Masters Program in Geospatial Technologies

QUANTIFICATION OF URBAN LAND USE INTENSITY
A Case of Dhaka City of Bangladesh

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DECLARATION

I hereby declare that, this research paper is the result of an independent investigation and had not been submitted to any other university or academic institution. Acknowledgement has duly been made where this paper is indebted to the work of others.

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ABSTRACT

Land use intensity as a measure of degree of development, is an important element of urban form. The intensity of urban land use types is determined spatially through enacting land use zoning. Cities are under circumstances of experiencing continuous land use change due to rapid urbanization process and resultant demand for land for various human needs. Dhaka city of Bangladesh, being one of the populous cities of the world, is observing mostly haphazard development in an unplanned way of horizontal and vertical use of city land. The existing land use policies of use zoning and height zoning failed to render a comprehensive development indication to ensure planned and sustainable growth of the city. This study is an effort to quantify the spatial pattern of land use activities in terms of their intensity by proposing an amalgamation of both horizontal and vertical measurement of the space used in the city. A cell-based GIS analysis of land use data was carried out to explore the amount and location of total development intensity for major urban land classes. The findings of the study can bring a new impression to city planners and researchers to look back to land use regulations in order to update it, and fix zone specific permitted degree of land usage to promote healthier growth of the city .

KEYWORDS

Quantification

Land Use Intensity

Land Use Planning and Zoning

Urban Form and Development

Cellular Automata

Geographical Information Systems

Spatial pattern

ACRONYMS

ASB – Asiatic Society of Bangladesh

BBS – Bangladesh Bureau of Statistics

CA – Cellular Automata

DAP – Detail Area Plan

DMDP – Dhaka Metropolitan Development Plan

FAR – Floor Area Ratio

ILDIs – Infrastructure-led Development Initiatives

LUI – Land Use Intensity

GIS – Geographic Information Systems

RAJUK – Rajdhani Unnayan Kotripokkho (Capital City Development Authority)

SPZ – Strategic/Spatial Planning Zones

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CHAPTER 1: INTRODUCTION

1.1 Background to the study

Land use dynamics, as a broad aspect, are studied significantly in the city planning and development context. It includes a wide range of theoretical and scientific discourses that relate the reasoning and effect of land use change to the socio-economic, physical and environmental systems of any geographic area under concern (Redman, 1999; Yeh et al., 2002; Islam et al., 2009). Land use[1] is a set of human activities that occur on a given geographic area (Brown et al., 2005; Min et al., 2007). These activities give land names by classifying it based on the use it serves, such as agriculture, utilities, commercial, residential, etc. On contrary, land use intensity (LUI) refers to the concentration of each activity on a land lot and explains the extent of its use. It is a scale that measures how much usage is distributed and how much of the land is being used at a location of the given land (Min et al., 2007). LUI is considered as an indication of the amount and degree of development in an area, and a reflection of the effects generated by that development in conformity with zoning ordinances, a development control policy measure (Ng, 2010). A typical value of land use intensity of 10,000 square feet per acre of land specifies allowable degree of development on that land and suggests preserving rest of areas from being built or human-modified. Research on such land use issues is being carried out actively, both in urban and rural areas that differ by the scale of human modification of land area. Intensity of land use activities especially in urban space is seen in two ways; land-use density and mass density (Robert, 2007). The first one is a measure of horizontal coverage of space by land use activities within a geographic boundary. On the other hand, mass density measures the three-dimensional volumetric extent of urban structures in terms of floor area ratio (FAR) to the land-area of the structure. Both measures have immense importance in studying the urban built environment. They explicate the overall land use structure defining the configuration of physical growth of an area.

Cities, as geographic units, are of typical example where land use and its intensity change frequently because of rapid increase in its population size. A city acts as a hub of employment opportunities and standardized civic amenities; thus it continuously offers

[1] The term ´land use´ differs from a synonymous expression ´land cover´ by the scale of human operation over space. Land cover is often meant to denote broad categories of land classes over a larger region involving natural land covers like desert, forest, sea.

people to come and be involved in a process of settling down there. This migration trend is alarming in big cities of the world, and is leading to numerous challenges of efficient utilization and management of land resource and other required facilities (road infrastructure, water, sewerage, etc.). Cities are expanding in demographic and geographic extent enabling increased human preference on land use location. Several studies found that there are location-decision factors that make people decide the location of a particular use-activity, such as neighborhood environment quality, proximity to work place and amenities, land price, ethnicity, etc. (Min et al., 2007; Crooks 2010). Residing tendency of citizens near work place and other facilities along with provision of transportation corridors by development authority encourages emergence of multiple employment centers at different locations of the city giving the city a polycentric growth form. This is a common experience for the cities of developing countries. They are undergoing rapid urbanization and frequent transition in land use structure as a result (Islam et al., 2009).

Dhaka, being the capital of Bangladesh and one such city, had expanded almost 18 times from its size in the year 1951, while over the same period population had increased 25 folds (Islam, et al., 2009). It has turned into a megacity having a population of 13 million and 37.45% of urban population of the country (BBS, 2001). The United Nations (2000) addressed Dhaka as a ′exceptional city′ due to rapid population growth, and the city would stand 4th position in the list of megacities of the world with a projected population of 21.1 million by the year 2015. The process of urban expansion over the years till today took place mostly in an unplanned way. The inner city is experiencing vertical expansion with high building density and horizontal expansion mostly by encroaching the peripheral lands (Islam et al., 2009). Several spatial development policies and interventions like urban consolidation, planned new area development, infrastructure-led development initiatives (ILDIs), control in urban core and of flood plain zones, were undertaken to optimize the land recourses with a goal to keep the city sustainable by maintaining a balance between compact development and urban open space (RAJUK, 1995). The Dhaka metropolitan development plan (1995-2005) was a holistic attempt by capital city development authority (RAJUK) that encompasses such policies and regulations to ensure healthy land use density through maintaining urban built-open space ratio with reduced alterations in fringe areas. But the city is still going through an uncontrolled development process featuring high density of population in certain locations, lack of open space, traffic congestion, poor quality of infrastructure and facilities (RAJUK, 1995; Islam et. el., 2009). It is losing high valued agricultural land, wetland, flood plains and other ecologically critical areas (Islam et. el., 2009). Studies (RAJUK, 1995; Alam, 2007; Islam et al., 2009) showed that recent land use practice by urbanites have brought unplanned conversion of planned residential areas or uses into mixed types through accommodating more than permissible commercial and other urban activities. These intermixing of land uses have given birth to some employment sub-centers[2] across the city which serves again as the nodes of further land use densification and alterations around it (RAJUK, 1995; Yeh et al., 2002). Therefore, the city ´Dhaka´ is evidently growing horizontally and vertically, and experiencing a change in the spatial distribution of land use intensity affecting the size and shape of the city- the overall morphological form of the city. The whole situation being in a process certainly threatens the living environment (Islam et al., 2009). Development density or land use control as such has become a critical issue for the city development authority, RAJUK.

In such a backdrop, land use intensity- the degree of development in a city, deserves to be examined carefully. It is an integral element of urban form. It is to be quantified in such a way that can aid in portraying the built-environment. The spatial composition of land use intensity essentially depicts the scale and distribution of development from which an understanding of managerial aspects of land resources for various urban activities can be achieved. Quantification of intensity can point out land-use conflicts, locations of height-intensive developments and therefore, reveals the integrity of existing zoning regulations for promoting planned development. The capital city development authority enacts land use policies for use and height restrictions based on the accessibility of plot to the existence and width of the road. They do not consider a comprehensive intensity scale, an index which might determine the proportionate growth of various use-activities in differentiated areas that accounts for both vertical and horizontal built density simultaneously. There has been several land use studies carried out in Dhaka city but none of them are directed towards computing a comprehensive intensity index. This study states a ground for computing the use intensity in such an inclusive way, and how location-decision factors are shaping the amount of use intensity on certain locations. The explorative analysis of the inclusive intensity pattern over the city space is believed to provide an information base for planners in reviewing land use plans and zoning provisions. The result of the study also has importance in estimating the future need of

[2] Employment sub-centers refer to the spaces outside of central spaces with large employment size that rival the city center (CBD) as places of work (Daniel, 2001).

facilities and utilities, in order to incorporate them into city infrastructure, transportation and environmental management plans.

In a nutshell, this study is intended to identify the spatial pattern of land use intensity through computing and investigating its relationship with the location-determining factors which are outlined and discussed in the research aim section.

1.2 Research aim and objectives

The main goal of the study was set to identify the spatial pattern of land use intensity in Dhaka city by suggesting a 2-D (horizontal) and 3-D (vertical) measure of use intensity of urban space. In light of the background of the study, a general question evolves while estimating such intensity,

What is the extent of land use, where and why?,

which again requires answering following two key questions:

(i) How to compute the use intensity of urban space considering 2-D and 3-D use space to know the extent of land use?

(ii) How use intensity varies spatially,- what variables explain the reasoning of land use intensity pattern?

Literature survey revealed that there had been no effort made in past, at least in the study area, which considers both types of land uses concurrently in computing intensity and identifying its possible implications on land use management. To get an idea of total urbaneness (could be defined as the extent to which the space is urban) of the study area, the inclusion of both types of measurement is necessary. This comprehensive quantification of land use intensity certainly answers the question of how rigorously land is urbanized and used. In any case, an effort can be made to understand the spatial characteristics of both types of land modifications. The study argues that urban land area is subject to expansion and modification due to a number of location-determining factors of use activities on the land. Urbanization and population pressure (Zhang et al., 2004), neighborhood living quality and human ethnicity (Crooks, 2010), employment opportunities and human preference for living near work place and urban amenities (Islam et al., 2009), infrastructure facilities and accessibility (Yeh et al., 2002; Kim et al., 2002), land value and citizens´ income level (Min et al., 2007), as well as land use regulations (RAJUK, 1995) have direct and indirect impact into the land use change process and amount. Land use regulations, in fact, impact the pattern of road and employment centers and population distribution across the area. All factors are somehow interrelated in a process of influencing urban land use form. These factors were generalized and categorized into four major determinants in relation to the social (urbanization) and physical characteristics (mixing of land uses, multiple employment centers) of the study area, which are as follows:

(i) Population density:

It covers the effect of urbanization and total population of the city on land use density. Urbanization is treated as an important component of land use and land cover change (Zhang et al., 2004). The growth in population size inevitably creates pressure on existing land resources and thus, tends to consume land previously used for agriculture and wetland (Yeh et al., 2002). Increased population density generates smaller land classes through landscape fragmentation (Zhang et el., 2004).

(ii) Proximity to adjacent land use classes

This includes human preference to be near certain neighborhood or community services. Residential location sometimes occur at the places where there is existence of certain amount of facilities such as neighborhood living quality as well as commercial, educational and recreational use activities. Again commercial activities might be located near the residential or educational establishments to get the minimum potential customers for its business operation. In principle, every use location has the chance or tendency to be located near other uses particularly in an organically grown city like Dhaka (Alam, 2007; Islam et al., 2009).

(iii) Proximity or accessibility to urban roads

There is direct impact of road network on the land use. Road facilities define the accessibility to land use activities. Urban street configuration influences the location of land uses through establishing the value of the land in addition (Min et al., 2007). Typically commercial activities take place along the road and residential away from the major road (Kim et al., 2002). Height zoning of any use is always based on the accessibility to and width of the road (RAJUK, 1995).

(iv) Location of urban employment centers

Urban development takes place around the central business district (CBD). Several urban growth theories like Von Thunen´s Concentric Theory, Christaller´s Central Place Theory, Sector Theory, Alonso model, showed the relation between one or more market centers and the gradual distance of settlements, urban firms or industry and agriculture (Kim et al., 2002; Zhang et al., 2004). The population (residential use) and employment (commercial use) density is inversely related with the distance from the city centers (Kim et al., 2002). Even though most of these theories were based on American societies or cities, the location of employment or such market centers is quite responsible in shaping the urban land use form.

Therefore, following objectives were chalked out to attain the goal of the present research:

Objectives:

(i) To compute the land use intensity.

(ii) To explore the pattern or form of use intensity over the city area.

(iii) To investigate the relationships between the location of use intensity and determinants.

The first objective necessitates developing a method on how to compute the intensity of land use activities in the study area, while the next two objectives attempt to identify the spatial effect of determinants on the distribution of land use activities and intensities.

CHAPTER 2: THE STUDY AREA

2.1 Geographic extent

The study area, Dhaka Metropolitan Area (DMA) is located between 23°42' to 23°54'N latitudes and 90°20' to 90°28'E longitudes, and bounded by the rivers Buriganga to the south, Turag to the west, Balu to the east and Tongi Khal[3] to the north (ASB, 2003). The city is situated at the center of the country geographically (Fig. 1). The DMA comprises an area of 117.32 sq.mile (about 301.13 sq.km.) including the area under the jurisdiction of Dhaka City Corporation (DCC) (BBS, 2007).

2.2 General features

Dhaka has emerged as an important strategic and business center in the 13th century (Islam et al., 2009) and gained a city status in 1947 (ASB, 2003). After the liberation war in 1971, the city became the capital and expanded phenomenally. The economy has grown in response to the city growth and mostly based on manufacturing industries with continuous support of better services (RAJUK, 1995). Rapid urbanization and recent urban physical configuration has brought significant changes in the geo-environment of the city area (RAJUK, 1995; ASB, 2003). The land was flood free, but recently is susceptible to water logging, flooding, congestion and pollution (Fig. 2-b, 2-c).

The city has experienced notable change in its physical development. The decade of 1980 was the period of major land conversion from rural to urban (RAJUK, 1995). It was calculated that, between 1983 and 1991 more or less 5,500 hector lands were converted to urban uses. Around two-third of this total land converted in the fringe areas, and the rest in the central urban areas of the city. At the same time, the population increased only 30% in the fringe area and 70% in the central urban areas (Fatema, 2003, cited in Islam et al., 2009).

The overall intensity of development in established areas of Dhaka is high (Fig. 2-a). There is a predominance of mixed uses leading to land use conflicts. There is low proportion of non-residential uses- parks, roads, commercial and industrial areas. There is slums and squatter settlement (Fig. 2-b) with particularly high densities, and proportion of

[3] Khal is a natural water body not big as river but more or less similar to lake in size.

population living in spontaneous grown areas rather than in planned zones (RAJUK, 1995).

Figure 1: Location of the study area, Dhaka Metropolitan Area (DMA)

Figure 2: Consequences of urbanization on land use and the built environment of Dhaka city.

Figure 2(a): Horizontal and vertical development in the city.

Figure 2(b): Land use and environment conflicts- growth of slums, water logging.

Figure 2(c): Excessive crowd and traffic congestion.

Source: Internet, October 11, 2010.

CHAPTER 3: DATA AND METHOD

3.1 Description of data

Computation of land use intensity in Dhaka city was carried out based on the land use data prepared in the phase of Detail Area Plan (DAP) under Dhaka Metropolitan Development Plan (DMDP) by the capital city development authority (RAJUK). The data was developed in vector format (ESRI shapefiles) through direct topographic survey during 2005-06. Population data used to compute population density was taken from the National Series, Population Census Survey 2001 (adjusted in 2007) carried out by Bangladesh Bureau of Statistics (BBS). The land use dataset contains location and attribute information of all geographic features like building structures, road, footpaths, water bodies, open space and agriculture. Each building structure is again attributed with the number of storey and the use it serves. Since there is a concern of estimating the accurate coverage of each class to develop an intensity index, the study directly dealt with vector format data. Representation of space in vector data model in terms of a series of points, lines, and polygons permits the inclusion of geometry and geographic detail (Crooks, 2010). It allows precise computation of geometric area over raster format or satellite image. Raster data are subject to missing geographic detail based on its resolution.

3.2 A cell-based computation technique

To quantify the land use intensity, the study incorporated a method of cell-based data computation by dividing the total space into continuous square grids of 258 and 188 row and columns respectively with a cell size of 100 meter by 100 meter. Cell-based geographic information system (GIS) mainly in the form of Cellular Automata (CA) model is considered as a powerful planning tool to store land use and other related information for urban growth simulation (Yeh et al., 2002). This study emphasized storing cell based intensity value for different land classes in order to be used as a databank for future update and development of zoning regulations.

Determination of cell size in CA is always critical and requires some justification. It depends on justifications of how the cell should behave in response to the model or study objectives. Following aspects were considered to settle the cell size on 100 meter:

- First of all, one of the main tasks of the study is to compute impact of adjacent land use classes on a specific use for each cell as a key determinant of land use location.

