Land cover change prediction of Dhaka City: A Markov Cellular Automata Approach

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Dhaka was announced as the second worst liveable city in the world according to a survey by the Economist Intelligence Unit (EIU), affiliated with the UK-based weekly the Economist on February 14, 2010. Dhaka is now one of the world's one of the fastest growing mega cities. In recent times, Dhaka has been challenged by numerous difficulties like unplanned urbanisation, extensive urban poverty, water logging, growth of urban slums and squatters, traffic jam, environmental pollution and other socio-economic problems.

In this regard, it is much needed to track the land cover changes over time and predict the future scenario of Dhaka city. In this article, the analysis is performed by a remote sensing based land cover prediction modelling method called 'Markov Cellular Automata'. Based on the past trend (from 1999-2009) of land cover changes, the future land cover map of Dhaka city for the year of 2020 has been generated.

The result shows that urban built-up areas will increase significantly. The major contributions for this transformation to built-up areas will be from water bodies and vegetation land cover types. The decision makers as well the city planners can initiate appropriate plans based on the outcome of this research. This kind of analytic research can be remarkable in making Dhaka a much liveable and planned city in near future.

Background

Dhaka, the capital of Bangladesh, is enriched with rich culture, history and heritage of about 400 years. Once upon a time, Dhaka was worldwide famous for its fine muslin (a kind of very smooth cloth), mosques and trade [1, 2, 3, 4]. Now Dhaka has turned into world's one of the biggest megacities [5]. Dhaka is now world's one of the most populous, most densely populated and most urban agglomerated cities [6, 7, 8]. It is going to be the wo... third largest city by 2020 [9].

Dhaka is attracting huge amount of migrants from all over the country due to better and well-paid job opportunities, better educational, health and other daily life facilities [5 and 9]. The kind increasing population pressure is putting adverse impact on Dhaka city like converting wetlands/natural vegetation/open space/bare soil to urban built-up areas [5, 10, 11]. If the population and urban growth trend of Dhaka city continues over the next few decades/ centuries (Figure 01 and Figure 02), then it is clear how spontaneously the city is growing. If this situation continues then Dhaka would soon become an urban slum with the least livable conditions for the city dwellers.

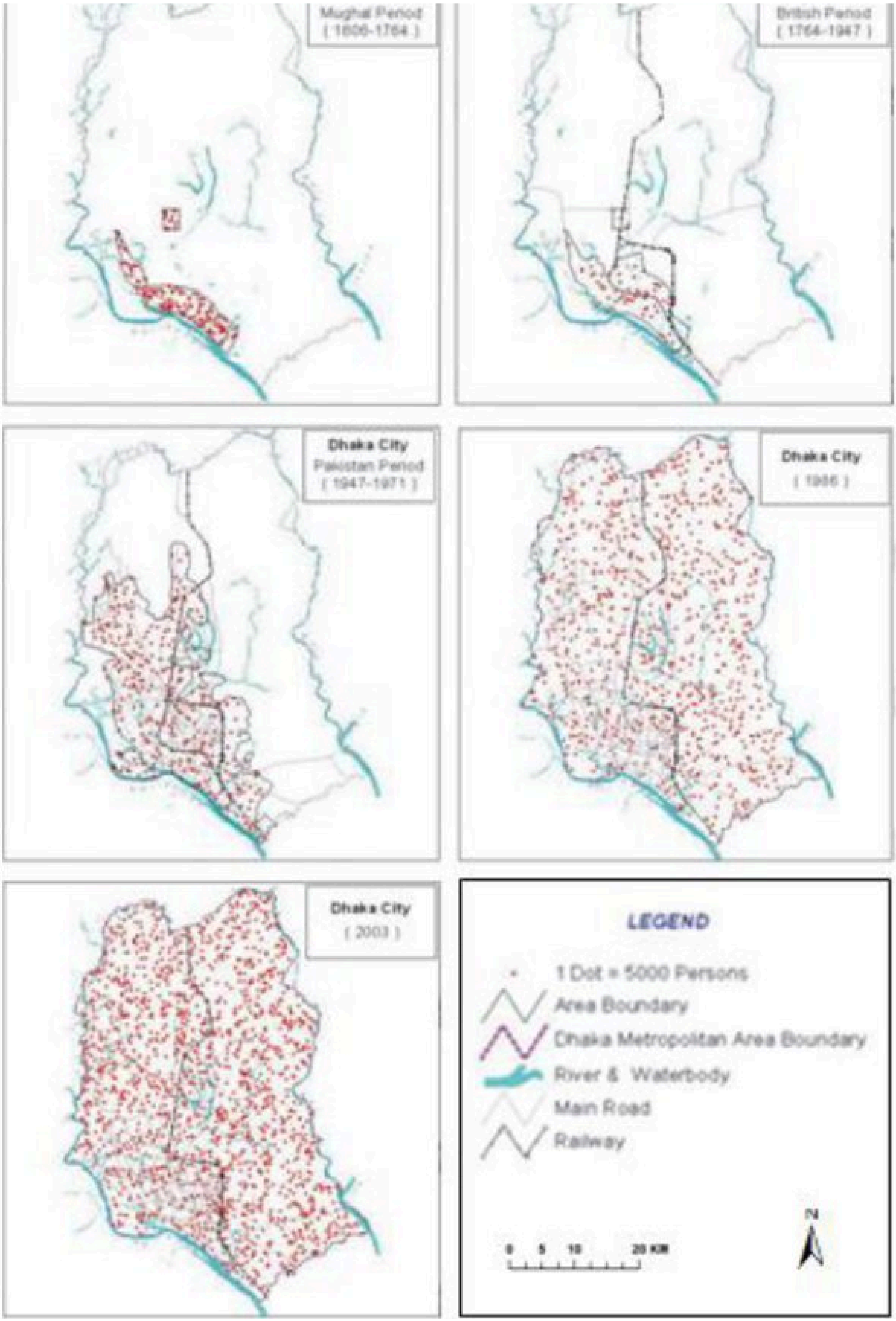


Figure 01: Changing Patterns of Dhaka City and its Population
Source: GIS Division, Bangladesh Centre for Advanced Studies

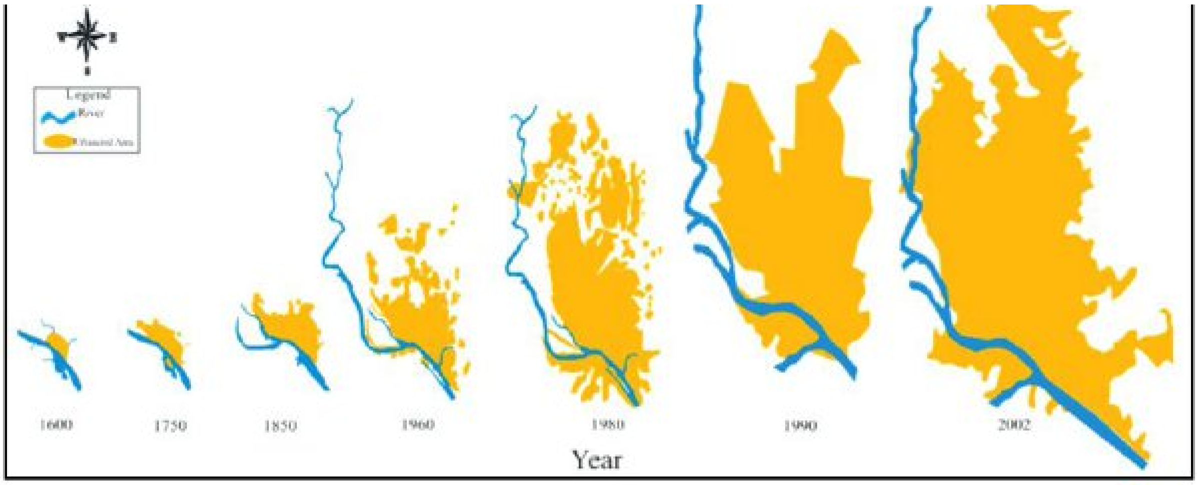


Figure 02: Historical Growth of Dhaka (Not to Scale)
Source: Urban Planning Department, Dhaka City Corporation, 2004

Objective

The objective of this research is to predict the future land cover change of Dhaka City.

