TEMPORAL MAPPING AND SPATIAL ANALYSIS OF LAND TRANSFORMATION DUE TO URBANIZATION AND ITS IMPACT ON SURFACE WATER SYSTEM: A CASE FROM DHAKA METROPOLITAN AREA, BANGLADESH

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ABSTRACT

Temporal urban mapping develops a historical perspective of urban development by combining a variety of data sources into an integrated, multi-scale, and multi-resolution database. Temporal map and databases can be used to document human-induced land transformations in Dhaka Metropolitan Area (DMA), where the human induced land transformation rate is very high. Two main features – Arial expansion, and population increase characterize this land transformation processes as well as growth. An unplanned urbanization and landuse change has resulted into impediment of the natural drainage system, which has substantially reduced its water carrying capacity. This in turn alters the physical characteristics of the basin resulting in a change of response. Temporal urban map and database provides the baseline information for the planner and decision-makers to monitor and predict the patterns and future trends of urbanization. Temporal urban mapping relies on modern mapping techniques, such as remote sensing and geographic information systems (GIS), to capture information from both historical and modern records. The map and database highlights the profound changes to the landscape that have incrementally developed over time. In this research attempt has been made to develop several temporal databases based on historical maps/information and aerospace data to map and analyze the human induced land transformations for the Dhaka Metropolitan Area (DMA). GIS and remote sensing (RS) were used to compile and create database that provided a visual and historical perspective of the urban expansion experienced in DMA since before 1608 to 1996. This historical overview of the urban expansion was used to project the future urban expansion trend for the year 2010. This paper reviews that temporal urban map and databases have immediate applications in monitoring urban sprawl, watershed analysis, environmental assessment, hydrologic modeling, sustainable development studies and developing predictive modeling techniques to better forecast future areas of urban growth of DMA. This can also play a vital role to bridge the technological gap between different professional.

1 INTRODUCTION

Dhaka, The Capital of Bangladesh is facing the growing problems of urban sprawl, loss of natural vegetation, loss of open spaces, and a general decline in the spatial extent and connectivity of wetlands and wildlife habitat. These problems can be generally attributed to increasing population. Dhaka have gone from being small provincial headquarter to being large connected economic, physical, and environmental features of Bangladesh. The problems that society faces because of the growth of Dhaka and a concentration of large number of human populations is just beginning to be fully recognized as a significant environmental problem. Landuse and land cover changes are immense in Dhaka but very difficult to grasp without temporal mapping when they occur incrementally. With the help of GIS and Remote Sensing technology, the rates at which these human-induced changes are occurring can be successfully monitored.

Temporal urban mapping reconstructs past landscapes by incorporating historic maps, census statistics, and commerce records to generate a progressive geo-referenced picture of urban change within DMA. The database is being developed to illustrate the spatial patterns and interactions among the physiographic and socio-economic variables contributing to urban growth. Historical overviews of urban development provide insights into the future. This database will be of much use to urban and regional planners, policy and decision makers, Earth scientists, and global change researchers for measuring trends in urban sprawl, monitoring impermeable surfaces, analyzing patterns of water pollution and sedimentation, understanding the impacts of development on ecosystems, and developing predictive modeling techniques to better forecast future areas of urban growth. The economic, environmental and political consequences of informed growth decisions are vital to the millions of people living in large metropolitan areas.

2 OBJECTIVES

In this research attempt has been taken to develop several temporal databases and maps based on historical maps/information and aerospace data to analyze the human induced land transformations for the Dhaka Metropolitan Area (DMA). This historical overview of the urban expansion was used to project the future urban expansion trend for the year 2010. The major investigations of this research were:

- Monitoring and detecting land conversion trends using multi-temporal, multi-date and multi-sensor aerospace data, topographic maps of different period, and other historic maps.
- Quantifying the rate of human induced change over the landscape.
- Assessing the impact of urbanization and landuse change on surface water system of the Dhaka City.

