BAJRACHARYA, PANKAJ R., PHD. Towards a Sustainable Urban Expansion: A Case Study of Cities in Bangladesh. (2021)
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The economic growth of Bangladesh over the last several decades has subsequently been followed by the rapid expansion of urban areas. Unfortunately, this expansion of the urban footprint has mostly occurred in an unplanned and chaotic manner through the conversion of natural areas to urban landscape due to the lack of regulation and policies guiding the country's urban planning. This has raised concerns about the sustainability and livability of these cities and urged the need for a robust planning framework targeted at promoting sustainable urban expansion. A well-xand enhancing the quality of life for everyone while minimizing environmental degradation and other potential adverse impacts of a growing number of city dwellers. This dissertation examines the extent of unevenness in urban growth patterns in Bangladesh and explores the application of Urban Growth Boundaries (UGB) as a mechanism to control and direct the growth of built-up urban areas to promote sustainable urban expansion of these cities. The first part of the dissertation examines the unevenness in the urban expansion in Bangladesh by comparing the urban footprint of the cities and municipalities in Bangladesh extracted using Google Earth Engine (GEE) and census population data for these areas. While a greater proportion of the population has been increasingly concentrated in the smaller and mid-sized cities over the last three decades, built-up urban areas, on the other hand, have been mostly clustered in the two largest cities— Dhaka and Chattogram— accounting for nearly 60 percent of the total built-up urban areas. These results shed light on the magnitude of continued spatial inequalities in urban development amongst cities and municipalities in Bangladesh despite there being an overall increase of evenness in the distribution of population over time. The second part of the dissertation explores the application of UGB delineation using Support Vector Machine (SVM) supervised machine learning algorithm as an urban growth restriction mechanism for the city of Chattogram, one of the world's largest port cities and the second-largest metropolitan areas in Bangladesh, as a case study. The application of the Support Vector Machine (SVM) supervised machine learning algorithm is a novel approach to the delineation of UGB and this model was used to simulate future built-up urban areas up to 2040 for Chattogram and to determine the UGB for the city. Although the delineation of the UGB is a crucial step for the adoption and implementation process of UGB for Chattogram, the overall success of the UGB policy is dependent on external factors that directly or indirectly impact the policy. The third part of the dissertation, thus, investigates the key considerations essential for the successful adoption and implementation of UGB for Chattogram. Through a systematic review of literature on UGB and planning policies on Chattogram, along with a web-based survey and unstructured interview with city officials, it examines the stakeholders' perceptions on current growth patterns, the potential application of UGB as an urban growth containment strategy, and concerns and support regarding the application of UGB. While there has been an overall positive response regarding a potential adoption of UGB for Chattogram, this paper identifies five key concerns that would need to be addressed for the successful adoption and implementation of UGB for the city of Chattogram. These key challenges are namely: policy and regulatory consideration, civic engagement and stakeholder input, bureaucratic consensus and coordination, institutional capacity, and external influences. While distinct, these concerns are highly interrelated and can be expected to have a substantial influence on one another and need to be addressed for the successful adoption of UGB. These key challenges including policy and regulatory consideration, civic engagement and stakeholder input, bureaucratic consensus and coordination, institutional capacity, and external influences. While parts III and IV of this dissertation specifically focuses on the city of Chattogram as a testbed for the application of UGB, a similar methodological approach could potentially be implemented for other cities in Bangladesh with the goal to promote sustainable urban expansion.

Keywords: Chattogram, Chittagong, Bangladesh, Sustainable urban expansion, Sustainability, Urban Growth Boundary, Support Vector Machine, GIS, Urban Policy, Developing Countries, Urban Growth, Google Earth Engine

TOWARDS A SUSTAINABLE URBAN EXPANSION: A CASE STUDY OF CITIES IN BANGLADESH

by

Pankaj R. Bajracharya

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Committee Chair

DEDICATION

To Yabaa, Mamu and Yubar for supporting me in every step …

APPROVAL PAGE

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CHAPTER I: INTRODUCTION

Over 55 percent of the world's population currently live in urban areas and this number is expected to rise to about 68 percent by the end of 2050 (UN/DESA, 2019). In the past, most of the increase in urban areas has occurred in the developed world, but more recently, the rapid increase in urbanized land has been driven by larger cities in the Global South (B. Cohen, 2006). Furthermore, in the future, this expansion of urban areas is expected to occur in mid to small-sized cities in the developing world (B. Cohen, 2006; Mabin et al., 2013; UN/DESA, 2019). A significant portion of this growth in the Global South has occurred in unregulated, unguided, and haphazard manners (B. Cohen, 2006; Fekade, 2000). While urbanization often been viewed as a sign of economic vitality and development (B. Cohen, 2006), the alarming rates of unmanaged urban expansion particularly in the Global South have often outpaced the capacity of these regions to supply basic amenities/services and provide necessary infrastructure such as sanitation, running water, electricity and paved roads to the expanding regions (Bhatta, 2010; Farrell, 2017). This aggressive and unplanned urban growth has been responsible for encroachment of vast tracts of agricultural lands, decrease in natural vegetation and biodiversity, increase in traffic congestion and air pollution, and an overall decrease in the quality of life in these cities (Bhatta, 2010; Seto et al., 2012). There is now more than ever an increasing pressure on these cities in the Global South to address the issues of unrestricted urban expansion. It is essential to develop innovative approaches and strategies to managing the rate and direction of urban growth and containing the extent of unplanned and unregulated urban expansion occurring in these cities (Hersperger et al., 2018).

1.1 Urban Growth in Bangladesh

Bangladesh, since its independence in 1971 has experienced fast-paced urbanization, with the total percentage of the population living in urban areas rising from just under nine percent to around 37% today (UN/DESA, 2019). Based on the current rates of urban growth, this number is expected to rise to 57% by 2050 (UN/DESA, 2019). Bangladesh has evolved from a traditional agricultural economy into a modern urban sector economy (Muzzini & Aparicio, 2013), which has resulted in greater economic opportunities in cities, especially in larger cities such as Dhaka and Chattogram (M. M. Hassan & Southworth, 2018), During the same period, Bangladesh has also witnessed increasing frequency of natural disasters and a continued loss of rural agriculture-based income, which ultimately led to a large-scale migration of the rural poor into the cities (Rouf, 2018). The ongoing shift in the country's population from rural to urban areas has subsequently expanded the overall urban footprints of these cities from the increasing demand for housing, infrastructure, and other essential services.

Unfortunately, this expansion of the urban footprint has mostly occurred in an unplanned and chaotic manner at the expense of productive agricultural land (López et al., 2001; Sultana et al., 2004), vegetated land (Y. Liu et al., 2015), encroachment of fragile wetland areas (Bhat et al., 2017) and with minimal regulatory oversight (Hashemi, 2006; M. M. Hassan, 2017; Suykens, 2017). In addition to the significant detrimental impact on the surrounding natural environment, the rate and extent of urban expansion have also led to major concerns regarding the adequate provision of basic amenities, land tenure, and other issues such as informal/slum settlements within these rapidly urbanizing areas (M. M. Hassan & Nazem, 2016; H. Z. Rahman, 2014). With urbanization generally being compared to economic progress and vitality of the region, theses adverse environmental impacts associated with unchecked urban expansion experienced in the cities of Bangladesh has often remained unaddressed (Bloom et al., 2008). Moreover, despite the economic progress of these cities, the socio-economic concerns have also not been sufficiently addressed (Florida, 2015; Nazrul Islam, 1997; H. Z. Rahman, 2014). These lingering issues are major threats to urban sustainability throughout the world in both developing and developed countries alike. While economic growth itself cannot be discouraged, the detrimental effects of the haphazard outward expansion of cities in Bangladesh are certainly to be discouraged.

1.2 Sustainable Urban Expansion and Spatial Thinking

Urban expansion has been defined by Viana et al. (2019) as a transformation of nonurban areas into urban areas surrounded by 50% or less of existing urban areas. However, the factors driving this urban expansion vary across different regions (Fragkias & Seto, 2009), and subsequently, what sustainable expansion of the urban areas means for the regions and the actions needed to accomplish this also varies. The core concept of urban sustainability and sustainable urban expansion explored in this research for the cities in Bangladesh is derived from the definition of sustainable urban developed by Camagni (1998, p. 272):

> A process of synergetic integration and co-evolution among the great subsystems making up a city (economic, social, physical and environmental), which guarantees the local population a non-decreasing level of wellbeing in the long term, without compromising the possibilities of development of surrounding areas and contributing by this towards reducing the harmful effects of development on the biosphere.

Modeling urban expansion patterns are required for managing sustainable urban expansion (Hersperger et al., 2018) because they not only assess the efficiency of a plan before implementing it but also help to forecast its consequences after implementation (Karimi et al., 2019). Given the dynamic and complex processes of urban expansion, it requires a deep historical understanding of urban growth and policies in the geographic context to identify land use/land cover (LULC) changes over time. Planners all over the world recognize the value of spatially explicit information and have embraced GIS (geographical information systems) technologies as an important means to integrate a variety of spatial data (e.g., image processing and socio-economic data) to analyze the growth of cities accurately (Karimi et al., 2019), especially in many parts of the developing world like Bangladesh (Morshed et al., 2016).

At the same time, urban growth management strategies and tools need to be applied and hence, there is a dire need for a policy instrument aimed at managing the unregulated chaotic urban growth of cities in Bangladesh (Ahmed, 2019; Hersperger et al., 2018). While many management strategies and tools have been applied in Bangladesh, such as comprehensive planning or master plan, zoning, subdivision regulation, development fees, property taxes (Ahamed & Hasan, 2010), Urban Growth Boundary (UGB) policy has not yet been discussed in country's urban policy literature (e.g Hassan & Nazem, 2016; T. Islam et al., 2016; M. M. Rahman, 2021). For example, existing national policies such as The Building Construction Rule, 1984 and 1996; Bangladesh Building Construction Act, 2008; The Environmental Conservation Rules, 1997; Private Residential land Development, 2004, etc. never mentioned the word UGB (Ahamed & Hasan, 2010). The UGBs are land use regulations that have been established, in most cases, by the local government with the goal of restricting the expansion of urban areas beyond a defined boundary (American Planning Association, 2002; Brueckner, 2007; Pendall et al., 2002). Implementing such a policy could be highly effective to regulate the rate and extent of urban expansion (W. Han et al., 2020; Jun, 2004; Ma et al., 2017).

1.2.1 Urban Growth Boundary

The origins of UGB as a concept can be traced back to UK's Green Belt policies. These policies were started as garden city movements conceptualized by Ebenezer Howard and brought forward in a resolution of the London City Council in 1891 (Thomas, 1963). The resolution advocated for a belt of greenery around the city that would restrict urban growth and over-spilling of the population of London while preserving agriculture, providing amities and a space for recreation (Thomas, 1963). Though, it wasn't until the 1960s that UGB was used as an urban planning tool (Ma et al., 2017). UGB was further popularized in the 1990s through the rise of compact cities and a new urbanism movement (Sinclair-Smith, 2014). Compared to greenbelts that control urban expansion through permanent green spaces around urban areas, UGB restricts and directs the expansion of urban areas through the use of policy and regulatory options such as zoning and further allows for periodic assessment of the boundary and change to the boundary as necessary (Pendall et al., 2002).

In simple terms, UGB can be defined as land regulations that have been put into place, in most cases, by the local government prohibiting urban growth and development beyond a defined boundary (American Planning Association, 2002; Brueckner, 2007; Pendall et al., 2002). They are designed to control the rate and pattern of urban expansion by delineating a specific boundary beyond which development of land for the purposes of housing or industrial and commercial use is not allowed (Cho et al., 2008). Furthermore, UGB is targeted at protecting non-urbanized vegetated or agricultural land outside the boundary while promoting compact, contiguous and sustainable growth of urban areas within the city (American Planning Association, 2002).

1.2.2 Urban Growth Boundary in the Developed Countries

Although the adoption of UGB as an urban growth control tool has been seen in both developed and developing countries, a majority of UGB that are currently in place are in the developed world. In the US, the first UGB established was around Lexington, Kentucky in 1958 (Nelson & Duncan, 1995). It consisted of the city of Lexington and Fayette County and was created, for the most part, to direct areas where capital improvements would be made to encourage urban development in the region (Ambrose & Gonas, 2003). Since then, UGBs have been an increasingly popular tool for land use planning, management, and urban containment with numerous UGBs being established in the US (Knaap & Hopkins, 2001; Pendall et al., 2002). The state of Oregon has been at the forefront in terms of implementing UGB as a direct urban growth containment policy with a focus on growth management and rural preservation (Nelson & Duncan, 1995). Owing to the 1973 legislation, Oregon required all cities within the state to demarcate growth boundaries and set aside land for future growth (Sinclair-Smith, 2014). In addition to Oregon, Washington (Staley et al., 1999) and Tennessee (TACIR, 2000) have also implemented UGB policies for their cities at the state level. In other states such as California, Colorado, Florida, Georgia, Kentucky, Maine, New Jersey, Pennsylvania, and Rhode Island, UGB has been employed as a tool for urban growth containment by various local level governing bodies (Anderson, 1999; Boyle & Mohamed, 2007; Nelson & Moore, 1993; Pendall et al., 2002).

Outside of North America, Australia has implemented UGB in Melbourne and has recommended the use of UGB for other cities such as Adelaide, with goals to encourage denser growth of the city and to protect agricultural land (Bunker & Searle, 2007; Planning Institute Australia, 2006). In New Zealand, UGBs were reintroduced in 1998 as a part of a Regional Growth Strategy for cities such as Auckland with a revised emphasis on the protection of the environment outside of the boundary, as compared to its previous focus on providing urban infrastructure with increased efficiency and reduced expenses (Grimes & Liang, 2009). In Europe, Belgium implemented its UGB program starting in 1997 under the Spatial Structure Plan. This plan demarcated boundaries for urban growth limitation and allocated space for natural and agricultural areas. It was structured such that at least 60 percent of new residential development was required to be within the boundary, while the remaining 40 percent of new residential development was allowed to be built outside the boundary but within the existing designated construction areas with a specified density target (Boussauw et al., 2013). UGBs in the Netherlands have been implemented as a part of the National Policy on Spatial Planning and focuses on concepts of urban densification, compaction of cities and sustainable spatial development with the preservation of open spaces (Nabielek, 2012; Vasili, 2013). In Spain, UGBs are administered at the municipal level but have been limited to certain regions within the country (Paül & McKenzie, 2013). Switzerland implemented the Land

Use Plan, which was similar in function to UGBs, by specifying areas as being building zones and non-building zones (Gennaio et al., 2009). These plans were initially started in various towns of Switzerland in the 1960s and continue to be used to date. Other countries such as Austria, Germany, and the UK have opted for green belts as a measure to control urban expansion (Siedentop et al., 2016).

1.2.3 Urban Growth Boundary in Developing Countries

Compared to the developed world, there have only been a handful of developing countries that have explicitly implemented UGB for urban growth restriction. It should be noted that the definition of a developing country used for this study has been based on the UN's World Economic Situation and Prospect (WESP). WESP defines 28 countries within the European Union along with Canada, US, Australia, Japan, New Zealand, Iceland, Norway, and Switzerland as developed countries and the rest of the world as either developing countries or countries in transition (United Nations, 2018). Based on this definition, five countries have been identified where UGBs have been explicitly implemented for the restriction of urban growth expansion: Albania, Chile, China, Saudi Arabia, and South Africa. In Albania, UGBs have been referred to as "Yellow Line Boundaries" or the Yellow Line of Construction (Jacobs & Craig, 1997); UGBs in China have been referred to as an Urban Construction Boundary (UCB) or an Urban Growth Control Boundary (UGCB) (Long et al., 2013); and in South Africa, they are popularly known as "urban edges" (Sinclair-Smith, 2014). For the remaining two countries, Chile and Saudi Arabia, they are simply referred to as UGB. Although the names given to the UGB in these countries are different, the implementation mechanism has been equivalent to the traditional UGB.

With UGB mostly being concentrated in the developed countries, literature discussing the adoption, delineation, and subsequent challenges related to the implementation of UGB have also primarily focused on these countries. To examine the literature on UGB within the developing countries, a systematic literature search was performed on literature published up to early 2019, when the review of the literature was conducted. The literature search was conducted using a variety of academic databases including Academic Search Complete from EBSCO, ProQuest, and Google Scholar based on keywords such as "urban growth boundary", "UGB", "urban construction boundary", "urban growth containment", "yellow line boundary", "urban edge" and other terms used to define urban growth boundaries. To obtain non-academic literature, a general google search was performed on similar keywords. Examination of the literature was restricted to only those countries that have been identified as developing countries or countries in transition and were further restricted to literature discussing the implementation of UGBs after 1960. Additionally, the use of greenbelts and natural boundaries as alternatives to UGBs were not considered in this study, as they require a different set of implementation processes and have different characteristics and challenges associated with them. Although the results from the literature search (Appendix A and B) is far from an exhaustive list of all the UGB related literature on developing countries published within the time period, it provides good insight into the trend of current research on the topic.

Results from the literature search indicated a distinct scarcity of research examining various aspects of UGB within the developing world. However, over the last decade, there has been a resurgence in the adoption of UGB within the developing countries (Bhatta, 2009; Tayyebi, Pijanowski, & Tayyebi, 2011). Likewise, there has also been an increase in the literature on the use of UGB for restricting urban expansion in the developing world (Figure 1). A significant proportion of the literature has been based on the five countries where UGB has been explicitly implemented, while the rest has been based on the hypothetical or potential application of UGB within various developing countries. Additionally, a majority of research within the literature discussing the hypothetical application of UGB has focused on exploring the methodological approaches that could be used for UGB boundary delineation. The result further indicated that only a limited number of research has investigated the concerns and other policy/regulatory challenges associated with UGB implementation within developing countries.

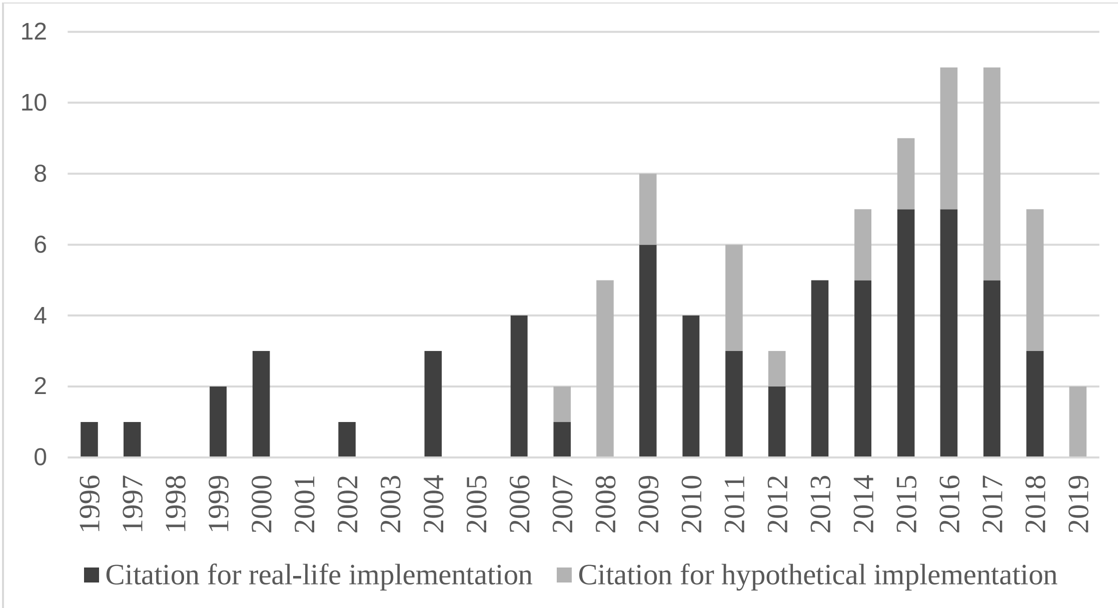


Figure 1: Results from the literature search indicating the distribution of the number of articles related to the real-life and hypothetical implementation of UGB in the developing world per year

The combination of GIS methods and urban growth boundary policy may allow researchers to manage the sustainable urban expansion of cities in Bangladesh when examining a complex urban system, the ordering of these urban areas generally gives an indication of the sustainability of urban growth. Urban growth generally occurs as a hierarchy regardless of the region, as indicated by the rank-size distribution (Batty, 2008; Modica et al., 2017). This consistency presented by the hierarchy of urban systems reflects the economic functions and the economies of scale that drive the growth and can further inform on the pressure on the resources needed to serve these demands in a given area (Batty, 2008; Chen et al., 2014). This application of this theory on city size can provide a much-needed dimension when exploring questions regarding the sustainability of cities and constructing related policies (Way, 2016). The adoption of UGB for the cities in Bangladesh would provide a robust planning framework to restrict and direct urban growth while focusing on sustainable urban expansion of the cities.

1.3 Research Objectives

The overall objective of this dissertation is to contribute to the existing literature examining sustainable expansion of urban areas. In particular, the research investigates the pattern of urban expansion occurring among the cities and municipalities of Bangladesh and proposes the use of UGB as a robust planning framework to promote sustainable urban expansion while discussing potential areas of concern that would need to be addressed for the proposal to be successful. With regards to this, the specific objectives of this research are to:

1. Examine whether there are continued spatial inequalities in urban growth patterns by comparing the urban footprint of the cities and municipalities in Bangladesh between 1990 and 2019

2. Explores the application of UGB delineation using Support Vector Machine (SVM) supervised machine learning algorithm as an urban growth restriction mechanism for the city of Chattogram, one of the world largest port cities and the second-largest metropolitan areas in Bangladesh, as a case study

3. Investigates the key considerations essential for the successful adoption and implementation of UGB through a systematic review of literature on UGB and planning policies on Chattogram, along with a web-based survey and unstructured interview with city officials.

1.4 Synopsis of Dissertation

The dissertation is organized as follows: Chapter I provides a brief introduction to the UGB along with its history and a quick summary with regards to the trends seen for research related to the application of UGB in developing countries. Additionally, it identifies some distinct gaps in the literature with regards to the use of UGB within developing countries and highlights the objectives of this dissertation. Chapter II examines the rank-size distribution of built-up urban areas and population within Bangladesh and compares the evenness of its distribution among the larger cities and smaller/midsized cities over the last three decades. Additionally, it highlights the uncontrolled expansion of the urban footprint and unsustainable rates of urbanization occurring in the largest cities in Bangladesh, Dhaka and Chattogram, and reinforces the need for the exploration of policies and regulations targeted at guiding the rate and direction of urban expansion in these cities. Chapter III explores a novel approach to the delineation of potential UGB for the city of Chattogram by using SVM for simulating built-up urban areas and in turn its application for the boundary delineation. Chapter IV investigates some of the key considerations that are likely to have a significant impact on the potential adoption and implementation of UGB for the city of Chattogram. This investigation is conducted through a review of policies, past academic/non-academic literature, and a survey of stakeholders regarding their perceptions of past and future urban growth in Chattogram and their concerns regarding the use of an urban growth restriction policy such as UGB for the city. Chapter V provides an overall conclusion while discussing the limitations and highlighting areas of related future research.

CHAPTER II: RANK-SIZE DISTRIBUTION OF CITIES AND MUNICIPALITIES IN BANGLADESH[1]

2.1 Introduction

Bangladesh has experienced significant growth in all segments of the community, accompanied by built-up urban areas since the 1970s (Rana, 2011; UN/DESA, 2019). Less than nine percent of the population in Bangladesh was urbanized in 1974, but today 37% of the country's population live in urban areas, and this amount is expected to rise to 57% by 2050 (UN/DESA, 2019). New infrastructural developments have arisen to provide housing, roads, schools, services and parks for this growing population, but mostly with minimal regulation and planning. As a result, there have been haphazard urban buildups at the expense of productive agricultural land (López et al., 2001; Sultana et al., 2004), vegetated land (Y. Liu et al., 2015) and fragile wetlands (Bhat et al., 2017), which are often encroached upon illegally. Consequently, the current urbanization pattern has adverse effects on the quality of urban life.

While urbanization has generally been portrayed as a sign of economic growth, with all others environmental adverse impacts being considered as a growing pain, this concept has been challenged by Bloom et. al. (2008)—there is no evidence of close links between the level of urbanization and the rates of economic growth in developing countries like Bangladesh. Even though the GDP per capita has been increasing in the country for the last three decades or so, and Bangladesh may soon be considered as a middle income country (UN/DESA, 2019), there has been a lack of subsequent socio-economic improvement in the distribution of benefits across the geography and the population (Florida, 2015; Nazrul Islam, 1997; H. Z. Rahman, 2014). As Bangladesh has experienced a change in its political and economic structure, moving from agriculture towards a more urban sector economy (Muzzini & Aparicio, 2013), there have been

[1] Bajracharya, P., & Sultana, S. (2020). Rank-size Distribution of Cities and Municipalities in Bangladesh. *Sustainability*, *12*(11), 4643.

increased economic opportunities and improved civic facilities in the cities (M. M. Hassan & Southworth, 2018). This, coupled with an increase in natural disasters, a decrease in agricultural productivity and a loss of income in the rural areas, has resulted in a rural-to-urban migration of the rural poor into urbanized areas, which has contributed to a large portion of the unregulated urbanization in these cities (Rouf, 2018). These patterns of uncontrolled and unrestricted urbanization, leading to the transformation of natural landscapes into built-up urban areas, and their impact on the local environment and the overall ecosystem of the region have raised questions about the sustainability and livability of these cities (H. Z. Rahman, 2014). A well-balanced and well-informed urbanization is unquestionably key to maximizing the benefits and enhancing the quality of life for everyone while minimizing environmental degradation and other potential adverse impacts of a growing number of city dwellers (UN/DESA, 2019).