Study area profile

The proposed study area for this research is Dhaka City Corporation (DCC) and its surrounding impact areas (Figure 03). DCC comprises of 90 wards (Figure 04). The study area covers old Dhaka, the oldest organic core part of Dhaka city, the planned areas and even the unplanned new generation organic areas that is called 'informal settlements.' This area almost covers the biggest urban agglomeration and is the central part of Bangladesh in terms of social and economic aspects [5, 6, and 10]. Therefore, this area has huge potential to face massive urban growth in near future.

Data collection

The Landsat satellite images (for the year 1999 and 2009) have been downloaded from the official website of U.S. Geological Survey (USGS). For the purpose of ground-truthing the base maps (for the year of 1995 and 2001) have been collected from the Survey of Bangladesh.

Landsat path 137 row 44 covers the study area. Map projection of tl ges is Universal Transverse Mercator (UTM) within zone 46 N– Datum WGS 84

Landsat satellite images (Figure 05), is 432 (RGB).

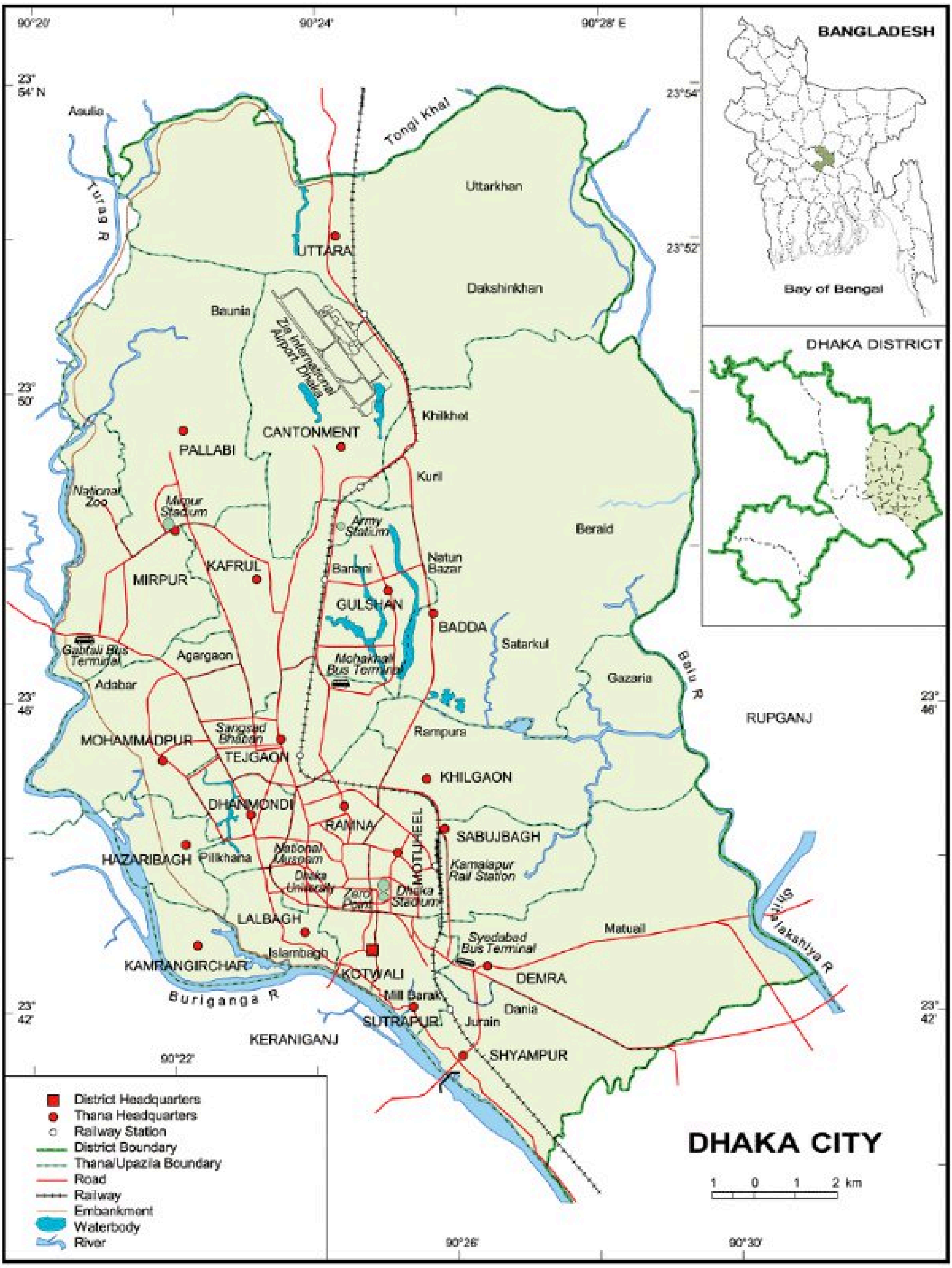


Figure 03: Dhaka Metropolitan Area
Source: Banglapedia, National Encyclopedia of Bangladesh, 2006

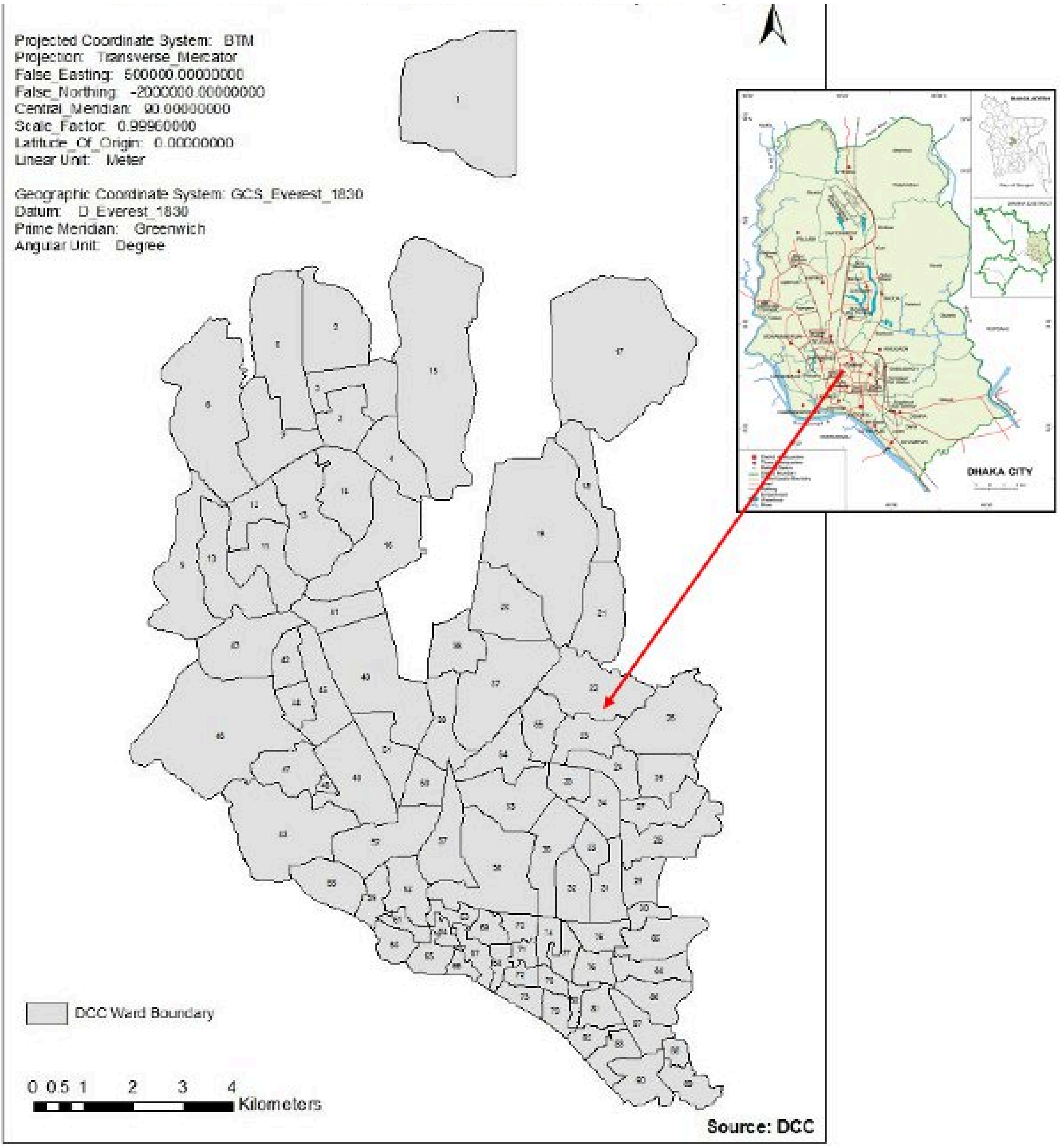


Figure 04: Dhaka City Corporation (DCC) Area
Source: Dhaka City Corporation, 2007