So, the cell size should be large enough to contain more than one land uses. In other sense, the minimum size of the cell is to be determined to the extent that it could contain at least two land use classes. If the cell size is below 100 meter, there could be a risk of having a lot of single-use cells which might reduce the samples of the determinant and thus, might also produce skewed result. To avoid such circumstances, the study assumes that there would not be any discrepancy in the final result if the cell size is kept big enough to contain multiple land classes within it.

- Secondly, the question is what will be the maximum limit of cell size then? In the study area, the maximum width of the road network including road side walkway is under 100 meter and does not even cross 75 meter (e.g. widest one is Manik Mia Avenue in front of National Assembly Hall, 60 meter approx.). Then, to avoid the cells with only road use and to include multiple land uses within a single cell, the cell size was fixed at 100 meter. The land classes that generally occupy bigger space are road, water body, agriculture and open space. But in the study area, only ´road´ among them occupies more land surface. That is why only road is taken under consideration in determining the cell size.
- Yet, there could be a trade off for smaller cell size through minimizing the cell size below 100 meter, such as 10 or 50 meter. But as mentioned this study wants to look at the decision aspect of land use location, it again presumes that the location decision for any particular land use activities by human extremely varies only between cells with a minimum size of 100 meter.

So finally, the cell size was kept as small as there could be a variety of use types which might have potentiality of being affected by location-determining factors.

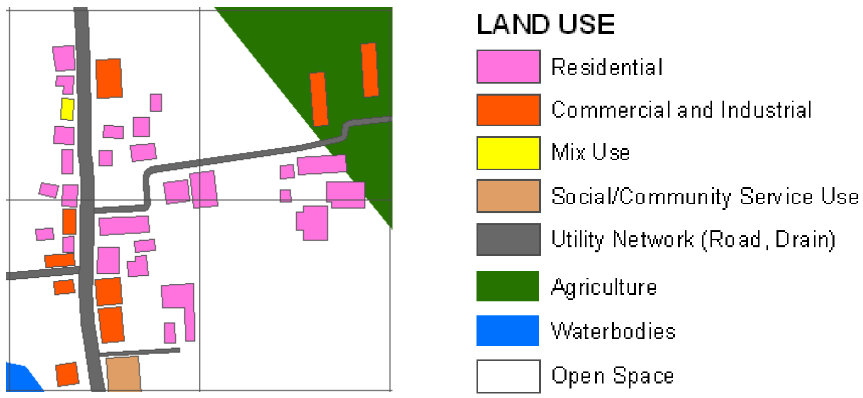
3.3 Major land use classes

The raw land use data contains geographic features with their functional identity in the study area. These dataset was then reclassified into 8 use-classes (Fig. 3) using ArcGIS according to the goal of the research. The classification was justified based on a similar land use study (Zhang et al., 2004), and simplified according to the major land use classes as mentioned in the Dhaka Metropolitan development Plan (RAJUK, 1995). The definition of land use classes are as follows:

1) Residential- land space used for only residence purposes

2) Commercial- space used for only commercial, business and industrial activities
3) Community service use- structures and space occupied by other than residential, commercial and industrial uses. These include religious, educational, recreational and community service uses like clubs, community centers.
4) Mix use- space used simultaneously by at least two of above uses. Mix use usually constitutes residential and other activities together.
5) Linear network – surface space occupied by urban linear utilities such as road, footpath, drain.
6) Water body- any water bodies inside the study area boundary including wetland and as identified by the topographic survey.
7) Agriculture- space used for cultivation inside the area of urban jurisdiction; fishery, nursery, crops
8) Open space– includes building bulk-free space, park, playground, garden, any urban green space, vacant or unused land usually not used by above mentioned use classes from 1 to 7.

Figure 3: Land use classes in the study area.



Intensity value was measured for each of the above 8 classes. Amongst all, land classes from 1 to 4 (building structures) contribute to both horizontal and vertical use measurement. Land classes from 5 to 8 (road, water, agriculture and green space) give horizontal score only. Again, classes from 1 to 5 constitute the intensity for total built-up area, whereas classes from 6 to 8 accounts for non-built-up area.

3.4 Data computation method

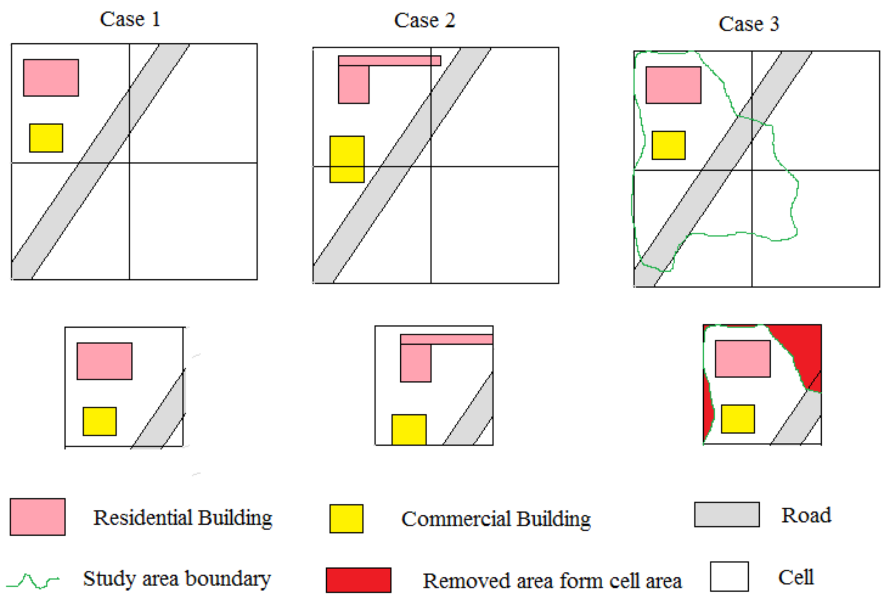
The main focus of the study is to compute cell-based intensity amount for identified land use classes, and impact scores for each class resulting from the location-determining factors. A fishnet (grid polygon layer) with unique cell-ID number was superimposed over the land use data using ArcGIS according to the maximum north-south and east-west extent of the study area. Overlaying the cellular lattice on the study area boundary and land use dataset put all layers into three distinct geographic setting (Fig. 2). The cell value computation is subject to this setting which needs to be clarified prior to developing computation equations.

Case 1: All features inside the cell boundary

Case 2: Features that are divided by the cell boundary, falls in-between cells.

Case 3: Cells sliced by the study area boundary (boundary affected cells)

Figure 4: Geometric setting of land features in relation to cell and study area boundary.



For all cases, as the basic idea is to compute the proportion of each land use with respect to the study area region, the area of any individual building that fall in-between two or more cells was divided by the boundary lines of cells (Fig. 4, case 2), and then computed. The area outside the study area was removed (Fig. 4, case-3) from cell area to estimate land use density.

3.4.1 Land use intensity computation

3.4.1.1 Horizontal intensity

The idea is to calculate the proportion of different land use classes that occupy the surface space of the cell area. A horizontal intensity for a land class is the ratio of total class coverage or area to the cell area (Zhang et al, 2004) and can be expressed as,

$$H_{ij} = \frac{\sum A_i}{A_j} \quad \text{……………………..} (1)$$

where, H_{ij} is the land use intensity computed horizontally for class i in the j^{th} cell, A_i is the ground area of the class i, *and* A_j is the cell area of j^{th} cell. The computed horizontal intensity value simply means the degree of use of land on a particular cell location.

The cumulative horizontal intensity can be measured by summing horizontal scores of all land classes and expressed as,

$$C_{hj} = \sum_{i=1}^{n} H_{ij} \quad \text{……………………..} (2)$$

where, C_{hj} stands for cumulative horizontal use intensity measured within a cell j, H_{ij} is the horizontal intensity of class i, and n is the number of total land class found in the j^{th} cell. This equation can be used to estimate the total built-up intensity that refers to an understanding of how much land surface is human-modified by their use activities. The amount of land left (termed as, open space) within a cell can be quantified when the value for built-up intensity is deducted from the cell area. These open space ratio across the study area provides essential information for urban consolidation[4] strategy formulation.

3.4.1.2 Vertical intensity

The main focus of vertical way of measurement is to find the location and amount of height-intensive development around the study area. To compute so, the equation is formulated based on the concept of Floor Area Ratio (FAR). FAR is defined as the ratio of gross floor area of a building to the ground or lot area on which the building is located, and expressed as,

$$FAR = \frac{S \times F}{G} \quad \text{……………………..} (3)$$

where, S indicates the number of storey in the building, F the floor area of each storey, and G the ground area.

FAR is one of the development control measure that determines the degree of development on a location. In this study, numeric value of vertical use intensity for a cell refers to the degree of vertical development in the cell, and was computed as the ratio of total used vertical space to the cell area. Vertical space of a particular use activity can be computed as the total floor area except the ground floor area of a building which is being used for that use only. The size of each floor inside a building can also vary, thus the computation equation for vertical use intensity can be expressed as,

$$V_{ij} = \frac{\sum F_i}{A_j} \qquad \text{……………………..} \ (4)$$

where, V_{ij} is the vertical intensity of a land class i within the cell j, F_i is the floor area of each storey being used for the class i except the ground floor area, and A_j is the cell area. Land classes like water, road and agriculture only has horizontal use intensity and does not contribute to vertical use of space. In addition, a building with only 1-storey does not offer vertical space too (floor space where activities can occur) and hence, counts a ′0′ in its vertical index. The building has only horizontal (ground) property.

The cumulative vertical development density taking account of all use classes can be measured and expressed as,

$$C_{vj} = \sum_{i=1}^{n} V_{ij} \qquad \text{……………………..} \ (5)$$

where, C_{vj} stands for cumulative vertical use intensity measured within the cell j, V_{ij} is the vertical intensity of class i, and n is the number of land class found in the j^{th} cell. The computed value indicates the degree and location of development while displayed on a map.

3.4.1.3 Total land use intensity

Total intensity of a use class that ultimately denotes the total concentration of that use can be measured by simply adding the horizontal and vertical intensity (equation 1 and 4) for that class. The equation can be written as,

$$T_{ij} = H_{ij} + V_{ij} \qquad \text{……………………..} \ (6)$$

where, T_{ij} is the total use intensity for a land class within the cell j.

In addition, the intensity of total built-up area in the study area can be estimated by summing the intensity values from all classes that occupy both horizontal and vertical built space. The equation stands as,

[4] Urban consolidation refers to a process of compact development through infilling of vacant space around already established urban areas/ urban core with a view to reduce development in fringe areas (Islam et al, 2009).

$$B_j = \sum_{i=1}^{n} (H + V)_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

where, B_j is the buit-up intensity, H and V stands for the horizontal and vertical scores for a class i found in the cell j.

3.4.2 Impact of location decision factors on land use

One of the objectives of this research is to find the relation between the use intensity and the use-location determining factors. The study worked with 4 generalized determinants that might cause the certain use intensity to be located on a particular area. Hence, the impact of the factors for each use-class was computed cell-wise. Following equations quantify the impact value for each factor.

3.4.2.1 Population density

Urbanization and population concentration at certain locations impact land use change. The more the population on a given area, the more the chance in land use modification, and intermixing of land uses (Islam et al., 2009). Hence, population density was considered as an important determinant of land use extent. In urban studies, population density is simply measured by,

$$D = \frac{P}{L} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

where, D is the density per area, P is the population number living in urban area, L is the total land used for urban activities.

In this study population density for each cell was estimated in a number of steps with the same idea from equation no. 8. The steps are:

(i) The boundary of study area (DMA) completely matches with the boundary of Dhaka Metropolitan Police area (Thana area[5]). Population figure of 22 Thanas that falls within the study area was taken to estimate density.

(ii) Space for only residential, commercial, community service and mix use activities among listed use-classes comprises the total land area to estimate population density. The reason of considering these 4 classes is rooted in the concept that, people in an urban area has direct modification access to these

[5] Thana resembles police station in Bangladesh (Dhaka Metropolitan Police Ordinance 1976, Bangladesh).

classes rather than other community use-classes like park, playground, water bodies, etc. They physically exist in and around these locations. The amount of total space obviously includes both horizontal and vertical space.

(iii) Therefore, at first, density for each Thana has been computed with the formula of,

$$D_t = \frac{P_t}{L_t} \qquad \text{……………………..} (9)$$

where, D_t, P_t and L_t are the population density, number of population and land space respectively for Thana *t*.

(iv) Secondly, cell population density was computed as the shared value of Thana density of a Thana within which that cell falls. The cell density is the proportionate population density of the Thana density that varies by the amount of land space each cell counts from above mentioned use-classes, and thus expressed as,

$$D_j = D_t \times \frac{L_j}{L_t} \qquad \text{……………………..} (10)$$

where, D_j is the cell population density, D_t is the Thana population density, L_j and L_t are the computed space of the cell *j* and of Thana *t* respectively.

3.4.2.2 Proximity to adjacent land use classes

The location decision of a use activity sometimes occurs due to the tendency of being near to other land uses and services, such as park, business center, shopping and educational facilities. The amount of occurrence or presence of other use activities adjacent to another specific use might affect the location occurrence of the specific use. This effect can be computed in terms of amount of intensity by deducting the total intensity (equation no. 6) of a use class from the total built-up intensity (equation no. 7) of a cell. The built-up intensity only includes residential, commercial, community and mix uses in this case. The equation is as follows:

$$A_j = B_j - T_{ij} \qquad \text{……………………..} (11)$$

where, B_j is the total built-up space intensity, T_{ij} is the total intensity and O_j is the intensity of adjacent land uses.

3.4.2.3 Distance from near road

Road network serves accessibility to the land use classes. In other words, land use activity takes place where there is provision or existence of road network facilities. Non-built-up area turns into populated space by different land activities. Again, the closer the land parcel is to the major network, the more expensive the land parcel is. Land value determines the occurrence location of use types (Min et al., 2007). Commercial and height intensive development occurs in close proximity to and along the major road network. This study measures the distance of each use location from the nearest road as an influential factor in determination of respective land use location. The distance was calculated simply by employing Euclidean Distance method. Since a cell might contain more than one similar type of use class in different locations within the cell, the equation for distance measurement can be expressed as,

$$\overline{R}_{ij} = \frac{d_1 + d_2 + d_3 + \cdots + d_n}{n} \quad \text{........................ (12)}$$

$$d_{ij} = \sqrt{(x_i - x_r)^2 + (y_i - y_r)^2} \quad \text{........................ (13)}$$

where, $\overline{R}_{ij}$ is the average distance of land class i from the road in the cell j, d_{ij} is the measured distance between the nearest road r and the use class i located in the cell j, (x_i, y_i) and (x_r, y_r) correspond to the location coordinate of the nearest point of land use and road respectively.

3.3.2.4 Distance from employment center

Land use follows a change in its amount and types with the gradient from the CBD (or employment centers) to the outwards fringe area (Zhang et al., 2004). At the heart of the city there is always a predominance of commercial activities. But in a polycentric city mostly grown in an uncontrolled way like Dhaka (Islam et al., 2009) there is intermixing of uses and overlapping of employment zones which are difficult to demarcate clearly. As such, intensity of different uses might also experience varied pattern at different locations of the city. In this background, distance of use location from the nearest employment centers was taken as the gradient distance along which use types might vary. This distance was also computed using Euclidean Distance method and can be expressed as,

$$\overline{E}_{ij} = \frac{d_1 + d_2 + d_3 + \cdots + d_n}{n} \quad \text{........................ (14)}$$

$$d_{ij} = \left(\sqrt{(x_i - x_c)^2 + (y_i - y_c)^2}\right) \quad \text{........................ (15)}$$

where, $\overline{E}_{ij}$ is the measured average distance value for the cell j from the employment center to the a use location, d_{ij} is the measured distance between the nearest employment center c and the use class i located in the cell j, (x_i, y_i) is the location coordinate of the nearest point of use and (x_c, y_c) is the employment center coordinate.