The urban system is complex. The complexities within the urban system are deeply rooted in the regularity that is seen in the ordering of the urban areas in a variety of spatial scales, regardless of the region (Batty, 2008; Modica et al., 2017). This consistency, presented by the hierarchy of urban systems, reflects the economic functions and the economies of scale that drive their growth and can further inform the pressure of the resources needed to serve these demands in a given area (Batty, 2008; M. Chen et al., 2014). Therefore, the application of theories on city size, while underexplored within the context of shaping of urban policy, can provide a much-needed additional dimension when exploring the questions of the sustainability and livability of cities, as well as constructing related policies (Way, 2016).

The primary goal of this study is to examine and update the rank-size distribution of urbanized areas of Bangladesh based on the most recent data available for measuring built-up urban areas and population. Rank-size rule distributions can be used simultaneously to support policies targeting smart development and the equitable distribution of resources needed in urban areas of Bangladesh. Previous studies (B. Jiang et al., 2015; Soo, 2005; Winidowa, 1992) have examined the rank-size distribution of urbanized areas for Bangladesh using different data approaches—population census data (Soo, 2005; Winidowa, 1992) or satellite data to define natural cities derived through the identification of areas of human activities and urban agglomeration (B. Jiang et al., 2015). Hence, a direct comparison between rank-size distributions of these studies has been difficult, particularly due to their use of different urban units for the analyses. In this study, to fill that gap, we establish a common urban unit based on the existing administrative boundaries and compare the conformity of the distribution of built-up urban areas and the distribution of population within these urban units in Bangladesh to Zipf's law. Due to the lack more recent up-to-date land cover data spanning the entire Bangladesh for different time periods, we use Google Earth Engine (GEE) to create a land cover classification and extract the built-up urban areas within the urban units and census data to extract the population living in these urban units. A direct comparison between the distribution of the two metrics provides valuable insight on the expansion of the urban footprint in reference to the increase in urban population and the sustainability of future urban development of the region. Understanding this urban distribution and the impetus behind these distributions is particularly important for developing countries such as Bangladesh in order to contribute towards a wide range of policy debates, including the optimal use of economic resources based on the urban hierarchy (Rosen & Resnick, 1980).

2.1.1 Zipfs Law

The hierarchical relations of city sizes and urban systems have been previously examined in the works of Christaller (1933) through the center place theory, that looks at the size and distribution of settlements, and Lösch (1940), who extended the central place theory by integrating economic and mathematical components in the theory. Similarly, Zipf's law is one of such theories examining the relation between the hierarchy of cities and their respective sizes (Arshad et al., 2018). Zipf's law, also known as the rank-size rule, is one of the prominent methodologies that have been implemented in the study of urban geography and examination of the city size distribution and growth of cities (Gabaix, 1999). The initial concept for Zipf's law was put forward as a special case of rank-size law by Auerbach, a German geographer, in 1913, who indicated that the distribution of the city sizes within a given region follows a Pareto distribution (Auerbach, 1915). This general rank-size law was revised and refined most notably by Zipf, hence being named Zipf's law (Soo, 2005). While Zipf's law is frequently used in reference to the size of the cities, it was implemented by Zipf (1949) to examine word frequency and has been used in a wide range of topics, including the size and income of companies (Okuyama et al., 1999), the expression of genes (Furusawa & Kaneko, 2003), the use of internet (Adamic & Huberman, 2002) and a variety of natural and physical phenomena (W. Li, 2002).

Mathematically, the Pareto distribution can be represented by the equation (1):

$$R_i = \frac{A}{S_i^b} \text{ or, } R_i = AS_i^{-b} \tag{1}$$

In the logarithmic form as equation (2):

$$\log{(R)_i} = \log(A) - b\log{(S_i)} \tag{2}$$

where i represents the city taken into consideration, S_i represents the population of the city i and R_i represents the ranking of the city i. A is the constant, with b representing the Pareto exponent (Arshad et al., 2018).

Equation (1) was restated by Zipf as Equation (3). Particularly when taken in terms of city-size states, the absolute size of the city is inversely proportional to the rank-size of the city. In other words, in the law states that are based on the ranking of the cities, the largest city will be roughly two times the size of the second biggest city, three times the size of the third biggest city and so on, or "the size of the nth city is approximately one-nth of the size of the largest city" (Beckmann, 1958). This relationship between the rank-size relation is also commonly referred to in the literature as the "Power law" (Newman, 2005). Mathematically equation (3):

$$S_i = \frac{K}{R_i^q} \text{ or, } S_i = KR_i^{-q} \tag{3}$$

where i represents the city taken into consideration, S_i represents the population of the city i and R_i represents the ranking of the city i. K is the constant, and q represents the Zipf's exponent (Arshad et al., 2018). This rank-size can be expressed in the logarithmic form as equation (4):

$$\log{(S)_i} = \log(K) - q\log{(R_i)} \tag{4}$$

Here, if the value of $q = 1$, the rank-size distribution is said to follow the Pareto distribution and satisfy Zipf's law. This suggests that within the urban system "the concentration ratio of population distribution and the dispersion ratio of population are completely equal" (Fang et al., 2017). If the value of $q < 1$, it suggests the population is relatively evenly distributed, with the urban population being more concentrated in the medium to smaller sized cities compared to the larger cities. Finally, if the value of $q > 1$, it suggests the population is unevenly distributed, with bigger cities hosting a larger portion of the population as compared to smaller and medium sized cities (Fang et al., 2017).

Additionally, Zipf's law, which is the static form, can be expressed dynamically as Gibrat's law, which indicates that the growth of the city does not depend on the initial size of the city (Gibrat, 1931). The formal definition of Gibrat's law states that the mean and variance of the distribution function are independent of the initial size of the city; instead, they depend on external functions such as the industrial activities within the city (Gabaix, 1999; Gabaix & Ioannides, 2004). Modica et al. (2017) indicates that previous studies by Champernowne (1953) and Simon (1955) have argued that that rank-size distribution arises if Gibrat's law is satisfied. Gabaix (1999) further suggested that once the drivers of city growth satisfy Gibrat's law, the distribution will converge to Zipf's distribution.

A generalization of Gibrat's law proposed by (Córdoba, 2008) suggested an allowance for city sizes to affect the variance of growth for the cities but not their mean growth rate considering Gibrat's law (Modica et al., 2017). This relaxing of Gibrat's law on non-proportional variances allowed for the examination of a divergence in Zipf's coefficient (See eq. 3) away from 1 (Córdoba, 2008). Modica et al. (2017) outlined the relationship between Zipf's law and Gibrat's law as follows: if Zipf1's law holds (i.e., Zipf's coefficient is 1), for Gibrat's law to apply, the mean and the variance should not depend on the size. If the rank-size distribution is more unevenly distributed (as given by Zipf's coefficient > 1), for Gibrat's law to apply, the mean needs to be independent of the size but the variance does not, indicating a greater volatility in growth for smaller cities. Finally, if the rank-size distribution is more evenly distributed (as given by Zipf's coefficient < 1), for Gibrat's law to apply, the mean needs to be independent of the size but the variance does not, thus indicating a greater volatility in growth for larger cities as compared to smaller cities.

Mathematically, Gibrat's law can be expressed as (Berry & Okulicz-Kozaryn, 2012; Eeckhout, 2004; Modica et al., 2017) equation (5):

$$\log(S_{i,t}) = \beta_t \log(S_{i,t-1}) + \varepsilon_i \qquad (5)$$

Here, i represents the city taken into consideration, t represents the time, S represents the size of the city, ε_i represents the independently and identically distributed error term and, β represents the coefficient. If the value of $\beta = 1$, Gibrat's law holds. If the value of $\beta > 1$, the size of the city is seen to diverge from the mean, and the growth is expected to be greater in larger cities. If the value of $\beta < 1$, the size of the city is seen to converge to the mean, and the growth expected is smaller for larger cities [15].

2.1.1.1 Literature Examining Zipf's Law in Developed Countries

There have been a large number of empirical studies in both developed and developing countries using Zipf's law to examine the distribution of urban areas and urban hierarchies. For the US, frequently cited studies—such as those by Krugman (1996), using population data from 130 metropolitan areas, Gabaix (1999), using population data for 1990 form the 135 largest metropolitan statistical areas, and Berry & Okulicz-Kozaryn (2012), using a regionally-integrated economic area with a population greater than 500,000—have concluded that Zipf's law holds for these urban regions. Internationally, Giesen and Südekum (Giesen & Südekum, 2010) used population data of large cities in Germany and concluded that the city rank-size distribution followed the Zipfian power law, while Budde and Neumann (2018) used a varying definition of urban region within Germany based on the population density across 1 km-square grid. These results indicated a moderate but systematic deviation away from Zipf's law when areas with lower density were included in the definition of urban regions (Budde & Neumann, 2018). Rastvortseva and Manaeva (2016) used 2014 population data to examine the rank-size of the Federal Districts in Russia and concluded that the Russian territory conformed to Zipf's law. However, for individual Federal Districts in Russia, the conformity to Zipf's law depended on the size of these Federal Districts. On the contrary, for countries such as Canada, using the 152 largest urban areas (Lalanne, 2014), and Poland, using urban communities as their urban units (Cieślik & Teresiński, 2016), the distribution of population was seen as not conforming to Zipf's law and was observed to be skewed towards the larger cities.

2.1.1.2 Literature Examining Zipf's Law in Developing Countries

The application of Zipf's law in developing countries has largely indicated a non-conformity of the rank-size distribution of urban areas. The results from the study by Gangopadhyay & Basu (2009) for India, using census data from 1941 to 2011 for cities, indicated that for the upper tail of the cities, with a population greater than 120,000, the city size distribution followed Zipf's law. However, other studies from India by Luckstead & Devadoss (2014), examining the rank-size distribution of cities from 1950 to 2010, also using census data, indicated that the cities exhibited a log-normal distribution instead of a Pareto distribution, particularly after the economic liberalization of India in 1980, resulting in an increased rate of urbanization. Arshad et al. (2019) used population data of five census years, from 1951 to 1998, to examine the city rank-size distribution at the national and provincial levels of Pakistan. The results of this study concluded that the city rank-size distribution followed Zipf's law at the provincial level, but not when these cities were examined at a national scale (Arshad et al., 2019). Tuholske et al. (2019) used OpenStreeMap data augmented with synthetic gridded population data to examine the change rank-size distribution of 4750 individual urban settlements across the continent of Africa from 2000 to 2015. The result resonated with the findings from a previous study by Jiang et al. (2015), which indicated a noticeable deviation from the Pareto distribution and concluded that the African urban settlements did not follow Zipf's law (2019).

In other cases, the conformity of urban areas within the given areas of interest to Zipf's law has been less concrete. For example, the examination of Zipf's law in Malaysian cities was performed using population census data for five points in time, from 1957 to 2007, by Soo (2007). The results indicated a rejection of Zipf's law for all years, except 1957, when the full population sample was considered. Over the years, the distribution of the city sizes moved away from the Pareto distribution and towards a greater degree of unevenness (Soo, 2007). Alternatively, when a truncated sample of only larger cities was considered, this trend was reversed, with an increased evenness in the distribution of population among the larger cities (Soo, 2007). For cities in Morocco, the adherence to Zipf's law was examined based on three truncated population census data at three different years, from 1982 to 2004 (Ezzahid & ElHamdani, 2015)[53]. The results from this study concluded that even though the Pareto coefficient for the cities at these levels was not statistically different from 1, the urban system for Morocco tended towards a more balanced distribution over time (Ezzahid & ElHamdani, 2015).

In the case of China, the empirical validity of Zipf's law for Chinese cities using census data from 1990 and 2000 has been examined by Gangopadhya & Basu (2013) at different levels of sample size truncation, at different time frames and using various definitions of urban areas. The results indicated that the city rank-size distribution of population in China followed Zipf's law, but only when the biggest cities in terms of population were considered, showing an increase in the Pareto coefficient over time. This increase in the Pareto coefficient was further confirmed by Peng (2010) and Ziqin (2016), both suggesting an increase in the concentration of population in the smaller and medium sized cities, leading to an evenness in the distribution of population in the biggest cities. Q. Huang et al. (2015) used naturally delineated cities or natural cities based on nighttime light data to identify their urban footprint and examine its conformity to Zipf's law (Q. Huang et al., 2015). The results indicated that the Pareto exponent showed a gradual increase from 1992 to 2008, showing an evenness in the distribution of urbanized areas (Q. Huang et al., 2015).

Examinations of Zipf's law have also been conducted at the regional and global scales. These large-scale investigations of the rank-size distribution of cities have included studies by Rosen and Resnick (1980) using population data from 1970 for cities in 44 countries. The results from the study calculated the average Pareto coefficient to be 1.136, not conforming to Zipf's law (Rosen & Resnick, 1980). More recently, a large-scale investigation of Zipf's law was conducted by Soo (2007) for 73 countries using population census data and based on the definition of urban areas as cities and urban agglomerations . The results derived for cities defined as urban areas was consistent with the previous study by Rosen and Resnick (1980) and rejected Zipf's law. The results differed when the definition of urban areas as urban agglomerations was used. Furthermore, using the Hills estimator instead of the Ordinary Least Square (OLS) method, the results were seen to be reversed (Soo, 2007). A meta-study conducted by Nitsch (2005) using 29 studies and 515 Pareto estimates from a wide range of territories and time period concluded that Pareto estimates significantly deviated and were higher than 1. This suggested that the cities around the world, on average, were seen to be more evenly distributed. Nighttime light data was used by Jiang et al. (2015) to determine if Zipf's law holds at a global scale, including a total of 30,000 cities around the world. This research concluded that Zipf's law held well for natural cities at a global scale and at a continental scale (except Africa), but showed considerable variation at the country scale and during different time frames.

Overall, Arshad et al. (2018), surveying the literature, divided the findings from the empirical studies related Zipf's law and rank-size distribution into five categories: 1. Studies that show urban areas within the selected area of interest conforming to Zipf's law; 2. Studies that reject the distribution of urban areas within the given areas of interest conforming Zipf's law; 3. Studies that have shown a mixed result when examining the distribution of urban units within those following Zipf’s law; 4. Studies that show the distribution of the urban areas moving away from Zipf's law as the country experiences urbanization; 5. Studies that have shown that city size distribution moves away from Zipf's law over time.

2.1.1.3 Literature Examining Zipf’s Law for Bangladesh

There have been several studies examining Zipf's law for Bangladesh (Table 1). Winidowa (1992) used national census data for Bangladesh from 1961, 1974 and 1981 for the analysis. In this study, areas identified as towns in the census were taken as the primary unit areas of study and included 77, 108 and 451 regions that were defined as towns for the years 1961, 1974 and 1981, respectively (Winidowa, 1992). The results indicated that the rank-size distribution for the towns in Bangladesh increasingly did not conform to Zipf's law, showing a gradual increase in the Pareto coefficient over the years, going from 1.0296 in 1961 to 1.1526 in 1974 and to 1.2654 in 1981. This indicated bigger towns in Bangladesh hosting a greater proportion of the population. Winidowa (1992) describes these deviations away from Pareto distribution as a function of “political divisions, the low degree of urbanization and a weak economic development level of the country” (p. 200). In other global studies associated with Zipf's law, the Pareto coefficient reported for Bangladesh has shown a large degree of variation. Soo (2007), using population data from 1991 for 79 cities in Bangladesh, calculated the Pareto coefficient at 1.0914, not significantly different from 1; while using urban agglomeration data, with a total of 43 agglomerations, the Pareto coefficient was calculated at 0.8068 and was shown to be significantly different from 1 (Soo, 2007). Similarly, D’Costa (1994) examined the rank-size distribution of urban centers in Bangladesh from 1901 to 1981 using population data. The results indicated a largely even or “deconcentrated” distribution of population for a majority of the time frame, with an increase in primacy from 1961 to 1971.

This was largely attributed to Pakistan's policies of developing major cities such as Dhaka and Chattogram, formerly belonging to East Pakistan, following its independence from India (D'Costa, 1994).

Nishiyama et al. (2008), also using urban agglomeration data from 1991, but with a total of 140 agglomerations, calculated the Pareto coefficient at 1.27 and found the value to be significantly different from 1 at one percent. In a more recent study, Jiang et al. (2015) used nighttime light data to derive natural cities for 1992, 2001 and 2010, with natural cities being defined as those with areas greater than 10 square kilometers. The result indicated a Pareto coefficient of 2.1 for 1992, 2.2 for 2001 and 2.1 for 2010 (B. Jiang et al., 2015). Currently, however, there is no study examining the city rank-size distribution using the most recent data for Bangladesh. The primary goal of this study is to examine the conformity of built-up urban areas and the population in these urban areas to Zipf's law and compare the rank-size distribution of the two.

Table 1: Studies examining Zipf's Law for Bangladesh

Author (Year)	Date Range	Sample	Findings
Winidowa (1992)	1961–1981	Population of towns based on census	The rank-size distribution did not conform to Zipf's law and showed a gradual increase in the Pareto coefficient away from 1 over the years
D'Costa (1994)	1901–1981	Population of urban centers	The rank-size distribution of urban centers showed a largely "deconcentrated" distribution with values of Zipf's exponent less than 1 in all years except 1961 and 1974, where it was greater than 1
Soo (2005)	1991	Population of cities and urban agglomerations	The rank-size distribution of population for cities conformed to Zipf's law but the distribution of urban agglomerations did not conform to Zipf's law, with the value of Zipf's exponent being less than 1
Nishiyama et al. (2008)	1991	Urban agglomerations	The rank-size distribution of urban agglomerations was unevenly distributed, with the value of the Pareto coefficient greater than 1
Jiang et al. (2015)	1992–2010	Natural cities derived based on nightlight	The rank-size distribution of natural cities showed an uneven distribution,

	data with areas greater than 10 sq. km.	with a Pareto coefficient greater than 1 for all three years

2.1.2 Some Considerations Regarding Zip's Law

This brief review of literature highlights a number of different considerations associated with Zipf's law and the rank-size distribution. These considerations follow an empirical point of view as well as a theoretical standpoint. One of the reoccurring issues while examining Zipf's law has been its sensitivity to the changes in the definition of the urban unit commonly referred to as Modifiable Aerial Unit Problem (Fotheringham & Wong, 1991). In other words, depending on the definition of the urban units based on which Zipf's law is being examined, there may be a change in the results. Historically, for Zipf's law, the size of the city has been estimated using the population within the administrative boundaries of the city (Budde & Neumann, 2018). Although the use of administrative boundaries as urban unit areas has been viewed as misleading and contributing to inconsistencies, particularly due to the political and social influence in the assignment of these boundaries. Rather than the boundaries acting as a demarcation for built-up urban areas and human activities (W. Wu et al., 2018), they serve as a good starting point. Other studies, such as by Rauch (2013) and Reggiani & Nijkamp (2012), have indicated that an urban agglomeration, which consists of the central city along with its hinterland, could provide the best representation for urban rank-size distribution, rather than only including the central cities. Previously, there has been no one uniform standardized definition of cities and urban areas (Buettner, 2015; McGranahan & Satterthwaite, 2014). The definition followed arbitrary rules, depending on the country (B. Jiang, 2019). However, more recently, advancements in geospatial technology and big data have made it possible to define cities based on the concept of natural cities through a variety of processes, such as the bottoms up approach, based on building footprints (B. Jiang, 2019) and nighttime light data (B. Jiang et al., 2015; W. Wu et al., 2018).

The difference in the identification of urban unit areas considered in the analysis has a significant impact on the estimates of Zipf's exponent derived from it. The impact of change in the definition of urban areas on the conformity to Zipf's law has been highlighted in a number of different studies, including Soo (2007) and Nitsch (2005), where the use of agglomeration data compared to population census data yielded two contrasting results. For the US, studies by Krugman (1996) and Gabaix (1999), using the US metropolitan level data, indicated its adherence to the Pareto distribution, but using census-defined places from the 2000 US census, Eeckhout (2004) showed that data at this scale deviated from the Pareto distribution. Additionally, Berry & Okulicz-Kozaryn (2012) indicated that the specific clustering of urban areas into a megalopolitan urban-economic region allowed the US city size to strictly follow the Zipfian distribution. More recently, an increasing number of studies have applied the concept of natural cities and are using remotely sensed images to investigate the conformity of city sizes to Zipf's law. The application of remotely sensed images to Zipf's law has included their use for urban area detection by land cover, land use classification (Fragkias & Seto, 2009; Kinoshita et al., 2008), nighttime light (Q. Huang et al., 2015; Small et al., 2011) as well as urban surface heat (B. Zhou et al., 2017).

The sizes of the samples used to analyze Zipf's law were also shown to have a significant influence on the results (Guérin-Pace, 1995). Using population data from French cities, Guérin-Pace (1995) showed an overall decrease in inequality in the distribution of population when samples of cities were truncated based on a threshold population size that resulted in the selection of cities at the top of the hierarchy. Similarly, using population data for Chinese cities, Gangopadhyay and Basu (2009) and Huang et al. (2015) found that a higher amount of truncation of tail-end data resulted in an increase in evenness in the rank-size distribution of cities. Peng (2010), using a rolling sample regression for Chinese cities, also concluded that an increase in the amount of truncation in the data led to a decrease in the Pareto coefficient, thus indicating an increased evenness in the rank-size distribution. Eeckhout (2004) further stated that for the power law to apply to cities, it is essential to introduce a truncation point into the analysis. Arshad et al. (2019), in the review paper, further noted that all the studies that have supported Zipf's law have worked with a truncated sample and data from the upper tail of the distribution, but also acknowledged that the choice of truncation points by the researchers introduces arbitrariness into the sample.

Skeptics such as Ausloos and Cerqueti (2016) have criticized Zipf's law as being inadequate to describe city rank-size and have suggested an alternative distribution based on arguments from theoretical physics. Benguigui and Blumenfeld-Lieberthal (2004) have also suggested that Zipf's law should not be used as a universal law and have called for an abandonment of the paradigm of Zipf’s law. Furthermore, methodological changes suggesting a reevaluation of Zipf's law, away from Eq. 3 and OLS regression, and the use of Rank—½ (Gabaix & Ioannides, 2004) and the implementation of recursive regression (Fazio & Modica, 2015) have been suggested. Additionally, there has also been much discussion related to the use of alternate distribution, such as a log-normal distribution (Eeckhout, 2004; Fazio & Modica, 2015; Ioannides & Skouras, 2013) and the double Pareto log-normal distribution (Giesen & Südekum, 2010; Reed & Jorgensen, 2004), better fitting the rank-size rule as compared to the Pareto distribution. These deviations away from the rank-size, seen as a result of the definition of urban areas and the truncation of data, along with the simplicity in the formula used to derive the distribution, have been some of the major sources of skepticism and controversy surrounding Zipf's law (Guérin-Pace, 1995).

In reality, the Pareto coefficient or Zipf's exponent value corresponding to 1 is rarely achieved (Guérin-Pace, 1995). However, rather than examining whether Zipf's law is accepted or rejected for a particular urban system, questions regarding how well or how poorly the theory fits the urban system should be evaluated (Gabaix & Ioannides, 2004). Guérin-Pace (1995) calls for change in the way in which city rank-size is interpreted and emphasizes the need to consider the deviations away from the Pareto distribution as a way to examine the "dynamic process of evolution of a city size and of the urban system" (p. 561) over time. Similarly, with respect to urbanization, Wu et al. (2018) describe Zipf's law as proving a universal degree of measure describing the urbanity of a system. Furthermore, Guérin-Pace (1995) underlines the need to investigate the explanations for the observed deviation away from the Pareto distribution. These deviations in the distribution away from Zipf's law can be attributed to a myriad of underlying distortions in urban systems, such as institutional factors, economic factors, the allocation of resources or even mere accidental factors (Arshad et al., 2019).

2.2. Material and Methods

2.2.1 Identification of Urban Areas for Bangladesh

The definition of urban units has a big influence on the overall outcome when examining Zipf's coefficient (Rosen & Resnick, 1980). There have been many calls by scholars for a consistent definition, allowing for the delineation of urban areas and urban population (Buettner, 2015; McGranahan & Satterthwaite, 2014). Urban areas have been identified based on a variety of definitions, which have included those based on administrative regions, population size, population density, population characteristics or a combination of these criteria (Buettner, 2015; McGranahan & Satterthwaite, 2014). An example of those based on economic activities is the requirement that the majority of the population be employed in non-agricultural activities (Borel-Saladin, 2017). Other definitions of urban areas have been based on administrative functions, facilities and infrastructure such as schools and municipal buildings within a geographic area (Borel-Saladin, 2017; B. Cohen, 2004). More recently, urban areas have been defined based on the concept of natural cities, derived through the identification of areas of human activities and urban agglomeration (B. Jiang & Jia, 2011; B. Jiang & Liu, 2012).