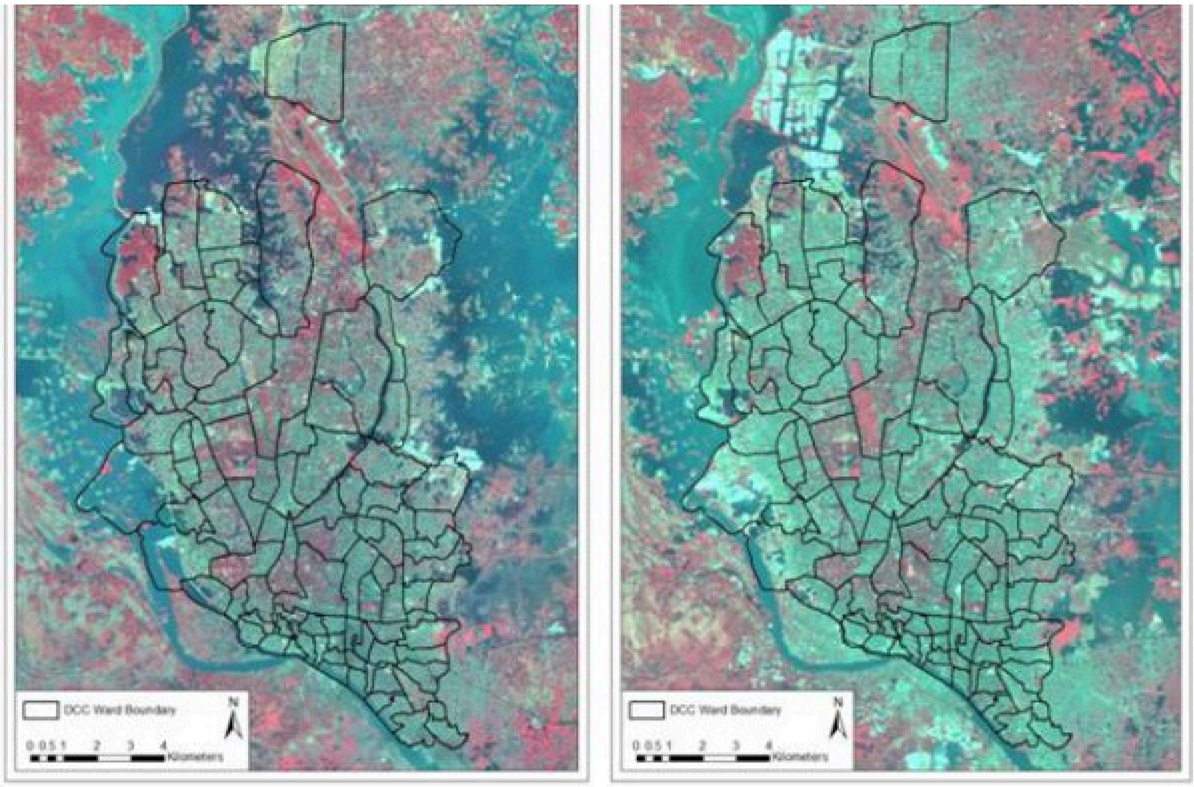


Figure 05: Dhaka City Corporation and its Surroundings

Methodology

To predict the future land cover of Dhaka city, remote sensing techniques have been used. The false colour composite (FCC) of RGB= bands 4, 3 and 2 has been chosen for this research (Figure 06).

Five land cover types have been identified for this research (Table 01). The training sites developed for this research are based on the reference data and ancillary information collected from various sources as mentioned earlier. The supervised image classification method is applied.

For this research, a hard classifier called Fisher Classifier has been chosen. Fisher performs linear discrimination analysis [13]. Fisher Classifier performs well when there are very few areas of unknown classes [14].

After this step, few misclassifications have been observed in the classified land use images of Dhaka city. In most cases it is really difficult to separate water bodies and low/cultivable lands categories. The reasons may be the seasonal variations of the satellite images for different years and the similar spectral properties of land covers in some cases.

landuse images. This post-processing operation replaces the isolated pixels to the most common neighbouring class [14]. Finally the generalised image is reclassified to produce the final version of land cover maps for different years (Figure 07).

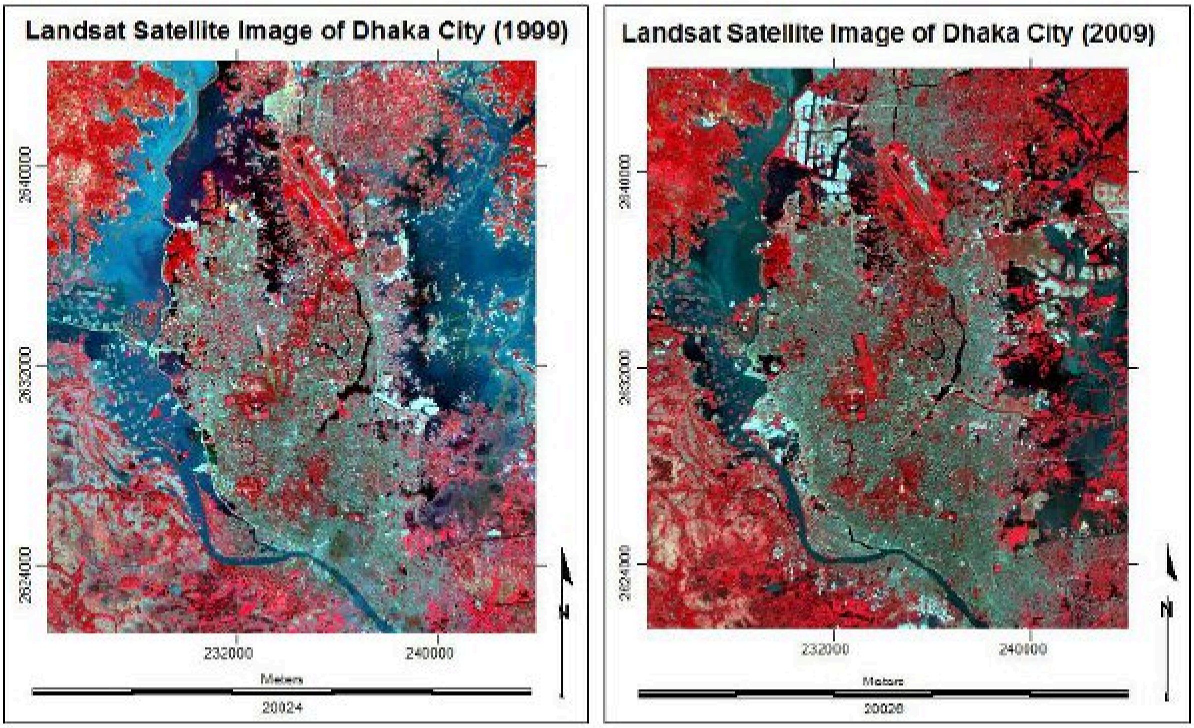
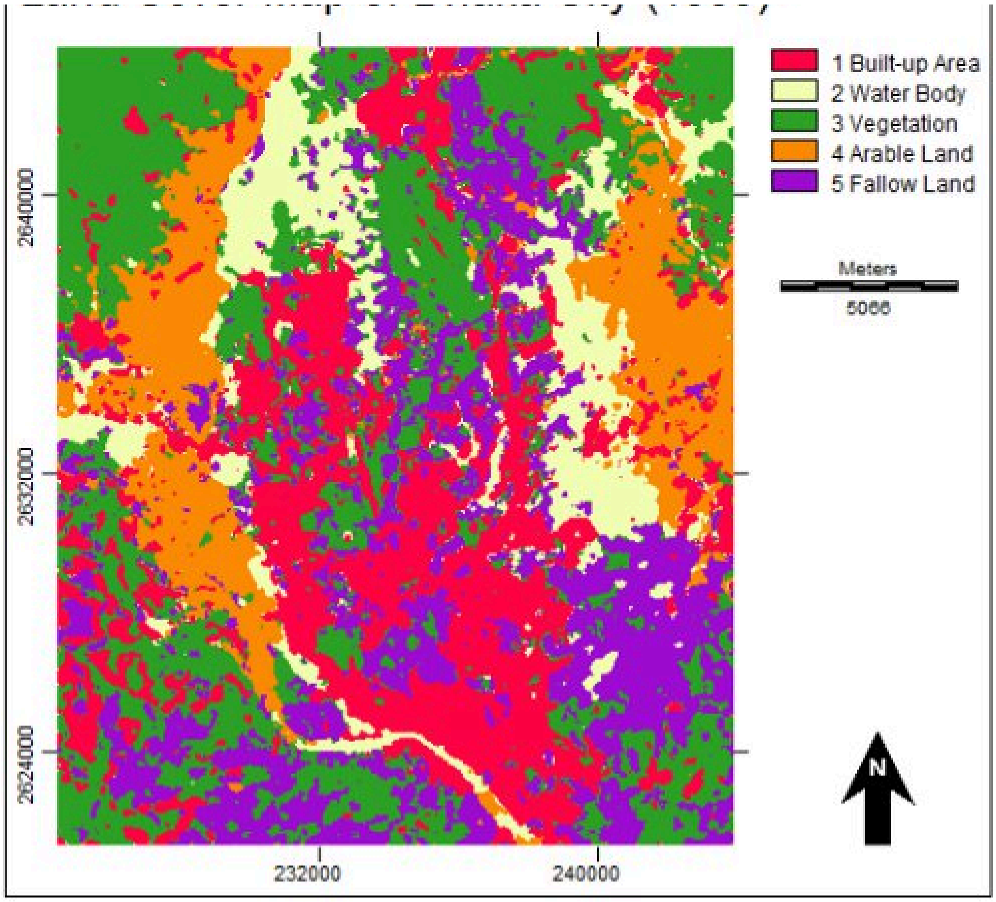