But before computation of distance form employment center, this study followed a combination of techniques suggested by Giuliano and Small (1991) and Hot Spot Analysis (Getis-Ord Gi statistics) in order to identify the location of employment sub-centers across the city area. Giuliano and Small used descriptive study to define sub-center employment zones based on cut-off employment ratio expressed in terms of number of jobs per acre of land. The potential employment zones are a set of contiguous units each with job density greater than the average density (the cut-off density). On the other hand, Hot Spot Analysis, the *Getis-Ord Gi statistic* is used to identify spatial clusters of high values (hot spots) and spatial clusters of low values (cold spots). The resultant Z score (standard deviation from the mean) and p-value (probability) tell where features with either high or low values cluster spatially by looking at each feature within the context of neighboring features. A feature with a high z-value is interesting, but may not be a statistically significant hot spot. To be a statistically significant hot spot, a feature will have to have a high value and be surrounded by other features with high values as well. Following step-by-step approach was considered to identify employment sub-centers in the study area:

(i) Identification of cells above cut-off employment density:

Cells with greater than the average employment density were identified. Employment density is generally measured as the number of jobs per area. But because of unavailability of such information in the study area employment density was computed as the ratio of land spaces used for commercial and mix use activities. These are the places considered to be of employment concentration. The higher the use intensity value for such uses on a location the higher the concentration of jobs. Since mix use might include non-commercial space, was weighted with the weight 0.5. Therefore, the equation stands as,

$$e_j = \frac{\{c + (m \times 0.5)\}_j}{A_j} \qquad \text{……………………..} \ (16)$$

where, e_j is the employment density for the cell j, c and m represents land space for commercial and mix use respectively, and A_j is the cell area.

(ii) Estimation of Getis-Ord Gi score for selected cells:

A Hot Spot analysis was performed using ArcGIS on average employment density values of the cells to calculate *Getis-Ord* Z-score. The critical Z score values when using at 95% confidence level are -1.96 and +1.96 standard deviations with a p-value larger than 0.05. Values between -1.96 to +1.96 at 0.05 significance level are unlikely to show any clustered pattern, and values less than -1.96 represent the clustering of low employment density values (Cold Spots). Hence, cells with a value greater than 1.96 standard deviation (Z-score) were kept as the cells of potential employment zones. A high positive z-score value of a cell means that the cell has employment density greater than the average density. The equation for *Getis-Ord* G_i^* *statistic* with respect to this study can be rewritten as,

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} e_j - \bar{e} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2}{n-1}}} \quad \text{……………………. (17)}$$

$$\bar{e} = \frac{\sum_{j=i}^{n} e_j}{n} \quad \text{…..………………. (18)}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} e_j^2}{n} - (\bar{e})^2} \quad \text{……………………. (19)}$$

where, e_j is the employment density for a cell j, $w_{i,j}$ is the spatial weight (distance) between cell i and j, n is the total number of cells, $\bar{e}$ is the average employment density across the study area, S is the standard deviation of employment density.

The spatial interaction among density cells was set to ´Zone of Indifference (ZoI)´ in ArcGIS with a distance threshold of 100 meter (equal to cell size) to detect cells with high to extreme employment density values. ZoI reduces the impact of neighboring cells which are outside the threshold distance of the given cell. It thus results into a selection of few cells in different parts (zones) of the area with high to extreme density.

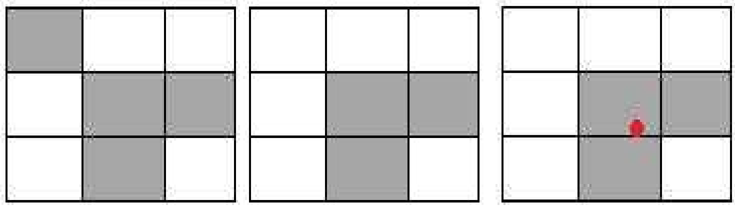
(iii) Polygon (cell) contiguity analysis

Final employment zones were developed by aggregating cells of high-to-extreme density (Fig. 5) which are contiguous and share a boundary of 100 meter (cell size).

(iv) Centroids of the employment zones

To be able to calculate the distance from the employment centers, center points (centroid) of each of employment zones were identified in ArcGIS and treated as the employment sub-centers (Fig. 5).

Figure 5: An illustration of identifying employment sub-centers.



Polygon contiguity   Centroid as city center

3.4.3 Spatial characteristics of use intensity

According to the research aim, the location characteristics of land use intensity involve knowing the distribution pattern of use intensity over the space. Tow aspects of intensity- where and why, were tried to uncover based on the hypothesis that, how the intensity values of each class are related to the location where they were measured and to the location-determining factors as a response to ´why´.

(i) Relation between intensity and the physical location of use:

Moran´s I spatial autocorrelation tool in ArcGIS was applied to identify the distribution of use classes over the study area based on their intensities. This essentially describes the relation between the amount of intensity and the location coordinate of each cell. Given a set of features and an associated attribute a Local Moran´s I (Index) identifies where high or low values cluster spatially. A positive value for I indicates that the feature is surrounded by features with similar values. Such a feature is part of a cluster. A negative value for I indicates that the feature is surrounded by features with dissimilar values. Such a feature is an outlier. The Local Moran's Index can only be interpreted within the context of the computed Z score or p-value. Z values (standard deviation) greater than 1.96 or smaller than −1.96 indicate spatial autocorrelation that is significant at the 5% level. On the other hand, Global Moran's I evaluates attribute values and gives a single value to tell whether the overall pattern is clustered, dispersed, or random. In general, a Moran's Index value near +1.0 indicates clustering while an index value near -1.0 indicates dispersion. A zero value indicates a random spatial pattern. The equation for Moran´s I is given as,

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j}\, z_i\, z_j}{S_o \sum_{i=1}^{n} {z_i}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$S_o = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

$$z_I = \frac{I - E[I]}{\sqrt{V[I]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$E[I] = \frac{-1}{n-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

$$V[I] = E[I^2] - E[I]^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

where, z_i is the derivation of an attribute (intensity) for cell i from its mean $(x_i - \overline{X})$, $w_{i,j}$ is the spatial weight (distance) between cell i and j, n the total number of cells. S_o is the aggregate of all spatial weight, z_I is the Z-score, $E[I]$ is the expected value of I under null hypothesis (there is no autocorrelation) and $V[I]$ is the variance of I.

The method for spatial weight estimation between cells was taken as the ´inverse distance´ with a critical distance of 100 meter. The assumption was that there is impact of the neighboring features on a given feature, and the impact should drop off with the gradual distance of 100 meter from the given feature.

In addition, this study also employed Gini coefficient estimation for each land class. The Gini coefficient is a measure of the inequality of a distribution developed by the Italian statistician Corrado Gini. It gives a numeric value in a scale of 0 to 1, where 0 expresses total equality and a value of 1 maximum inequality. While Moran´s I tells where high and low intensities are located, Gini coefficient measures how the intensities are distributed or located over the space. The higher the Gini, the more the land use intensity is dispersed and vice-versa. The equation of Gini coefficient for the study can written as,

$$G_i = \frac{\sum_{j=1}^{n} \left| A_j - L_{ij} \right|}{2} \qquad \text{……………………..} (25)$$

where, A_j is the ratio of cell area to the total study area for the cell j, L_{ij} is the ratio of land use intensity of a class i of the cell j to the total use intensity for the class i in the study area and G_i is the Gini coefficient for the land class i.

(ii) Relation between use intensity and determinants

Linear regression equation was used to assess the relation between the use intensity and location-decision factors. Regression looks at asymmetric problems where one variable depends on another. The simple form of the equation is,

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\dots\dots + \beta_n X_n + e \qquad \text{……………………..} (26)$$

where, e is a zero-mean random variable, $\beta_0, \beta_1, \dots\dots.\beta_n$ are unknown parameters for n number of predictors (X_1, X_2, …… X_n), and Y is the dependent variable. The equation with a single predictor stands as,

$$E(Y) = \beta_0 + \beta_1 X_1 \qquad \text{……………………..} (27)$$

where, $E(Y)$ addresses the dependent variable Y as random.

To investigate the relation between the intensity location and determinants, location coefficient instead of raw amount of intensity at each cell location was used. Since the amount of intensity for a use class varies spatially, it should be weighted and scaled with respect to the study area in order to be used in regression model as the ´dependent variable´. This comparative coefficient indicates a location tendency and advantage for a class to be occurring at a particular location (cell) across the study area. As suggested by Min et al. (2007), the standard value for location coefficient was set as 1. Coefficient value below 1 represents smaller tendency than the average tendency or propensity to be enough for a class to be occurring at a particular cell. Alternatively, value greater than 1 tells that the location propensity for a specific use in that cell is greater than in other cells. The coefficient was calculated as,

$$Q_{ij} = \frac{T_{ij}}{A_{is} \div A_s} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (28)$$

where, T_{ij} is the total amount of intensity of a use class i in the cell j estimated from equation no. 6, A_{is} is the total area (horizontal and vertical) occupied by class i in whole study area, A_s is the total study area, and Q_{ij} is the location coefficient for the class i.

Finally, it can be concluded that, the location coefficient of a use at a cell location is a function of population density, amount of adjacent land uses, average distance from the nearest road and employment sub-centers, and can be regressed into the following form:

$$Q_{ij} = \beta_0 + \beta_1 D_j + \beta_2 A_{ij} + \beta_3 \overline{R}_{ij} + \beta_4 \overline{E}_{ij} \qquad \ldots\ldots\ldots\ldots\ldots\ldots.. (29)$$

where, Q_{ij} is the location coefficient of a class i located in the cell j, β_0 is the intercept, $\beta_1 \ldots \beta_4$ are the slopes of population density (D_j), adjacent land uses (A_{ij}), average distance from road ($\overline{R}_{ij}$) and average distance from employment center ($\overline{E}_{ij}$).

3.5 Data analysis and presentation

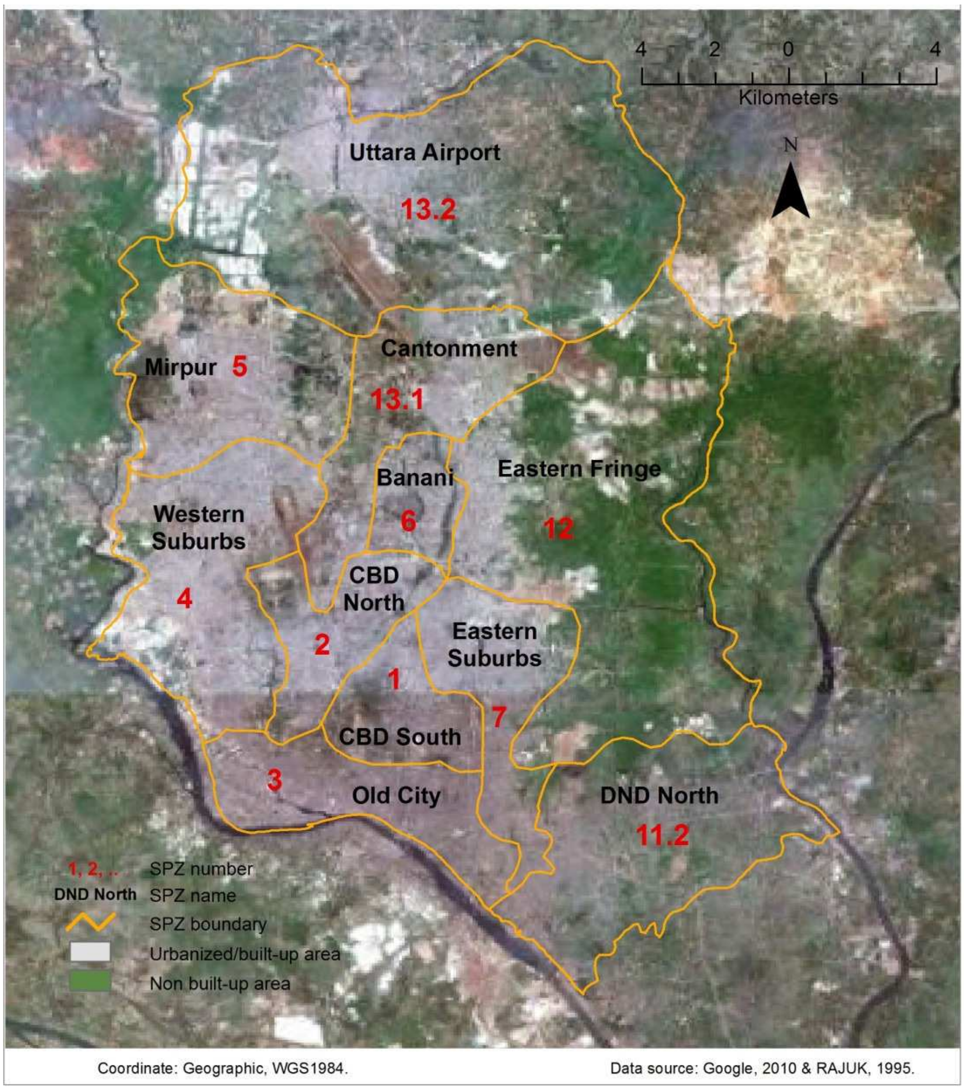
The raw data was processed and computed in ArcGIS 9.3, and then converted into image grid to be statistically analyzed in an R-package called ′rgdal′. Results and findings from the computation were given in the form of graphs, maps, and tables using both R-2.11.1 and ArcGIS-9.3.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Status of existing land use intensity

The Dhaka megacity (DMDP area) is divided into 26 strategic/spatial planning zones (SPZs) by the Capital City Development Authority, RAJUK based on the physical characteristics and development potential of the corresponding areas. These zones were demarcated in conformity with the special land use types and other administrative boundaries such as city corporation boundary, and included in the development plan to recommend zone-specific land use policies and development schemes for future growth. The present study area includes 11 SPZs of which mostly are urbanized except some extreme eastern areas of the Eastern Fringe (zone 12) and Uttara Airport (zone 13.2). These areas, as identified in DMDP plan area, are in the process of being urbanized in near future (Fig. 6).

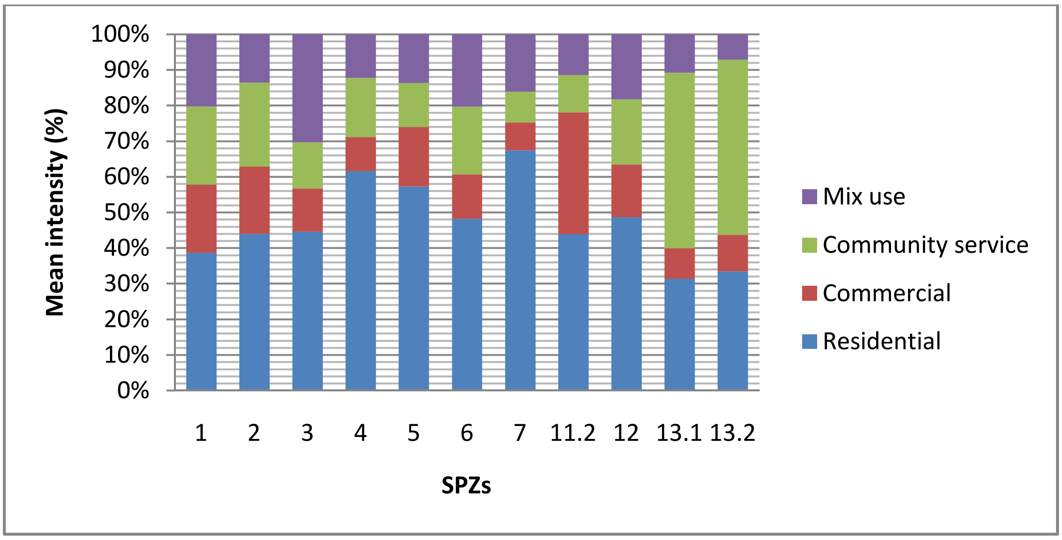
Figure 6: Strategic Planning Zones (SPZs) within the study area.



Urban growth and intensity of land use activities are interrelated and always of a prime importance to planners in preparing land use development plan. The urban land classes which are tremendously subjective to human modifications are residential and commercial. Other classes like community facilities, green and open spaces are often provided by the city development authority at certain locations. However, the intensity of these classes varies SPZ to SPZ and requires careful attention of the authority to provide a workable land use density with quantitative demarcation of each use type. Hence, the study tried to identify the spatial distribution of intensity overlaying the SPZs boundary on the land use activities occurring in the city.