For this study, we derived the definition of urban units using a two-step process by combing traditional administrative boundary data with the concept of natural cities (B. Jiang & Jia, 2011). Traditionally, the urban administrative hierarchy structure in Bangladesh has been divided into four categories— namely megacities, Statistical Metropolitan Areas, Pourashavas or municipalities and other urban areas (OUA) based on the population size and the administration/governance hierarchy (Nazrul Islam, 1997). Currently, Dhaka is the only megacity in Bangladesh that includes an agglomeration of Dhaka City Corporation, along with several municipalities and a number of villages or union parishads (UP) (Nazrul Islam, 1997; United Nations, 2019). The Statistical Metropolitan Areas, also known as City Corporations, have been defined as larger areas showing urban characteristics, where the definition of urban, as given by the Bangladesh Bureau of Census, includes a central place with infrastructure such as paved roads, electricity, water supply and sanitation, and where a majority of the population is working in the non-agricultural sector (M. S. Rahman et al., 2019). Smaller urban areas that also show urban characteristics have been defined as Pourashavas or Municipalities by the Ministry of Local Government, Rural Development and Cooperatives (Nazrul Islam, 1997; S. Islam, 2015). Finally, Other Urban Areas (OUA) are usually Upazila headquarters that have big market areas but have not been officially declared as Pourashava (S. Islam, 2015).

The administrative boundaries for city corporations and municipalities, as defined by the Bangladesh Bureau of Statistics for 1991, were used as the baseline for the spatial extent to identify built-up urban areas, where human activities and urban agglomerations occur, using Google Earth Engine (GEE) based land cover classification. The population data for the municipalities and city corporations was derived from the 10-year census from 1991, 2001 and 2011 for these revised urban areas. Although there was not a perfect overlap between the number of municipalities listed for population data and those used to examine the built-up urban areas, due to the revision of municipalities in the later years, a comparison between the two can provide a valuable understanding of the distribution of population and urban areas in Bangladesh.

2.2.2 Google Earth Engine

As a result of the limited availability of land cover maps for the whole of Bangladesh for multiple time periods, we employed GEE to produce land cover data. This GEE-based land cover map was specifically targeted to extract built-up urban areas in Bangladesh. GEE has gained much traction with regards to its application in the field of remote sensing. It stands out as a platform that provides simultaneous and instant access to a wide variety of public and private data as well as a diverse set of scalable computation and remote sensing applications, all into one online framework, thus creating a powerful tool for researchers, practitioners as well as other stakeholders interested in using remote sensing and geographic information methodologies (Azzari & Lobell, 2017). More importantly, the integrated GEE system, making use of the cloud-based infrastructure, considerably reduces the need for local machines with high processing power and decreases the need for bandwidth intensive download of large remotely sensed data files (Gorelick et al., 2017). These features within the GEE platform have provided the access and processing power needed to work with freely available, large and relatively high spatial and temporal resolution data such as Landsat (Midekisa et al., 2017). Additionally, the ease of use of the platform for users with limited knowledge of programming languages and remote sensing techniques (Alonso et al., 2016), as well as capabilities within the system for advanced programmers to incorporate sophisticated methodologies, make it a flexible and a powerful tool (H. Huang et al., 2017). As Azzari & Lobell (2017) state, the GEE platform, "by simplifying access and processing of large amount of satellite data, are changing the paradigm in land cover monitoring from a static, product-based approach into a more dynamic and application-specific one without any loss of accuracy" (p. 65).

The GEE platform has been previously implemented to examine a wide variety of topics, ranging from inspection of wetland degradation in Costa Rica (Alonso et al., 2016) to the identification of mining areas in Brazil (Lobo et al., 2018), snow mapping and hydrologic modeling (Sproles et al., 2018) and automated mapping of crop land (Xiong et al., 2017), as well as disaster management and earth sciences related research (Mutanga & Kumar, 2019), to name a few. However, a significant portion of the literature associated with GEE still involves its application in land cover and land use mapping.

2.2.3 Data for Classification

Data used for land cover classification using the GEE platform comprised the Landsat 5 Top of Atmosphere (TOA) for 1990, 2000 and 2010 and the Landsat 8 TOA for 2019. Spectral bands corresponding to Blue, Green, Red, Near Infrared, Short Infrared 1, Short Infrared 2 and Thermal Infrared available within the Landsat images were used for classification. A four-image collection corresponding to the four years were created using 14 individual Landsat image tiles mosaicked together (except for 2019, where only 13 tiles were used). The Landsat TOA tiles used in the mosaic were limited to images collected during the months of January to May and with a cloud cover of less than 5 percent. Although not ideal, in cases when the cover was less than 5 percent, data from the following year for those months was used.

2.2.4 Training and Validation Points

The classification scheme used in this study was loosely based on the Fine Resolution Observation and Monitoring of Global Land Cover (FROM-GLC) level I scheme, one of the most commonly used global land cover products (Feng et al., 2016), that was originally introduced by Gong et al. (2013). For this study, the FROM-GLC level I scheme containing seven categories (cropland, forest, grassland, shrubland, water, bareland and snow/ice) was simplified to 5 categories. The simplification process involved combining forest, shrubland and grassland into a single category classified as vegetation, renaming bareland to barren/sand, renaming cropland to agriculture, eliminating the snow/ice class and adding the urban area category to the classification.

The use of higher-resolution images for the creation of training and validation points has been a well-used methodology. This methodology has been previously implemented in studies such as Hansen et al. (2008) and Midekisa et al. (2017), where Landsat images were used to create training and validation data points. Traganos et al. (Traganos et al., 2018) used ArcGIS's based World Image base map to manually digitize the training data and (Mutanga & Kumar, 2019) used high resolution Rapid-eye images for validation purposes. The training and validation data points used in this study for the purpose of classification were derived from a visual inspection of freely available high-resolution images ranging from 30 cm to 15 cm at its highest (Google, 2019) to medium resolution images from Landsat, using Google Earth (GE). Through the inspection of high-resolution images, the areas identified as built-up urban areas included concrete buildings, metal and clay rooftops, asphalt roads as well as other built infrastructures; the barren/sand category included areas along the beach and riversides that had sandy deposits and rockfaces on the side of hills; and the agriculture category included areas that were being actively farmed at the time when the image was acquired as well as areas that were not being actively farmed at the time of the image acquisition. Finally, the snow/ice class was eliminated because it was largely irrelevant for Bangladesh.

For training purposes, Bangladesh was divided into 9 different sections (See Figure 2) using the fishnet tool available in ArcMap. The classification for each of the sections was performed separately and later combined into a complete map of Bangladesh. The training sample polygons used in the classification were manually digitized on Google Earth (GE), referencing the high-resolution images for the time period when Landsat images or high-resolution images were not available. These reference training polygons consisted of a total of 975 (+/- 10 depending on the year) polygons distributed across the five different classification categories and evenly distributed across the entirety of Bangladesh among the 9 individual sectors (Figure 2). Additionally, changes to the shape, location and number of the training polygons were made for each of the four years in order to reflect the changes in land cover conditions over the years.

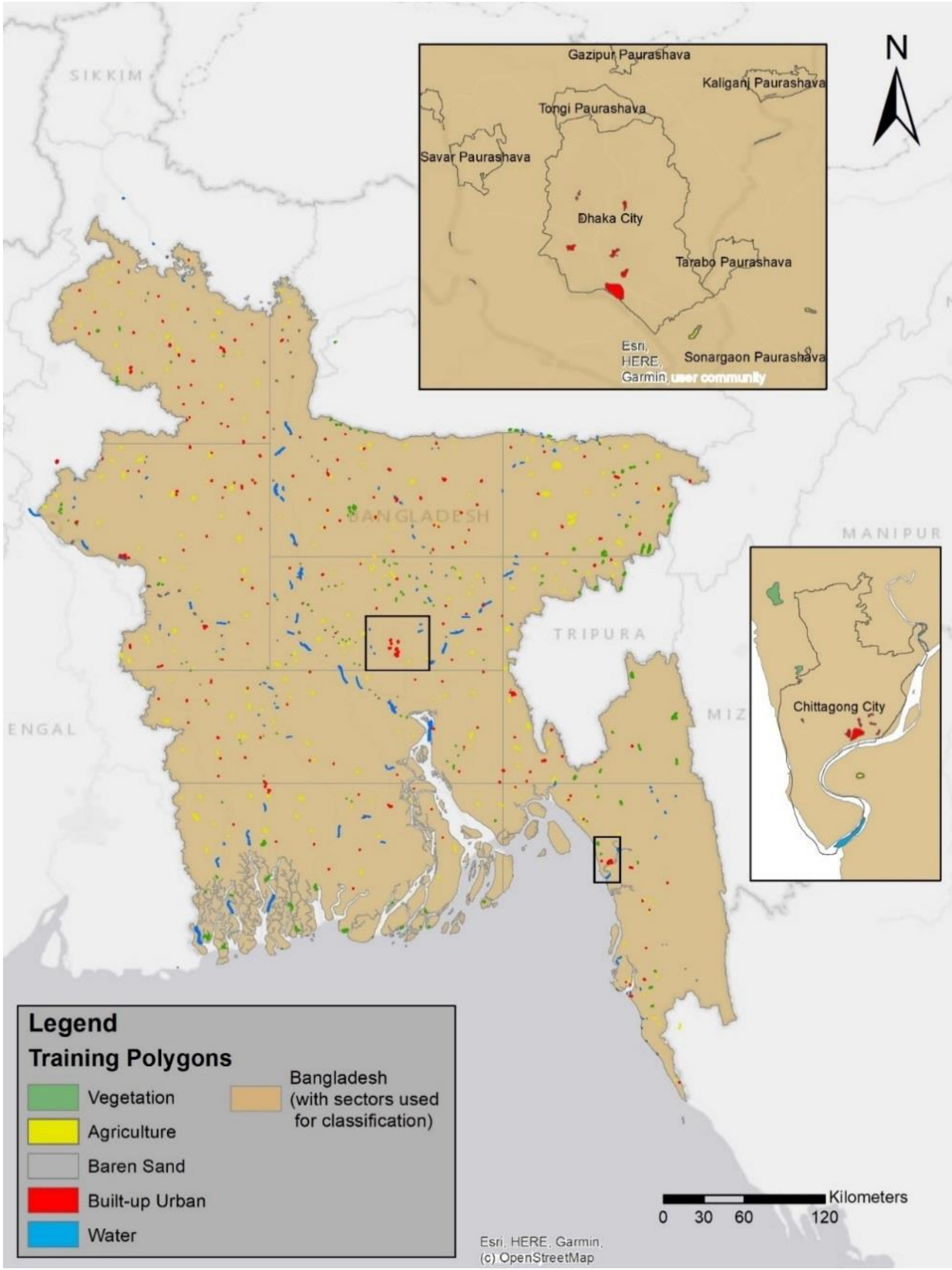


Figure 2: Highlighted classification sectors and referenced training sample polygons used in land cover classifications in Bangladesh.

For the validation of the classified land cover, considering the entirety of Bangladesh, 1150 to 1200 sample validation points were manually digitized such that they were evenly distributed amongst the five land cover classes (see Figure 2). When only the cities and municipalities of Bangladesh were considered, 500 random points were generated within these cities and the municipalities using ArcGIS (Figure 4). These validation points were manually referenced, using high-resolution images within the GE, when available, or using Landsat images when high-resolution images were not available. Additionally, changes to the location and the number of the validation points were made for each of the four years in order to reflect the changes in land cover conditions at the given point over the years.

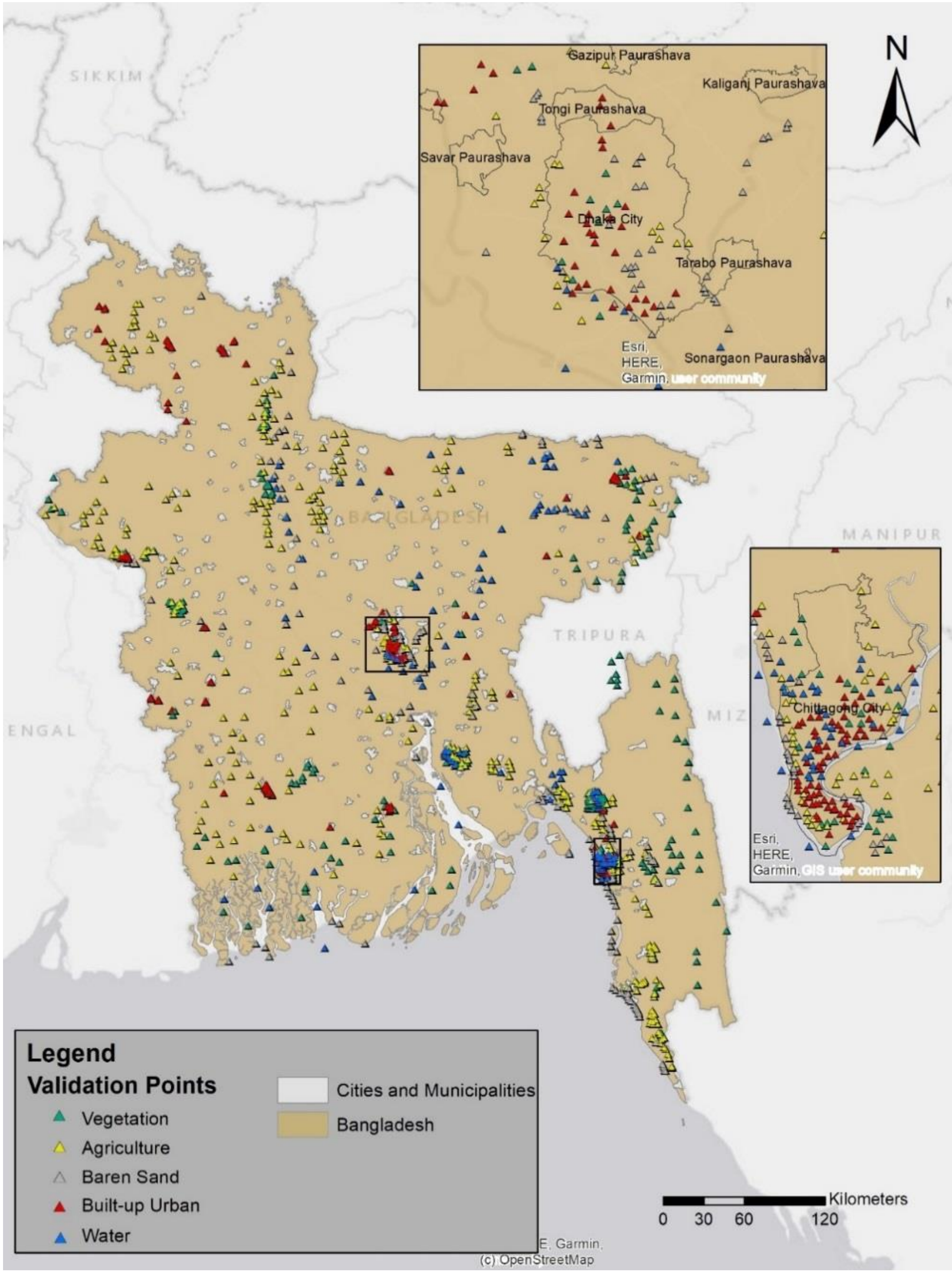


Figure 3: Map of Bangladesh highlighting the validation sample points used for the validation of land cover classification when considering the entirety of Bangladesh.

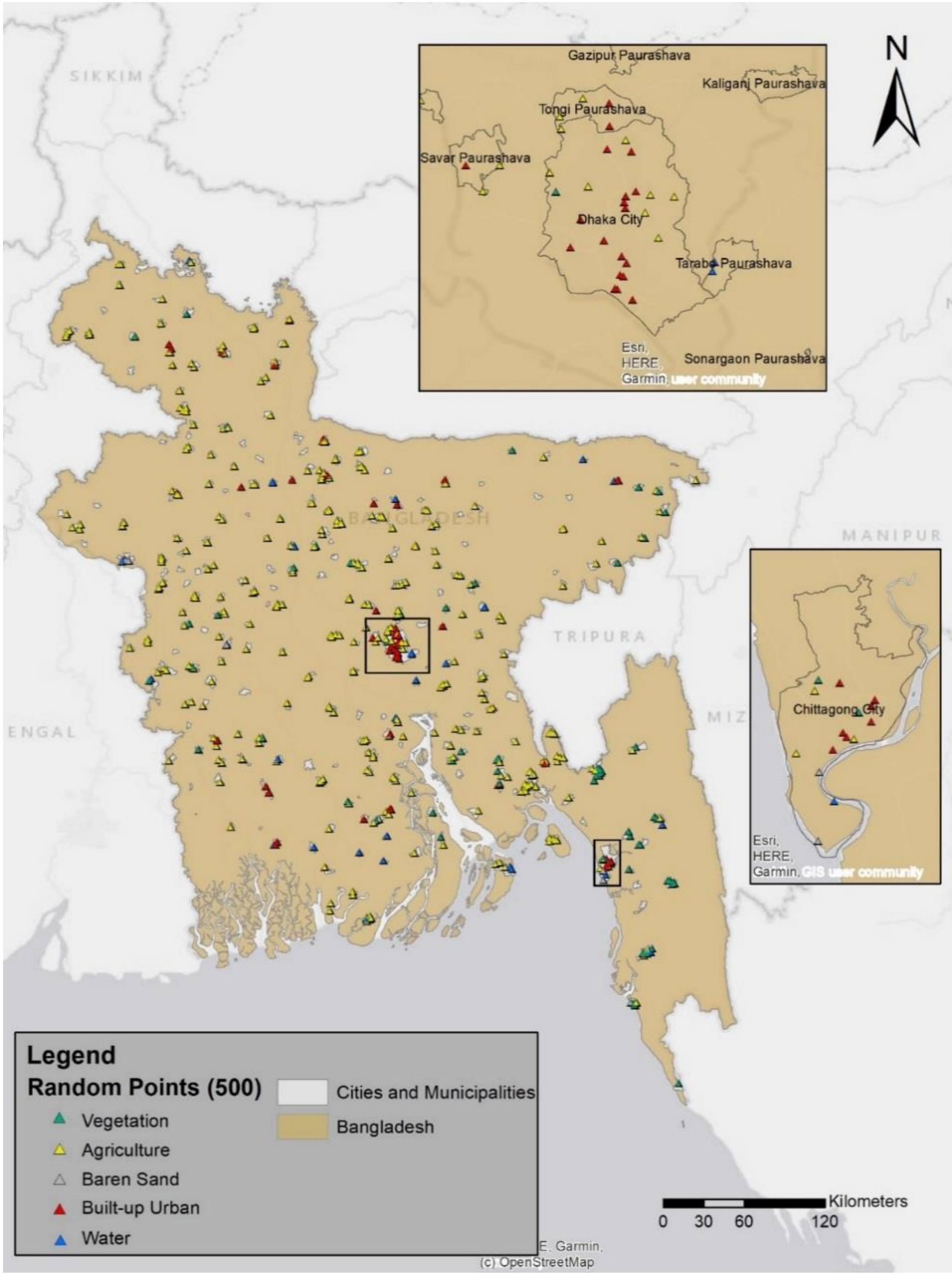


Figure 4: Highlighted validation sample points of land cover classification when only the Cities and Municipalities were considered.

2.2.5 Classification Using Classification and Regression Tree (CART)

In this study, the classification of land cover was performed using Classification and Regression Trees (CART), a machine-learning-based supervised classifier (Breiman, 2017), available within the GEE platform. According to Steinberg & Colla (2009), “The CART decision tree is a binary recursive partitioning procedure capable of processing continuous and nominal attributes as targets and predictors” (p. 181). In other words, CART is a machine-learning-based method of creating prediction models by recursively partitioning the data and fitting a simple prediction model in each of these partitions (Loh, 2011). De’ath & Fabricius (2000) describe the methodology as being flexible, robust and easily interpretable, with the ability to handle missing values and the capability of handling a variety of data types such as numeric, categorical, ordered as well as survival data. Additionally, the well-known problem of imbalanced classes in machine learning has been explicitly addressed by the authors of CART. Regardless of the extent of imbalance in the training data, CART automatically adjusts to the imbalance without the need for external actions such as sampling or weighing (Steinberg & Colla, 2009). The classification methodology associated with CART has been best described as a tree-like structure where data from the root node splits into two children, which further split into its grandchildren (Steinberg & Colla, 2009). The best split of the node is based on the split that minimizes the sum of squares (Berk, 2008). Once the maximum number of splits is reached, the tree is pruned based on the split that contributes the least to the overall performance of the tree, resulting in the smallest misclassification error (Loh, 2011). This mechanism produces sequences of nested trees, each of which is a candidate for the optimum tree (Steinberg & Colla, 2009). Finally, based on cross validation, the predictive performance of each of the pruned trees is evaluated and the final right-sized tree is identified (De’ath & Fabricius, 2000; Steinberg & Colla, 2009).

Amongst other supervised classifiers available within GEE, based on the past studies, CART was determined to have the best performance in comparison. A previous study by Farda (2017) revealed that when using supervised machine learning for classification in GEE, CART was shown to outperform the Support Vector Machines (SVM) classifier. Comparing the classification accuracy of CART, SVM and Random Forest (RF), Goldblatt et al. (2016) indicated that among the three, SVM had the lowest classification accuracy, followed by CART and RF. These results were further verified by Shelestov et al. (2017) in a review of the performance of classification algorithms available within GEE, where the authors indicated CART as having the best performance as compared to other algorithms.

The land cover classification results produced using CART were exported to the Google drive in the Tiff format for the 9 individual sectors. These exported sectors were combined as a single map using ArcMap. In order to get a smoother representation of the classified areas, the majority filter tool also available within the ArcMap was run. Finally, areas classified as built-up urban areas within the cities and municipalities were extracted from the results. The steps involved in the land cover classification process are highlighted in the flowchart (Figure 5).

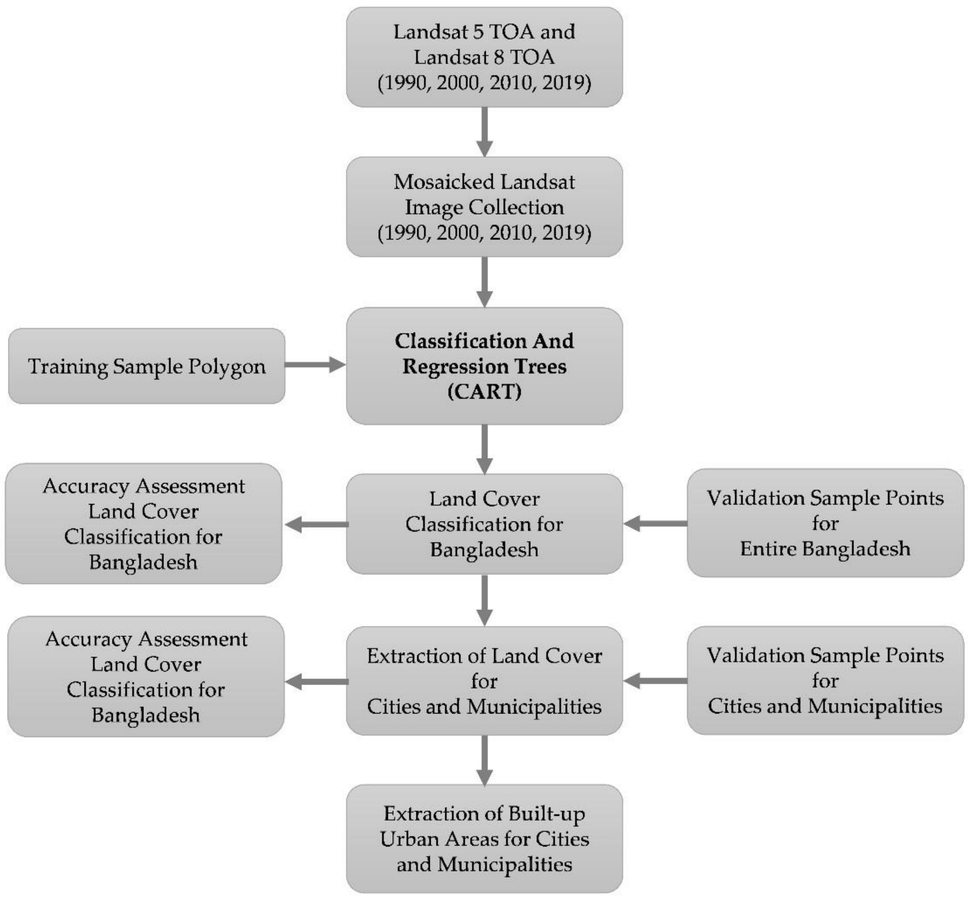


Figure 5: Flowchart indicating the steps involved in the land cover classification.