Figure 06: False Color Composite (RGB=4, 3 and 2) Maps of the Study Area

Land Cover Type	Description
Built-up Area	All residential, commercial and industrial areas, villages, settlements and transportation infrastructure.
Water Body	River, permanent open water, lakes, ponds, canals and reservoirs.
Vegetation	Trees, Shrub lands and semi natural vegetation: deciduous, coniferous, and mixed forest, palms, orchard, herbs, climbers, gardens, inner-city recreational areas, parks and playgrounds, grassland and vegetable lands.
Low Land	Permanent and seasonal wetlands, low-lying areas, marshy land, rills and gully, swamps, mudflats, all cultivated areas including urban agriculture; crop fields and rice-paddies.
Fallow Land	Fallow land, Earth and sand land in-fillings, construction sites, developed land, excavation sites, solid waste landfills, bare and exposed soils.

Table 01: Details of the Land Cover Types


1 Built-up Area
2 Water Body
3 Vegetation
4 Arable Land
5 Fallow Land
Meters
5066
N
2640000
2632000
2624000
232000
240000

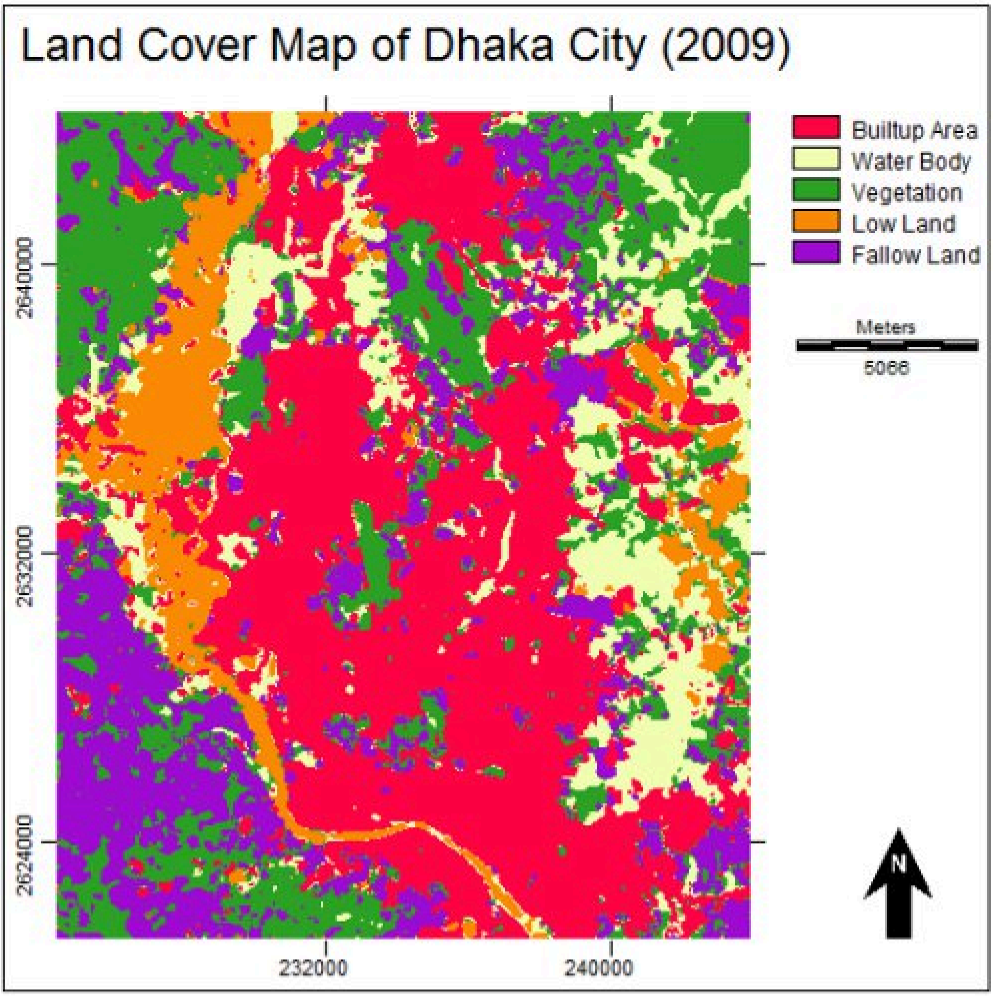

Land Cover Map of Dhaka City (2009)
Builtup Area
Water Body
Vegetation
Low Land
Fallow Land
Meters
5066
N
2640000
2632000
2624000
232000
240000

Figure 07: Land Cover Maps of Dhaka City

Land Cover Type	1999		2009		Change of Area (km^2) 1999-2009
	Area (km^2)	%	Area (km^2)	%	
Built-up Area	108.564	24.35426	166.885	37.438	**+58.321**
Water Body	51.078	11.45838	60.337	13.536	**+09.259**
Vegetation	130.115	29.18882	98.518	22.100	**-31.597**
Low Land	62.926	14.11625	40.716	9.134	**--22.210**
Fallow Land	93.087	20.88229	79.314	17.792	**-13.773**
Total	**445.770**	**100**	**445.770**	**100**	**0**

Table 02: Summary of Land Cover Classification Statistics between 1999 and 2009

From Table 02, it is clear that over the years built-up area has increased distinctly. It is also noteworthy that there is an evident decrease in vegetation and low land. The water body has increased slightly and loss in fallow land is also found. It is now possible to predict the land cover change map of Dhaka city using Markov Cellular Automata (CA_Markov) modelling.