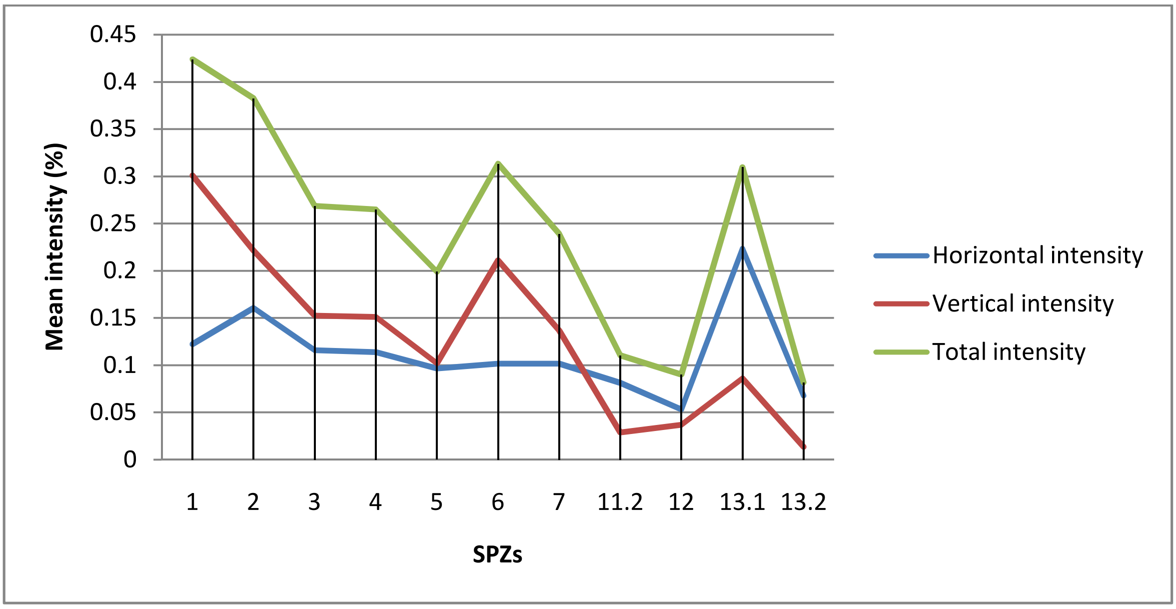
Figure-7 compares the distribution of mean land use intensity of majorly modified land classes in selected 11 SPZs. Irrespective of the physical size of SPZs, the graph shows that, zones from 1 to 12 contain residential activities higher than that of the zone 13.1 and 13.2. The large portion of community use activities in zone 13.1 and 13.2 is simply because of the larger area occupancy by cantonment and airport in these zones respectively. Intermixing of land uses among zones varies between 7% to a maximum of 30% with highest in old part of the city (zone 3). The average vertical development is higher than the horizontal occupancy of areas for zone 1 to 7 (Fig. 8). On the other hand, rest of the zones has experienced higher horizontal growth than vertical growth. While zone 13.1 is more built-up horizontally than all other zones, central business districts (Zone 1 and 2) reports high percentage of total builtness considering both horizontal and vertical growth.

Figure 7: Percentage distribution of mean intensity of land use classes (residential, commercial, community and mix uses) in SPZs.



Data source: Annex-1, Table-1.1.1.

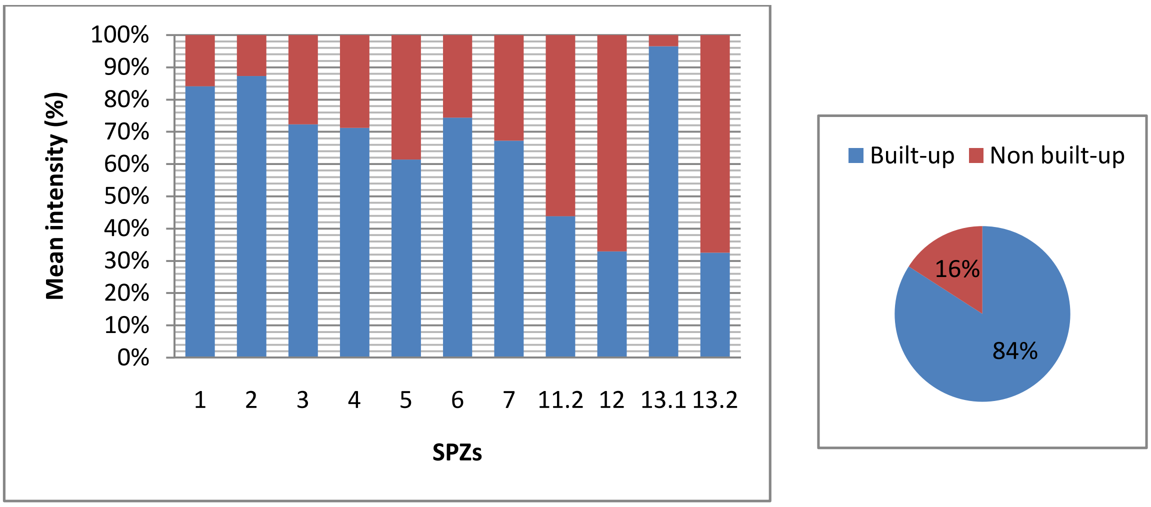
Figure 8: Mean horizontal, vertical and total intensity of land classes (residential, commercial, community and mix uses) in SPZs.



Data source: Annex-1, Table-1.1.1.

Considering all other land classes the study estimated that, 84% of the city area is composed of built-up regions (Fig. 9). If cantonment area (zone 13.1) is excluded from the analysis since it is a restricted zone where development takes place under the authority of Cantonment Board not by RAJUK (capital development authority), central business district (north and south) reports highest built-up intensity. Zone 3 to 7 reports medium built intensity followed by a lower intensity in zone 11.2, 12 and 13.2.

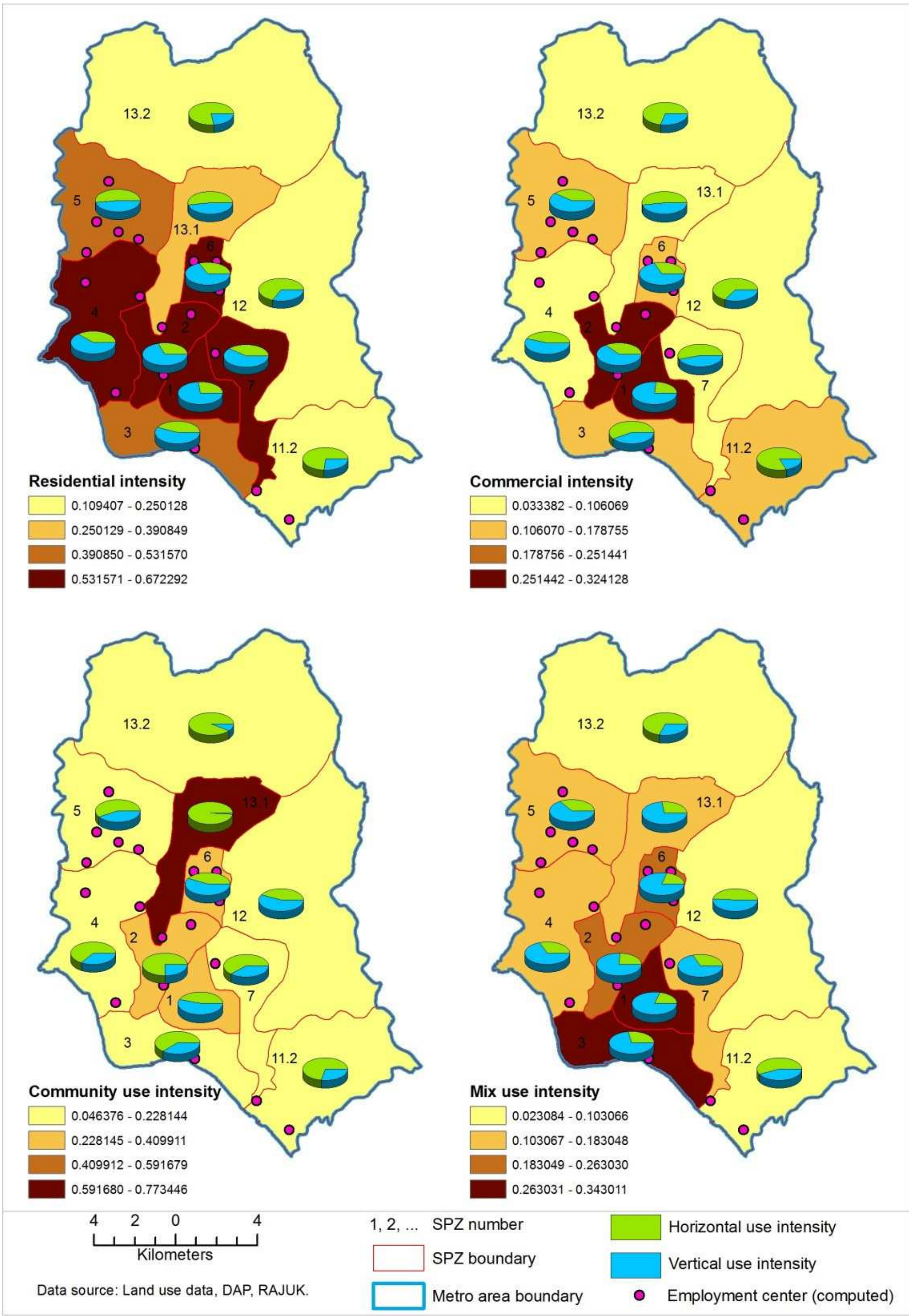
Figure 9: Built-up and non built-up area intensity in the study area



Data source: Annex-1, Table-1.1.1.

The above findings were mapped (Fig. 10) to get a quick comparison between the intensity levels of major land classes. The map had been produced from the equal interval of intensity values for the classes.

Figure 10: Mean land use intensity in SPZs



4.2 Spatial form of land use intensity

As mentioned earlier in the Data and Method chapter, an investigation was made to identify the location characteristics of the land use classes that might vary by their level of intensity. Spatial autocorrelation (Moran´s Index) and spatial distribution of inequality (Gini coefficient) was applied to measure and evaluate the location consequences of land use intensity over the whole city area. The pattern of land use intensities as concluded from a comparison of coefficient values is as follows:

Table 1: Estimated Global Moran´s I and Gini coefficient for urban land use activities.

Land use type	Global Moran´s I		Gini coefficient	
	Score	Remarks	Score	Remarks
Residential	0.71	Cluster (Strong)	0.63	Uneven (Moderate)
Commercial	0.52	Cluster	0.83	Uneven (Strong)
Community use	0.89	Cluster (Strong)	0.8	Uneven (Strong)
Mix use	0.56	Cluster (Weak)	0.84	Uneven (Strong)
Vertical development	0.61	Cluster	0.71	Uneven (Strong)
Total built-up area	0.76	Cluster (Strong)	0.55	Even (Weak)

Data source: GIS-based computation

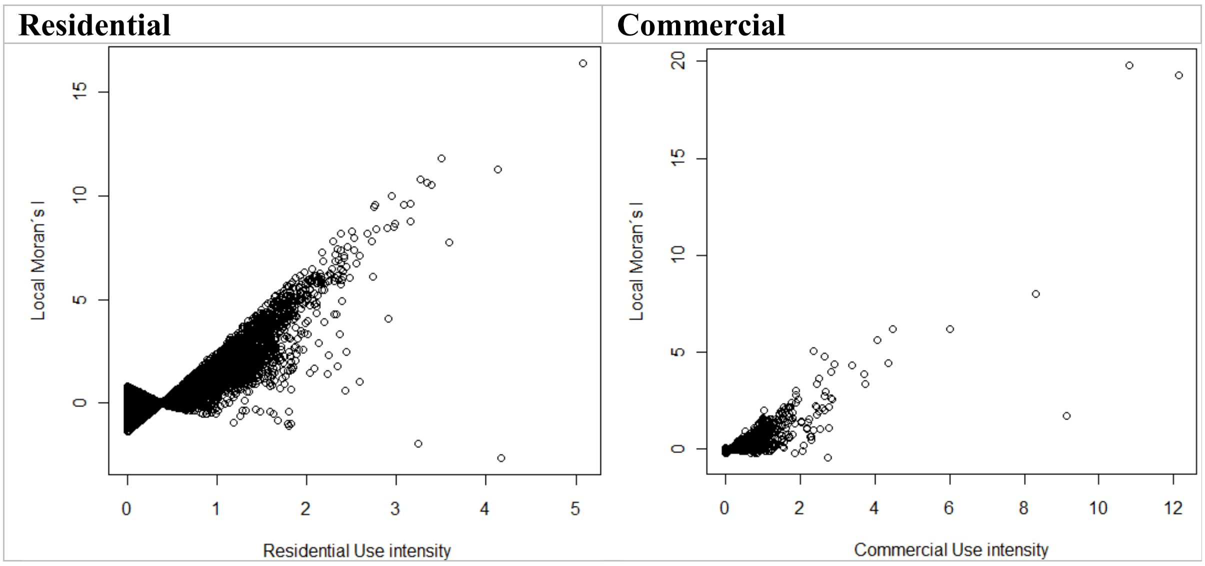
Global Moran´s Index is measure of spatial clustering with a value that ranges from negative 1 (dispersion) to positive 1 (clustering), while Gini coefficient measures distribution of any feature over the whole space in a scale of 0 (even distribution) to 1 (uneven distribution). The degree of land use dispersion and clustering can be well understood when coefficient values form the above two methods are compared to each other (Table-1).

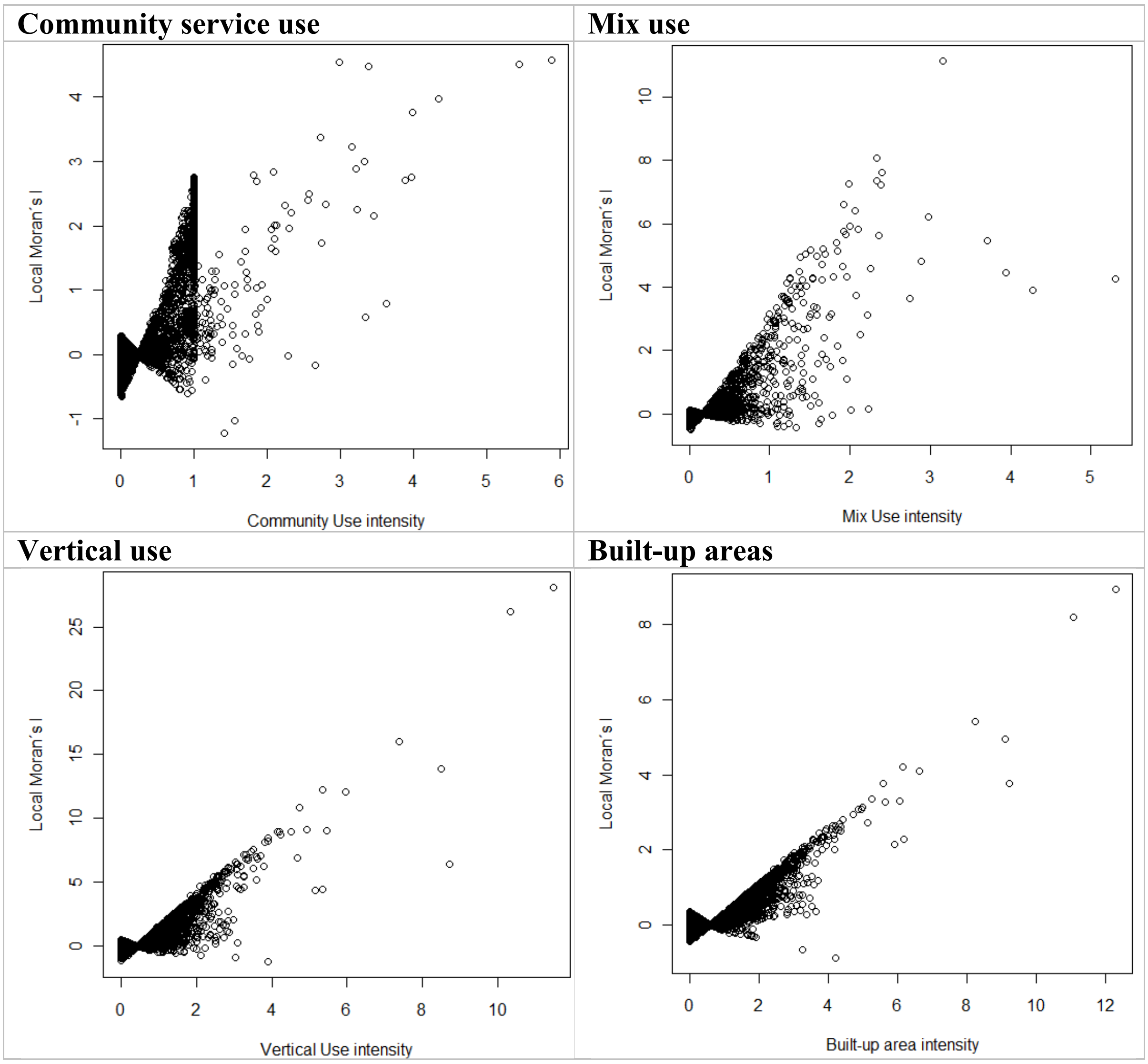
The location of residential activities seems strongly clustered (for a higher Moran´s I, 0.71) and shows a moderate unevenness in its distribution (for a semi-higher Gini value, 0.63). On the other hand, commercial establishment and community service and mix use reports strong uneven distribution which ultimately indicates that, they have a sort of clustering among themselves. Moran´s scores for these classes support each of the estimated values of Gini coefficient and tell that, the pattern is evidently spatially clustered and undergoing a pocket-type development. Commercial, community and mix type land classes have certain location preference to be occurring. The intensity of vertical development observes clustering as well with higher level of unequal distribution. The high inequality simply indicates that, the development of high-rise building structures is taking place at fewer locations. The comparatively low positive Gini score for built-up areas (0.55) tells that, the city is more or less evenly distributed with intensified built-up surface (for higher Moran´s value, 0.76).