3 METHODOLOGY AND MATERIALS

Interpretation (visual and automatic) was done to identify the built-up areas; lands are in the process of transformation from multi-resolution, multi-scale and multi-sensor of aerospace data and other historic data sets. An integrated GIS technique was developed to combine the data sets of different time spans (1955, 1975, 1989, and 1996) in order to reconstruct the past landscape. Linear regression technique was applied for projecting / predicting the future urban land transformation trends until year 2010. In order to examine the impact of urbanization on surface water system, the old natural drainage system was reconstructed from historical aerial photographs and TOPO maps with the aid of visual interpretation. Temporal urban mapping for the DMA focuses on the use of multi-sensor multi-temporal aero-space data, existing land use maps, digital census information, and existing time series TOPO maps (Table 1.).

Data layers	Date	Scale
-Topo Map 79I/5 and 79I/6	1960,1972,1991,&1997	
Table 1. Landuse Map	1986,1996 and 2000	1:50,000
Table 1. Aerial photograph	1955	1:50,000
Table 1. Aerial photograph	1975	1:40,000 (approx.)
Table 1. Aerial photograph	1983	1:30,000 (approx.)
Table 1. SPOT PAN (Hard copy)	1989	1:50,000 (approx.)
Table 1. TM (FCC) (Digital image)	1996	1:25,000 (approx.)
- IRS-1C PAN (Digital image)	1996	Path: 110 & Row : 55

Table 1. Maps and other Aerospace datasets used for creating temporal urban map data for the Dhaka Metropolitan City.

4 TEMPORAL URBAN MAPPING IN DMA

4.1 Evolution of Dhaka City

The evolution of Dhaka city was on the north bank of Buriganga river, until 1950 its growth was confined more or less between the Buriganga river in the south, Turag river in the west, Sitalakha river in the east and Balu river in the north east and Tongi khal in the north. The four hundred year history of the Dhaka City can be divided into five different stages of development:

i)	Pre-Mughal Dhaka:	Before 1608 A.D.
ii)	Dhaka under the Mughals :	1608 - 1764 A.D.
iii)	Dhaka under British :	1764 - 1947
iv)	Dhaka after Independence : (From British Rules)	1947 - 1971
v)	Dhaka becomes Capital of : Independent Bangladesh	Since 1971

Its geographic location and topographic setting have influenced the physical or areal extent of the city. A number of water channels criss-crossed through and around the city were used for natural drainage system within DMA. Another important feature of Dhaka’s topography is the low-lying area all around Dhaka, which stretches from the Buriganga bank in the south towards the north practically to the Tongi khal. These are playing significant role for storing excess urban storm runoff during monsoon and consequently reducing the flooding risk. A stretch of high land is flanked on either side by low-lying areas or backswamp and low riverbeds (Chowdhury and Faruqui, 1991). Often these low-lying areas or backswamp creep right into the heart of the higher area e.g. west to east and east to west direction depression are located in Mirpur to Cantonment and Baridhara - Khilkhet - Uttara areas respectively. The physical and topographical features of the city have always influenced the growth of the city. Therefore, the expansion of Dhaka city has not been easy and without difficulty.

The growth of the city before 50's was very low and gradual (Chowdhury and Faruqui, 1991). After 1950, Dhaka City has experienced significant but discontinuous and uncontrolled expansion. This growth is characterized by two main features – areal expansion and population increases. Present limit of Dhaka city which is known as “Greater Dhaka City” is in the North and North-West are Tongi and Savar across the Turag river and in the West is up to Mirpur, South and South-West is Keraniganj, Kamrangirchar, across the Buriganga river and in the East and South East is Rupganj, Narayanganj and Sitalokhya river. City is growing almost in every direction e.g. horizontal and vertical expansion.

4.2 Spatio-Temporal Analysis of Land Transformation due to Urban Development

Temporal database provided a visual and historical perspective of the urban growth experienced in DMA between before 1608 (Pre Mughul period) and 1996. Past landscapes were reconstructed using historic maps, aero-space data, land use/land cover maps, Topo Maps, and reports/books to generate a geo-referenced time series map documenting the changes in DMA. Database development was limited to the temporal mapping of urban and built-up areas, geomorphologic units, principal transportation routes, and natural drainage system to aid in understanding the spatial and temporal land transformations that occurred over time in DMA.