CA_Markov modelling

In Markovian processes the future state of a system in time t2 can be modelled based on the immediate preceding state; time t1 [14]. A Markov chain is a random process where the following step depends on the current state. Markov produces a transition matrix (Table 03), a transition areas matrix (Table 04) and a set of conditional probability images by analysing two qualitative landuse images (Figure 08) from two different dates (1999 and 2009) [13]. In both tables (Table 03 and Table 04), the rows represent the older land cover classes and the columns represent the newer land cover categories. Here class_1 to class_5 chronologically represent built-up area, water body, vegetation, low land and fallow land respectively. Table 03 shows the probability that each land cover category will change to other categories in 2009.

	Class 1	Class 2	Class 3	Class 4	Class 5
Class 1	0.6085	0.0470	0.0937	0.0335	0.2174
Class 2	0.3259	0.3701	0.1260	0.0915	0.0865
Class 3	0.1931	0.0459	0.3971	0.0178	0.3462
Class 4	0.1774	0.2629	0.1304	0.4083	0.0211
Class 5	0.4692	0.1621	0.1931	0.0180	0.1576

Table 03: Markov Probability of Changing among Land Cover Types

	Class 1	Class 2	Class 3	Class 4	Class 5
Class 1	112832	8710	17367	6204	40315
Class 2	21846	24812	8449	6136	5798
Class 3	21141	5020	43467	1944	37893
Class 4	8023	11893	5898	18472	953
Class 5	41353	14287	17016	1584	13886

Table 04: Cells Expected to Transition to Different Classes
Table 04 represents the number of cells/pixels (30 m × 30 m) that will be transformed over time from one land cover type to other types.

Markov Chain Analysis also produces related conditional probability images (Figure 08) with the help of transition probability matrices. These images are called conditional because the probability is conditional to the current state [13]. These images, which have been projected from the two previous land cover images, are useful for future prediction of landuse change. Each conditional probability image shows the possibility of transitioning to another land cover class [14].

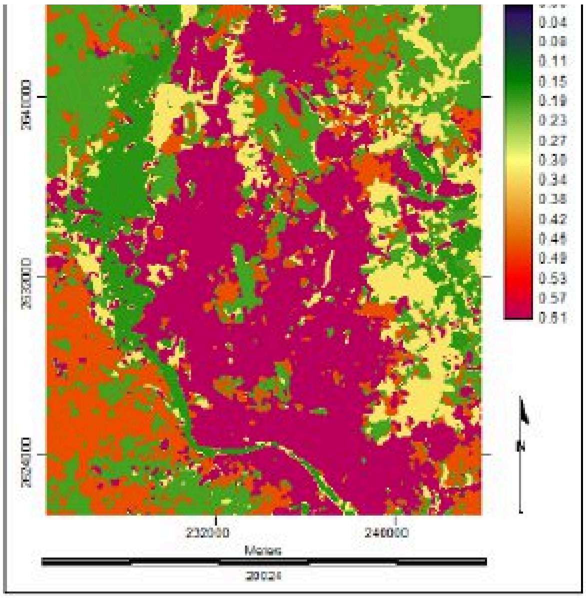
After analyzing Figure 08, it is clear that most areas will convert into built-up area (class_1). The Markovian Conditional Probability of being class_1 ranges to 0.61 which is the highest among all land cover types. This probabilistic prediction is dependent upon the past trend of the last ten years (1999-2009). There it is found that most areas are being converted to built-up areas and this Markovian conditional probability images are following the same trend that is observed from the past.

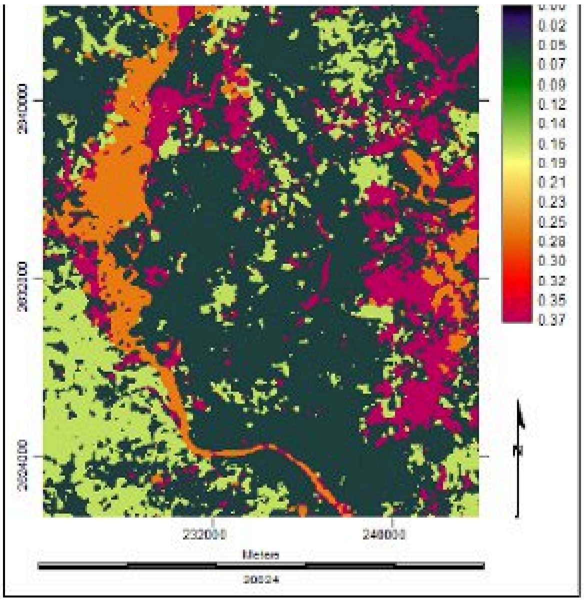
Proximity (areas will have a higher tendency to change to a class when they are near to existing areas of the same class) is one of the basic spatial elements of many land change events [13]. These can be very effectively modelled using Cellular Automata (CA). A cellular automaton is a cellular entity that independently varies its new state based on its previous state and that of its immediate neighbours according to a specific rule. Cellular automata consider the composition of associations of pixels around one pixel [14]. Clearly there is a similarity here to a Markovian process.

Automata depend not only upon the previous state, but also upon the state of the local neighborhood. It integrates four basis components: grid cells, rule, state and neighbour [14].

Markov Analysis provides no sense of geography or it has very limited spatial knowledge. On the other hand, Cellular Automata adds spatial character to the model [13]. CA_Markov combines both the concept of Markov Chain Analysis and Cellular Automata Modelling [13]. Therefore, combining both Markov Chain and CA (CA_MARKOV) will be much more accurate and logical for predicting the future land cover change for a certain area. CA_Markov is useful for modelling the state of several categories of a cell based on Markov transition areas matrix; transitional suitability images and a user defined contiguity filter [13, 14, and 15].

The estimating year is 2020 (t2) that is based on the transitional years 2009 (t1) and 1999 (t0). Therefore for this research purpose, 11 iterations are considered for future prediction.


0.04
0.08
0.11
0.15
0.19
0.23
0.27
0.30
0.34
0.38
0.42
0.46
0.49
0.53
0.57
0.61
232000
240000
Meters
20024


0.02
0.05
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0.09
0.12
0.14
0.16
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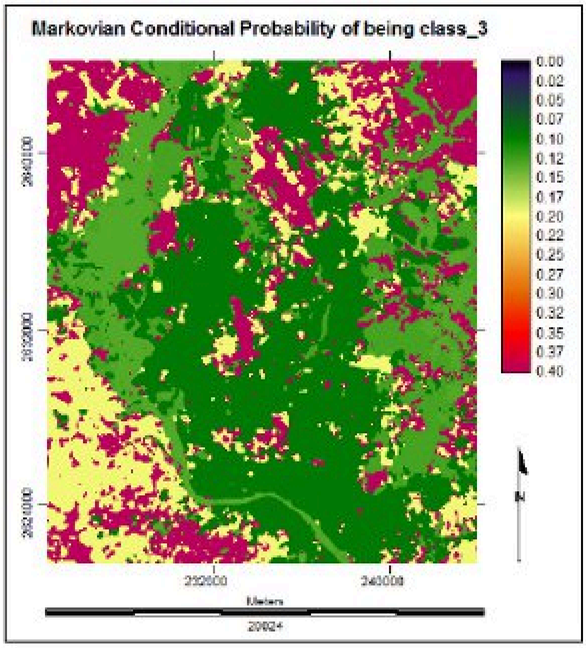
Markovian Conditional Probability of being class_3
0.00
0.02
0.05
0.07
0.10
0.12
0.15
0.17
0.20
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0.25
0.27
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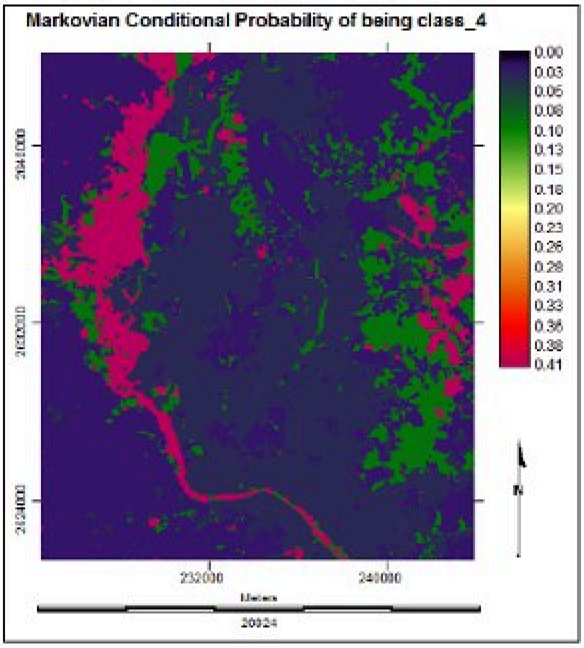