The estimated Local Moran´s Index aided in analyzing the form of urban land classes in a bit interesting way (Fig. 11). The index identifies outliers with negative I values, and features with positive I value that describes spatial clustering. Figure-11 tells that, majority of the residential cells (which have index value above 0) are surrounded by similar valued cells which ultimately indicate a pattern of clustering of residential activities. There are few outliers (index value below 0) which are a sign of some sporadic residential settlements. Index values do not vary a much but observe a smooth change (almost with 45 degree slope) with a continuous progress in intensity values. It reveals a pattern of continuity among high valued clusters and among low valued clusters, and thus, expresses a reduced degree of extreme clustering of residential activities.

On the other hand, majority of commercial establishments (with index value above 0) reports clustering as well as displayed in the figure no.-11. But, the data values (Moran´s I) do not reveal smooth increase with the increase in intensity score, and hence, it can be inferred that, the commercial clusters are not continuously clustered over the city area.

Figure 11: Scatter plot of Local Moran´s Index and use intensity of land classes



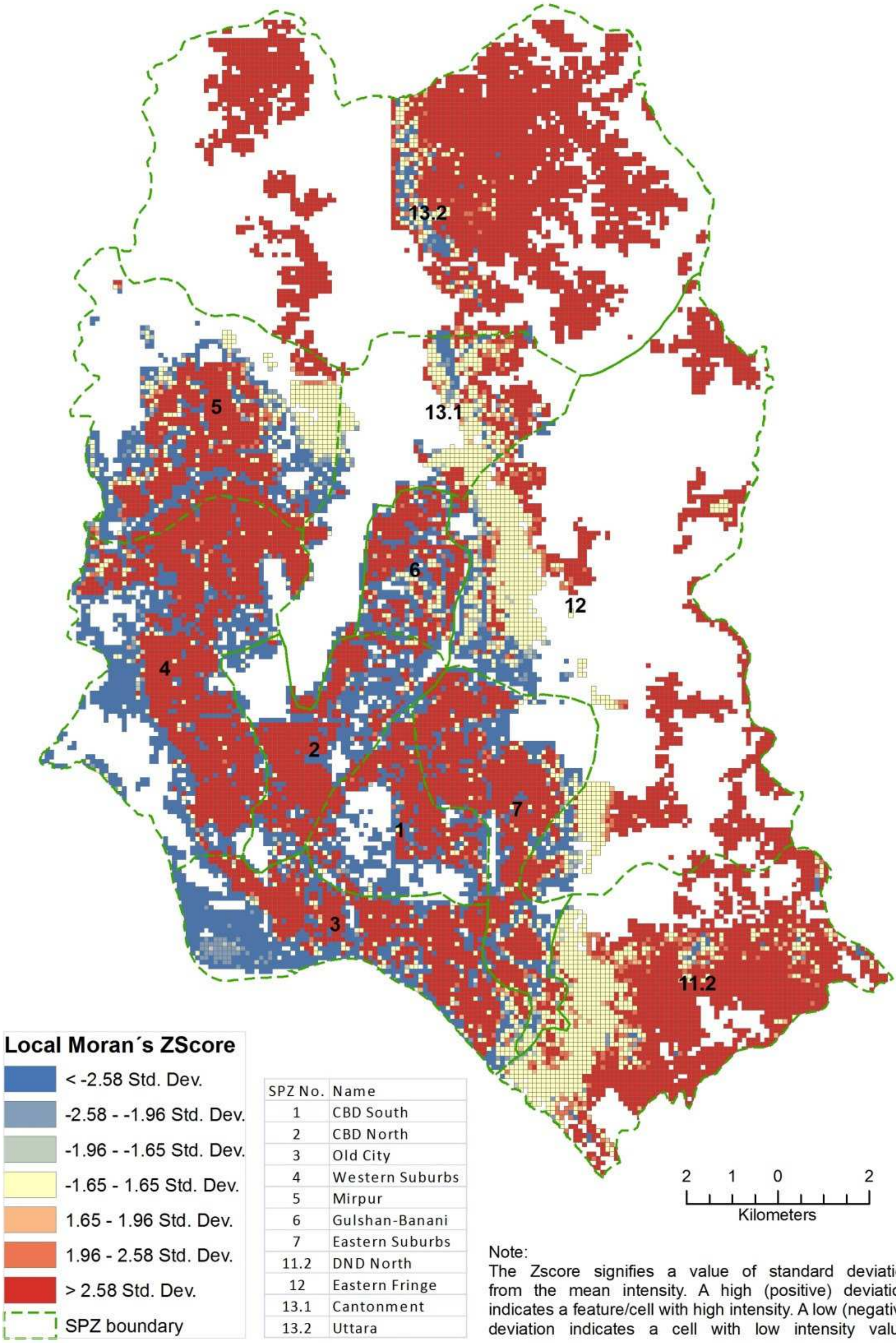


Data source: GIS-based computation

The result of the estimated Local Moran´s Index for community service use shows clustering of activities but does not show continuity among high or low valued clusters. Mix type development shows irregular clustering (discontinuous) over the city area too. But, in the case of vertical intensity and built-up intensity, both the high and low valued clusters seem continuous (due to an almost 45 degree change in index values with the increase in intensity value).

The overall anatomy of urban form as the consequences of land use activities in Dhaka city can be better understood as shown from figure 12 to 17. The maps were prepared with the estimated Local Moran Z-score which signifies clustering of land use activities based on the high and low intensity values. Positive Z-value shows clustering of high intensity values and negative Z-value shows tendency of low intensity values to be spatially clustered.

Figure 12: Spatial pattern of residential use activities



Note:
The Zscore signifies a value of standard deviation from the mean intensity. A high (positive) deviation indicates a feature/cell with high intensity. A low (negative deviation indicates a cell with low intensity value.

Figure 13: Spatial pattern of commercial use activities

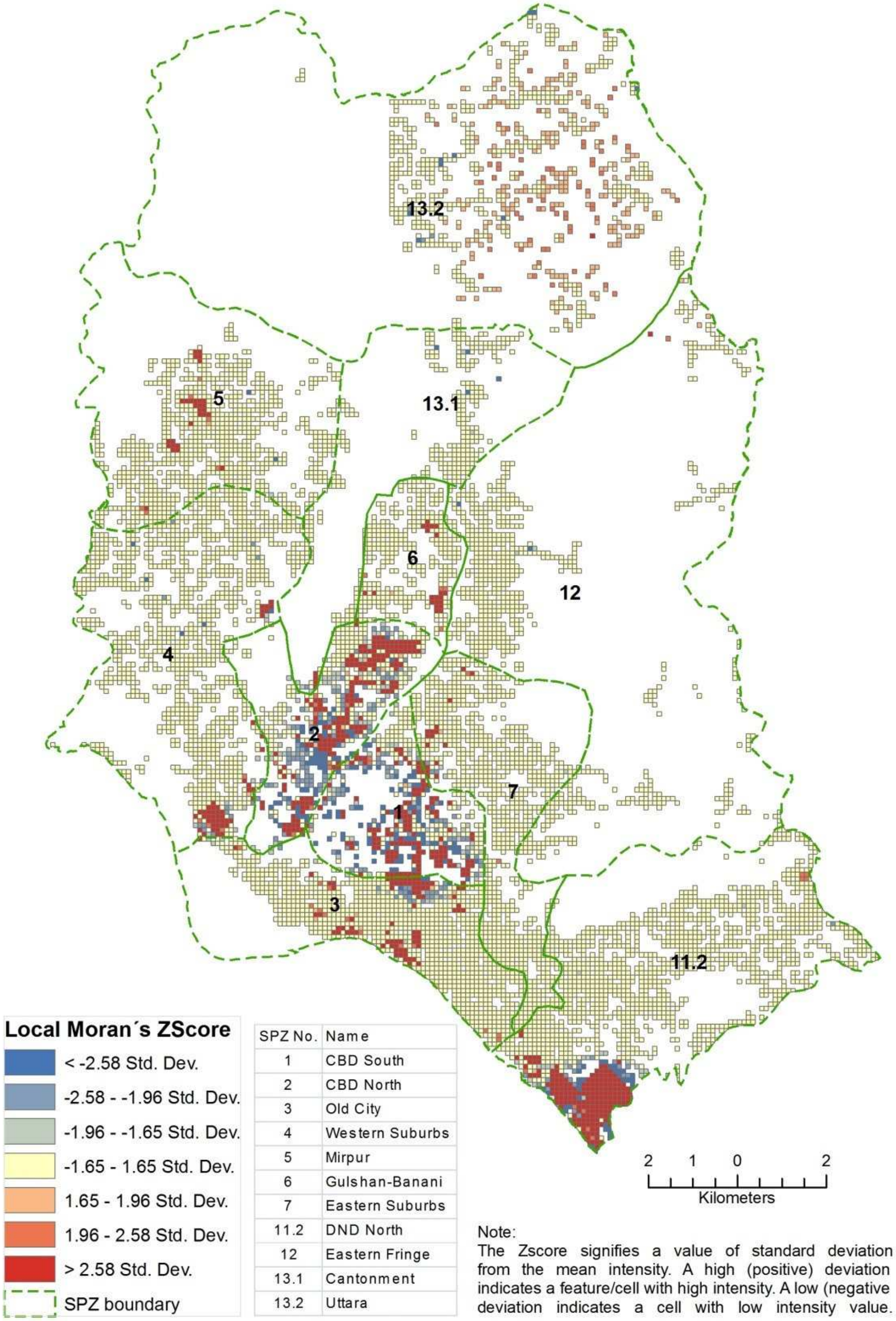
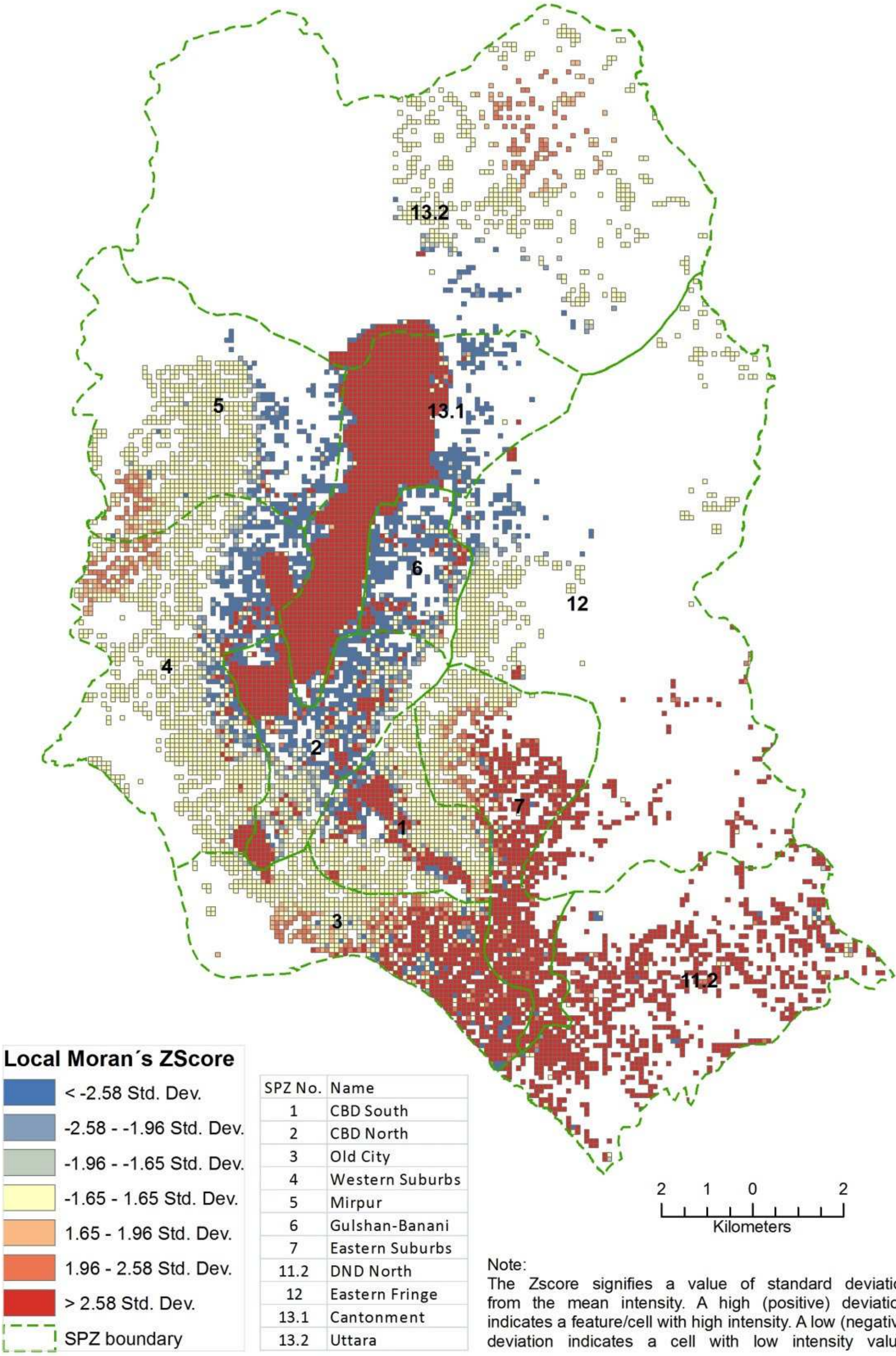


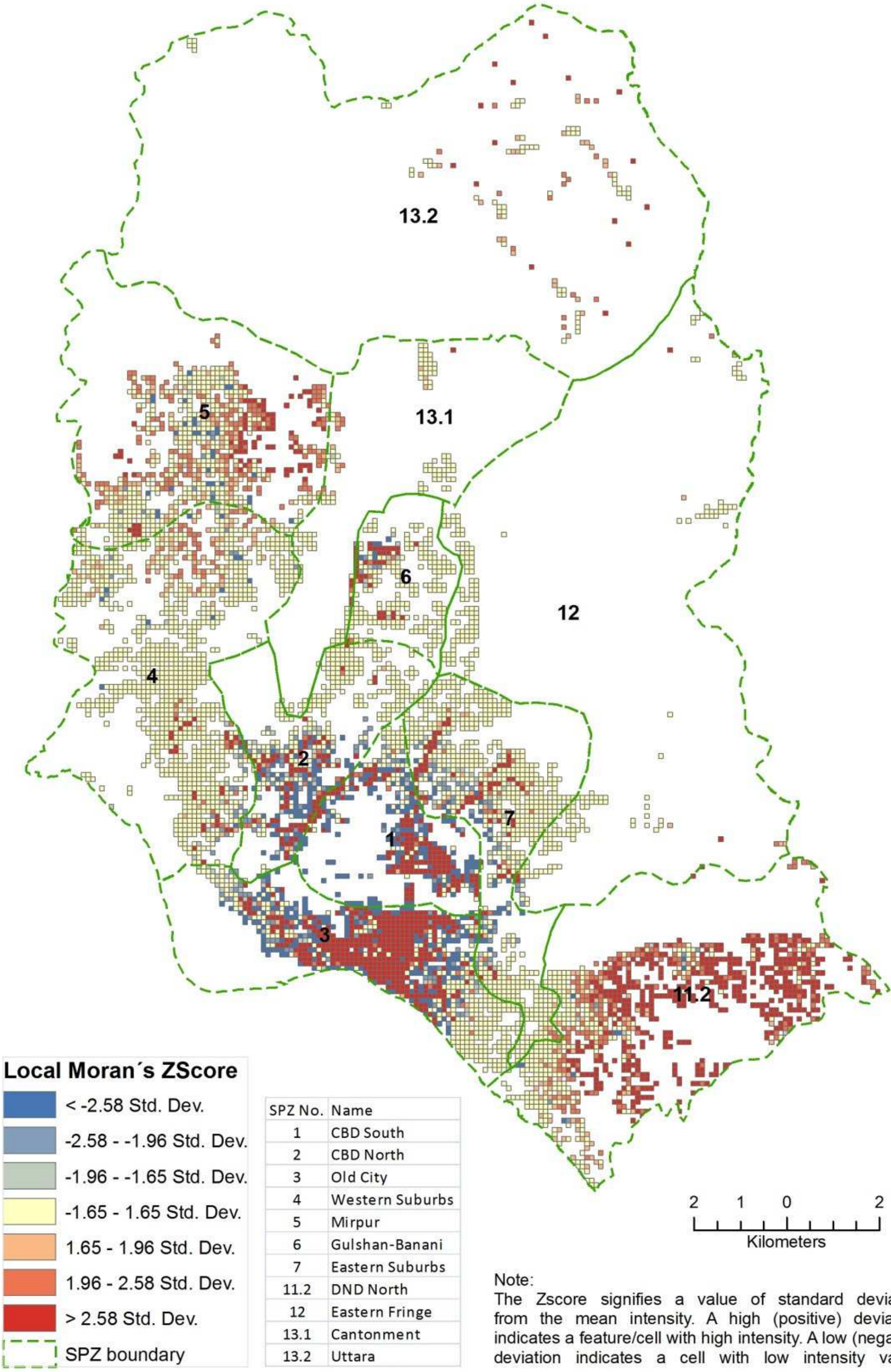
Figure 14: Spatial pattern of community service use activities



SPZ No.	Name
1	CBD South
2	CBD North
3	Old City
4	Western Suburbs
5	Mirpur
6	Gulshan-Banani
7	Eastern Suburbs
11.2	DND North
12	Eastern Fringe
13.1	Cantonment
13.2	Uttara

Note:
The Zscore signifies a value of standard deviation from the mean intensity. A high (positive) deviation indicates a feature/cell with high intensity. A low (negative deviation indicates a cell with low intensity value.