2.3 Results

2.3.1 Validation and Classification Results

The assessment of accuracy is an important component within the context of remote sensing, as it associates the remotely sensed and classified images with the observations in reality (Traganos et al., 2018). The accuracy of the classifier was examined by using the widely implemented confusion matrix or error matrix methodology (Stehman, 1997). The overall accuracy of the land cover classification for the whole of Bangladesh was calculated between 70.45 and 72.68 (See Table 2). The Kappa coefficient, which indicates the measure of agreement between the actual land cover and the predicted land cover (J. Cohen, 1960), was calculated between 57.74 and 62.68 for their respective time frames (See Table 2). Although the Kappa value is relatively low, based on the commonly cited scale for interpretation of Kappa values by Landis & Koch (1977), the agreement between the predicted and the actual land cover was defined as being between moderate and substantial levels. Furthermore, when only the cities and municipalities were taken into consideration, the accuracy of the classification showed significant improvement. The overall accuracy of land cover classification within the cities and municipalities was calculated between 84.2 and 87.4 percent, and the kappa coefficient was between 73.06 and 77.81 for the 4 years, respectively (See Table 2). Based on Landis & Koch (1977), this level of agreement between the predicted and actual land cover was shown to be substantial.

Table 2: Validation accuracy assessment for land cover classification of Bangladesh using Google Earth Engine (values in percentage).

	All of Bangladesh				**Cities and municipalities**			
	1990	2000	2010	2019	1990	2000	2010	2019
Overall Accuracy	70.61	72.21	70.45	72.68	87.4	87.4	84.2	84.8
Overall Kappa Coefficient	57.74	62.68	60.51	62.4	77.11	77.81	73.06	73.1
Producer Accuracy Urban Built-up Land Cover	40.4	47.75	62.93	61.27	73.53	74.47	81.48	85.96
User Accuracy Urban Built-up Land Cover	57.14	75.22	85.88	91.58	86.21	87.5	93.62	79.03

As the study is largely concerned with built-up urban areas, the producer accuracy and the user accuracy for the built-up urban areas are also computed. Producer accuracy provides information regarding how well a particular region is being classified and is derived by taking the ratio of validation samples that were correctly classified and the actual number of validation samples in the class (Banko, 1998; Traganos et al., 2018). User accuracy provides information regarding the reliability of the map and is derived by dividing the total number of validation samples in a given class by the total number of validation samples that are claimed to be in the class (Banko, 1998; Traganos et al., 2018). The producer accuracy of the built-up urban areas for the entirety of Bangladesh was calculated within the range of 40.4 and 62.93 percent, and the user accuracy was calculated in the range of 57.14 and 91.58 percent (Table 2) between 1990 and 2019. When considering only the cities and municipalities, the producer accuracy ranged from 73.53 to 85.96 percent, and the user accuracy ranged from 79.03 to 93.62 percent over the given years.

One of the major challenges faced during the classification process was due to the typical structure of built-up urban areas in the smaller municipalities in Bangladesh. In these locations, the built-up areas were generally comingled with, and surrounded by, vegetation such as trees and shrubs (Figure 6). Considering the Landsat resolution of 30 m, this proximity of vegetation alongside the built-up areas contributed to a higher degree of error in the classification, particularly for urban areas.

Figure 6: Screen capture from Google Earth for Ranisankali, Bangladesh, showing the difficulty in classification resulting from a mixture of built-up urban areas comingled with vegetation.

The land cover classification results for the cities and municipalities in Bangladesh revealed agriculture as being the most dominant land cover class, followed by vegetation (Figures 7 a—d). Agriculture and vegetation accounted for just over 90 percent of the land cover within the municipalities, changing from 93.92 percent of the total land cover in 1990 to 90.11 percent in 2019. In the case of built-up urban areas, although it accounted for a relatively small percentage of the total land cover occupied within the cities and municipalities of Bangladesh, the actual amount of built-up urban areas within the cities and municipalities more than doubled in the last 30 years, increasing from 152.68 sq. km. to 333.64 sq. km. in 2019, which was an increase from 2.89 percent in 2010 to 6.31 percent in 2019 (Table 3). Conversely, the largest overall decrease in land cover was seen for agricultural land cover, with a decrease of just under 230 sq. km. during the same period (Table 3).

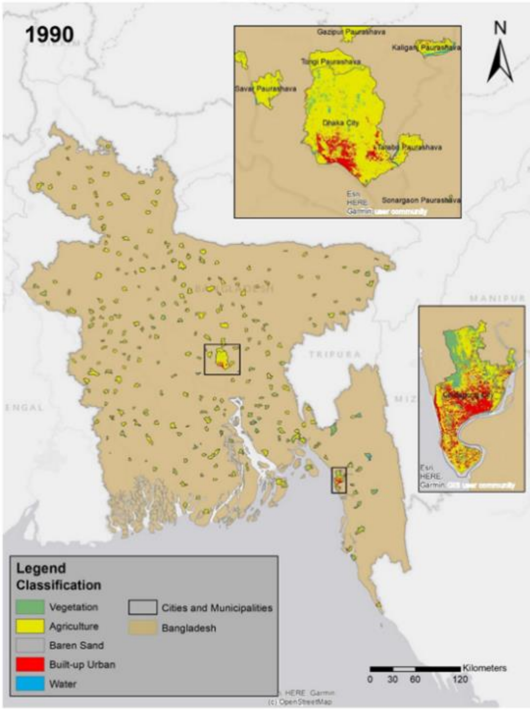
Table 3: Land cover classification results for Cities and Municipalities in Bangladesh using Google Earth Engine (values in sq. km.).

Land Cover	Built-up	Agriculture	Barren Sand	Vegetation	Water
1990	152.68	4215.57	44.26	748.8	124.69
2000	215.22	4186.06	28.93	719.94	136.04
2010	301.47	3871.72	25.88	929.57	158.2
2019	333.64	3987.39	71.31	776.6	117.94

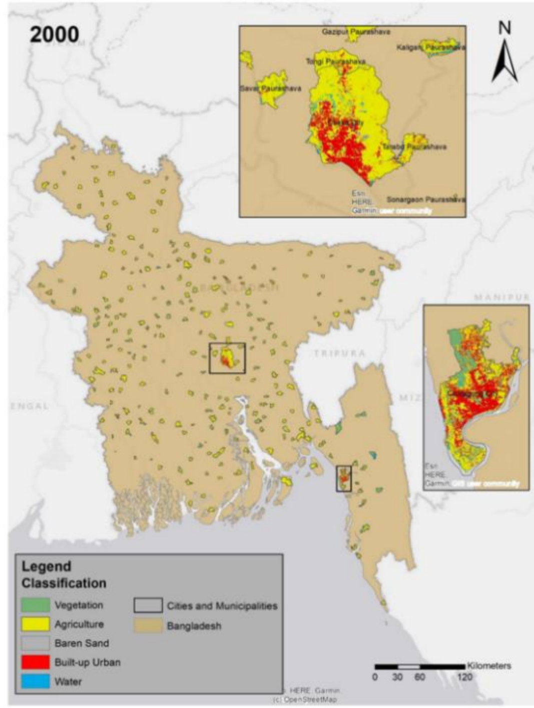
When specifically examining the location of the built-up urban areas, a majority of these areas were located within the two major cities, Dhaka and Chattogram. These built-up urban areas in Dhaka and Chattogram accounted for 50 to nearly 60 percent of the total built-up urban areas within the cities and municipalities in Bangladesh over the last 30 years (Table 4).

Table 4: Total built-up areas (values in sq. km.) and percentage within Dhaka and Chattogram.

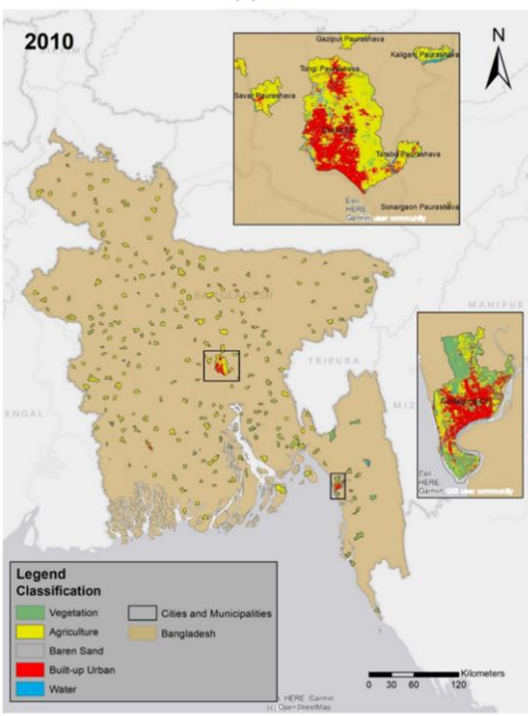
Year	1990	2000	2010	2019
Dhaka City Corporation	55.24	71.22	109.35	113.76
Chattogram City Corporation	31.93	56.12	59.15	65.84
Remainder of Cities and Municipalities	65.51	87.88	132.97	154.04
Total	152.68	215.22	301.47	333.64
Percentage of Built-up areas within Dhaka and Chattogram	57.09%	59.17%	55.89%	53.83%



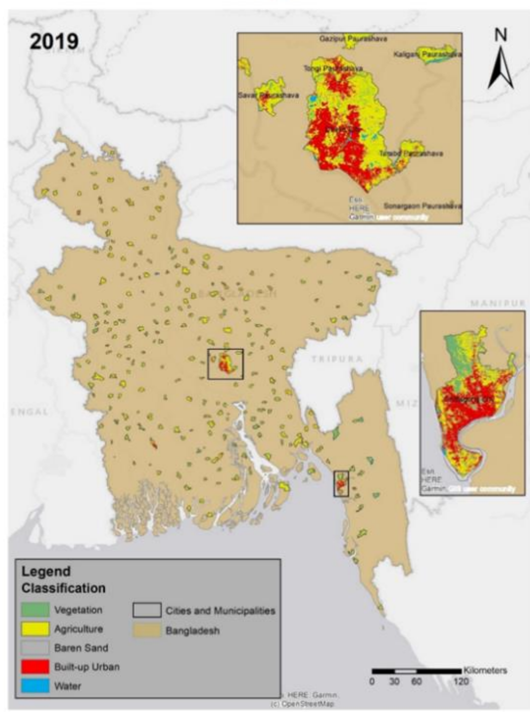
(a)



(b)



(c)



(d)

Figure 7: Land cover classification for Cities and Municipalities in Bangladesh for: (a) 1990; (b) 2000; (c) 2010; (d) 2019.

2.3.2 Conformity to Zipf's Law

The conformity to Zipf's law for the distribution of population and built-up urban areas within cities and municipalities in Bangladesh was tested using the OLS regression (see Eq. 4), and Wald's T-test was used to examine if the value of Zipf's coefficient (*q*) significantly differed from 1. To examine the distribution of population and built-up urban areas in top end cities and municipalities, particularly in a heavy-tailed distribution, a grouping of these top end cities and municipalities was derived using head/tail breaks. Head/tail breaks provide a naturally determined method of categorizing the data based on inherent hierarchical levels within the data (B. Jiang, 2013) and hence reduced the arbitrariness when truncating the samples. Based on the head/tail breaks depending on the year, for population, the upper 8.52 percent to 13.18 percent, and for built-up urban areas, the upper 10.36 percent to 13.83 percent of cities and municipalities were considered as top tier (Table 5).

Table 5: Percentage of cities and municipalities designated as top tier based on head/tail breaks based on population and urban built-up areas for each year.

	Year	**Percentage of data designated as top tier**
Population	1991	13.81%
	2001	10.71%
	2011	8.52%
Built-up Urban Areas	1990	10.36%
	2000	10.94%
	2010	11.48%
	2019	13.83%

When examining the conformity of population within the cities and municipalities to Zipf's law, results from the OLS regression for 1991 indicated the Zipf's coefficient to be 1.01, and the T-test showed that the value was not significantly different from 1. This signaled that the distribution of population within the cities and municipalities for 1990 conformed to Zipf's law. Over the next 20 years, the Zipf's coefficient in reference to population decreased to 0.87 and to 0.85 for 2001 and 2011, respectively, both of which were significantly different than 1 at 1 percent significance level (Table 6). From this result we can infer that there was an overall increase in evenness in the distribution of population amongst the cities and municipalities in Bangladesh, as seen in the more horizontal profile of the plot showing the relation between population and rank (Figure 8). These results can be attributed to an increase in population within the mid-sized and smaller sized cities as compared to that of larger cities from 2001 to 2011, hence leading to an evening out of the overall distribution of population amongst the cities and municipalities in Bangladesh.

When limiting the distribution to the top end cities and municipalities, the Zipf's coefficient of population was calculated to be 1.18, 1.32 and 1.27 for 1991, 2001 and 2011, respectively (Table 6). For all 3 years, the coefficients were seen to be statistically different than 1 at 1 percent significance level, and thus they did not conform to Zipf's law. From this we concluded that when only the top end cities and municipalities were considered, the population was still seen to be unevenly distributed, with most of the population being concentrated in the top portion of the top end cities and municipalities.

Table 6: Zipf's law result for cities and municipalities in Bangladesh based on population.

Cities and Municipalities	**All**			**Top End**		
Year	**1991**	**2001**	**2011**	**1991**	**2001**	**2011**
q	1.0147	0.8718	0.8525	1.1863	1.3023	1.2783
Standard Error	0.0154	0.0101	0.0080	0.0325	0.0401	0.0402
R-squared	0.9481	0.9676	0.9729	0.9779	0.9777	0.9767
p-values for t-test (q = -1)	0.3386	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

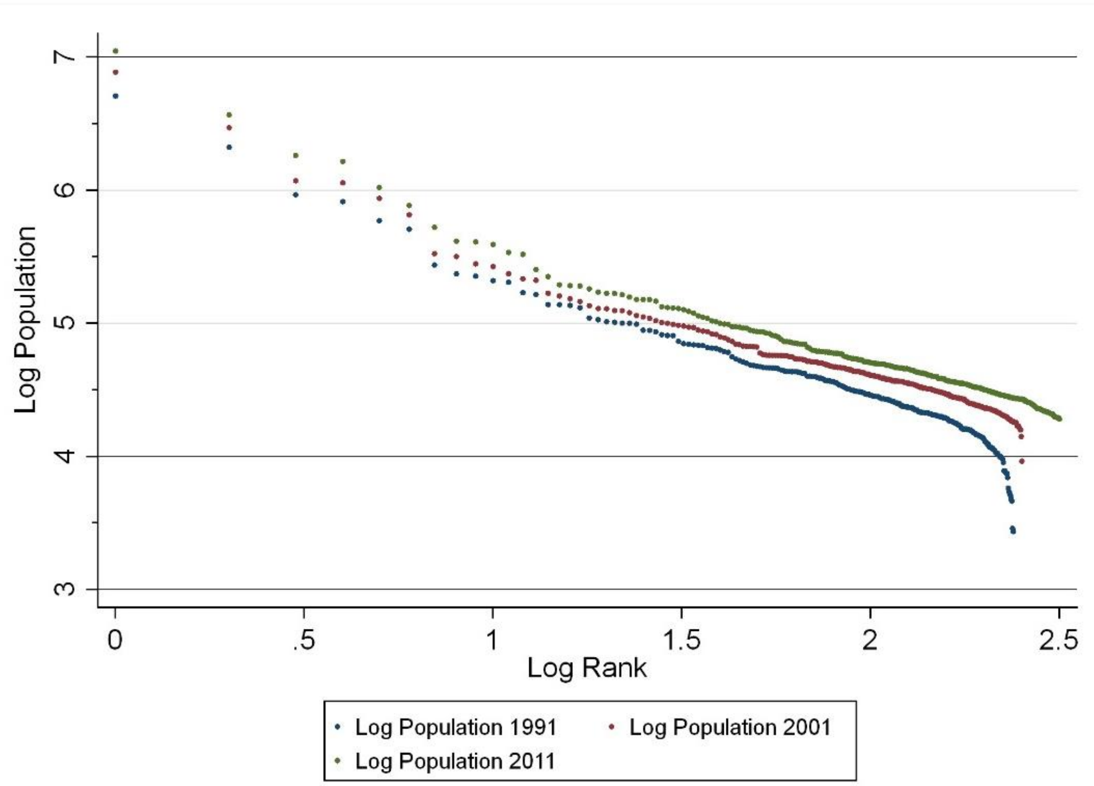


Figure 8: Plot showing the relationship between the population and rank of the cities and municipalities in Bangladesh.

Likewise, when examining the conformity of built-up urban areas within the cities and municipalities to Zipf's law, the results from the OLS regression indicated the value of Zipf's coefficient for all four years to be significantly different from 1. The Zipf's coefficient for these top end built-up urban areas ranged from 1.68 in 1990 to 2.04 in 2019 (See Table 7). The increasing values of Zipf's coefficient indicated an increased unevenness in the distribution of built-up urban areas within the cities and municipalities over the years (See Figure 9). Here, the bigger cities were seen to host a larger share of the built-up urban areas as compared to the mid and smaller sized cities. These results can be attributed to a continued increase in urban buildup and the extension of the urban footprint occurring in the larger cities as compared to mid and smaller sized cities over the last three decades.

When the truncated sample of top end cities and municipalities was considered, the results also indicated an unevenness in the distribution of built-up urban areas in these cities. The Zipf's coefficient values in the truncated sample were, however, smaller than their corresponding full sample values and ranging from 1.21 in 1990 to 1.11 in 2019 (Table 7). Not all of the Zipf's coefficient values were statistically significant at 1 percent significance level, but they were statistically significant at 5 percent significance level. This indicates that while the distribution of built-up urban areas in the cities tended towards conforming to Zipf's law—a major portion of these built-up urban areas is still concentrated in the upper portion of the top tier cities.

Table 7: Zipf's law results for cities and municipalities in Bangladesh based on built-up urban areas.

Cities and Municipalities	**All**				**Top End**			
Year	**1990**	**2000**	**2010**	**2019**	**1990**	**2000**	**2010**	**2019**
q	1.6848	1.9256	1.8882	2.0464	1.2160	1.2001	1.1769	1.1186
(standard error)	0.0446	0.0550	0.0585	1.6116	0.0806	0.0845	0.0699	0.0513
R-squared	0.8517	0.8291	0.8113	0.7981	0.9045	0.8857	0.9163	0.9349
p-values for t-test (q = -1)	< 0.01	< 0.01	< 0.01	< 0.01	0.0131	0.0256	0.0162	0.0273

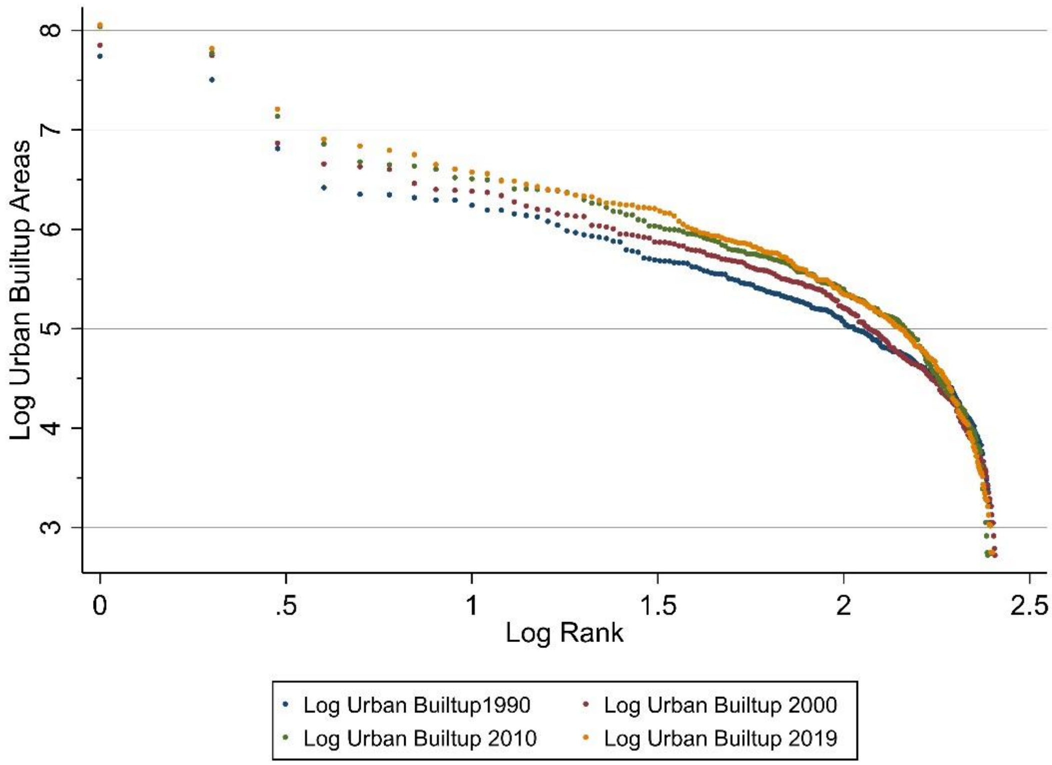


Figure 9: Plot showing the relationship between the urban built-up areas and rank of the cities and municipalities in Bangladesh.

These results examining the conformity to Zipf's law highlight the inequalities and skewness of urban development while highlighting the increase in population and a subsequent expansion of the urban footprint within the cities and municipalities of Bangladesh. As indicated by the value of the Zipf's coefficient for population, while there has been a greater increase in the concentration of population in the small and mid-sized cities between 1991 and 2011 as compared to larger cities, in contrast, the growth of built-up urban areas has largely been concentrated in the biggest cities in Bangladesh, as indicated by the value of the Zipf's coefficient for built-up urban areas based on all the cities and municipalities and the truncated sample of top end cities and municipalities. The most recent data, from 2019, further indicates that this trend of greater expansion of the urban footprint in the bigger cities has continued during the recent period between 2010 and 2019. When examining the truncated sample of the population within the top end cities and municipalities for the same period of time, we see that the increase in the population of the top end cities has been concentrated in the biggest cities. This is further confirmed by inspecting the density of these cities and municipalities. Based on the 100 × 100 meter population density data from worldpop.org, as published by the University of Southampton (2019), we find that while the footprint of the urban areas has increased, the population densities within these built-up urban areas have also increased at a similarly fast pace. For the top two cities in Bangladesh, Dhaka and Chattogram, between 2000 and 2019, the population density per 100 sq. meters within the built-up urban areas increased from 291.34 and 158.91 to 565.94 and 242.28, respectively (Table 8). This indicates that even though there has been an overall expansion in the urban footprint of the cities and municipalities in the top end cities, the increase in population in these cities has resulted in a subsequent increase in population density in these top end cities.

Table 8: Comparison of population density between Dhaka and Chattogram, in Bangladesh.

	Population Density per 100 sq. meters		
City	**2000**	**2010**	**2019**
Dhaka City Corporation	291.34	401.34	565.94
Chattogram City Corporation	158.91	227.26	242.28

2.4 Discussion

The distribution of population and built-up urban areas conforming to Zipf's law provides much information on the expected size of these urban areas with regards to their respective ranks. However, based on previous research, we see that a perfect conformity of city rank-size to Zipf's law does not always occur (Anderson, 1999; Eeckhout, 2004; Gabaix & Ioannides, 2004; Guérin-Pace, 1995; Soo, 2005). These deviations away from Zipf's law offer distinct insights into the specifics of the distribution of population or urban areas within these cities. In particular, when looking at Bangladesh, the departure from Zipf's law for the rank-size of built-up urban areas and the population within the cities and municipalities sheds light on the changes in the distribution of the urban footprint of these areas relative to the change in distribution of population within these urban areas over the years, since 1991. Furthermore, it draws attention to the rapid pace of development of built-up urban areas and the expansion of the urban footprint occurring in the biggest cities, such as Dhaka and Chattogram, compared to the relatively low levels of increase in built-up urban areas in small and mid-sized cities and municipalities, where most of the population growth has been seen.

These spatial inequalities in urban development have led to the unsustainable expansion of urban areas within Bangladesh and have also contributed towards inducing social conflicts within the country (M. S. Rahman et al., 2019). The literature suggests that the strategic distribution of public expenditure can significantly aid in decreasing the level of development inequalities between the cities (Mahmood et al., 2003), but in Bangladesh these public investments, along with the private capital investment and administrative decisions, disproportionately favor a select few major cities (Mahmoud et al., 2008; Rana, 2011). The majority of programs, such as those aimed at building roads and bridges, along with ventures in technological innovations, have been targeted for areas that are already urbanized and well-off. Meanwhile, there is a lack of adequate investment flowing into mid and smaller sized cities that are experiencing an increase in population; a decision that has largely been driven by political influences (Mahmoud et al., 2008). These disparities in investment tilted towards the bigger cities have led to a further rise of these cities as the primary economic drivers of the country and have contributed to the pull factor of these cities, resulting in an increase in population as well as in the urban footprint of these areas. Conversely, economies in smaller and mid-sized cities have mostly remained agriculture-based, with diminished levels of revenue potential and an overall lower income per capita (M. S. Rahman et al., 2019). This has contributed to the push factor of these regions. While there has been an expansion of urban built-up areas in the bigger cities of Bangladesh, these push and pull factors have led to the migration of poorer and vulnerable population from rural areas into these cities, which has contributed to a similarly large increase in the population density in these cities (N. Islam, 2011). A considerable portion of the increase in the urban footprint within these cities has been unplanned and unguided, with disregard to environmental and human considerations, leading to major concerns regarding the sustainability of these urban areas. The increased pressure on the local capabilities and natural resources of these cities due to the increases in population and urban footprint of the cities have not been addressed with adequate infrastructural upgrades and facilities to support the expansion, leading to issues with pollution, traffic, crime and environmental degradation (M. M. Hassan, 2017). Despite higher influxes of investments in these bigger cities, basic amenities such as water, roads, electricity and sewage and the overall planning necessary to support the increasing population and urban footprint of these cities have been insufficient. Furthermore, the lack of infrastructure and services is particularly prominent in slum settlements within these bigger cities (Degert et al., 2016). This uncontrolled and unrestricted expansion can be attributed to the lack of—or, at times, selective—enforcement of policies, inefficient allocation and distribution of resources, along with an inadequate urban planning strategy, which has largely stemmed from a lack of good governance (Rana, 2011). There is a distinct need for equitable provisions for physical infrastructure (Choguill, 1988) and a targeted pro-poor strategy within the context of urbanization and urban development (Sowgat & Roy, 2013), to promote a current and future sustainable urban development that is in balance with the environment (Choguill, 1988).