Land conversion boundaries due to urbanization and infrastructure information (roads, railway and embankment) and physiographic units were derived from a variety of sources ranging in scale and resolution. Sources included historical topographic maps, land use and land cover maps, aerial photographs, Landsat TM, IRS-1C PAN, and SPOT PAN imageries. The temporal urban database was compiled using a variety of image processing techniques including visual interpretation and automated spectral classification. GIS was used to assemble and integrate the data in order to create the spatio-temporal urban map for the DMA (Figure 1).

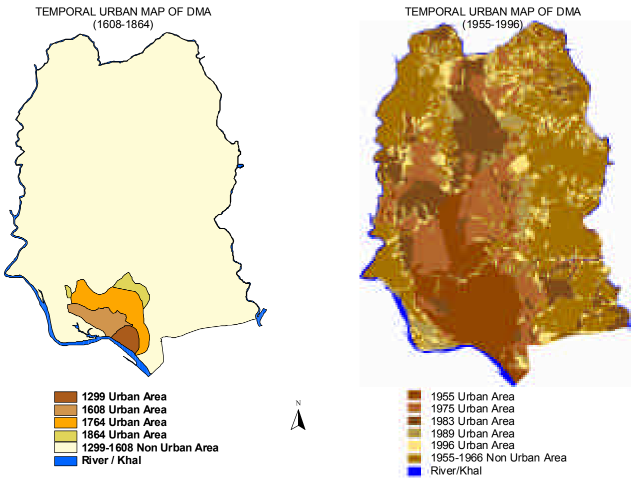

Figure 1. A historical perspective of urban development dramatically conveys the spatial patterns and rates of urban land use change experienced between before 1600 and 1996 for the Dhaka Metropolitan Area.

It is evident from the interpretation and integration of multi-temporal and multi-resolution aerospace data and other maps that Dhaka City has experienced a significant urban growth in the period of 1955 to 1996. Using GIS, the computed total area of Greater Dhaka Metropolitan City is about 28,522 hectares (ha.), while the urban and non-urban areas are 17,743 ha. and 10,110 ha. respectively. During this period (31 years) 62.21%, land has been converted to urban from rural. Table 2(a) illustrates the urban expansion in terms of area and percentage during 1955 - 1996 and Table 2(b) is showing the projected urban expansion for the year 2010. It was projected that by the year 2010 the total urban area will be 22,001 hectares (ha.), indicating that 77% area will be urbanized in the Greater Dhaka Metropolitan City. Figure 2. 2. is showing the past, present and future (projected) urban expansion scenarios of the Greater Dhaka Metropolitan City. Dhaka is having horizontal expansion along with the vertical intensification. This vertical intensification has started late 80's and added a new dimension in the city growing process. This recent phenomenon of high rise building in both commercial and residential sectors, clearly manifest the city to adopt this process to cope with the ever increasing population pressure and unavailability of land within central part of DMA.

Description			% of Urban Area Increase	Cumulative % of Urban Area Increase
Type	**Expansion Period**	**Area (Ha.)**		
Urban	1299-1608	221.00	1.24	1.24
Urban	1608-1764	472.00	2.66	3.90
Urban	1764-1864	928.00	5.23	9.13
Urban	1864-1947	237.00	1.34	10.47
Urban	1947-1955	2,068.61	11.66	22.13
Urban	1955-1975	4,647.40	26.19	48.32
Urban	1975-1983	4,242.55	23.91	72.23
Urban	1983-1989	2,078.89	11.72	83.95
Urban	1989-1996	2,847.50	16.05	100.00
Non Urban		10,110.58		
Water Bodies		668.25		
Total Urban	1299-1996	**17,742.92**		
Total Area		**28,521.74**		

Table 2(a). Rate of Urban Expansion from 1299 to 1996 in Dhaka City.

Areal Extent	Projected Year	Projected Urban Area (Ha.)	% of Projected Urban Area Increase	Cumulative % of Projected Urban Area
Urban	1996-2010	7,984.35	24.00	124.00
Total Urban	2010	22,001.22	77.14	

Table 2(b). Projected Urban Expansion Trend for Dhaka City in the year 2010.