Figure 15: Spatial pattern of mix use activities



SPZ No.	Name
1	CBD South
2	CBD North
3	Old City
4	Western Suburbs
5	Mirpur
6	Gulshan-Banani
7	Eastern Suburbs
11.2	DND North
12	Eastern Fringe
13.1	Cantonment
13.2	Uttara

Note:
The Zscore signifies a value of standard deviation from the mean intensity. A high (positive) deviation indicates a feature/cell with high intensity. A low (negative deviation indicates a cell with low intensity value.

Figure 16: Location of vertical development

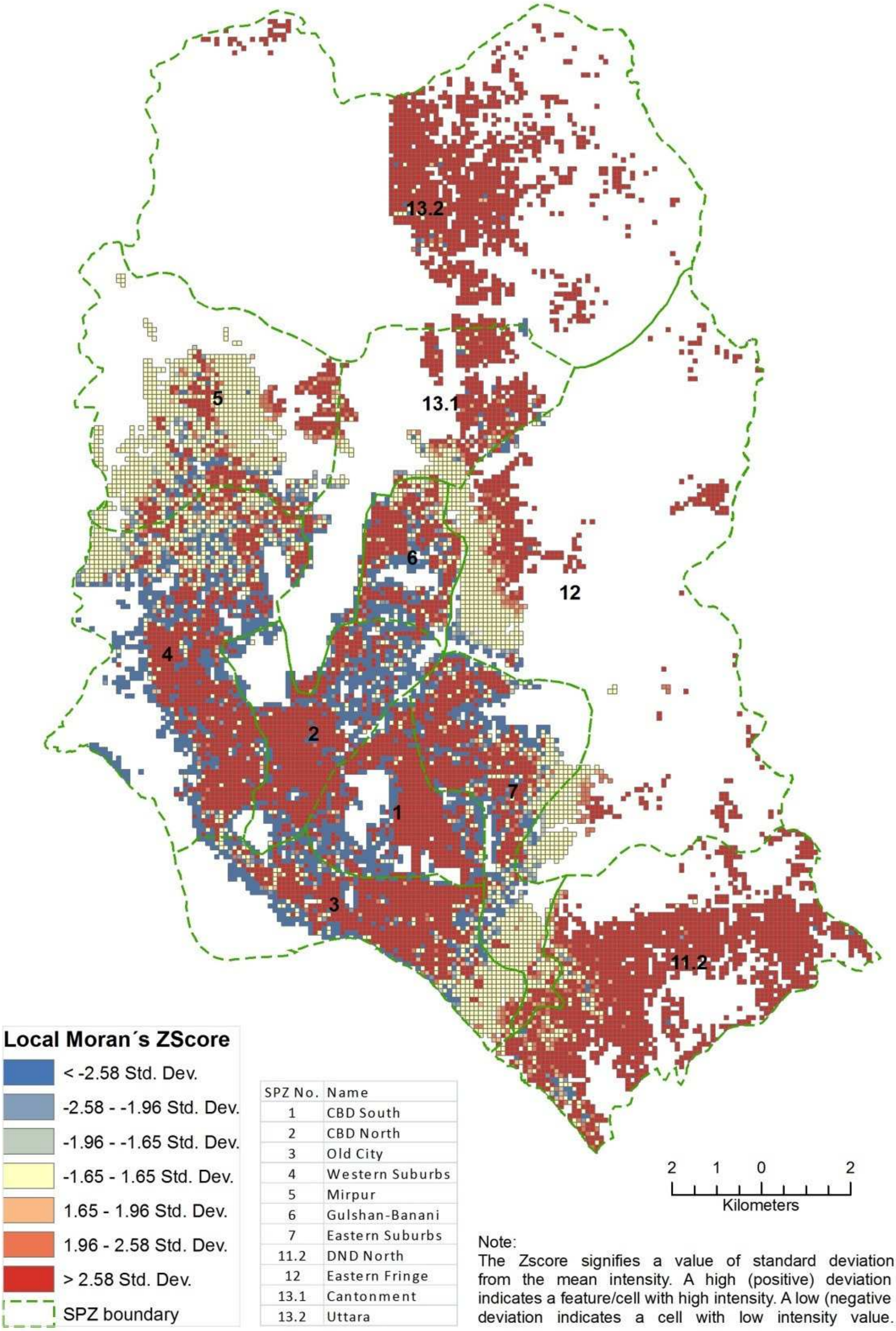
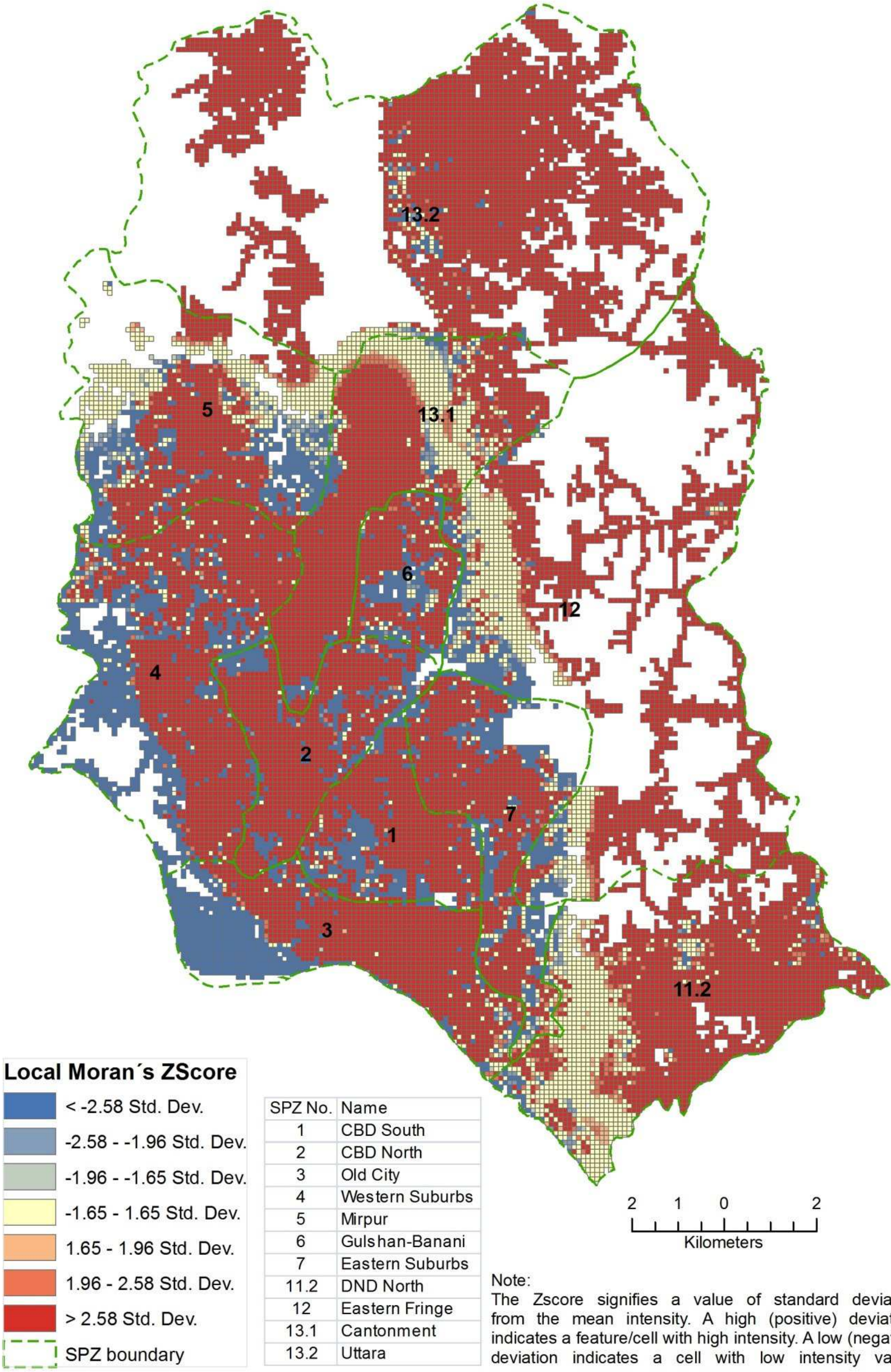


Figure 17: Spatial intensity of built-up areas



SPZ No.	Name
1	CBD South
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6	Gulshan-Banani
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12	Eastern Fringe
13.1	Cantonment
13.2	Uttara

Note:
The Zscore signifies a value of standard deviation from the mean intensity. A high (positive) deviation indicates a feature/cell with high intensity. A low (negative deviation indicates a cell with low intensity value.

4.3 Impact of determinants of land use activities

The regression analysis on the location characteristics of land use intensities was aimed to find out why and how the spatial pattern varies over the city in such a way as identified on maps in previous section. The common believe for spatial variation is due to the configuration of urban form and urbanization. In theory, a city takes a particular shape according to the size of the population it accommodates and the resultant demand for land consumption. Urban streets and employment centers together with the location of certain facilities (all types that again occupies land) modifies the amount and type of land use activities. The study formulated regression equation to assess the impact of factors responsible for determining the location of land use classes. The equation and the selected factors as abbreviated in the model are:

(i) Population density (D)
(ii) Proximity to adjacent land use classes (A)
(iii) Distance from the nearest access road (R)
(iv) Distance from employment center (E) (Identified employment centers through Hot Spot Analysis were mapped in the figure 1.2.5 in Annex-1).

Regression equation:

$$Q = \beta_0 + \beta_1 log(D) + \beta_2 log(A) + \beta_3 log(R) + \beta_4 log(E)$$

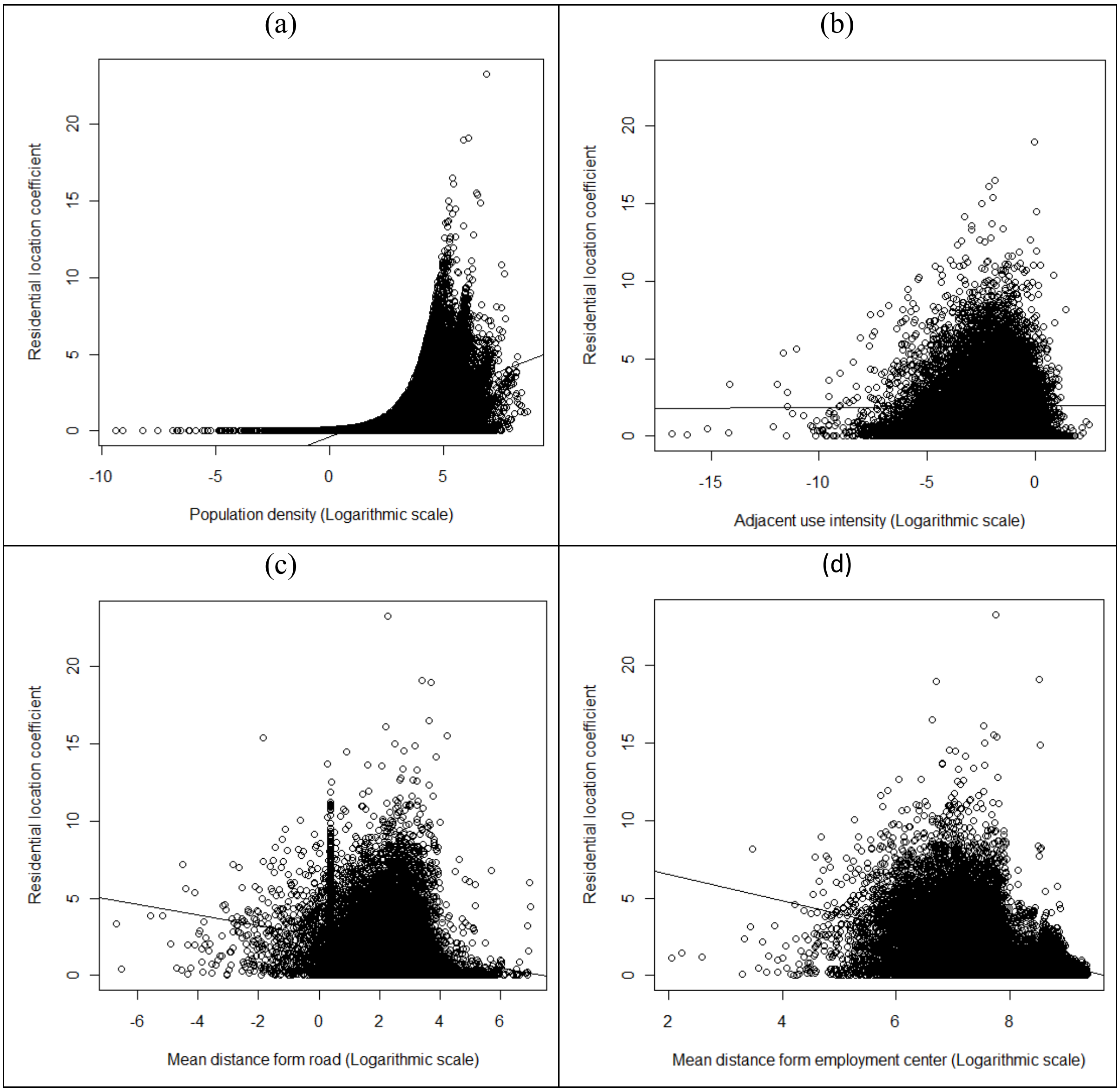
where, Q is the location coefficient for any land use intensity

Multiple regression equation can describe the effect on dependent variable when the independent variables are not strongly correlated with each other. The study found that there is very week correlation among the determinants. The estimated highest correlation coefficient between any two determinants of each land class does not exceed 0.5. The highest linear dependency as recorded are 0.29, 0.33, 0.42 and 0.43 for residential, commercial, community service and mix use location intensity respectively (Annex-1, Table 1.1.2 to 1.1.5). Therefore, the impact on the location of use intensities is as follows:

4.3.1 Residential use location

Based on the findings as shown in figure no. 18 the study found that, all the selected determinants have impact on the location decision of residential activities around the study area. The regression line in figure 18-a tells that, there is a sharp increase in the location coefficient of residential activities with progressive increase in population density (D). On the contrary, residential use intensities decline with the distance form road (R) and employment center (E) (Fig. 18-c, 18-d). Figure 18-b suggests that, the location coefficient of residential activities does not vary a much with the increase in the intensity amount of adjacent other land uses.