2.5 Conclusion

The issues of urban development and sustainable urban growth are extremely complex, particularly for a developing country such as Bangladesh, with significant constraints on financial resources. With regards to the increasing urban footprint of the bigger cities, as indicated by the nonconformity to the Zipf's coefficient for built-up urban areas, policies that are aimed at curtailing the uncontrolled haphazard urban expansion, particularly in the bigger cities, would need to be implemented. Moreover, for a successful realization of these urban growth restriction strategies, supporting policies targeting smart development, the equitable distribution of resources and a pro-poor urban development would also need to be prioritized and implemented simultaneously. These policies would need to focus on the planned and guided development of built-up urban areas within the city limits, in a manner that minimizes the impact on the natural environment and surrounding area while addressing the socio-economic issues of informal settlements, slums and the reduction of non-income poverty, such as the availability of urban services (Sowgat & Roy, 2013). With regards to the increasing concentration of population in the mid and smaller sized cities, as indicated by the nonconformity to Zipf's coefficient for population, policies primarily targeted at the reduction of economic stagnation, increased opportunities and an overall economic development of the region, with an emphasis on guided urban growth that ensures environmental consciousness in these cities, would need to be implemented. In both cases, the policy tools put into place would have to be multifaceted and aimed at environmental conservation and natural resources management with sustainable urban expansion, while keeping in mind the underlying factors of economic growth, poverty alleviation strategies and an overall improvement in living standards that would impact the push and pull factors of the region. These policies would need to be employed at different administrative levels, from the central to the local government, with a common policy goal. Most importantly, the success of these agendas, targeted at sustainable development and growth, as well as improved livability, will primarily depend on the good governance, efficient implementation and enforcement of these policies, without its misuse (Faguet & Shami, 2008; Zaccai, 2012).

Traditionally, developmental planning and policymaking in Bangladesh has been based on a sectoral format, as opposed to a spatial approach (M. S. Rahman et al., 2019). The integration of a spatial approach within the overall planning and policy framework would entail the examination of anthropogenic characteristics and natural features, along with socioeconomic attributes such as economic conditions and disparity in access and living conditions (Nadin, 2006). Using a spatial framework would allow for identifying geographically explicit development issues while defining clear outcomes through the incorporation of different economic, environmental, cultural and social agendas specific to the particular locality, and thus allowing for the implementation of targeted policies for the region (Albrechts, 2004; Nadin, 2006). Additionally, the use of spatial planning aimed at territorial development could act as the strong base needed to improve intra-governmental partnerships and coordination, and to incorporate other stakeholders under its umbrella. However, the implementation of a spatially explicit plan has generally been seen as one of the weakest links within the overall planning framework, and has been frequently carried out without sufficient theoretical exploration or methodological rigor (Stefanović et al., 2018). The incorporation of robust theoretical underpinning, such as Zipf's law, to substantiate empirical observations would augment the spatial component of the overall urban developmental planning framework of Bangladesh, and would no doubt pave the way to usher in targeted policies such as the Urban Growth Boundaries, aimed at restricting and guiding the direction of urban expansion for cities and municipalities in Bangladesh

CHAPTER III: URBAN GROWTH BOUNDARY DELINEATION USING SUPPORT VECTOR MACHINE FOR THE CITY OF CHATTOGRAM, BANGLADESH[2]

3.1 Introduction

Over the past several decades, Bangladesh has experienced healthy economic growth largely driven by a transition from a rural agriculturally based economy towards a modern urban economy (Muzzini & Aparicio, 2013). Given that more opportunities now are available in larger cities, there has been a surge of migration from the rural areas into the cities (Md Uddin & Firoj, 2013). This has resulted in rapid expansions of urban footprints particularly among the largest cities in Bangladesh, such as Chattogram (Bajracharya & Sultana, 2020). However, due to the lack of adequate forward-looking planning, the city's expansion has largely taken place in an unregulated and chaotic manner (M. M. Hassan & Nazem, 2016). For Chattogram, one of the world largest port city and the second-largest metropolitan areas in Bangladesh, large scale housing projects and constructions have taken place without prior approval, subdivision/sales of land have taken place in areas that lack provisions for basic amenities, and encroachment of agricultural land and filling up of lowland areas have taken place to make space for built-up areas (M. M. Hassan & Nazem, 2016). A large portion of this urban expansion has occurred in the form of slums and squatter settlements which have little to no access to facilities and services (N. Uddin, 2018). This indiscriminate and rapid rate of urban expansion has led to issues such as pollution, sanitation, traffic congestion, and crime within the city and have impacted the local environment, putting adverse pressure on the overall ecosystem of the region (M. M. Hassan & Nazem, 2016). These high levels of unregulated expansion, accompanied by the lack of infrastructure and facilities to service these regions and the resulting adverse environmental impacts have led to questions regarding the overall sustainability and livability of the city of Chattogram (N. Uddin, 2018). These

[2] Bajracharya, P., & Sultana, S. (2021). Urban Growth Boundary Delineation Using Support Vector Machine for the City of Chattogram, Bangladesh. *GeoJournal, (To Be Submitted)*.

concerns have heightened the need for policy and regulatory tools to restrict and direct the expansion of urban areas for Chattogram.

The Urban Growth Boundary (UGB) is one of such planning/policy tools that can be implemented for the purpose of restricting and directing the spatial and temporal growth of Chattogram. While there are various aspects of the policy that would need to be considered for the implementation of UGB, a proper delineation of the boundary is one of the most crucial aspects necessary for the success of the UGB implementation process (Sinclair-Smith, 2014). In the past, the lack of well-researched evidence-based delineation of UGB, specifically within the developing, has resulted in major concerns regarding the effectiveness of the UGB. For China, the limited success of the UGB implemented in the first planning period has been attributed to the ineffective delineation that was produced solely based on the planned-economy architecture that had been used for the past several decades (Long et al., 2013). The archaic methodology used for delineation vastly underestimated the 10-year growth trajectory of the city, thus leading to insufficient allocation of land within the UGB and an ineffective UGB (Hao-ying Han et al., 2009). Similarly, for Saudi Arabia, the inefficiencies in the UGB have also been linked to delineation issues that have mainly arisen from technical limitations and institutional deficiencies due to the absence of trained planners, surveyors, and architects in most of the municipalities (Al-Hathloul & Mughal, 2004). These delineation issues have been further exacerbated by the use of outdated base maps and census data, hence leading to an overall inefficient UGB (Al-Hathloul & Mughal, 2004). For Albania and Chile, the delineation process of the UGB has been largely arbitrary with limited use of spatially explicit data used in the delineation process leading to ineffective implementation of UBG (Allkja, 2012; Aquino & Gainza, 2014; Dino et al., 2016).

While there have been a wide variety of methodologies that have been recommended by researchers addressing the concern regarding UGB boundary delineation, there is still no one universally accepted model for the process (Bhatta, 2009). However, in recent years, a large number of studies exploring the delineation of UGB has involved the utilization of machine learning techniques (Tayyebi, Pijanowski, & Tayyebi, 2011; J. Yang et al., 2019) as well as other quantitative techniques (J. Liu et al., 2017; X. Zheng & Lv, 2016) for boundary delineation. In this study, to create a methodologically robust evidence-based UGB delineation for the city of Chattogram, we examine the application of Support Vector Machine (SVM) supervised machine learning algorithm for the process. For the delineation of the boundary, we use SVM to simulate the future growth of contiguous built-up urban areas for 2040 using a variety of freely available data from 2000 to 2019 for the city. Next, based on the results from the simulation of contagious built-up urban aeras, we delineate the UGB for Chattogram. The remainder of the paper is organized as follows: Section 3.2 provides a brief literature review of the urban growth boundary. Section 3.3 discusses the dilemma with UGB delineation Section 3.4 summarizes the basic principles of SVM, its implementation procedure for UGB delineation, and the data collection and processing methodology. Section 3.5 discusses the results of the model and UGB delineation and Section 3.6 provides the discussion and conclusion regarding the delineation of a potential UGB for Chattogram.

3.2 Management of Urban Growth with the Urban Growth Boundary

Urban Growth Boundary (UGB), in simple terms, can be defined as land regulations that have been put into place, in most cases, by the local government to prohibit urban growth and development beyond a defined boundary (American Planning Association, 2002; Brueckner, 2007; Pendall et al., 2002). They are designed to protect non-urban land outside the boundary and to promote compact, contiguous, and sustainable urban development (American Planning Association, 2002). The UGB as an urban growth policy tool has been implemented in a wide variety of cities in both the developed and the developing world. In the United States, several states including Oregon (Nelson & Duncan, 1995), Washington (Comprehensive Plans—Urban Growth Areas., 2018) and Tennessee (TACIR, 2000) have implemented UGBs for various cities within the state. Outside of North America, developed countries such as New Zealand (Grimes & Liang, 2009), Belgium (Boussauw et al., 2013), Netherlands (Nabielek, 2012; Vasili, 2013), and Spain (Paül & McKenzie, 2013), to name a few, have also effectively utilized UGB as a prominent urban growth restriction strategy.

Compared to the developed countries, the adoption of UGB in emerging economies and developing countries has been limited. Nevertheless, over the last few decades, there has been an increase in the use of UGB policies in these countries, with countries such as Albania (Bertaud, 2006), China (P. Jiang et al., 2016), Chile (Zegras & Gakenheimer, 2000), Saudi Arabia (Mubarak, 2004), and South Africa (Sinclair-Smith, 2014) explicitly implementing UGB as an urban growth restriction tool. Although the concept of UGB remains the same in both developed and developing countries, it should be noted that the planning and implementation of the UGB for developing countries will require distinctly different approaches as compared to developed countries, particularly due to differences in the nature of urban expansion observed in these countries (Seto et al., 2011). For developed counties, such as the US, urban sprawl has been largely signified by low density, non-residential development and UGBs have been used to restrict this expansion (Bengston et al., 2004). In comparison, for developing countries, urban sprawl, particularly around the periphery of megacities and emerging cities, is associated with the expansion of compact and high-density built-up areas, usually consisting of informal dwellings and slums (Bhatta, 2010; Jones, 2002). Furthermore, the urban sprawl in developing countries is often linked to rapid growth of a city leading to the inability of the city to provide sufficient services to its citizens hence resulting in poor, unplanned neighborhoods that lack basic necessities such as sanitation, running water, electricity and paved roads (Bhatta, 2010; B. Cohen, 2006). Thus, when planning for a potential UGB within a developing county, these additional issues regarding urban growth would need to be specifically addressed in the adoption and implementation process for the UGB to be successful.

That said, several studies related to both developed and developing countries in which UGB has been implemented have expressed concerns regarding the overall impact of UGB in slowing the urban sprawl of the city and its ability to address the growth of the city (Cho et al., 2008; Jun, 2004; Kline & Alig, 1999) and regarding the containment of built-up urban areas within the designated boundary (Horn, 2009; Long et al., 2013; Pllumbi, 2013). For developing countries specifically, the limited success of the UGB has been largely attributed to issues with urban governance which have been further exacerbated by inefficiencies in the delineation of the UGB brought about due to a lack of necessary up-to-date data, the lack of institutional capacities, and external political pressures (Al-Hathloul & Mughal, 2004; Hölzl & Nuissl, 2014; Long et al., 2013; Zegras & Gakenheimer, 2000). Despite these criticisms, there has been a growth in popularity of UGB as an urban growth restriction tool. Countries such as China (He et al., 2018), Saudi Arabia and (FSCP, 2016), and South Africa (Horn & Van Eeden, 2018) have been in a continuous process of updating and upgrading the UGB based on the needs and requirements of the cities. When implemented properly, UGB can offer planners and decision-makers a clear and consistent direction for urban growth restriction policies by minimizing speculations, ensuring an orderly transition of undeveloped/rural land to developed/built-up urban land (Bhatta, 2009) while preserving the character and providing a sense of community in cities where it is implemented (Staley et al., 1999).

3.3 Methodological dilemma with the delineation of UGB

A review of the literature showed utilization of a variety of methods for the UGB delineation process. However, there is no one consensus or a universally accepted model with regards to the delineation of the UGB (Bhatta, 2009). Sinclair-Smith (2014) divides the process in which UGBs are delineated into three approaches. For the first approach, little or no quantitative assessment was performed for boundary delineation. The UGB implemented in Saudi Arabia during its first iteration (Mubarak, 2004) and the UGB delineated in China during the first planning period (Long et al., 2013) provide good examples of this approach. Long et al. (2013), due to the lack of analytical framework supporting the design of the boundaries, goes as far as to imply that the spatial plans for the Chinese cities during the period were more akin to artwork by urban designers rather than a plan to establish growth boundaries. In Albania, the UGB delineation was based on boundaries separating agricultural land from urban land for cities with population greater than 10,000 (Abitz, 2006; Allkja, 2012; Jacobs & Craig, 1997). Whereas in Chile, the delineation of the boundary changed numerous times based on the subsequent political principles guiding these policies (Jirón & Padzerka, 1999).

The second approach to UGB delineation is defined as the conventional approach. This approach is seen as being governed through guidelines provided by planning agencies such as American Planning Association (APA) (2002) in Growing Smart Legislative Guidebook - Model Statutes for Planning and the Management of Change or through systems such as the inventory based system, as proposed by Knaap and Hopkins (2001), that applies the concept of event-driven inventory for urban growth management. A large proportion of UGBs in the United States is based on these approaches. The APA guidelines propose using a future forecast for land demand to reserve sufficient developable land for the UGB over a set time period, generally over the next 20 years (American Planning Association, 2002). It further recommends integration of 110 to 125 percent of projected urban growth as a long-term land use planning strategy. Sinclair-Smith (2014) explains that the purpose of including additional land within the UGB, than what is required, is to prevent owners from monopolizing vacant land, thus allowing for effective and competitive real estate markets. As compared to the time-drive approach, where the expansion of an established UGB to accommodate future growth occurs at a set time interval, the inventory control system proposed by Knaap and Hopkins' (2001) suggests an event-driven approach where an increase in the developable land for the UGB is triggered only after the available land within the UGB is diminished to a predetermined level. The inventory control system for UGB extension was further revisited by Han and Lai (2012). Here, the authors translated the inventory approach into a decision network framework, where rather than the extension of UGB being based on one single event occurring, the change in the delineation would be based on the analysis of the complex system of linked actors, problems, and solutions that have an impact on the expansion of urban areas within the city. In a comparison of the new Decision Network Framework for time-driven approach with the event-driven inventory approach, results indicated that the Decision Network Framework supported system to be more efficient and cost-effective at UGB allocation (Haoying Han & Lai, 2012).

The third category of approach used in the delineation of UGB utilized growth simulation models that included scientific and quantitative techniques to predict future growth and, based on it, delineate the appropriate UGB. This included a variety of methodology that made use of constrained cellular automata (CA) to support the establishment of UGBs. Compared to the traditional method, the CA-based system, as used by Long et al. (2013), included containment conditions such as macroeconomic, locational, institutional, and neighborhood constraints aiding in the simulation of urban growth within the model. This in turn resulted in a more effective spatiotemporal simulation of urban expansion and an overall improvement in UGB delineation (Long et al., 2013). Other CA-based urban land use change modeling techniques such as SLEUTH, have also been used for predicting urban growth and, based on it, creation of urban containment policies (P. Jiang et al., 2016; J. Liu et al., 2017).

Bhatta (2009) utilized the Ideal Urban Radial Proximity (IURP) based design to examine the implementation of UGB for Kolkata, India. However, IURP does not provide any simulation or modeling of urban growth processes and patterns, but rather is a theoretical construct that used a radial distance from the city center to create a circular urban growth boundary beyond which urban growth would be restricted. The use of radial distances was also implemented for the UGB models by Tayyebi, Pijanowski, and Tayyebi (2011) for the city of Tehran, Iran. The authors used artificial neural networks to predict the radial extension of urban areas in individual azimuth and, based on the growth of the urban area, an urban growth boundary for each azimuth was designated (Tayyebi, Pijanowski, & Tayyebi, 2011). Tayyebi, Pijanowski, and Pekin (2011) also used the information on the radial distance from the center of urbanized areas for individual azimuth to delineate UGB using two separate rule-based methods, the Distance Dependent Method (DDM) and the Distance Independent Method (DIM). DDM used the points on the initial urban boundary to estimate the growth of urbanized areas and predict the future UGB for subsequent time periods using percentage increments across individual azimuth. DIM, on the other hand, used rate of change in distance from the center of the urbanized areas for two different time periods within each azimuth to predict the boundary for the next time period (Tayyebi, Pijanowski, & Pekin, 2011). The use of radial distance in delineating UGBs was further investigated by Tayyebi et al. (2014) by using it in conjunction with Spatial Logistic Regression (SLR). The SLR-UGB model considered the impact of spatially explicit biophysical factors such as topography to derive its impact on urban growth and hence simulate future urban growth boundary changes across each individual azimuth. Another interesting approach that has been used to allocate UGB is the application of the ant colony optimization (ACO) technique. Considering UGB as a problem of spatial optimization for land use allocation, Ma et al. (2017) used the Ant Colony Optimization (ACO) method for optimizing land use for UGB delineation with the purpose of creating a balance between urban growth, planning regulation and characteristics of the landscape.

3.4 Methodological Approach for this paper

In this study, we investigate a novel approach by using Support Vector Machines (SVM) to aid in the UGB delineation process. To the best of our knowledge, SVM has not been used as a part of the delineation methodology for UGB. SVM is a well-established methodology that has previously been used in a wide variety of research related to monitoring machine condition and faults (Widodo & Yang, 2007), language and speech recognition (Campbell et al., 2006), diagnosis of diseases (Sartakhti et al., 2012) and recognizing human motion patterns (Schuldt et al., 2004). Additionally, SVM has also been extensively used in examining and modeling urban growth (Griffiths et al., 2010; B. Huang et al., 2010; Karimi et al., 2019; Samardžić-Petrović et al., 2016). The primary reason for using SVM in this study is due to the exceptional performance of this methodology as a classifier in general (Kotsiantis et al., 2007) but specifically in forecasting land use change and urban growth as compared to other methodologies such as the logistic regression approach (B. Huang et al., 2010) or Artificial Neural Network or Decision Tree (Samardžić-Petrović et al., 2017). For this study, we use SVM to simulate the urban expansion of the contiguous built-up urban footprint for the City of Chattogram, and based on results from the simulated future urban expansion, we propose a potential delineation of the UGB for the city.

3.4.1 SVM

SVM was initially proposed by Vapnik and Lerner (1963) as a new generation of machine learning algorithms inspired by statistical learning theory and designed as a linear classifier, which was later extended to include regression (Vapnik, 1995). SVM operates by projecting the input data into Hilbert space where it can be separated by an optimal separating hyperplane situated in a multi-dimensional space, maximizing the margin between the closest data classes to the plane (B. Huang et al., 2010; Q. Yang et al., 2008). This maximization of the margin between the two classes allows for minimizing the upper bound of the generalization error (Samardžić-Petrović et al., 2016). This approximate implementation of the Structural Risk Minimization (SRM) principle provides a good generalization performance of the SVM (Xie, 2006). Furthermore, an n-class classification in SVM is achieved as a sequence of one-versus-all binary classification to reach the final decision (Belousov et al., 2002).

For a linear case of SVM, let us assume a training dataset consisting of k data points that are separable into two classes as represented by

$$T = (x_1, y_1), (x_2, y_2), \dots . (x_k, y_k)$$

with the parameters $x \in R^n$ in an n-dimensional space and its corresponding class label y $\in$ {+1, -1} (Vapnik, 1995).

In the training phase, SVM is used to generate the hyperplane that best separates the two classes +1 and -1. This hyperplane can be represented by H_1: $w'.x + b = +1$ and H_2: $w'.x + b = -1$, where a majority of class +1 lies above H_1 $(w'.x + b > 1)$ and a majority of class -1 lies below H_2 $(w'.x + b < -1)$. Here, H_1 and H_2 are the supporting vectors or decision boundaries responsible for determining the optimal hyperplane, w' is the transpose of the n dimensional coefficient vector which determines the orientation of the hyperplane w, and b is the offset or the bias (Samardžić-Petrović et al., 2016). The hyperplane itself can be represented as $H\!: w'.x + b = 0$ (Statnikov, 2011).

In Figure 10, while there are no data points between the H_1 and H_2 decision boundaries, the points that are located on H_1 and H_2 are the support vectors determining the optimal hyperplane while other points on the training data set do not contribute towards defining the hyperplane (Statnikov, 2011; Xie, 2006).

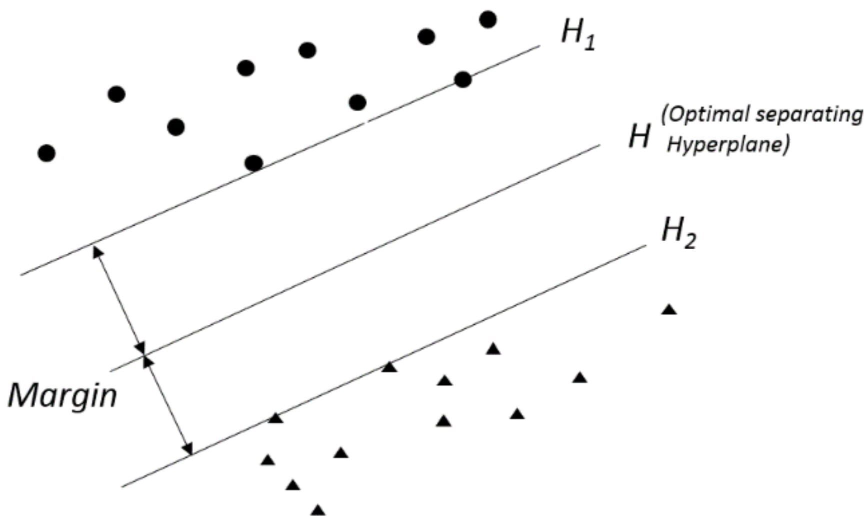


Figure 10: Binary classifier with Optimal separating hyperplane

Scaling the coefficient vector and the offset for all data points we get $w'.x_i + b \geq +1$ for positive examples, $y_i = +1$ i.e. those points lying above H_1 when $i = 1,2 \,..\, n$ and, $w'.x_i + b \leq -1$ for negative examples, $y_i = -1$ i.e. those points lying below H_2 when $i = 1,2 \,..\, n$. This is equivalent to (Xie, 2006), $y_i(w'.x_i + b) \geq 1$.

Distance of a point x_i, from the hyperplane ($H\!: w'.x + b = 0$) is given by (Xie, 2006),

$$d(w, b; x_i) = \frac{|w'x_i + b|}{||w||}$$

Based on this, the distance between H_1 and H_2 can be denoted by

$$d(H_1, H_2) = \min_{x_i : y_{i=+1}} d(w, b; x_i) + \min_{x_i : y_{i=-1}} d(w, b; x_i)$$

$$= \frac{1}{||w||} \min_{x_i : y_{i=+1}} |w'x + b| + \min_{x_i : y_{i=-1}} |w'x + b|$$

$$= \frac{2}{||w||}$$

Maximization of the distance between H_1 and H_2 can be obtained by minimizing the norm of $||w||$.

The optimal hyper place separating the two separable training data class satisfies the following (Xie, 2006).:

Minimize: $F(w) = \frac{1}{2} w'w$

Subject to: $y_i(w'.x_i + b) \geq 1$ $i = 1, 2 \ldots n$

In practice, however, as not all training datasets are perfectly linearly separable by a hyperplane, these imperfect separations are accounted for by a non-negative slack variable ξ that is incorporated into the constraints to consider for misclassification errors (Xie, 2006).

Minimize: $F(w) = \frac{1}{2} w'w + C \sum_{i=1}^{n} \xi_i$

Subject to: $y_i(w'.x_i + b) + \xi_i - 1 \geq 0$ $i = 1, 2 \ldots n;$ $\xi_i \geq 0$

Here, ξ_i is the positive slack variable representing the distance between the misclassified points and C is the penalty parameter representing the trade-off between the margin size and the number of misclassified training points. To minimize misclassification error and to maximize the margin size, Lagrange multipliers α and β are introduced and solve for the saddle point of the Lagrangean function (Vapnik, 1995).