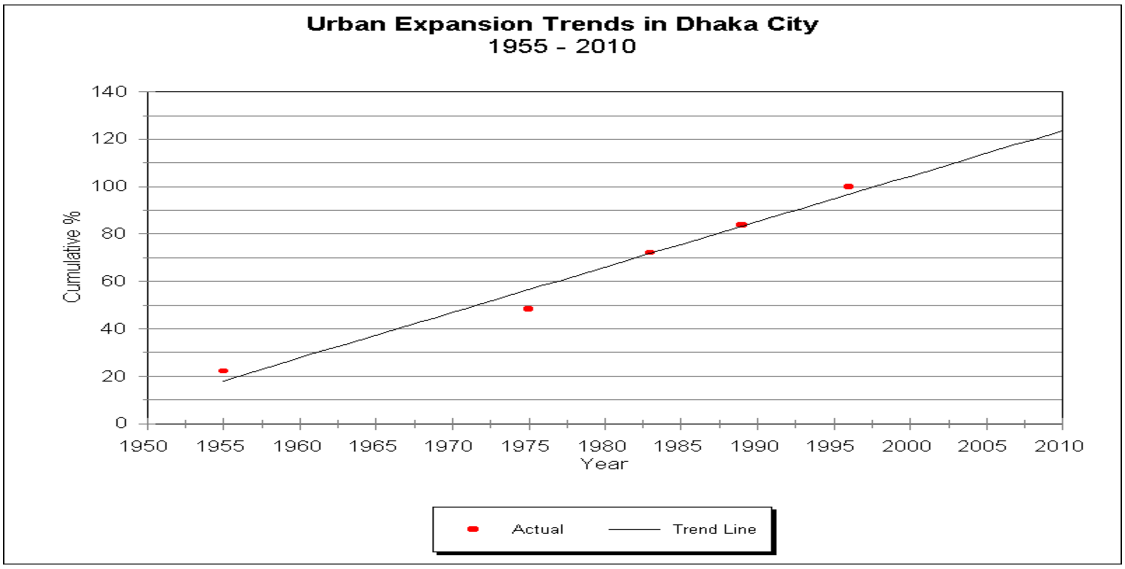

Figure 2. Urban Expansion Trend of Dhaka Metropolitan Area: Past, Present, and Future.

4.3 Relationship between Geomorphological Settings and Land Conversion Trend in DMA

In this section attempt has been taken to quantify the influence of topographical settings in the land conversion process. In order to establish this relationship a geomorphological map and associated attribute was prepared from 1955 aerial photograph and Reconnaissance Soil Survey Report respectively. In this map 10 major unit and 5 sub-unit was identified based on geological origin, lithology, and surface morphology and land elevation. Using GIS map overlay technique geomorphological map was overlaid with the urban expansion trend map in order to quantify the rate of urbanization per geomorphic unit in the period of 1955-1996. Result of this analysis giving the clear indication that topographical settings have the direct influence in the urbanization process (Table: 3). From this result, it is also evident that urbanization especially its structural growth in Dhaka City has followed typical and natural trend of spatial encroachments filling the higher lands to the lower lands during the period of 1955-1996. Thus, the **first level** urban development took place at the relatively higher terrace, elevation ranging between 10-12 AMSL. Within a range of 15 Km from the city center most of the high land is already built-up and occupied by man’s activities (Islam, 1996). The **second level** of urban development took place in the relatively medium terrace elevation between 6 - 9 AMSL. Due to the high rate of population increase and shortage of higher land, **recent** and the **third level** of urban development is taking place on the low terrace, depression, backswamps having elevations between 2 - 5 AMSL. Which is susceptible and vulnerable to riverine flooding and act as a natural storage area of urban storm water runoff for a longer period annually. This is also giving a very clear indication of drastic reduction of the natural storage areas by the urbanization process over the period. This process started from the mid 80'ies and continuing without proper planning. These depression and back swamps having important role in the ecological and environmental balance of Dhaka City.

Geomorphic Unit	**Year**								
	1996	**1989**	**1983**	**1975**	**1955**	**1864-1947**	**1764-1864**	**1608-1764**	**Before 1608**
High, medium, low Madhupur terrace and natural levee	86%	91%	94%	94%	95%	100%	100%	100%	100%
Depression, abandoned channel and point bar	14%	9%	6%	6%	5%	0%	0%	0%	0%

Table 3. Relationship between Geomorphological Settings and Land Conversion Trend in DMA during 1608-1996.