Markovian Conditional Probability of being class_4
0.00
0.03
0.05
0.08
0.10
0.13
0.15
0.18
0.20
0.23
0.26
0.28
0.31
0.33
0.36
0.38
0.41
232000
240000
Meters
20024

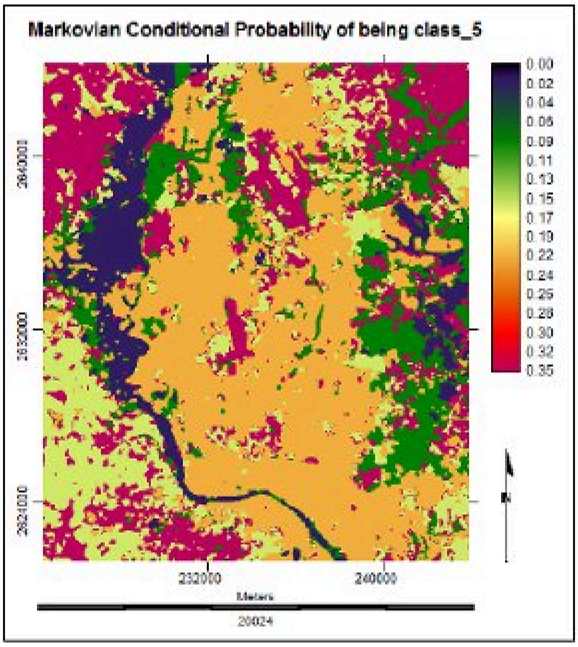

Markovian Conditional Probability of being class_5
0.00
0.02
0.04
0.06
0.09
0.11
0.13
0.15
0.17
0.19
0.22
0.24
0.26
0.28
0.30
0.32
0.35
232000
240000
Meters
20024

Figure 08: Markovian Conditional Probability Images

In this research, a 5×5 mean contiguity filter has been used (Figure 09). This kind of CA contiguity filter rules out to change landuse randomly. It adds some spatial character to the model [13].

0	0	1	0	0
0	1	1	1	0
1	1	1	1	1
0	1	1	1	0
0	0	1	0	0

Figure 09: The 5×5 Mean Contiguity Filter for CA_Markov Modelling

Distance and suitability images

These suitability maps are prepared based on Multi Criteria Evaluation (MCE) process where fuzzy set membership is used for standardising criteria [13]. For this research purpose, the factors or land cover constraints have been standardised to a continuous scale of suitability from 0 (the least suitable) to 255 (the most suitable). The 0-255 range provides byte data type [14].

The basic assumption for preparing suitability images is the pixel closer to an existing land cover type has higher suitability. Here the suitability decreases with distance. Therefore a simple linear distance decay function is appropriate for this basic assumption. Monotonically decreasing linear fuzzy set membership function has been chosen for this research as there is no complex relationship in the basic assumption (the far from an existing land cover type, the lower the suitability value for a pixel).

At the very beginning, the Boolean images for each land cover type have been prepared. Then the distance images (Figure 10) for each of the Boolean land cover images have been generated. The unit of measurement is in meter here. The distance images are produced using simple Euclidean featured image. The lowest and highest values obtained from the distance image are used as the input for fuzzy set membership analysis. Then the distance images have been standardised to the same continuous suitability scale (0-255) using fuzzy set membership analysis process (Figure 11).

At the end, the Markov transition area matrix, all the suitability images, the 5×5 CA contiguity filter and the base map of Dhaka city (2009) are used to predict the future land cover image for 2020. The CA_Markov predicted final land cover image (2020) of Dhaka city is illustrated in Figure 12.