Minimize: $L(\alpha) = \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \alpha_j y_i y_j (x_i{}' x_j)$

Subject to: $\sum_{i=1}^{k} \alpha_i \, y_i \; = 0$, $0 \leq \;\; \alpha_i \; \leq$ c , *i = 1, 2 … n;*

Additionally, to extend the linear machine learning to non-linear cases in SVM, the kernel method is used to map the non-linearly separable classes to higher dimensional feature spaces, where they can be separated using a linear optimal hyperplane (Xie, 2006). As all the training data that appears in the previous equation are in dot product, the kernel function defined as $\sum_{i=1}^{n} K\,(x_i \, , x_j) = \Phi(x_i).\,\Phi(x_j)$ is introduced, resulting in (C. Huang et al., 2002)

$$L(\alpha) = \; \sum_{i=1}^{k} \alpha_i - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \, \alpha_j y_i y_j K(x_i{}' x_j)$$

Some of the common kernel functions include the linear function $\mathrm{K}(x, y) = \; x_i . x_j$, polynomial function $\mathrm{K}(x, y) = \; (1 + x_i . x_j)\,^{q}$, and Radial Basis Function (RBF) $\mathrm{K}\,\left(x_i, x_j\right) = exp(-\gamma \;||x_i - x_j||^2)$, where q and γ are the parameters for the polynomial and RBF kernel functions respectively (Xie, 2006).

3.4.2 Study Area

The study area for this paper is the City of Chattogram in Bangladesh. Located in southeastern Bangladesh, nestled between the Karnaphuli river in the East and the Bay of Bengal to the West, Chattogram is the second-largest city in the country. It is also the commercial capital of Bangladesh, having the busiest seaport in the country accounting for 92% of import/exports cargo (Monir, 2017) and holding around 40 percent of the country’s large scale industries (Mia et al., 2015), it contributes 50% of the tax revenue and around 11% of the GDP for Bangladesh (Muzzini & Aparicio, 2013). With a population of just over 4 million, the city of Chattogram accounts for 9.07% of the overall population and 20% of the overall built-up area of all the municipalities in Bangladesh (Bajracharya & Sultana, 2020; BBS, 2014). This alarming rate of increase in the urban footprint of Chattogram driven by industrial growth, infrastructural development, and a massive rural to urban in-migration has come at a cost of loss of surrounding agricultural land, vegetation, and lowlands (M. M. Hassan & Nazem, 2016). This has heightened the need for urban growth restriction policies such as UGB for the city.

3.4.3 Data Collection and Preparation

The expansion of the city's urban footprint depends on the interaction between a variety of environmental, socioeconomic, and topographic parameters. In this study, we used 14 parameters (Table 9) to estimate urban growth and simulate a future urban pattern urban expansion of Chattogram using SVM. The result from this simulation was then used to delineate the potential UGB for Chattogram. Selection of the 14 parameters used in the simulation was based on findings from past literature that drew from urban theory and models identifying key drivers that directly or indirectly influence urban expansion.

The pressure from increasing population density is a critical driver of urban expansion of an area (Meyer & Turner, 1992), thus was also included in the analysis. The topography of a particular region also significantly affects the potential for future urban build-up (York et al., 2011). When considering a location for urban expansion, there is a higher likelihood of new urban build-up occurring in areas that are flatter as compared to areas with steeper slopes (Clarke & Gaydos, 1998). As a result, the slope parameter was considered in this study. Availability of transportation and access to transportation has also been identified in numerous studies as an important driver of outward urban growth, with a higher degree of urban build-up occurring along with transportation nodes and routes (Cervero, 2013; Sultana & Weber, 2014). Taking this into consideration, in this study we use distance to major roads and distance to major railroads within Chattogram as transportation parameter. With regards to economic factors, proximity to job sites and infrastructures, particularly in and around the central business districts, have been seen as prime drivers of urban expansion (Deng & Srinivasan, 2016). To account for this, distance to big commercial areas and industrial parks within Chattogram were also included in the analysis. Environmental factors such as access to greenspaces (Tayyebi, Pijanowski, & Tayyebi, 2011) and water bodies such as rivers and canals (Jin & Mountrakis, 2013) have been an important draw for urban growth. In order to incorporate these environmental factors into the analysis, distance to the Karnaphuli river, upon which banks Chattogram lies, distances to the numerous ponds, an important part of the landscape that are scattered throughout Chattogram, and the distance to Kerfa Bagan forest was considered in the study. Neighborhood characteristics also play a critical role in understanding the probability of land converting to urban areas (X. Li & Yeh, 2002). Additionally, with current land cover also have a significant influence on the future land cover of a region

(Samardžić-Petrović et al., 2016), land cover information on Chattogram for 1990, 2000, and 2019 (Figure 11) that was derived previously from Google Earth Engine using Landsat data were used in the analysis (see Bajracharya & Sultana, 2020). The 3x3 Moore's Neighborhood of each cell for each of the land cover classes was then calculated and used in the analysis. Finally, areas where urbanization is not allowed (i.e. areas that are not protected areas, areas that are not a water feature, and areas designated for parks) were identified and excluded from the analysis. The remaining areas were designated as areas where urbanization is allowed and was included in the analysis.

Table 9: Parameters used in SVM to aid in the delineation of the potential UGB for Chattogram

	Data	**Description**
1	Population Density	Raster with showing population density
2	Slope	Derived from DEM
3	Distance to Road	Euclidean distance of a cell to roads
4	Distance to Commercial Areas	Euclidean distance of a cell to commercial area
5	Distance to Rail	Euclidean distance of a cell to railway lines
6	Distance to Ponds	Euclidean distance of a cell to ponds
7	Distance to Rivers	Euclidean distance of a cell to rivers
8	Distance to Forrest and Parks	Euclidean distance of a cell to forest and parks
9	Neighborhood Urban cells	Number of urban cells in 3x3 neighborhood
10	Neighborhood Vegetation cells	Number of vegetation cells in 3x3 neighborhood
11	Neighborhood Agriculture cells	Number of agriculture cells in 3x3 neighborhood
12	Neighborhood Water cells	Number of water cells in 3x3 neighborhood
13	Neighborhood Barren cells	Number of barren cells in 3x3 neighborhood
14	Urbanization Allowed	Cells where urbanization is allowed

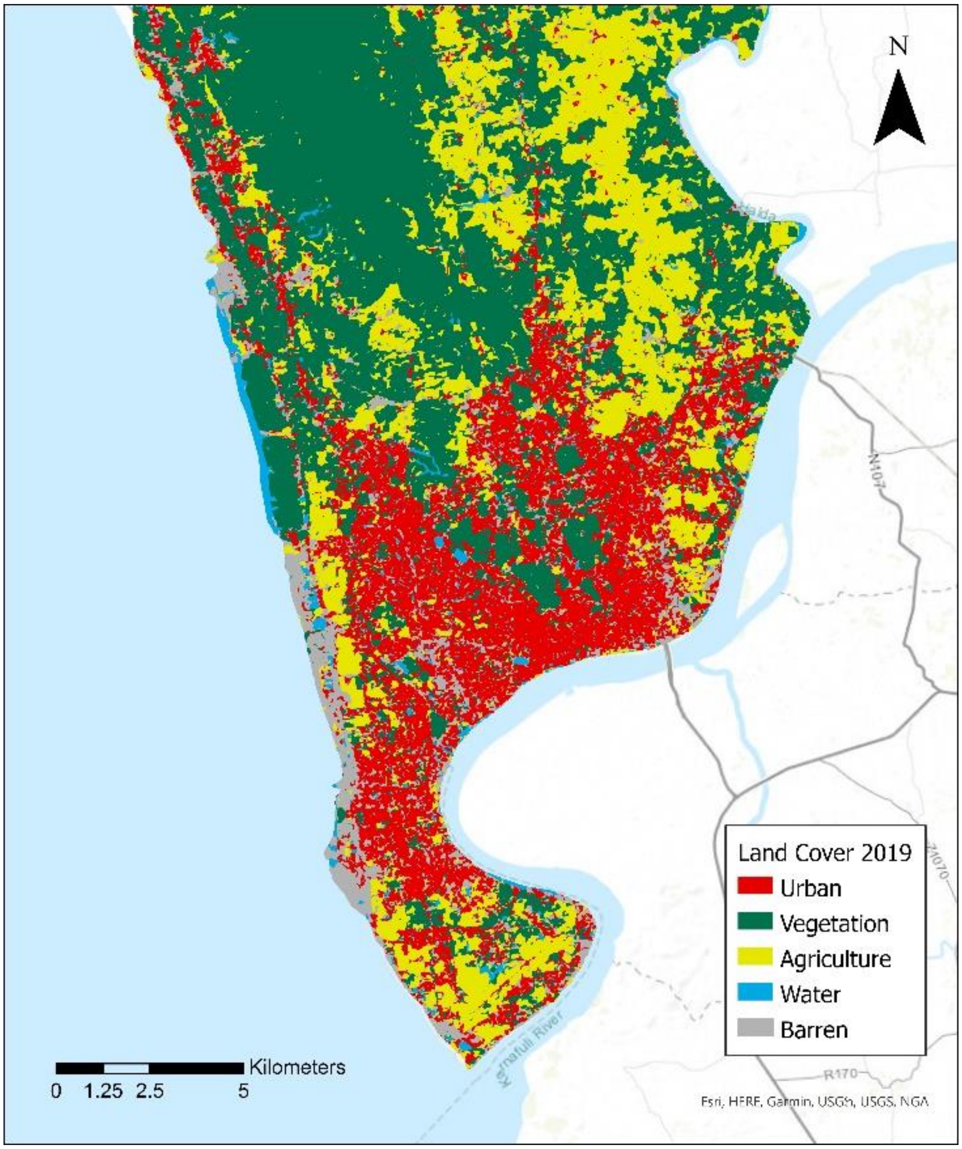


Figure 11: Land cover classification of Chattogram for 2019
(Source: Bajracharya and Sultana 2020)

With contiguity of urban areas being an important part of the UGB (Weitz & Moore, 1998), contiguous urban patches were created using cells classified as urban in the land cover data. Due to the scattered pattern of built-up urban areas, particularly around the fringes of the city core of Chattogram, isolated patches of built-up urban areas were disregarded, and the largest contiguous patch was selected for the analysis (Tayyebi, Pijanowski, & Tayyebi, 2011). Cells within the contiguous built-up urban areas were allocated the value of +1 and all other areas were allocated the value of -1. This variable was taken as the target variable for the SVM.

One of the limitations of this simulation has been the minimal use of socio-economic parameters in the analysis particularly due to the limited availability of spatially explicit, fine-scale data for the region. Inclusion of these parameters such as GDP per capita (J. Han et al., 2009), migration patterns (R. Chen et al., 2014) along with availability of schools, hospitals (Adams, 2003), and other amenities/civic institutions (Clark et al., 2002; Heying, 1995) discussed in the literature that drives land use change, could provide a better understanding of externalities that trigger urban expansion (Vaz et al., 2012). Further research would be essential to collect such socio-economic data that would aid in on future urban expansion simulation and the subsequent delineation of the UGB for Chattogram.

Although the availability of up-to-date high-resolution spatially explicit data and digital maps for developing countries including Bangladesh has been limited (M. M. Hassan & Nazem, 2016), all the data used in this study was collected through freely available sources. Preparation of the spatial data including computation of Moore Neighborhood, calculation of Euclidean distances for proximity, conversion from DEM to slope and extraction of contiguous areas and reclassification of data was performed using ArcGIS 10.7 software (ESRI, 2019). All the datasets were converted into 30m by 30m resolution (Figure 12) and exported as an ASCII format. However, the large water bodies surrounding Chattogram (Karnaphuli river and Bay of Bengal) were excluded from the analysis. As the scale of the feature vectors have a significant influence on the SVM results, and with normalization of the features providing a considerable superior generalization performance (Herbrich & Graepel, 2001), normalization between the values of 0 to 1 was performed for all the predictor datasets. To train the SVM, as classifiers tend to perform poorly in an imbalanced training dataset (Akbani et al., 2004), a balanced training dataset was created containing an equal number of randomly selected cells that changed to urban cells from 2000 to 2010, and those that remained same over the given time period.

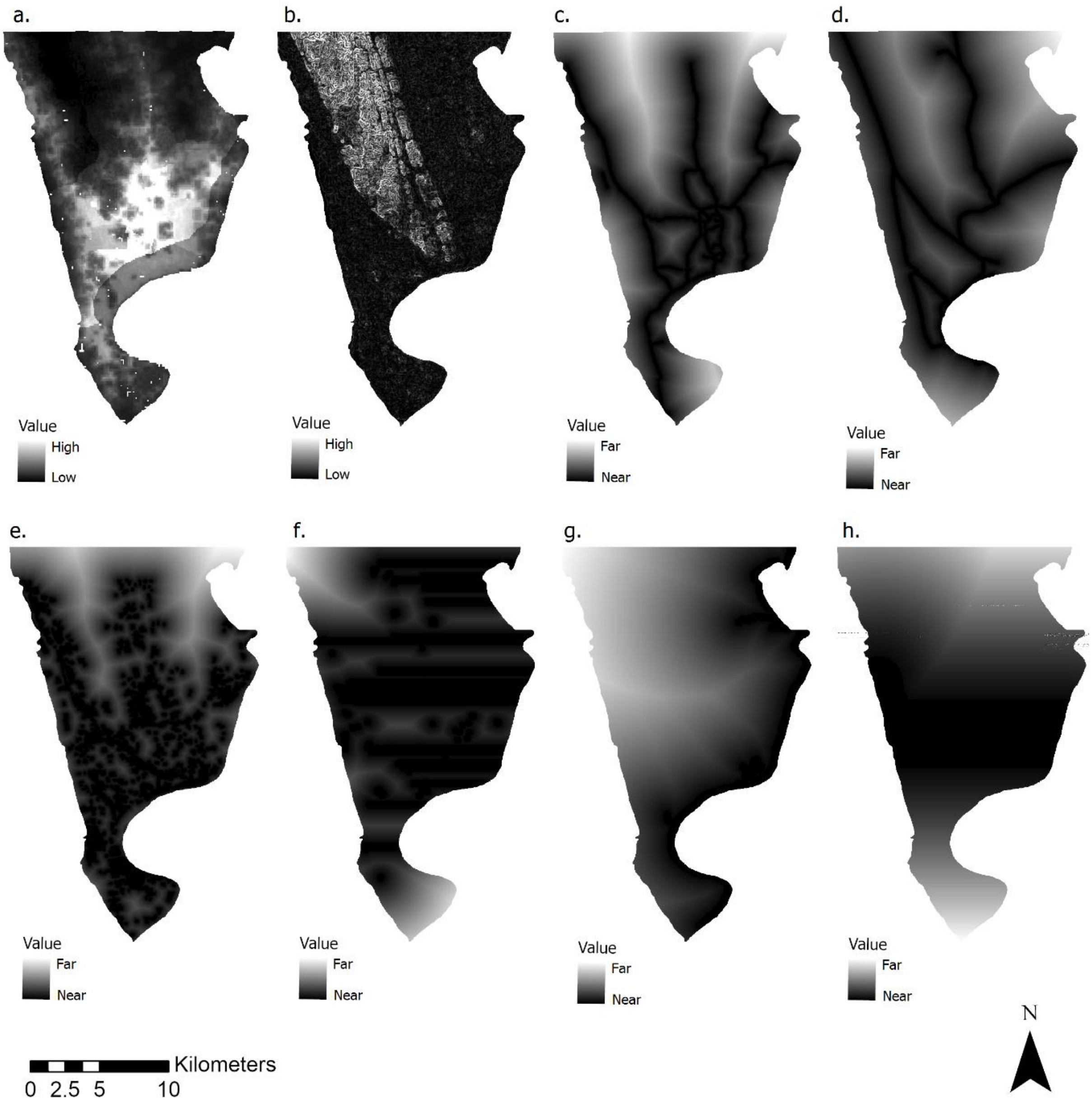


Figure 12: a. Population Density, b. Slope, c. Distance to Roads, d. Distance to Rail, e. Distance to Commercial Areas, f. Distance to Ponds, g. Distance to Rivers, h. Distance to Forest and Parks

3.4.4 Model Implementation

The SVM model for this study was developed using Kernlab (Karatzoglou et al., 2019), a kernel-based machine learning library available through the R library. Past literature indicates that the RBF kernel is a widely implemented kernel function in land cover and urban growth simulation (B. Huang et al., 2009; C. Huang et al., 2002; Samardžić-Petrović et al., 2016) and performs better than other kernel functions (Karimi et al., 2019; Kavzoglu & Colkesen, 2009; Man et al., 2018; Okwuashi et al., 2012), thus the RBF kernel function was used for the analysis. The RBF kernel function requires the use of two hyperparameters, C and γ (Samardžić-Petrović et al., 2016). These hyperparameters used in the model have a significant impact on the model (Dong et al., 2005). The C hyperparameter is the penalty parameter that adds a penalty for misclassification of data points. A lower value of C indicates a smaller penalty for misclassified data points, so a larger decision boundary is chosen in the model at the expense of misclassification of datapoints. A higher value of C indicates a larger penalty for misclassified datapoints, so a smaller decision boundary is chosen in the model to minimize the misclassification of datapoints. Very low values of C will likely underfit the training data and very high values of C will likely overfit the training data (Dong et al., 2005). The γ hyperparameter impacts the distance of influence of the training datapoints. A lower value of γ indicates a larger radius with more datapoints grouped together. While a higher value of γ indicates a smaller radius with fewer datapoints being grouped together. Very high values of γ decreases the accuracy of the training dataset (Dong et al., 2005).

For this study, the SVM model was first trained using predictor variables from the 2000 dataset and the built-up urban areas target variable for the 2010 datasets using the RBF kernel function. Next, the trained model was applied to the 2010 predictor dataset to simulate the built-up urban area target variable for 2019. The hyperparameters for the RBF kernel function used in the SVM model were tuned through a grid search process for each pair of $C \in \{0.1, 1, 5, 10, 50, 100\}$ and $\gamma \in \{0.1, 1, 5, 10, 50, 100\}$ to determine the best performance combination of these hyperparameters for the model. Lastly, the best performance combination of the hyperparameters obtained from the grid search was used to create the final SVM model which was applied to the 2019 predictor data to simulate the growth of built-up urban areas for 2040. The resulting growth of the built-up urban area was used in the delineation of the UGB for Chattogram. A detailed representation of the model is shown in Figure 13.

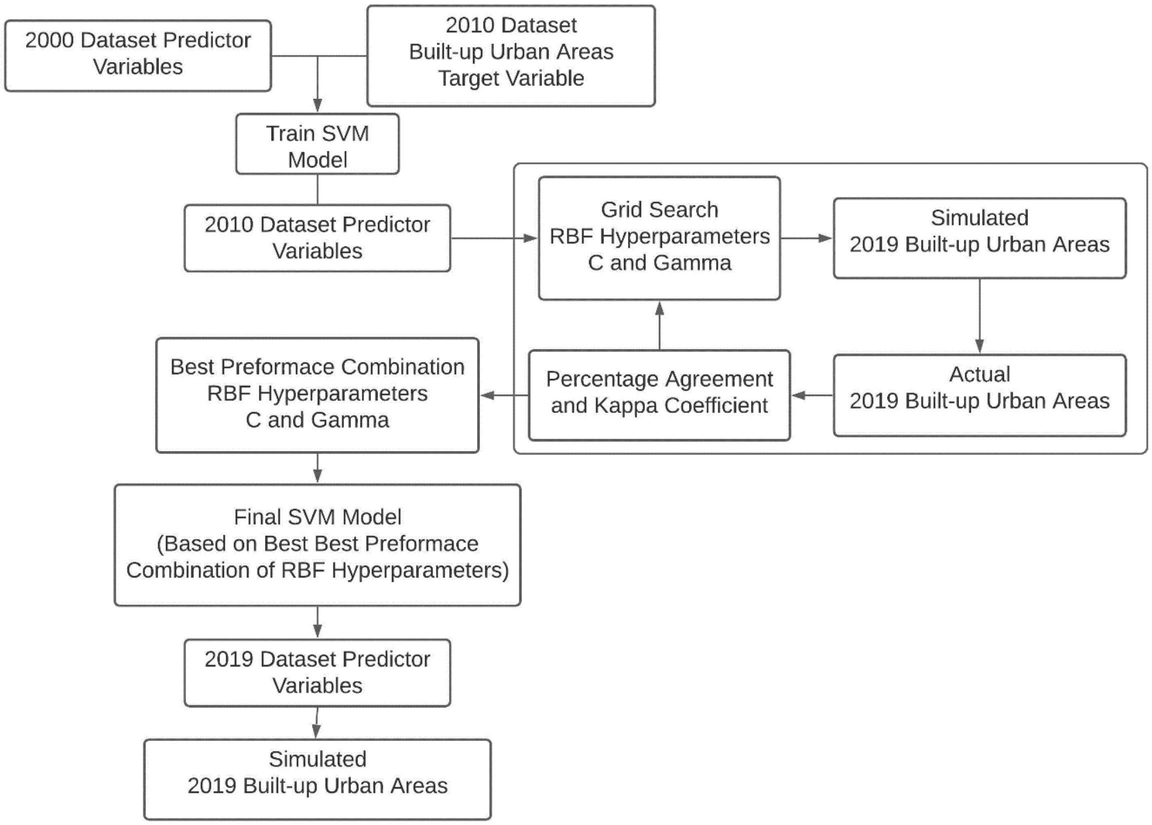


Figure 13: Diagram of SVM based simulation of built-up urban areas for 2040

3.5 Results and UGB Delineation

For the SVM model, the best performance assessment of the RBF kernel hyperparameters was conducted by comparing the percent agreement of the built-up urban areas simulated by the model for 2019 with the actual built-up urban areas for 2019 and its Cohen's kappa statistics (McHugh, 2012). The percent agreement indicated the overall accuracy of the correct predictions made by the model while Cohen's kappa coefficients indicated the magnitude of agreement between the two beyond those that occur due to chance (J. Cohen, 1960). Results from the hyperparameter turning showed that a C value of 5 (Table 10) and a γ value of 0.1 (Table 11) provided the best performance combination for the model. This combination produced an overall percentage agreement of 91.79% and a Cohen's Kappa Coefficient of 0.7699, showing a substantial agreement (Landis & Koch, 1977).

Table 10: Results from the Grid Search examining Percentage Agreement between predicted built-up urban areas for 2019 and actual built-up areas for 2019

		Gamma (γ)					
		0.1	z1	5	10	50	100
	0.1	90.50%	91.28%	21.75%	21.64%	24.40%	22.40%
	1	91.50%	91.67%	90.83%	57.34%	24.40%	22.40%
Cost	5	91.79%	91.49%	90.75%	60.75%	24.40%	22.67%
(C)	10	91.70%	91.30%	90.72%	60.75%	24.40%	22.67%
	50	91.68%	90.87%	90.69%	60.63%	24.40%	22.67%
	100	91.64%	90.73%	90.68%	60.58%	24.40%	22.67%

Table 11: Results from the Grid Search examining Cohen's Kappa Coefficient between predicted built-up urban areas for 2019 and actual built-up areas for 2019

		Gamma (γ)					
		0.1	1	5	10	50	100
	0.1	0.7446	0.7513	0.0092	0.0002	0.0000	0.0000
	1	0.7652	0.7618	0.7165	0.2473	0.0100	0.0036
Cost	5	0.7700	0.7530	0.7133	0.2786	0.0144	0.0050
(C)	10	0.7685	0.7472	0.7122	0.2784	0.0144	0.0050
	50	0.7639	0.7349	0.7113	0.2773	0.0144	0.0050
	100	0.7619	0.7309	0.7112	0.2768	0.0144	0.0050

The SVM model based on the best performance combination of the hyperparameters was applied to the 2019 dataset, using it as the predictor variable to simulate the future built-up urban areas for 2040 in Chattogram. Keeping in mind the overall goal of the UGB to promote contiguous urban growth, isolated patches of built-up urban areas simulated by the model that appeared outside of the largest contiguous built-up urban area were excluded from the analysis. The results from the SVM model-based simulation for 2040 predicted an increase of 18.27 sq. km of contiguous built-up urban areas from base 2019 levels over the next twenty-year time period for the city of Chattogram. A majority of growth in the built-up urban areas is expected to occur in the North-Eastern region (5.33 Sq. Km) and along the South-Western region (3.81 Sq. Km) of Chattogram (Figure 14). Alarmingly, a large portion of this expansion in the South-Western corner of Chattogram is expected to occur in areas with a high risk of flooding due to its proximity to the bay. The other regions of the city showed limited expansion of built-up urban areas. When examining the land cover change (Fig 15), current agricultural land cover with 6.07 Sq. Km is predicted to be the biggest land cover type to be converted into the contiguous built-up urban land cover. This is followed by inclusion of 5.28 Sq. Km of built-up urban land cover, that were previously scattered outside of the contiguous area and are now included as a part of the contiguous region for 2040, and nearly equal amounts of vegetated (3.76 Sq. Km) and barren (3.75 Sq. Km.) land cover being converted as a part of the contiguous built-up urban region.