Figure 18: Regression plot of residential location coefficient with determinants



However, the multiple regression model of the residential location coefficient shows a predictive power of about 27% with multiple R-squared value at 0.2697 (Annex-1, Figure-1.2.1). The model is as follows:

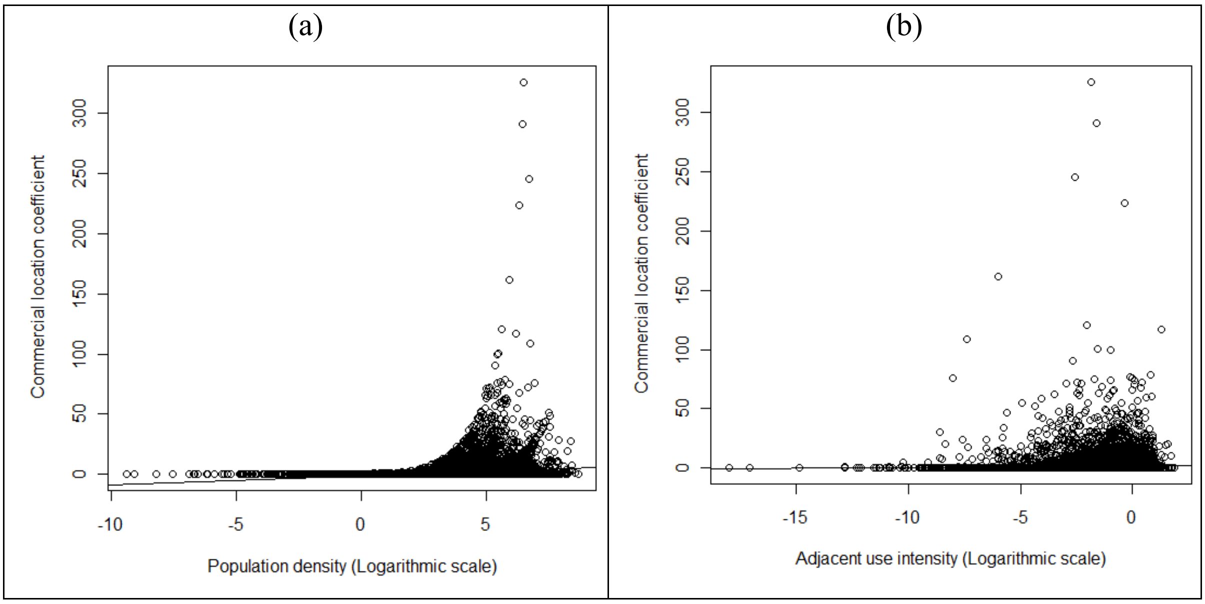
$$Rs = 2.286 + 0.703\ log(D) - 0.089\ log(A) - 0.096\ log(R) - 0.418\ log(E)$$

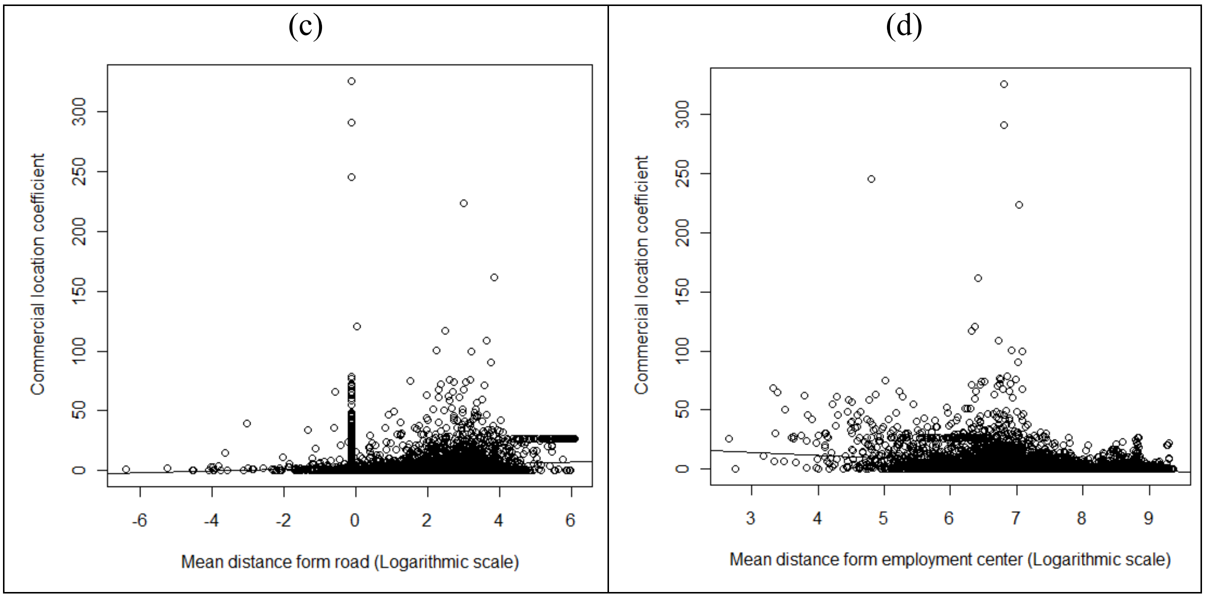
where, Rs is the location coefficient of residential land use intensity. The result of the regression model recommends that, the location propensity of residential use activities can be described by all the selected predictors. The regression coefficients of the determinants indicate that, how dependent variable changes due to a change of one unit in independent variables. Residential use intensity increases if the population size increases, and it decreases with the increased effect of adjacent other land types and distances from road and employment centers. Since 27% of the dependent variable (residential intensity) can be explained by the predictors, the model is good to be used for prediction.

4.3.2 Commercial use location

Commercial use location does not experience much of impact due to the selected determinants in comparison to residential location. Figure 19-a and 19-b respectively show that, the population density and adjacent uses around the commercial establishments have a very slight impact on the commercial use locations. The regression fit in figure 19-c tells that, commercial establishments are located along the road network only since the coefficient values remain almost constant with the increase in distances of commercial activities from the nearest road. Figure 19-d tells about the slight dispersion of commercial activities around the employment center showing a declination trend of activities with distances from the center.

Figure 19: Regression plot of commercial location coefficient with determinants





The multiple regression result on commercial use activities shows that, the change in the location characteristics of commercial activities can only be predicted by population density (D), adjacent uses (A) and distances form employment centers (E) with a very low power of about 12% at a multiple R-squared value of 0.1232 (Annex-1, Figure-1.2.2). The model looks as follows:

$$C = 10.906 + 1.95\, log(D) - 2.271\, log(A) - 2.567\, log(E)$$

where, C is the location coefficient of commercial land use intensity.

Commercial use intensity claims to have a less good fit due to a relatively low R-squared value (0.1232) compared to the R-squared value of residential use intensity (0.2697). The intensity is reduced with the increased effect of adjacent other land types and distances from employment center, but is increased with the increase in population density.

4.3.3 Community service use location

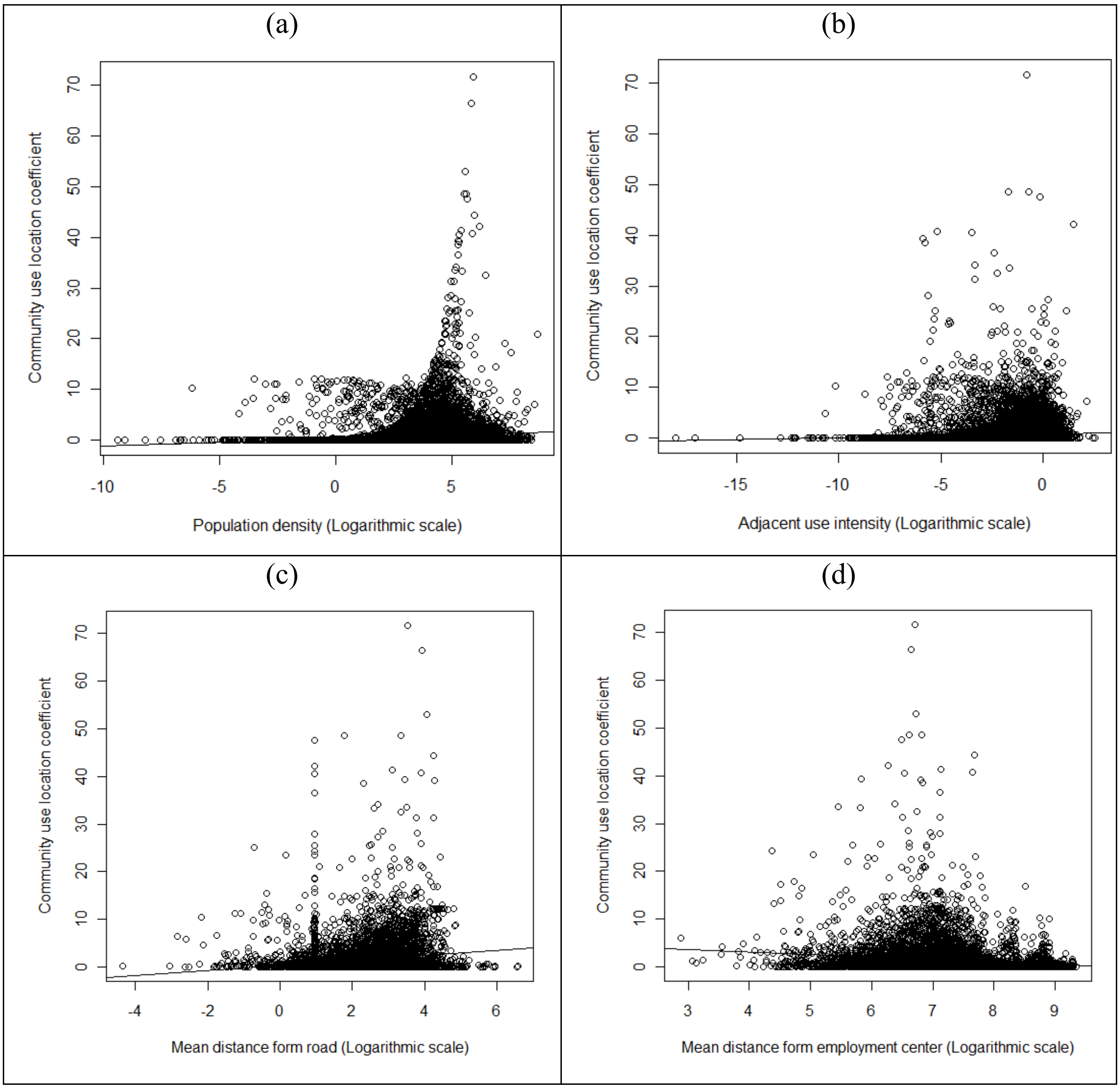
The land class that occupies community facilities is very interesting to look at, since this class is less human-modified. The regression plots in figure-20 still show some impact of the determinants in the spatial distribution of community facilities. The location trend of community use class observes a spatial pattern at distances from the road (Fig. 20-c) and to proximity to employment centers (Fig. 20-d). Increase in population density impacts a little (Fig. 20-a), whereas adjacent land types has almost no impact on the location of community facilities (Fig. 20-b). The multiple regression model suggests that, the location pattern can be described with all the selected factors with a very low predictive power of

8% with multiple R-squared value at 0.08325 (Annex-1, Figure-1.2.3) and looks as follows:

$$Cs = 2.073 + 0.556\, log(D) - 0.709\, log(A) + 0.358\, log(R) - 0.634\, log(E)$$

where, *Cs* is the location coefficient of community service use intensity. Even though the model has a very low R-squared value, it can be used for the prediction of community use intensity. One distinguishing feature of the result is that, the intensity of community use class increases with the increased distances from the road.

Figure 20: Regression plot of community use location coefficient with determinants



4.3.4 Mix use location

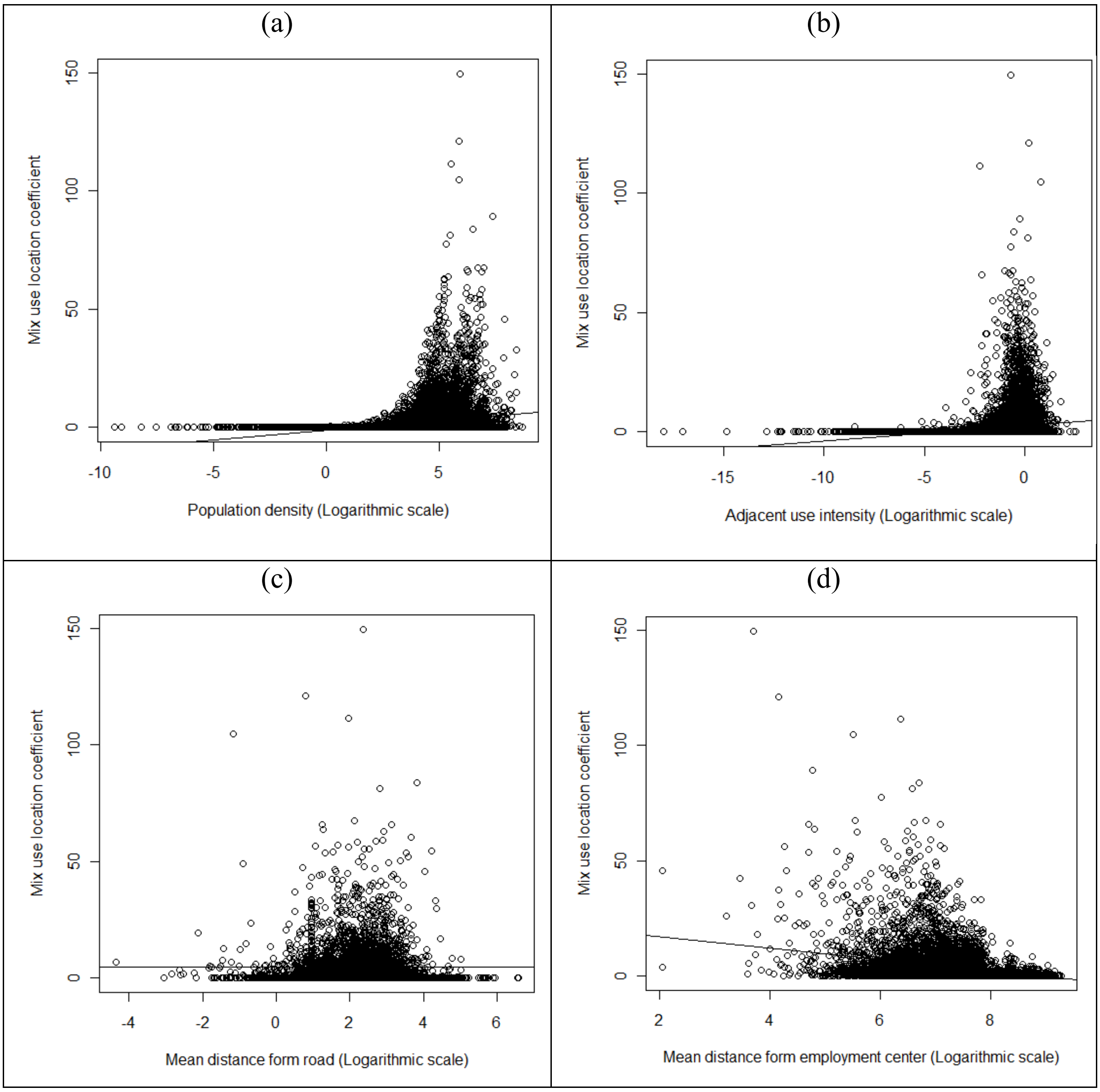
The predicted regression fit for the location coefficient of mix use activities suggests that, the tendency of location can be explained by factors except distance form road. It provides a fit with a very low predictive power of about 10% at R-squared value of 0.1035 (Annex-1, Figure-1.2.4) which appears as,

$$M = 10.303 + 1.791\, log(D) - 0.549\, log(A) - 2.1\, log(E)$$

where, M is the location coefficient of mix use intensity.

Figure-21 provides a basis to conclude that, mix use location intensity increases with an increase in population size (Fig. 21-a), and takes place at close proximity to employment centers since the coefficient quickly falls down with distances from the employment center (Fig. 21-d). On the other hand, figure 21-c tells that, mix use activities take place along the road (due to observed constant coefficient for all distances). Existence of other adjacent land types encourages the location occurrence of mix use types slightly (Fig. 21-b).

Figure 21: Regression plot of mix use location coefficient with determinants



CHAPTER 5: SUMMARY AND CONCLUSION

5.1 Key findings and observations

The study was designed to compute the spatial characteristics of land use activities with the help of required geo-processing and geo-statistical tools available in ArcGIS (Moran´s I, Hot Spot analysis) and R (Correlation and Regression analysis). The strength of geospatial technologies in analyzing land use data lies in the fact that, how well the study objectives were attained. In other words, how the computed results appear in accordance with the objectives previously set in Chapter 1, Section 1.2. The key findings of the study demonstrated that the objectives had successfully been achieved which are as follows.