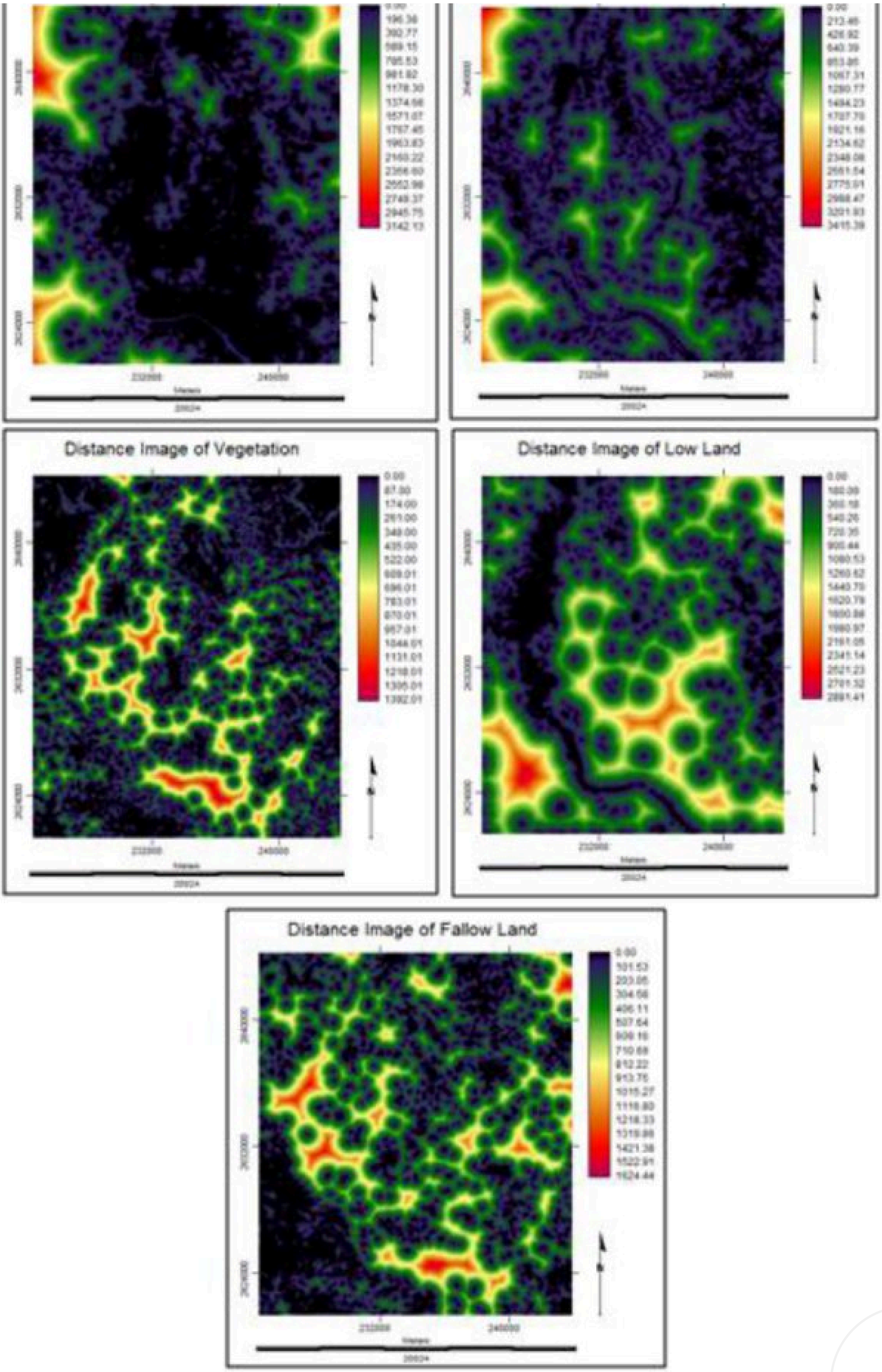
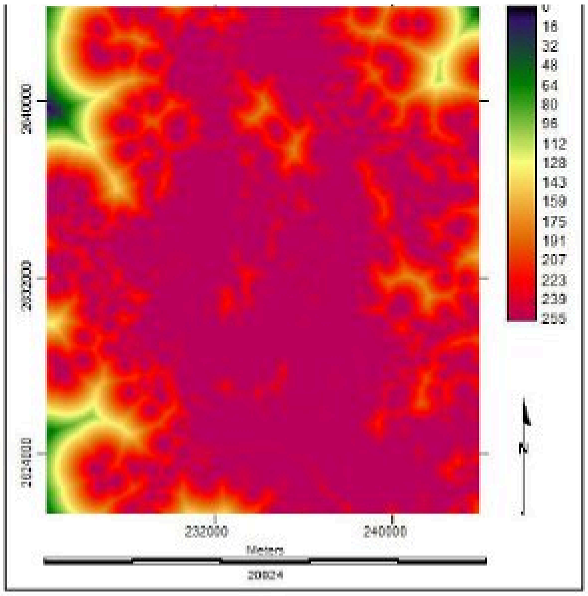
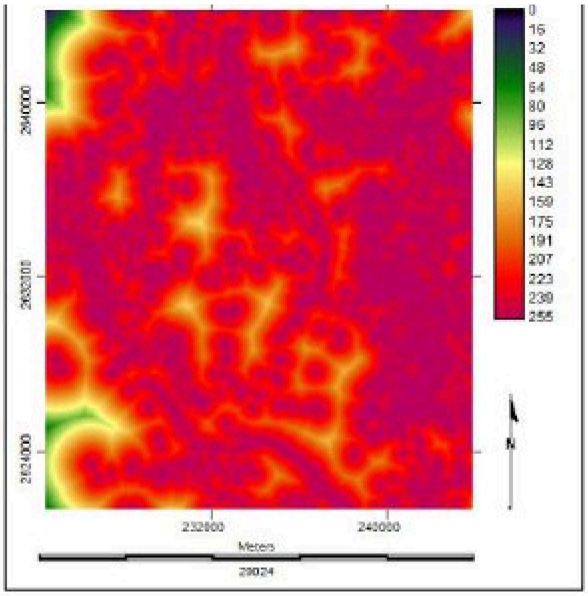
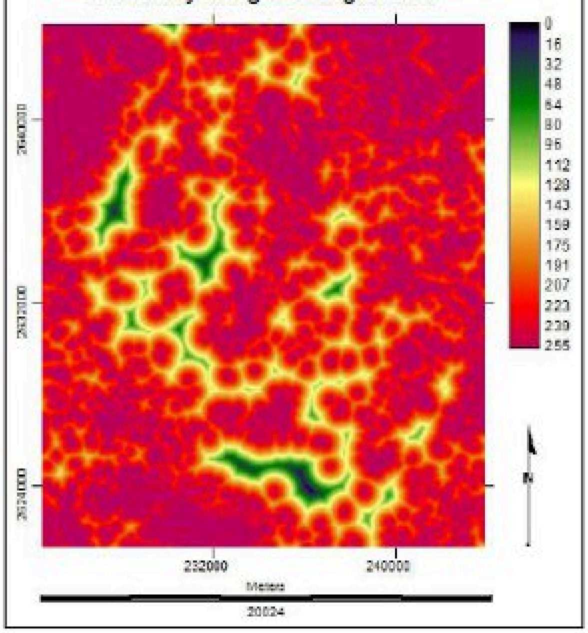


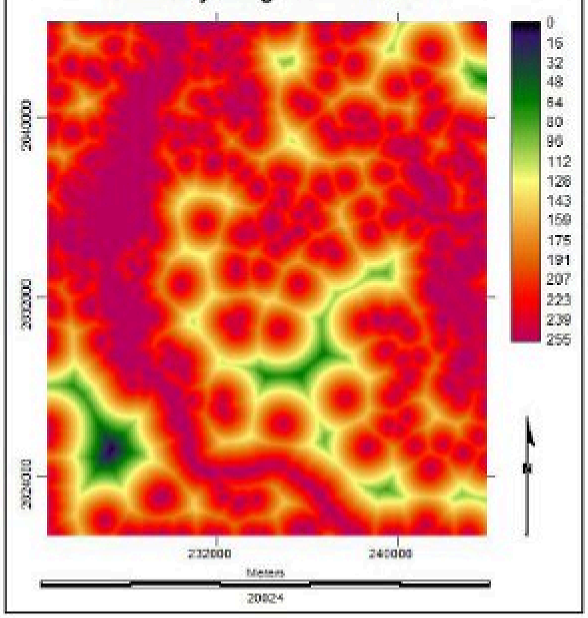
Figure 10: Distance Images of each Land Cover Type [Unit: Meter]