This is followed by built-up urban land cover including parcels that were previously scattered outside of the contiguous area. With the inclusion of this scattered land area, the built-up urban land cover comprises 5.28 Sq. KM as part of the contiguous region for 2040. Nearly equal amounts of vegetated (3.76 Sq. Km) and barren (3.75 Sq. Km.) land cover are converted as part of the contiguous built-up urban region.

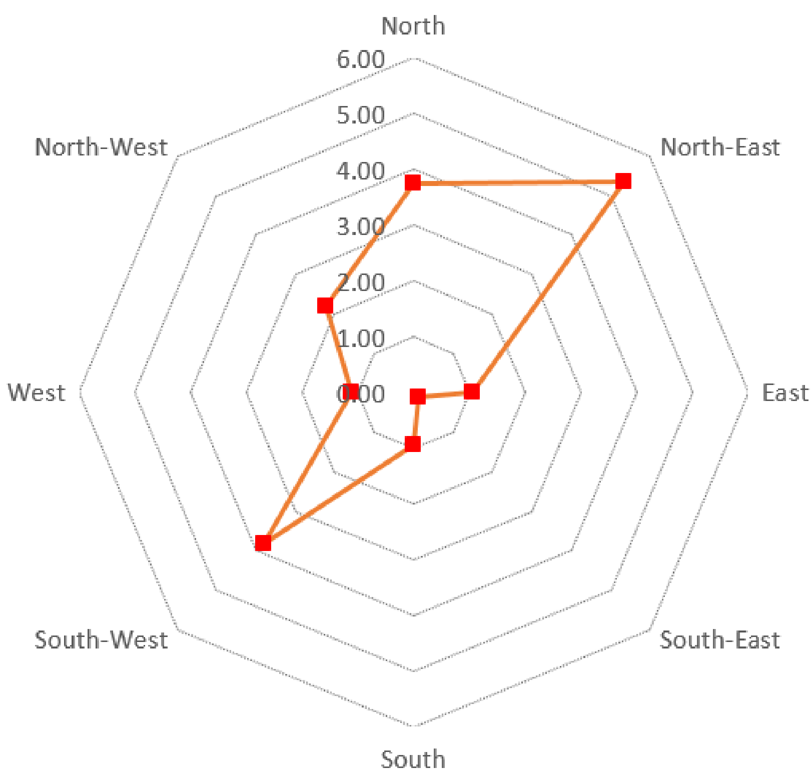


Figure 14: Directional expansion of contiguous built-up urban footprint for Chattogram with area presented in Sq. Km.

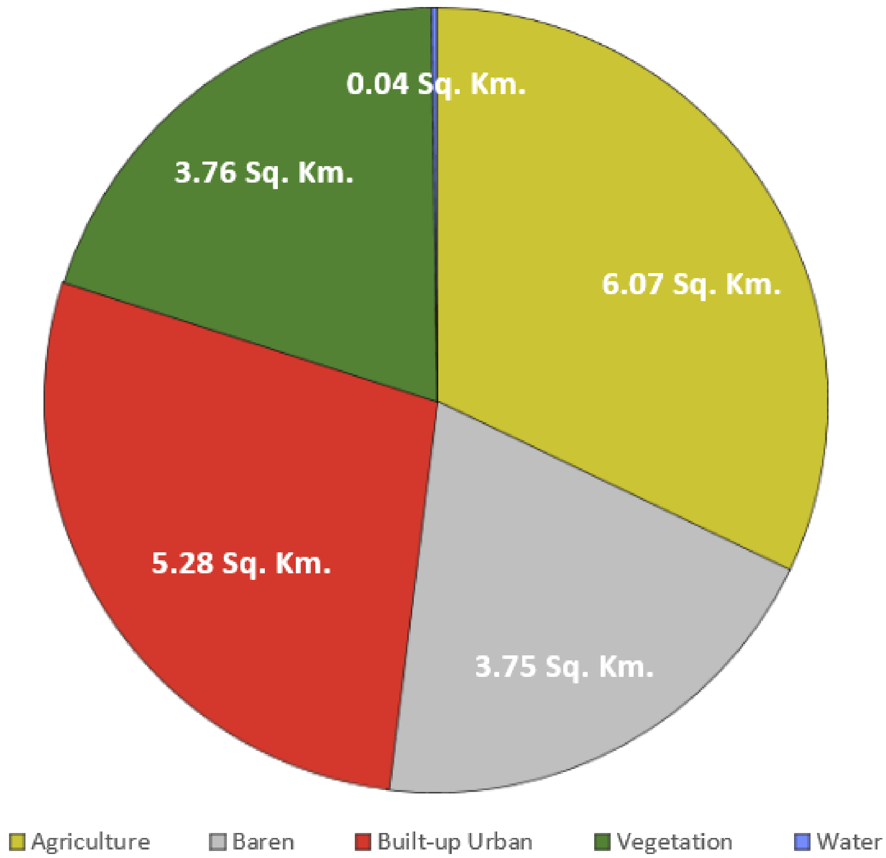


Figure 15: Land cover type in 2019 that is predicted to be converted into built-up urban land cover in 2040.

The UGB in this study, as shown in Figure 16, was delineated for the year 2040 using the predicted expansion of contiguous built-up urban areas for the city of Chattogram as the reference. This delineation was specifically created based on the business as usual assumption, without accounting for any unforeseen future influences from unprecedented changes in population, economy, environment, policies or politics (Bhatta, 2009). While the current delineation of the UGB for Chattogram is based only on land cover data, topographic features, and population density information due to limited accessibility of freely available data, the actual establishment of the UGB would require further investigation into the social, economic and environmental aspects for UGB delineation. More research would need to be undertaken in terms of collection and incorporation of information such as t environmental hazards, slum settlement, and industrial/economic activities. This would be extremely beneficial for the process of knowledge-based delineation of the UGB for the city.

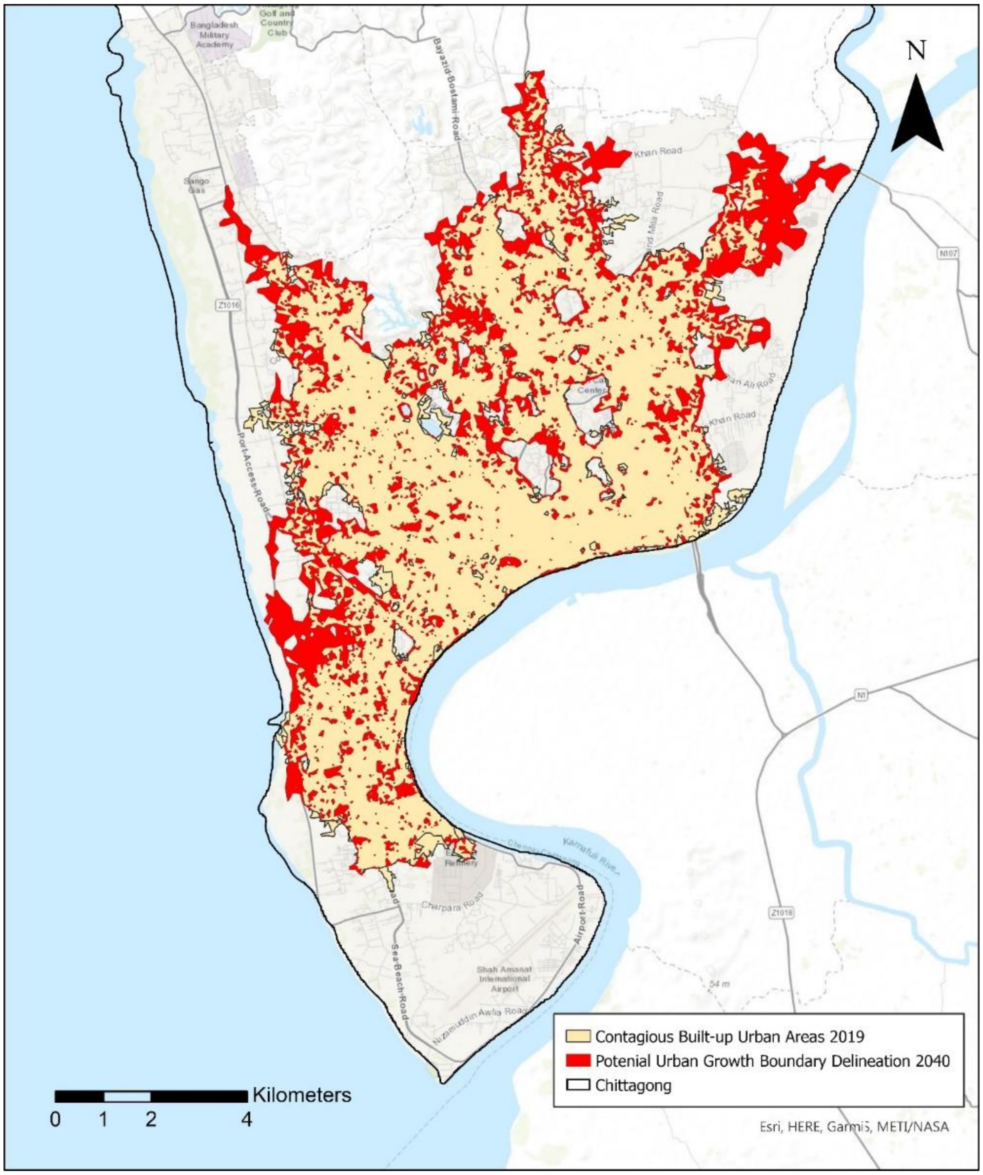


Figure 16: Delineation of the potential Urban Growth Boundary for Chattogram.

3.6 Discussion and Conclusion

The explosion of population and rate of expansion of built-up urban areas has necessitated the use of policies such as the UGB for the purpose of restricting and directing the rate and extent of built-up urban expansion. This is especially pertinent for cities within developing countries such as Chattogram that have not only experienced the rapid rates of expansion of built-up urban areas, but have also suffered from issues of haphazard and uncontrolled expansion due to the lack of policies targeted toward urban growth restriction. Use of UGB for Chattogram could provide a robust planning framework necessary to create a forward-looking urban growth policy aimed at restricting and directing the expansion of built-up urban areas while emphasizing sustainable urban growth. The UGB delineated in this study can act as an effective blueprint or model that could be used for the potential adoption of a UGB in Chattogram.

The current delineation of the UGB for Chattogram presented in this study has been based on the simulation of future contiguous built-up urban areas using SVM. However, it should be noted that this delineated serves only as a reference and a concept for the potential establishment of a UGB for the city of Chattogram. In addition to the delineation of the boundary, the successful implementation and realization of a multifaceted and complex policy tool such as a UGB would require a holistic approach involving cooperation and coordination from different levels of government, non-government, and the private sector (Popescu, 2013). Additionally, policy alienation amongst stakeholders, particularly due to a lack of input from the stakeholders, can be a significant threat to the success of the UGB policy (Shakil et al., 2016). With this in mind, examining the perception of the stakeholders on the past and present urban expansion of the city of Chattogram, and their concerns regarding the implementation of a growth restriction mechanism such as a UGB for the city would be beneficial. This would allow planners and policymakers to incorporate stakeholder input in the policymaking process in order to assess and address their concerns regarding the potential UGB policies for Chattogram. Moreover, the use of UGB should not be static. If adopted, the UGB for Chattogram would need to dynamic with frequent monitoring and necessary adjustments made to the delineation based on any changes to various factors impacting the expansion of built-up urban areas. Along with the delineation and adoption of the UGB, other supporting policies, and regulatory considerations will be essential in strengthening the UGB and ensuring its overall success. These supporting policies will need to address underlying issues related to the haphazard and uncontrolled urban expansion within Chattogram such as management of informal settlements and strict enforcement of these boundary lines. Furthermore, in addition to the variables previously discussed in this study, the boundary delineation is likely to be highly impacted by other exogenous factors that are difficult to account for in the model such as influences from private developers, political influences, policy/regulatory mandates, donor organizations and NGO. These changes should be in adherence to the concepts of sustainability and sustainable urban growth. Finally, although the delineated boundary for the actual adoption and establishment of the UGB for the city of Chattogram will more than likely look different from what has been proposed in this study, the lessons learned and the insights gained from this study will certainly be valuable for planners and policymakers and encourage the debate on the need for sustainable urban growth for the city of Chattogram.

CHAPTER IV: THE KEY CONSIDERATIONS OF POTENTIAL ADOPTION OF URBAN GROWTH BOUNDARIES IN BANGLADESH: A CASE STUDY OF CHATTOGRAM [3]

4.1 Introduction

Bangladesh has experienced rapid urbanization since independence in 1971 (UN/DESA, 2019). Even though accelerating urban growth has often been viewed as a sign of vitality for the economy of Bangladesh, such urban growth has mostly occurred in an unplanned and chaotic manner (M. M. Hassan & Nazem, 2016) due to lack of proper implementation of urban planning and policy frameworks (Hashemi, 2006; M. M. Hassan, 2017; Suykens, 2017). Such development has a tremendous impact on the environmental characteristics of cities (i.e., loss of large amounts of agricultural and vegetated lands) and a significant detrimental effect on the quality of life resulting from pollution, sanitation, traffic congestion and crime (M. M. Hassan & Nazem, 2016; H. Z. Rahman, 2014). In response to this unplanned growth, several urban growth management strategies and tools have been applied in Bangladesh such as comprehensive planning or master plan, zoning, subdivision regulation, development fees, property taxes (Ahamed & Hasan, 2010). However, Urban Growth Boundary (UGB) policy has not yet been discussed in the country's urban policy literature (e.g Hassan & Nazem, 2016; T. Islam et al., 2016; M. M. Rahman, 2021). For example, existing national policies such as The Building Construction Rule, 1984 and 1996; Bangladesh Building Construction Act, 2008; The Environmental Conservation Rules, 1997; Private Residential land Development, 2004, etc. have never mentioned the word UGB (Ahamed & Hasan, 2010). The UGB is a land use regulation that has been established, in most cases, by the local government with the goal of restricting the expansion of urban areas beyond a defined boundary (American Planning Association, 2002; Brueckner, 2007; Pendall et al., 2002). Implementing such a policy could be highly effective to regulate the rate and extent of urban

[3] Bajracharya, P., Sultana, S., & Adri, N. (2021). The Key Considerations of Potential Adoption of Urban Growth Boundaries in Bangladesh: A Case Study of Chattogram. *Land Use Policy (To Be Submitted)*.

expansion (W. Han et al., 2020; Jun, 2004; Ma et al., 2017). In this study, we use Chattogram—one of the world's largest port cities and the second-largest metropolitan area in Bangladesh, as a case study to examine the potential adoption of a UGB policy within Bangladesh.

Like many other countries (Bhatta, 2009; Bonilla, 2007; He et al., 2018), the potential adoption of UGB for the city of Chattogram as an urban growth management strategy would be a large-scale and complex undertaking that is likely to impact a wide range of policies and stakeholders (Ma et al., 2017). As such, it is also likely to face a host of challenges concerning the political, economic, and social conditions within Chattogram (Jafrin & Beza, 2018; Sabrin & Kamal, 2014; N. Uddin, 2018). These issues would need careful consideration for the potential adoption of UGB for the city to be successful. Furthermore, it is necessary to gauge the interest and the concerns of stakeholders to support such a policy. The goal of this paper is to investigate the key considerations that are vital for a successful implementation of UGB for Chattogram through a systematic review of the literature and a web-based survey of stakeholders' perceptions on current growth patterns of Chattogram, the potential application of UGB as containment strategy, and concerns regarding the application of UGB in Chattogram. These considerations discussed in the paper along with the results from the survey provide critical insight for a potential formulation, adoption, and implementation of the UGB for the Chattogram. The remainder of the article is organized as follows: Section 4.2 briefly discusses the literature on UGB and challenges in the implementation process of UGB within developing countries. Section 4.3 discusses the research objective, the setting, and the methodology used in the paper. Section 4.4 highlights the stakeholders' perception of the urban growth of Chattogram and the adoption of UGB based on the survey. Section 4.5 examines the key concerns related to the adoption and implementation of UGB for Chattogram. The last section concludes with a discussion on the complexities related to the potential implementation of UGB for Chattogram and the way forward.

4.2 Literature on Urban Growth Boundary and Policy Challenges

The origins of UGB can be traced back to the United Kingdoms' Green Belt policies conceptualized by Ebenezer Howard in 1891 that advocated for a permanent belt of greenery around the city with the goals to restrict urban growth and over-spilling of the population of London while preserving agriculture and providing amities and a space for recreation (Thomas, 1963). This idea was further extended by Patrick Abercrombie and implemented under the Great London Plan of 1944 (Thomas, 1963). Compared to the greenbelts from which it conceptualized, the UGB in use today restricts urban expansion through the application of regulatory options such as zoning while allowing for periodic assessment (Nabielek, 2012) and change of these boundaries (Pendall et al., 2002). But, it wasn't until the 1960s that UGB was used as an urban planning tool (Ma et al., 2017) and was further popularized in the 1990s through the rise of compact cities and new urbanism movements (Sinclair-Smith, 2014).

While UGB has been extensively used in the developed countries such as the United States (Nelson & Moore, 1993), Netherlands (Nabielek, 2012), New Zealand (Grimes & Liang, 2009), and Spain (Paül & McKenzie, 2013), its adoption in developing countries has been limited. To the best of our knowledge, there have only been five developing or transitioning countries where UGB have been explicitly implemented as an urban growth control mechanism: namely Albania (Felstehausen, 1999), Chile (Hölzl & Nuissl, 2014), China (Long et al., 2013), Saudi Arabia (Al-Hathloul, 2017) and South Africa (Sinclair-Smith, 2014). Amongst these developing countries, China (He et al., 2018; Ma et al., 2017), Saudi Arabia (Alshebli, 2018; FSCP, 2016), and South Africa (Horn & Van Eeden, 2018; Sim et al., 2016) have been in the forefront with significant research being done in the delineation and implementation of UGB policies (Alkhayyal, 2017; Alshebli, 2018; Y. Chen et al., 2019; Y. Li et al., 2019). Although there still have been several challenges that have impacted the application of UGB in these countries, substantial support has been given by the government in the assessment of these policies, addressing the challenges and making improvements to these policies as required (FSCP, 2016; Ma et al., 2017; Sim et al., 2016). Similarly, over the last few decades there has been a resurgence in the literature examining the adoption of UGB within other developing countries where it has not been previously implemented (Table 12). Yet, such studies have not been found for any cities in Bangladesh.

Table 12: Selected literature examining the use of UGB as a mechanism to contain the urban footprint within the developing countries

Country	**City**	**Research**	**References**
Ecuador	Quito	Examined the possible use of growth management strategy such as UGB for Quito, Ecuador; Hyderabad, India and Xi'an China	The World Bank (2008)
El Salvador	Santa Tecla	Conducted a cost benefit analysis of the application of urban containment policies including UGB for Santa Tecla City, El Salvador	Bonilla (2007)
India	Kolkata	Used Ideal Urban Radial Proximity (IURP), to designate UGB for Kolkata	Bhatta (2009)
Iran	Tehran	Used distance dependent and distance independent rule based spatiotemporal models to predict future urban growth of Tehran and subsequently delineate the UGB	Tayyebi et al.(2011)
Israel	Nationwide	Evaluated the application of UGB along with other urban growth management policies based on a given set of goals for Israel	Frenkel and Orenstein (2012)
Malaysia	Iskandar	Used the GIS based Binary Urban Suitability Model for delineating urban growth limits for Iskandar Malaysia	Ismail et al. (2018)
Serbia	Belgrade	Investigated the possible application of current urban development policies and urban land use tools such as UGB to manage the urban sprawl of Belgrade Metropolitan Area, Serbia	Zeković et al. (2015)
Taiwan	Taipei	Provided a theoretical examination of the impact of hypothetical urban construction boundaries on the behavior of developers Taipei, Taiwan	Lai and Wang (2016)

Based on previous experiences with the implementation of UGB in developing countries (Brown, 2017; Dino et al., 2016; Long et al., 2013), a lack of a well-structured and forward-thinking UGB policy framework, coupled with a lack of good urban governance have resulted in large inefficiencies in the adoption and execution of UGB. This is particularly evident in the implementation of UGB for places such as Chile, and Albania where the absence of clear regulations, inadequate evidence-based policies, and an unclear definition of jurisdiction have led to issues in the administration of the UGB process (Hölzl & Nuissl, 2014; Peters, 2009). UGB in these countries have also suffered from a lack of institutional capacities needed to support and enforce property rights (Valletta et al., 2006) and housing policy (Rojas, 2015) within the UGB. These policy and regulatory issues, in addition to the subpar nature of urban governance in these countries (McCawley, 2015) have contributed towards large amounts of urban growth beyond the designated boundary for the UGB (Felstehausen, 1999; Zegras & Gakenheimer, 2000). Owing to this dysfunctional urban governance, the previous implementation of UGBs have also suffered from policy conflicts and disparate policy objectives amongst bureaucrats, policymakers as well as different levels of the government. This has resulted in large inefficiencies in the UGB boundaries (P. Zhao, 2011) and misuse of these policies by the political and social elite for unjustified expansion of the boundary, making these UGB virtually non-existent (Hölzl & Nuissl, 2014; Pllumbi, 2013).

4.3 Research Objectives, Settings, and Methodology

Chattogram, the second largest metropolitan city in Bangladesh, has experienced a rapid large-scale expansion into surrounding natural areas and valuable ecological sites such as wetland, lakes, and hill-tracts (M. M. Hassan & Nazem, 2016) (Figure 17) resulting in serious environmental consequences. With a population of over 4 million, it accounts for around 9.07 percent of the overall population (BBS, 2014) and 20 percent of the built-up areas within the municipalities in Bangladesh (Bajracharya & Sultana, 2020). Chattogram is also well known as the country's largest industrial hub and it is one of the busiest port cities in the world with strong linkages to the domestic and world economy (Mia et al., 2015). Unlike other cities in Bangladesh, the topographic setting of Chattogram is also unique, which comprises of hills and narrow valleys, surrounded by water bodies such as the Karnaphuli river to the South, the coastal plain, and the Bay of Bengal to the West and the floodplain of the Halda to the East (Chisty, 2014). Chattogram is also known for its historical significance with a diverse cultural heritage dating back to 4 B.C (Jafrin & Hossain, 2019). Given the historic significance, the scenic and panoramic natural beauty of Chattogram, it has become a major tourist destination in South Asia (A. Hassan, 2012). However, there are growing pressures on land and surrounding ecology resulting from the consequence of economic activities, which may affect the environment directly or indirectly. Hence, there is a need for introducing an urban growth restriction policy (Al Mamun & Kim, 2019) such as the UGB (Ren et al., 2020) to provide Chattogram with a holistic planning and policy framework to protect and preserve areas and make the city more sustainable and livable than its present situation.

Successful adoption and implementation of a potential UGB for the city of Chattogram as an urban growth management strategy would require a wide range of policies and stakeholder's participation. Thus, this paper:

1. Examines the perception of stakeholders on the past and future urban growth of Chattogram and gauges the interest of the stakeholders in the adoption of urban growth restriction policies such as UGB for the city.
2. Assesses the concerns of the stakeholders regarding the potential application of UGB for Chattogram.
3. Identify key considerations for successful adoption and implementation of the UGB policy for Chattogram.