Madhupur Terrace occupied 20076 hectares of land, which is 70% of the total physical extent of DMA. Suitable land elevation and flood free nature of Madhupur Terrace is providing favorable condition for urban growth. Therefore, highest urbanization was took place in this geomorphic unit in the period of 1955-1996. This unit is almost filled-up with various kinds of infrastructure, high, and medium density urban areas. The Madhupur Terrace occurs in the central part of Dhaka City and reaches up to the northern bank of the river Buriganga. Only a narrow strip of natural levee of the Buriganga separates the terrace from direct contact of the river. The existing urban areas of this geomorphic unit generally consists of Postagola, Sadarghat, Sutrapur, BakshiBazar, Azimpur, Lalbag, Segunbagicha, Ramna, Hazaribag, Dhanmondi, Lalmatia, Mohammadpur, Tejgoan, Mahakhali, Sher-e-Bangla, Badda, Gulshan, Banani, Mirpur Cantonment, Uttara and Zia International Airport.

First urbanization was took place in the Old Natural Levee unit during the Sultani or Pre-Mughal period (1299-1608). Its suitable land elevation, favorable geological settings, hydrological and environmental characteristics along with a flood free drainage condition playing significant role to flourish Dhaka in this geomorphic unit. This unit occupied 583 hectares of land and at present only 3.28% of the total urban area of Dhaka City is on this terrace. This linear strip of elevated natural levee is running from Postagola in the southeast to Lalbag in the northwest.

In recent days, urbanization has been taken place in the depression and abandoned channel, which are not geologically suitable for urban expansion. This unit comprises Goran, Adabar, Shyamoli, Badda, Uttar Khan, Dhakhsin Khan, Kallyanpur, Agargoan, Kazipara, Paikpara, Saidabad-Jatrabari, the middle and north western part of Mirpur belong to these unit. Depression, Abandoned channels and pointbar occupied 7785 hectares of land, which is 28% of the total physical extent of Dhaka City. From the aforementioned result (see Table: 3) it is evident that in 1996, 14% urbanization was took place in this ecologically important unit. Urban expansion is continuing through massive landfilling process with peat and garbage with following the geo-scientific treatment. According to the 'Urban Structure Plan 1995' urban expansion will be encroached in these unit by the year 2015 due to the urban need of the growing population and shortage of higher land.

5 IMPACT OF LAND TRANSFORMATION ON SURFACE WATER SYSTEM IN DMA

The growth of DMA represents a dramatic transformation of natural landscape. This growth and expansion characterized by a rapid and uncontrolled development, leads to wasteful use of land resources, higher infrastructure cost, excessive energy demand,, and consumption and degradation of environment. Land pressure is greater due to the high rate of population growth. This land conversion rate is not only threatening the agricultural land but also the local watershed, damaging and reducing the local water resources and increasing the risk of flooding in DMA.

5.1 Imperviousness Resulting in Increase of Surface-Runoff

Impervious areas are defined as "the land surface having an infiltration capacity equal to zero" (Fleming, 1975 cited by Lazaro ,1990). Impervious area was defined in the study area as any man-made constructions feature of impermeable nature and considerably diminish the water storage capacity.

Due to the rapid and uncontrolled urbanization, the impervious area has increased significantly. Based on interpretation of aerial photograph (1955,1975 and 1983), SPOT Panchromatic (1989) and IRS-1C Pan (1996) image it was estimated that 85% of the total urban areas are impervious in nature. These assumptions were made based on image signature in terms of tonal, textural and pattern variation and local knowledge. Although percentage impervious areas varies in different residential units (High, medium and low residential area). Middle class residential areas contribute the higher values in impervious lands. On the basis of the above-mentioned estimate, the degree of imperviousness is 53% in the middle class residential areas. Impact of imperviousness in the surface water system of DMA could be summarized as:

- Reduce infiltration / sub-surface flow.
- Reduce ground water recharge.
- Changes in the flow regime of the khals.
- Increase surface runoff.
- Increasing pressure on storm water drainage system.
- Increasing pressure on open-drain systems.
- Failure in existing drainage system.