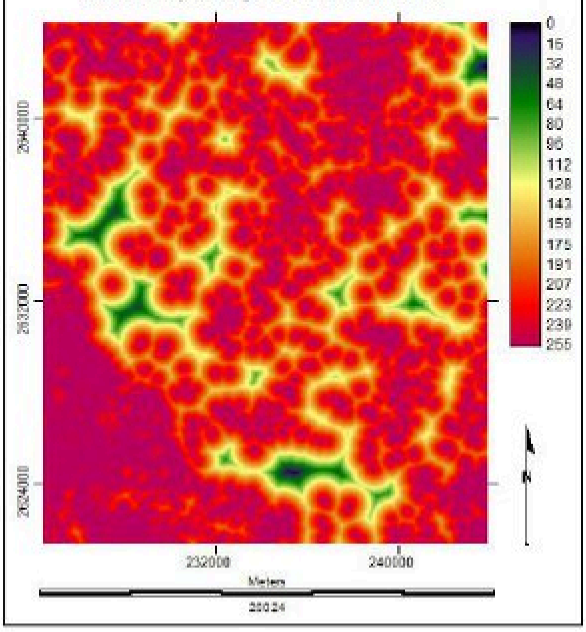




Suitability Image of Vegetation



Suitability Image of Low Land



Suitability Image of Fallow Land

Figure 11: Suitability Images of each Land Cover Type

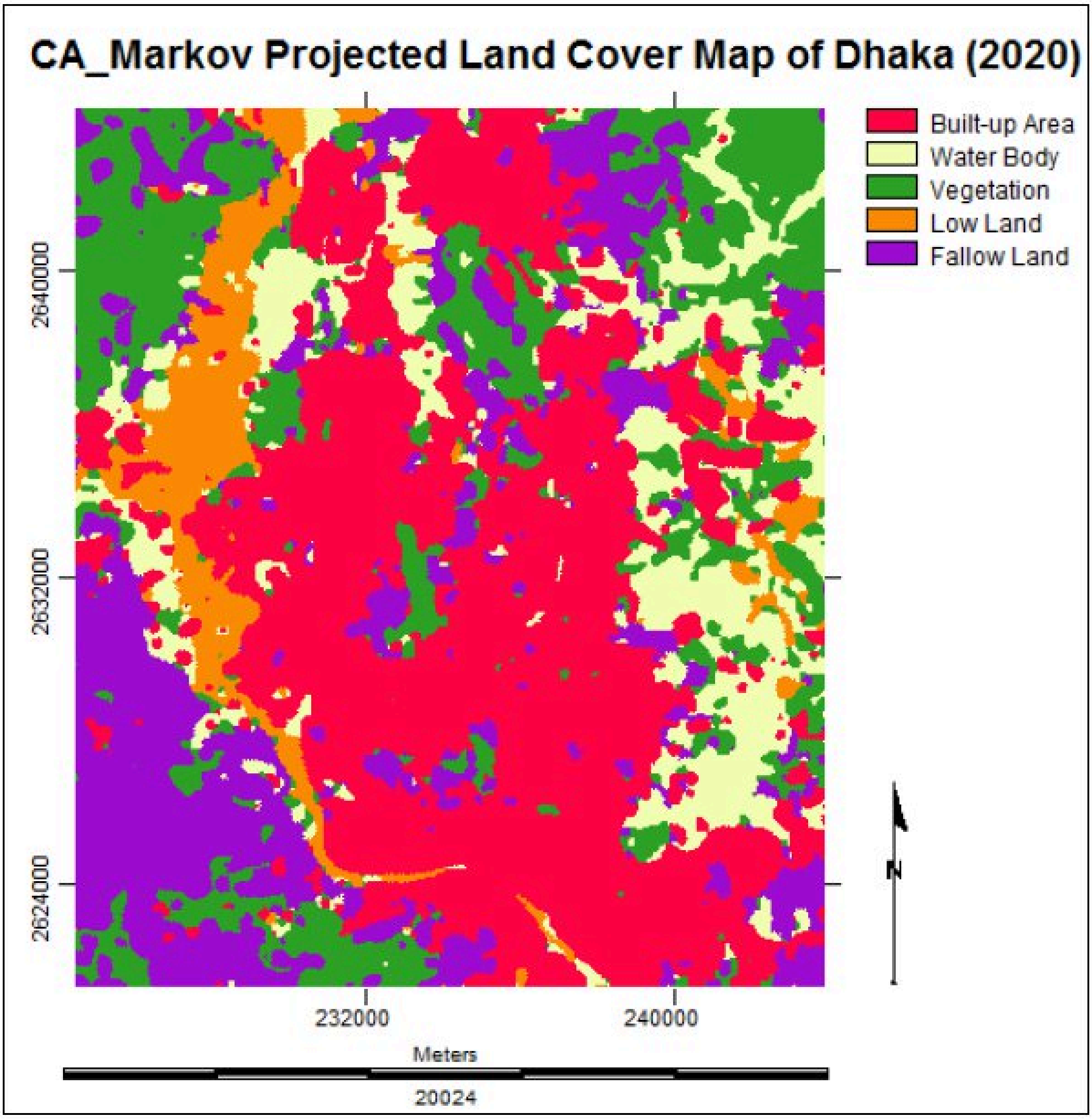


Figure 12: CA_Markov Projected Land Cover Map of Dhaka City (2020)

The city will expand on south-eastern and north-eastern parts in 2020 (Figure 12). Over the years built-up area will increase intensively (Table 05). Water body and vegetation will decrease. On the other hand, fallow land will increase significantly. Therefore the primary concern will be the change in built-up areas.

Figure 13 illustrates the different land cover types that contribute to convert into built-up area both in graphical and quantitative forms.

Built-up Area	166.885	37.438	184.665	41.426	**+17.780**
Water Body	60.337	13.536	58. 250	13.067	**-02.087**
Vegetation	98.518	22.100	82.975	18.614	**-15.543**
Low Land	40.716	9.134	30.914	06.935	**-09.802**
Fallow Land	79.314	17.792	88.966	19.958	**+09.652**
Total	**445.770**	**100**	**445.770**	**100**	**0**

Table 05: Summary of Land Cover Classification Statistics between 2009 and 2020

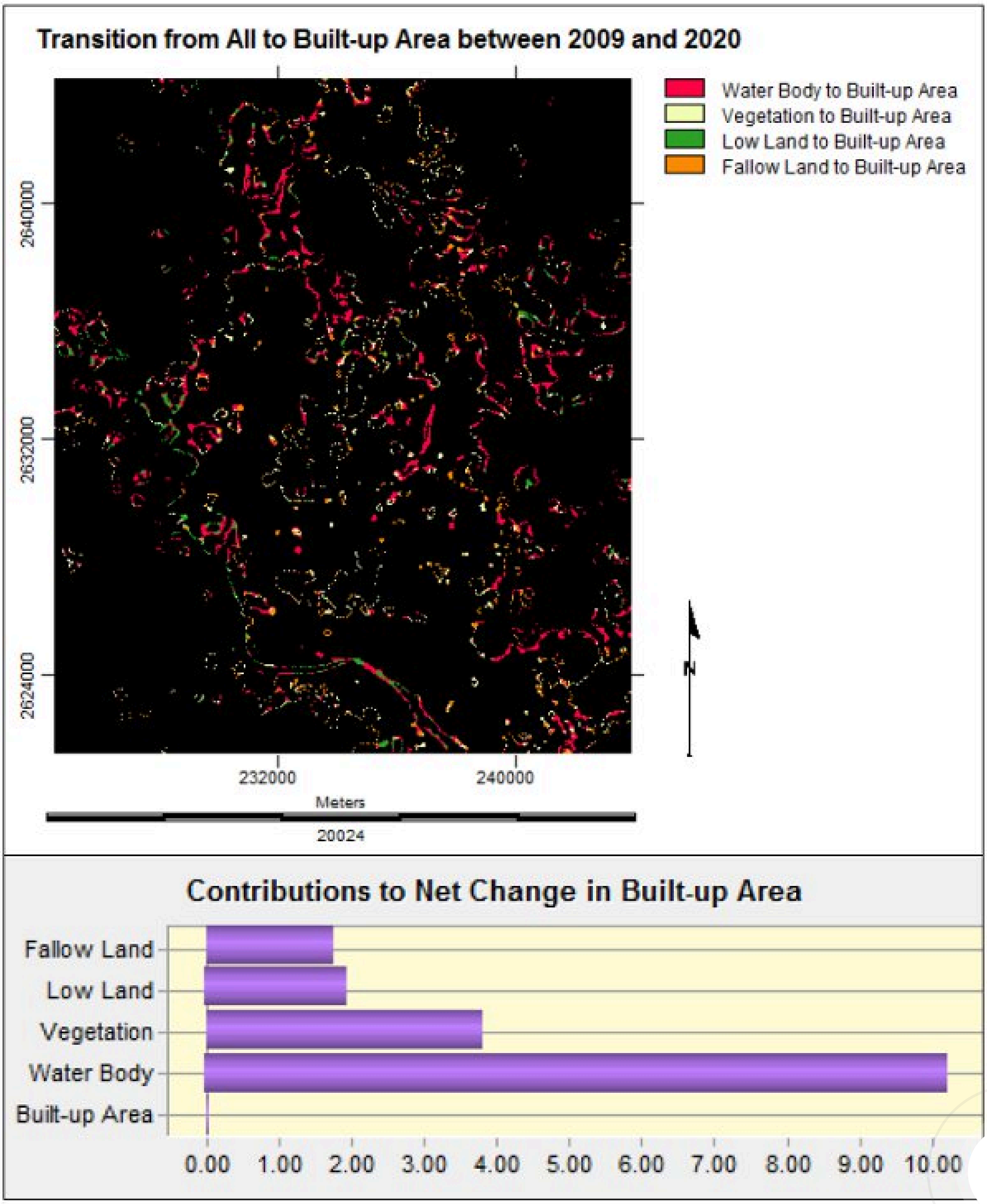


Figure 13: Change in Built-up Areas over the Years (2009-2020) [Unit: sq. Km.]

From Figure 13, it is clear that water body will convert into built-up areas most (almost 10 sq.km.). Vegetation will also be significantly changed into built-up areas (approx. 4 sq.km.). There will be also be a significant contribution from low lands and fallow lands.

This analysis proves that over the years (2009-2020), the urban built-up areas will increase notably in Dhaka city. The major contributions for this transformation to built-up areas will be from water bodies and vegetation. This analysis is based on the past trend (1999-2009) of land cover change. Therefore the urban planners should place high emphasis on land cover change pattern of Dhaka city.

Conclusion

Dhaka is one of the fastest growing cities in the world. Many parts of this city are unplanned. This kind of research will contribute shaping the urban form of the city in a planned manner. The decision makers as well the city planners can initiate appropriate plans based on the outcome of this research. This kind of analytic research can be remarkable in making Dhaka a much more liveable and planned city in near future.

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