority scenario is considered, cultivated lands and water areas convert to forest area and grassland, which will become the main feature of land use and land cover change in the future. Under the economic growth scenario, steep inflation of built-up areas will become the main feature of land use and land cover change in Bangladesh in future. Thus, to protect ecological conservation and cultivated lands from conversion, and strictly control the expansion of built-up areas, important land use adjustments are necessary to accelerate overall ecological and sustainable economic development. Thus, the output of the current research will generate valuable information for supporting the systemic management of the existing land resources. At the same time, the findings will also assist in planning and policy development as a future guide of different land conversion directions targeting the quantities of each land use types. The results will also help to present the tradeoffs among different land use patterns in specific regions of Bangladesh.

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