Imperviousness creates specific hydrological processes in the urban area. When rain falls on city two parallel processes takes place, which depends on the characteristics of the water-receiving surface. Major parts of the rainwater infiltrate into the unpaved areas at the beginning of the rainfall, but the excess rainwater creates a huge volume of surface runoff. After ponding, it starts moving slowly towards the low lying areas of the city. Land development or urbanization process within the city in the low lying areas reduces the natural storage areas and increasing impervious areas day by day. Imperviousness is reduces the storm runoff "lagtime" and consequently it is increasing the flood peaks. Therefore waterlogging is very common problem during the rainy season in Dhaka City. DMA, itself does not have a proper and well-planned storm water drainage system. A huge amount of runoff, produced by the storm event in the period of June to October, can't be discharged through the existing storm water system. Most parts of DMA, especially where natural drainage channels disturbed and demolish by the human interference are facing sever waterlogging and associated environmental problems during monsoon. Resulting disruption of the socio-economic life of the city dwellers as a by-product. If the stipulations of the urban planners become true that the eastern part of DMA is going to be urbanized by the year 2010, then this could result in increased flood peaks even for the normal annual floods.

5.2 Reduction of Natural Water Retention Areas Due to Land Development through Landfilling

The depressions, abandoned channel, and low-lying areas are acting as depression storage in DMA which is retaining excess storm runoff or over flow of rivers thus delaying and lowering the flood peak and also slowing down the average speed of the flood water. It is evident from the temporal map and database that DMA expansion is stretching towards the low-lying areas, which is vulnerable to annual internal and external flooding. Therefore, localized flooding is experienced in previously well drained and flood free area due to construction of buildings, interfering with existing corridors for overland flow.

A large number of backswamps and depressions are already filled by means of land filling. In addition, the process of land development through land filling buries a large number of natural channels. 'Flood Alleviation Measures' through construction of embankment in the western part and eastern part of the city will speed up the urbanization process in the low-lying area using landfilling methods. Through these practices, the 'Natural Storage Function' will be disrupted. The adverse effects of landfilling in the surface water system are stated below:

- It is reducing the storage area for the rainfall-generated runoff, which aggravated the internal flooding in terms of frequency, duration, and depth.
- Disrupting the hydraulic link between major and minor channels.
- It is affecting the ground water regime of the city.
- Destruction of the ecological balance of the city and its surrounding area and reducing the natural fish breading ground.

As entire DMA is surrounded by rivers from three sides, existence of natural water retention areas are essential particularly along the rivers would cope with overflow of river and storage of urban storm runoff during monsoon.

5.3 Increasing Sediment into the Natural Drainage System of DMA

Due to the rapid and uncontrolled urbanization a large amount of sediment are producing from the construction materials and being dumped in the near by wetlands and transported through surface runoff during monsoon. This is causing the clogging the natural watercourses and reducing the water storage capacity of the wetlands as well as man made drainage system within DMA. Therefore, it is increasing the risk of flooding.

5.4 Increasing Water Pollution in and around DMA

Due to the high population density DMA is producing 0.47 kg/capita/day which is 227,153 tons/year (DMDP, 1992) of waste. Uncontrolled and direct disposal of untreated solid waste in the khals, wetlands and surrounding rivers, open dumps and poorly managed or designed landfills are major causes of surface water and ground water contamination of DMA. Apart from the domestic waste, most cases dying, lather and food-processing industries in and around DMA is directly dumping their untreated waste into the khals wetland and surrounding rivers. This is causing severe surface water pollution and eutrophication and poses a significant risk to health.

6 CONCLUSION

Urbanization results in profound changes to the landscape, specifically the proliferation of asphalt and concrete, and the displacement of agriculture and forestland. The study of the temporal mapping of DMA successfully demonstrated the utility of integrating existing historic maps with aerospace data and related geographic information to dynamically map urban land characteristics for large metropolitan areas. These mapping provide a strong visual portrayal of recognized growth patterns, and dramatically convey how the progress of modern urbanization results in profound changes to the landscape.

Historical overviews of urban development provide insights into future development and expansion trends. This maps and database will contribute to the research and technology base needed to understand the dynamics of urban phenomena. A temporal database and map of urban land transformations, depicting these changes, is needed by urban and regional planners, policy and decision makers, earth scientists, and global change researchers to measure trends in urban sprawl, analyze patterns of water pollution and sedimentation, understand the impacts of development on ecosystems, and develop predictive modeling techniques to better forecast future areas of urban growth.

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