Knowing the intensity of development:

Driven by the development of a cell-based land use intensity computation method, the study generated an intensity index of urban land use activities that are occurring across the study area. Study results showed that, 84 % of the city space is already built-up (Fig. 9, Chapter 4) with an average intensity of 1.05 including both horizontal and vertical development (Annex-1, Table-1.1.1). The intensity value simply signifies the urbanness of Dhaka city, and can draw a conclusion regarding the development extent in the city if compared to the value of other cities computed in the same way. The intensity value of SPZs can be compared to each other to foster zone-specific development requirements based on the existing concentration and composition of different land use activities. In the study area, residential activities are occurring intensively in zone 1, 2, 4, 6 and 7 followed by a bit less intensity in zone 3 and 5, whereas commercial activities are occurring in zone 1 and 2 followed by zone 3, 5, 6 and 11.2 (Fig. 10, Chapter 4). If cantonment area is excluded from the analysis, again zone 1 and 2 remain with higher concentration of community facilities. Mix type uses are typically exhibited with high intensity in zone 1 and 3 followed by zone 2 and 6. Zone 1 and 2 is the central business district (CBD) area where the overall land use intensity as well as residential activities is higher which can be seen as a sign of land use conflicts. Ideally, based on the theory of urban planning and examples of good cities, residential development should not be encouraged in and close proximity to central business district in high or excessive intensity. If the trend of intensity continues to increase in zone 1 and 2, and if total development and use-specific intensity is not set as controlling measures, the zones might experience threatened living environment in near future.

Exploring the spatial form of the city:

The Dhaka city is no more being expanded based on central business district. It has got some sort of polycentric form as identified by this study (Annex-1, Fig. 1.2.5). It can be explicitly inferred that, land use densification has already been started around these centers. The distribution of differentiated land uses over the city space (Fig. 12-17, Chapter 4) are interesting in the sense that, they are observing a pattern of clustering which might be the attention of development authorities to decide to encourage or not to encourage more uses in those clusters. The regression results on the location characteristics of land use intensity (Annex-1, Fig. 1.2.1 -1.2.4) suggest that, urbanization and physical layout of the city impact and can predict the location of human-modified land use types (residential, commercial, community and mix use types). The summary findings of regression results are as follows:

- The location intensity of all types increase with the increase in population size of the city.
- There is very little impact of adjacent other types of land uses on the location of residential, commercial and community use types. But mix type uses do occur with high intensity if there is a high amount of other types, such as residential, commercial or community uses.
- Distance from nearest road as a measure of accessibility to land classes defines that, residential activities occur near the road that is to say alternatively, residential activities take place where there is easy accessibility to road. Community services are located away from the road while commercial and mix uses occur along the road. Commercial and mix types, therefore, cannot be predicted by distances from road.
- One distinguished outcome of the study is the location occurrence of residential activities near the employment centers, around small or medium size business centers including CBD. This reveals a polycentric growth of the city. As observed, all other types are also located centering the employment spaces.

5.2 Implication of land use intensity quantification

To understand the pattern of development in a city or in different zones of it, quantification of land use intensity is of utmost importance. The degree and location of total development intensity can really reflect the true form of urban growth only when both horizontal (2-D) and vertical (3-D) expansion of the city is measured. While land use modifications without maintaining appropriate planning rules is inevitable in cities of higher urbanization rate, quantification of intensity helps to understand the need for any use re-adjustment on land surface or any additional new land requirement to accommodate growing population with adequate urban facilities. At the same time, the computed intensity might question the integrity of existing zoning or development control measure if it is not working properly. Determination of a comprehensive development density for varied land classes in different zones of the city based on the existing use intensities in those zones is necessary then. However, the feasibility of the method and findings of the study depends greatly on relating and evaluating the study findings with the outcome or success rate of existing urban development and environment plans, and even small to large scale city management programs.

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ANNEX-1: RESULTS OF INTENSITY COMPUTATION

1.1 Tables

Table 1.1.1: Mean intensity scores of land use classes.

SPZs	Horizontal scores									Vertical scores					B	NB
	R	C	CS	M	L	A	W	O	TH	R	C	CS	M	TV		
1	0.18	0.08	0.17	0.07	0.16	0.00	0.03	0.32	1.00	0.48	0.25	0.20	0.28	1.20	1.85	0.35
2	0.21	0.11	0.27	0.05	0.12	0.00	0.06	0.18	1.00	0.46	0.18	0.09	0.16	0.89	1.65	0.24
3	0.21	0.07	0.09	0.09	0.09	0.00	0.03	0.41	1.00	0.27	0.06	0.05	0.23	0.61	1.16	0.45
4	0.26	0.05	0.11	0.04	0.08	0.00	0.10	0.36	1.00	0.40	0.06	0.06	0.09	0.60	1.14	0.46
5	0.24	0.05	0.06	0.04	0.07	0.00	0.09	0.46	1.00	0.22	0.08	0.04	0.07	0.41	0.87	0.54
6	0.20	0.05	0.10	0.05	0.12	0.00	0.13	0.34	1.00	0.40	0.11	0.13	0.20	0.85	1.37	0.47
7	0.27	0.04	0.05	0.05	0.09	0.00	0.08	0.43	1.00	0.38	0.03	0.03	0.10	0.55	1.04	0.51
11.2	0.14	0.12	0.03	0.03	0.05	0.02	0.12	0.49	1.00	0.05	0.03	0.01	0.02	0.12	0.49	0.63
12	0.12	0.03	0.03	0.03	0.02	0.04	0.17	0.57	1.00	0.06	0.02	0.04	0.03	0.15	0.38	0.77
13.1	0.20	0.05	0.60	0.04	0.06	0.00	0.05	0.00	1.00	0.19	0.05	0.01	0.10	0.34	1.30	0.05
13.2	0.09	0.02	0.15	0.02	0.02	0.01	0.08	0.62	1.00	0.02	0.01	0.01	0.01	0.05	0.34	0.71
Mean	0.19	0.06	0.15	0.05	0.08	0.01	0.08	0.38	1.00	0.27	0.08	0.06	0.12	0.52	1.05	0.47

R=Residential, C=Commercial, CS=Community service, M=Mix use, L=Linear network, A=Agriculture, W=Water, O=Open space, B=Built-up, NB=Non Built-up, TH=Total horizontal, TV=Total vertical.

B=(R+C+CS+M+L); NB=(A+W+O); O=(All built-up horizontal scores – All non built-up horizontal scores).

Table 1.1.2: Correlation among determinants of residential use location

```
> cor(as.data.frame(rtq)[2:5])
                 PD      AU_IMP     DIST_RD     DIST_EC
PD       1.00000000  0.22021677  0.05173549 -0.01566870
AU_IMP   0.22021677  1.00000000 -0.04165617 -0.15001418
DIST_RD  0.05173549 -0.04165617  1.00000000  0.28778788
DIST_EC -0.01566870 -0.15001418  0.28778788  1.00000000
```

Table 1.1.3: Correlation among determinants of residential use location

```
> cor(as.data.frame(ctq)[2:5])
                PD     AU_IMP    DIST_RD    DIST_EC
PD      1.00000000 0.32877579 0.19767462 0.06198526
AU_IMP  0.32877579 1.00000000 0.02086036 0.04522631
DIST_RD 0.19767462 0.02086036 1.00000000 0.26435489
DIST_EC 0.06198526 0.04522631 0.26435489 1.00000000
```

Table 1.1.4: Correlation among determinants of community service use location

```
> cor(as.data.frame(otq)[2:5])
                PD    AU_IMP    DIST_RD    DIST_EC
PD      1.00000000 0.4162704 0.08843882 0.07886017
AU_IMP  0.41627044 1.0000000 0.17416889 0.13105454
DIST_RD 0.08843882 0.1741689 1.00000000 0.37789704
DIST_EC 0.07886017 0.1310545 0.37789704 1.00000000
```

Table 1.1.5: Correlation among determinants of mix use location

```
> cor(as.data.frame(mtq)[2:5])
               PD    AU_IMP   DIST_RD   DIST_EC
PD      1.0000000 0.3409427 0.1980973 0.1682233
AU_IMP  0.3409427 1.0000000 0.2952602 0.1980447
DIST_RD 0.1980973 0.2952602 1.0000000 0.4268652
DIST_EC 0.1682233 0.1980447 0.4268652 1.0000000
```

1.2 Figures

Figure 1.2.1: Regression results- Residential use intensity location

```
> rmg=summary(lm(RLQ~Log_PD+Log_AU+Log_DIST_RD+Log_DIST_EC, ru))
> rmg

Call:
lm(formula = RLQ ~ Log_PD + Log_AU + Log_DIST_RD + Log_DIST_EC,
    data = ru)

Residuals:
    Min      1Q  Median      3Q     Max
-5.5174 -0.9398 -0.3223  0.6910 15.6990

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.28589    0.17500  13.062  < 2e-16 ***
Log_PD       0.70328    0.01437  48.947  < 2e-16 ***
Log_AU      -0.08852    0.01084  -8.167 3.52e-16 ***
Log_DIST_RD -0.09610    0.01402  -6.856 7.44e-12 ***
Log_DIST_EC -0.41829    0.02058 -20.321  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.823 on 11081 degrees of freedom
  (19038 observations deleted due to missingness)
Multiple R-squared: 0.2697,     Adjusted R-squared: 0.2694
F-statistic:  1023 on 4 and 11081 DF,  p-value: < 2.2e-16
```

Figure 1.2.2: Regression results- Commercial use intensity location

```
> cmg=summary(lm(CLQ~Log_PD+Log_AU+Log_DIST_RD+Log_DIST_EC, cu))
> cmg

Call:
lm(formula = CLQ ~ Log_PD + Log_AU + Log_DIST_RD + Log_DIST_EC,
    data = cu)

Residuals:
     Min       1Q   Median       3Q      Max
-22.3292  -2.9086  -0.8752   0.8833 315.9620

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.90555    1.00152  10.889   <2e-16 ***
Log_PD       1.94981    0.09716  20.069   <2e-16 ***
Log_AU      -2.27061    0.09735 -23.325   <2e-16 ***
Log_DIST_RD  0.03556    0.07764   0.458    0.647
Log_DIST_EC -2.56728    0.11304 -22.711   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9.112 on 8358 degrees of freedom
  (21761 observations deleted due to missingness)
Multiple R-squared: 0.1232,     Adjusted R-squared: 0.1228
F-statistic: 293.6 on 4 and 8358 DF,  p-value: < 2.2e-16
```

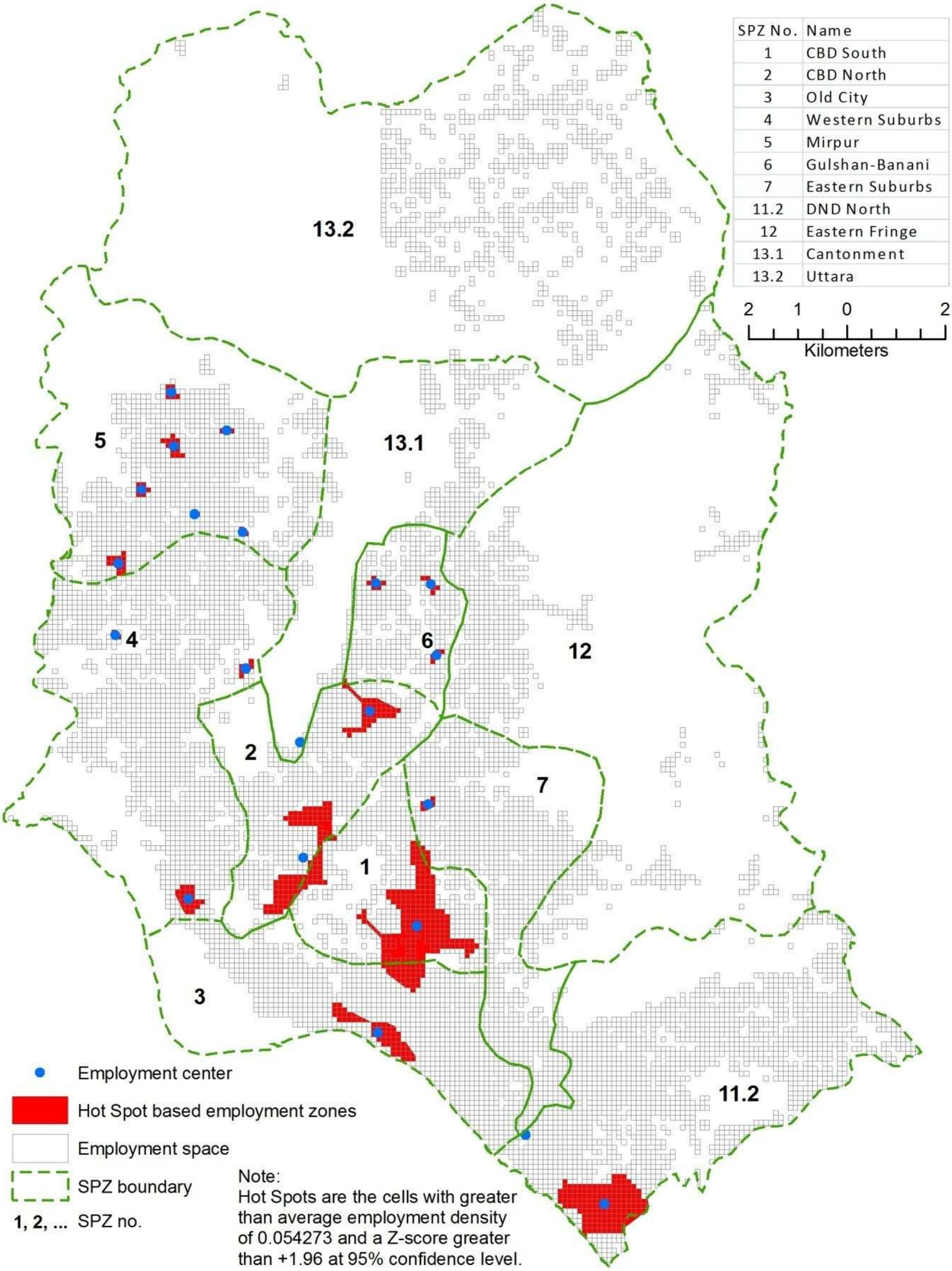
Figure 1.2.3: Regression results- Community use intensity location

```
> csmg=summary(lm(OLQ~Log_PD+Log_AU+Log_DIST_RD+Log_DIST_EC, ou))
> csmg

Call:
lm(formula = OLQ ~ Log_PD + Log_AU + Log_DIST_RD + Log_DIST_EC,
    data = ou)

Residuals:
    Min      1Q  Median      3Q     Max
-6.7001 -1.1976 -0.5703  0.1868 68.7319

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  2.07260    0.35151   5.896 3.87e-09 ***
Log_PD       0.55637    0.03533  15.746  < 2e-16 ***
Log_AU      -0.70905    0.03552 -19.962  < 2e-16 ***
Log_DIST_RD  0.35814    0.03670   9.758  < 2e-16 ***
Log_DIST_EC -0.63449    0.03900 -16.268  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.941 on 8013 degrees of freedom
  (22106 observations deleted due to missingness)
Multiple R-squared: 0.08325,    Adjusted R-squared: 0.08279
F-statistic: 181.9 on 4 and 8013 DF,  p-value: < 2.2e-16
```

Figure 1.2.4: Regression results- Mix use intensity location

```
> mmg=summary(lm(MLQ~Log_PD+Log_AU+Log_DIST_RD+Log_DIST_EC, mu))
> mmg

Call:
lm(formula = MLQ ~ Log_PD + Log_AU + Log_DIST_RD + Log_DIST_EC,
    data = mu)

Residuals:
    Min      1Q  Median      3Q     Max
-13.180  -3.898  -1.523   1.261 136.039

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 10.30268    1.09238   9.431  < 2e-16 ***
Log_PD       1.79146    0.10431  17.175  < 2e-16 ***
Log_AU      -0.54925    0.13949  -3.937 8.32e-05 ***
Log_DIST_RD  0.15001    0.09669   1.552    0.121
Log_DIST_EC -2.10047    0.12822 -16.382  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7.886 on 6468 degrees of freedom
  (23651 observations deleted due to missingness)
Multiple R-squared: 0.1035,     Adjusted R-squared: 0.103
F-statistic: 186.7 on 4 and 6468 DF,  p-value: < 2.2e-16
```

Figure 1.2.5: Identified employment centers in the study area



Masters
Program
in **Geospatial Technologies**

Dissertation submitted in partial fulfilment of the requirements
for the Degree of *Master of Science in Geospatial Technologies*

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