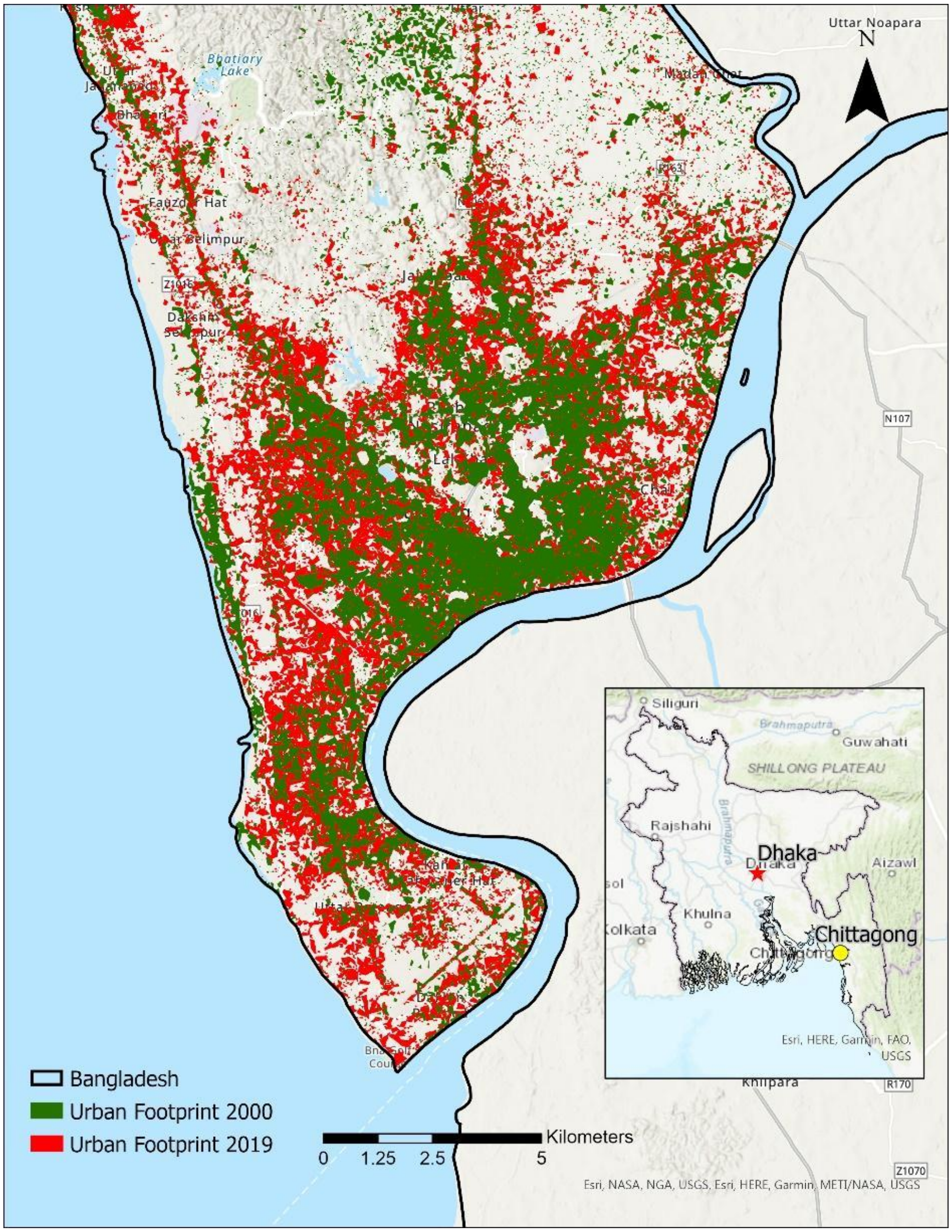


Figure 17: Urban Footprint of Chattogram for 2000 and 2019

As the methodological approach for this study, we combined a systematic review of the literature along with an exploratory anonymous online survey to investigate the key consideration regarding the adoption and implementation of UGB for the city of Chattogram. We examined the common and recurring issues that have been discussed in the past implementations of UGB within the five developing countries where it had been previously implemented, and its relevance within the current socio-economic, political, and policy scenario for Chattogram. We conducted a multidisciplinary literature review from a wide variety of English-based peer-reviewed international academic journals. Additionally, we also reviewed non-academic literature, including reports from think tanks, research organizations, government, along with policy and regulatory reports, city master plans and national regulation, laws, and planning proposals relevant to urban development for the city of Chattogram. Academic journal databases and academic search engines including Academic Search Complete and Google Scholar were used to obtain academic literature whereas the google search engine was used to obtain non-academic literature.

The online survey conducted in this study was divided into two sections. The first section explored the perception of urban growth of Chattogram and the need for urban growth restriction, while the second section examined the concerns regarding adoption and implementation of policy such as UGB for Chattogram. Questions for the survey were created based on common and reoccurring themes that were derived with reference to the results literature review. The survey was conducted using Qualtrics survey software. It consisted of close-ended quantitative questions as well as options for open-ended questions to obtain any additional qualitative responses. The survey was distributed through “Planners Forum of Bangladesh” and “Bangladesh Environment Network” Facebook groups which mostly consisted of planning professionals, academics, and researchers in the field of planning, environment, and sustainability. The primary goal of this survey was to elaborate, enhance and clarify the results obtained from the literature review (Greene et al., 1989) while further validating the finding and strengthening the overall conclusion of the study (Schoonenboom & Johnson, 2017). Additionally, an unstructured interview was conducted with city officials via zoom.

4.4 Stakeholder perception on potential adoption and implementation of UGB for Chattogram

The first section of the survey examined the perception of the respondents on the current and future state of urban growth of Chattogram and the need for urban growth restriction policy for the city. The online survey resulted in a total of 41 valid responses, and of which, 29 respondents completed the entire survey. The demographics of the survey indicated 89.66% of respondents being male and 10.34% female, with 96.67% of the respondents being between the ages of 18 – 60 and the rest older than 60 years. Examining the perception of urbanization among the respondents, a majority of respondents (69.57%) strongly agreed that the urban expansion of Chattogram had occurred in an uncontrolled/unplanned manner over the past 20 years (Table 13) and further 91.30% indicated that this uncontrolled urban expansion would get worse or at least remain the same level as now in the next 20 years (Table 13). While all the respondents indicated that there is a need for a plan/policy aimed at restricting the expansion of Chattogram (86.96% strongly agreed and 13.04% somewhat agreed), no respondent indicated that there was a definite growth restriction policy for Chattogram with 57.14% of the respondents indicating that there "maybe" such policies. A follow-up question to those respondents who answered "maybe" on what those policies might be yielded only limited answers with one respondent indicating the availability of policies such as "CRDP, CUS and ADR"[4] and other respondent indicating that these policies were "rarely enforced". These survey responses highlight the need, and additionally a lack thereof an urban growth management policy such as the UGB for the city of Chattogram.

Table 13: Perception of Citizens and Stakeholders on Urban Growth and Urban Growth Containment Policy

	Response	**% of respondents**
Gender	Male	89.66%
	Female	10.34%
Age	18-20	3.33%
	21 – 60	93.34%
	Older than 60	3.33%
Whether urban areas in Chattogram have expanded uncontrollably over the past 20 years	Strongly agree	69.57%
	Somewhat agree	26.09%
	Neither agree or disagree	4.35%
How the urban areas in Chattogram is expected to expand	In a more uncontrolled and unplanned matter	56.52%
	At the same level as now	34.78%

[4] **CDRP**: Project through the Asian Development Bank that aimed at integrated area planning while emphasizing economic activities around the city. https://www.adb.org/sites/default/files/project-documents/39298/39298-013-emr-en_2.pdf
CUS: Center for Urban Studies: Organization aimed at studying urban and regional issues in Bangladesh. http://cusdhaka.org/about-cus
ADR: Alternative Dispute Resolution – A civil justice delivery procedure without formal judicial processes https://www.banglajol.info/index.php/IIUCS/article/view/20
405/14120

	In a more controlled and planned manner than now	18.75%
Whether there is a need for plan/policy to restrict urban expansion for the City of Chattogram	Strongly agree	86.96%
	Somewhat agree	13.04%
	Unsure	0.00%
	Somewhat disagree	0.00%
	Strongly disagree	0.00%
Whether the citizens of Chattogram would approve an urban growth boundary or similar policies being implemented for the City of Chattogram to restrict uncontrolled expansion of urban areas	Yes	42.11%
	Maybe	47.37%
	No	10.53%
Whether there is an urban growth containment policy in place for the City of Chattogram	Yes	4.76%
	Maybe	57.14%
	No	38.10%

4.5 Key concerns for successful adoption and implementation of UGB for Chattogram

In this section, through the online survey and a comprehensive literature review, we have identified five key thematic concerns that would need to be addressed for the successful adoption and implementation of UGB for the city of Chattogram. While distinct, these concerns are highly interrelated and can be expected to have a substantial influence on one another (Figure 18).

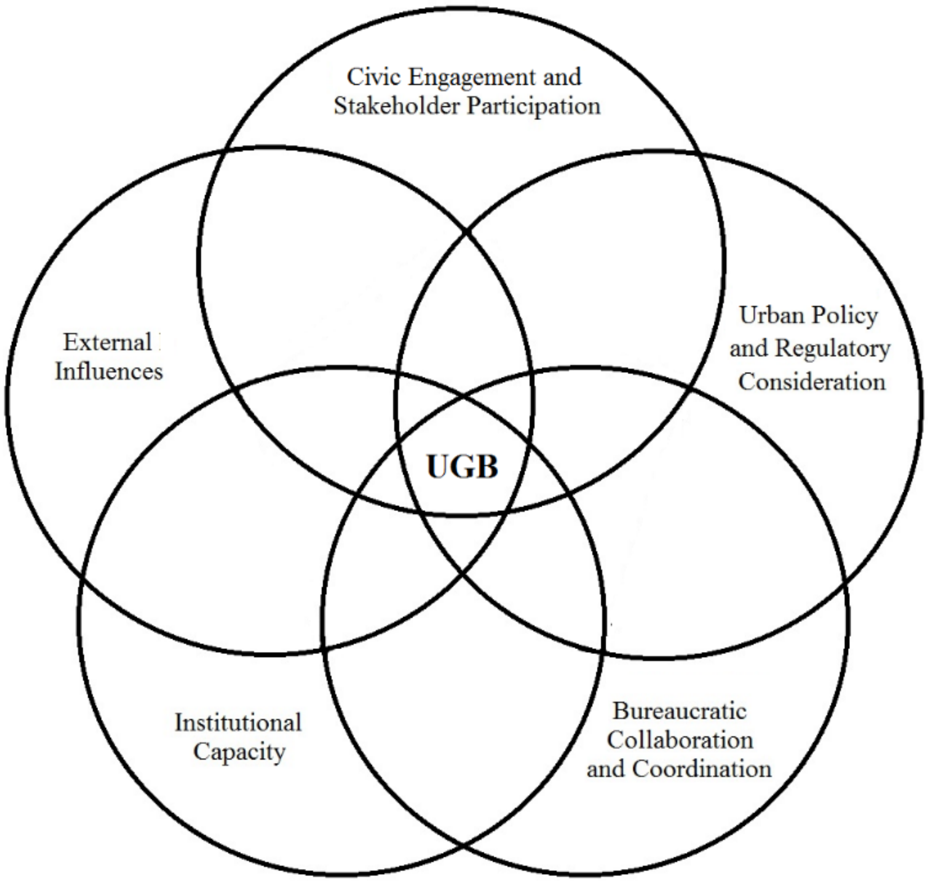


Figure 18: Relationship between the five key consideration and successful adoption and implementation of UGB

4.5.1 Urban Policy and Regulatory Considerations

Given the lack of robust urban planning guidelines for the city of Chattogram (Hashemi, 2006), policy and regulatory issues are one of the major factors that would need to be considered for the potential implementation of UGB. There have been various iterations of planning proposals for the city including Master Plan 1961, Master plan 1995, and Structure Plan 1995 – 2005, with the most recent being the Detailed Area Plan (DAP) (Jafrin & Beza, 2018). The DAP was created with the objective of guiding future urban development, accommodating population growth, planning for sustainable development as well as providing guidelines for government, and private sector development and non-government initiatives for up to year 2015 (CDA, 2009). However, this was not the reality, as the DAP guidelines were not published or implemented until 2009, 14 years after they were originally written (Suykens, 2017), and hence the guidelines were outdated and ineffective. This lack of up-to-date planning guidelines has resulted in a detrimental impact to civic facilities and necessary infrastructures such as water, gas, waste management, and transportation for the city, as they have not been able to keep up with the growing demands (Hashemi, 2006). Likewise, this absence of concrete forward-looking urban planning guidelines has significantly contributed to the unplanned and unregulated urban expansions within Chattogram.

A policy such as UGB could provide the robust framework for the city of Chattogram, necessary to create a forward-looking planning strategy aimed at restricting and directing the rate of future urban growth and creating a structure to implement other planning tools within the framework (R. Karim, Former Chief Town Planner of the Chattogram City Corporation, personal communication, February 2021). However, the formulation and implementation of a potential UGB must be undertaken with clear goals of urban growth management while addressing issues with good urban governance and the lack of supporting policies essential for its success (Aminuzzaman, 2013).

Learning from the past, effective implementation of a large scale, all-encompassing UGB plan for Chattogram, will call for a well-designed and well-formulated UGB policy backed by a good urban governance process, an efficient planning body, and competent enforcement and accountability strategy. The success of the potential UGB for Chattogram will be contingent on the availability of supporting policies that complement and work in synergy with the proposed UGB as a part of the overall good governance (Aminuzzaman, 2013). For Bangladesh, components such as lack of supporting policies, conflicts and strategic disagreements between various governing bodies, missing coordination and synergic links between policies, and overall challenges with good urban governance and planning have been identified as major weaknesses in the policy formulation process (Aminuzzaman, 2013; Nazrul Islam, 2013; Panday & Panday, 2008; N. Uddin, 2018). These weaknesses in policy formulation have also been highlighted in the survey. 63.16% of the respondents of the survey have indicated inadequate policies and regulations supporting UGB as being a high concern and 31.58% of the respondents have indicated conflicts between various governing bodies barring the successful adoption and implementation of UGB for Chattogram as being major sources of concern (Table 14). This can be a formidable challenge in the policymaking process, particularly if no legislative and structural changes are made within the current system addressing these concerns (Aminuzzaman, 2013).

Table 14: Concern among the respondents with regards to the impact that each of the following would have on the adoption and implementation of UGB for Chattogram

	High Concern	**Medium Concern**	**Low Concern**	**No Concerns**
Inadequate policies and regulations supporting the UGB	63.16%	26.32%	10.53%	0.00%
Conflict between various governing bodies related to UGB policy formulation	31.58%	52.63%	15.79%	0.00%
Informal settlements /slums being created outside the UGB	75.00%	10.00%	15.00%	0.00%
Disconnect between the policy objectives set by planners and the needs at the local level	5.00%	55.00%	35.00%	5.00%
Lack of input from the public and other stakeholder input in planning the UGB	70.00%	15.00%	15.00%	0.00%
Opposition from local citizens	20.00%	25.00%	50.00%	5.00%
Lack of coordination between policymakers and bureaucratic entities	42.11%	52.63%	5.26%	0.00%
Improper delineation of urban growth boundary due to lack of institutional capacity	65.00%	15.00%	20.00%	0.00%
Urban growth boundary policy not being properly enforced	65.00%	30.00%	5.00%	0.00%
Clientelist/patronage politics impacting the UGB	60.00%	40.00%	0.00%	0.00%
Impact of political opposition on adoption and implementation of UGB	35.00%	45.00%	20.00%	0.00%

Successful adoption and implementation of UGB would require a holistic policy approach that would address issues pertinent to urbanization and the sustainable urban development of Chattogram underscored by supporting policies. This holistic approach would need to cut across different levels of government, non-governmental organizations, and the private sectors (Popescu, 2013) to enhance the overall impact of the proposed UGB. For example, amongst the biggest issues seen in Chattogram has been the prolific growth of informal settlements in Chattogram (Suykens, 2017; Minhaj Uddin, 2012; N. Uddin, 2018). These informal settlements account for nearly 35 percent of Chattogram's population and are an undeniable part of the urban landscape of the city

(Suykens, 2017). In the eyes of the law, they are deemed illegal with no property rights, no basic amenities and are considered as sources of socioeconomic deprivation and environmental degradation (Suykens, 2017). Furthermore, these informal settlements have contributed significantly to the unsystematic, haphazard, and uncontrolled expansion of built-up areas around the city (N. Uddin, 2018).

With 75% of the respondents in the survey indicating the informal settlements and slums being created outside the designated boundary as a major concern for successful implementation of the UGB for Chattogram (Table 14), supporting policies addressing the underlying issue of informal and slum settlements with a focus on the sustainable urban expansion of Chattogram would need to be explored. The current law on informal settlements as it stands, would need to be reassessed and policies geared towards pro-poor, safe, and affordable housing, resettlement of informal housing within the city, upgrading the informal housing, and programs to assess land tenures would need to be considered (Burra, 2005; N. Uddin, 2018). Similarly, planners and policymakers would also need to dedicate the resources to address other related issues such as transportation, water, drainage, sewage and provide strategies that would complement the potential adoption of UGB for Chattogram. Most importantly, these changes for the city of Chattogram would need to occur within the construct of the good decentralized local urban governance structure that provides a mixture of democratic practices, as well as fiscal and administrative autonomy from the central government of Bangladesh, which currently seems to be lacking (Huq, 2015).

With regards to policy and regulatory consideration, it is essential for evidence-based monitoring, evaluation, and enforcement of these policies particularly for developing countries that have a weak urban governance system (Cloete, 2009; Segone, 2009). In developing countries, such as China, Saudi Arabia, and South Africa, where there have been multiple iterations and systematic updates on the UGB, evaluation of the performance of past UGB have resulted in subsequent changes to UGB delineation as well as re-evaluation of methodological approaches to the UGB policies (Alkhayyal, 2017; P. Jiang et al., 2016; Sinclair-Smith, 2014). However, when examining past and current policy formulation and implementation processes in Bangladesh, there is a clear lack of a formal and systematic mechanism for research, analysis, and impact assessment of policies and policy interventions (Aminuzzaman, 2013). Furthermore, the policy review and assessment process in Bangladesh has been described as an "alien concept in the public administration system in Bangladesh" (Aminuzzaman, 2013, p. 453). Taking this into account, for an intended UGB for Chattogram to be successful, it would require a monitoring and evaluation process as an explicit part of the policies governing the UGB. The evaluation processes would need to focus on the impacts of the UGB for the city of Chattogram and highlight any issues regarding accountability, enforcement, informal settlements, and transportation that are likely to arise for the city. Finally, as a part of the holistic approach, these policies would have to be implemented in conjunction with other government, non-government, and citizen stakeholders with a vested interest in sustainable and managed urban growth in the city.

4.5.2 Civic Engagement and Stakeholder Participation

In recent years, there has been a big push towards public participation and incorporation of stakeholder input as a part of the policy formulation and implementation process (Abelson & Gauvin, 2006; Bai et al., 2010; Lane, 2005). This is also the case with regards to policies on UGB. In previous implementations of UGB in places such as Portland, Oregon and Cape Town, South Africa, input from public stakeholders has been an important component of the UGB to make any changes to the delineation of the boundary or the policies related to the UGB (City of Oregon, 1997; Sinclair-Smith, 2014). However, in developing countries where UGBs have been implemented, there has not been extensive incorporation of stakeholder input or much civic engagement in the formulation and implementation process of the UGB. In China, policy formulation for UGB, particularly in the earlier iteration, was done as a part of a traditional, state-owned centrally-planned-economy-based system, without consultation with the stakeholders (Long et al., 2013). Similarly, for Saudi Arabi, due to the lack of formal structure for public participation within the policymaking process, there was no input from the citizens incorporated as a part of UGB formulation (Gadou & Quazi, 2009). In an extreme case, for Albania, rather than UGB policies working together with the stakeholders and local communities towards the goal of limiting the extent of urban expansion of the city, it had been used as a strategy to systematically segregate the poor outside the UGB (Pllumbi, 2013). In all of these cases, a disregard for local level stakeholder inputs has resulted in a disconnect between the policies being implemented and the needs at the local level. However, when referring to the survey, a majority (55%) of respondents have indicated only a medium level of concern with regards to there being a disconnect between policy objectives set by planners and the needs at the local level, with only 5% of the respondents indicating this as being a major concern (Table 14). In the previous implementation of UGB, these mismatches between the policy objectives and the needs at the local level have led to inefficiencies in the UGB and thus is a crucial issue to address UGB (P. Zhao, 2011).

When considering policy formulation in Bangladesh, a country with a "top-down" policy approach, there is a severe lack of public participation (Swapan, 2016), and an outright deficiency of formal space for civic societies to express their opinion as a part of the overall policy formation process (Huq, 2015). The citizenry is only seen to have a voice over the governing and policymaking bodies through their votes during elections, whereas during other times citizens are largely neglected and excluded from participation (Banks, 2008). This dearth of public participation in the governance and policymaking process has allowed the control of planning and decision making by the ruling party and the interests groups while neglecting the needs at the local level (M. M. Khan, 1997). While there has been some push for an integration of more civic engagement stakeholder input in the urban governance and decision-making process, in reality, ordinances such as the Local Government (City Corporation) Act 2009 have kept the policy and budget making processes largely contained within the state actors (Huq, 2015).

This sentiment is also reflected in the survey with 70% of the respondents indicating the lack of public participation and input from stakeholders being a major issue with regards to adoption and implementation of UGB in Chattogram (Table 14). As the issue of rapid, unregulated, and haphazard urban growth is a complex multidimensional challenge (Bai et al., 2010), a UGB policy for Chattogram would need to be planned and implemented in a holistic approach that includes civic engagement and stakeholder participation as an explicit part of the policy design and formulation process. Inclusion of public participation as a part of the strategy for UGB policymaking process would provide planners with local knowledge and critical insight into the needs of the citizenry. This would allow for a practical, relevant, and achievable formulation of the UGB as well as aid in the creation of supporting policies (Dungumaro & Madulu, 2003) specifically addressing the concerns of the citizens such as improvements in pro-poor housing, and infrastructure upgrades. However, what is observed is a systematic exclusion of citizen participation in the policymaking process. This lack of influence amongst the local citizens of

Chattogram in the potential adoption and implementation of UGB is also clearly remarked in the survey. Findings from the survey show that 47.37% of the respondents have indicated citizens of Chattogram having a low influence and only 21.05% of respondents having a high influence in the implementation process of UGB for the city (Table 15). Furthermore, the survey revealed that a majority of the respondents perceive that private companies, such as construction companies and real-estate developers, would have the largest influence on the adoption and implementation process of UGB for Chattogram. The survey showed that 50% of the respondents indicated that these companies would have a high influence and 45% indicated that companies would have a medium influence in the policymaking process for UGB adoption, while only 5% of the respondents indicated that these companies would have a low influence (Table 15). For a successful adoption and implementation of UGB for Chattogram, input from external stakeholders will be an important factor. This process should be inclusive, with participation from not only the business elite and interest groups that have been seen to dominate the policymaking process (Huq, 2015), but should specifically include the marginalized population living in informal settlements that have been systematically excluded from the political and policymaking process (Banks, 2008).

Table 15: Perception of respondents on the level of influence that each has on the adoption and implementation process of a potential UGB for Chattogram

	High	**Medium**	**Low**	**None**
Influence of Central Government on UGB adopt and implementation	42.11%	36.84%	21.05%	0.00%
Influence of Chattogram City Government on UGB adopt and implementation	47.37%	26.32%	21.05%	5.26%
Influence of Citizens of Chattogram on UGB adopt and implementation	21.05%	26.32%	47.37%	5.26%
Influence of private sector such as real estate developers and construction companies on UGB adopt and implementation	50.00%	45.00%	5.00%	0.00%
Influence of NGO and Donor organizations on UGB adopt and implementation	5.26%	21.05%	57.89%	15.79%

Another issue that is generally raised when considering the incorporation of stakeholder input and civic engagement in the policymaking process is that of collective action problems whereby disagreement and conflict between various stakeholders and civic entities lead to opposition against the policy and potentially a catastrophic policy failure (Rydin & Pennington, 2000).

Formulation and implementation of UGB without a proper form of public participation is likely to create policy alienation and rejection amongst the citizens (Shakil et al., 2016). This is not only detrimental to the effectiveness and performance of the policy but also the overall legitimacy of the implementers (Tummers, 2017). Although most respondents in the survey have indicated their concern regarding that the opposition from the local citizens in Chattogram against a potential UGB for the city as being low (50%) (Table 14), to address the issue of inclusivity and avert policy alienation, the UGB policymaking process would need to go beyond just a simple expansion of public participation (Rydin & Pennington, 2000). Rather, it would need to focus on building social capital within the community through interaction and social relations to build trust and transparency (Coleman, 1988). Additionally, as the type and extent of public participation and civic engagement is determined by "the definition of the planning problem, the kinds of knowledge used in planning practice, and the conceptualization of the planning and decision-making context in which it is embedded" (Lane, 2005, p. 297), these concepts would need to be considered by planners and policymakers involved in the potential adoption of UGB for Chattogram.

Although the current institutional setup for planning and policymaking process in Chattogram and Bangladesh has not been optimal for a comprehensive public participation process due to constraints in the institutional framework, limited human and financial resources, inadequate human and financial resources, and an overall lack of political motivation (Swapan, 2016), a push towards greater incorporation of public participation in the polity making process would be effective in bringing the concerns of the citizen into the forefront (Bai et al., 2010).

4.5.3 Bureaucratic Collaboration and Coordination

Another important consideration for the effective adoption of UGB is a consensus between different state and local governing bodies as well as other non-governmental and donor organizations. In the past implementation of UGB within the developing countries, the lack of consensus between the different government agencies and non-government organizations has exacerbated the problem of policy and regulatory considerations previously stated and has led to concerns regarding the overall effectiveness in the implementation of UGB. For China, the lack of coordination between the state and local government has resulted in conflicting policy objects at the different government levels leading to the overall questionable effectiveness of the UGB (P.

Zhao, 2011). With the push for decentralization occurring in China, the local governing bodies have been given the power to make autonomous decisions, but lack the financial resources (P. Zhao, 2013). As a result, at the local level, economic development and expansionary policies have been prioritized, with preferential treatment given to private land developers. This has caused the development of built-up areas outside the UGB and a scattered urban footprint (P. Zhao, 2013; P. Zhao et al., 2010). Moreover, there has also been insufficient support from the Chinese political leadership towards these boundary policies which has contributed to the deviations away from the goals of the UGB and has undermined its overall effectiveness (L. Zheng, 2014). For Albania, this lack of coordination between different governing actors has created overlapping jurisdictions and bureaucratic red-tapes that have severely stifled the process of land ownership within the boundary (Bertaud, 2006). Consequently, there have been large increases in the buildup of informal housing outside the designated UGB thus diminishing the effectiveness of the boundary (Bertaud, 2006). Furthermore, for Johannesburg, South Africa, lack of collaborative efforts between the municipal and provincial government has created disputes over the UGB delineation, which has led to the eventual dissolution of the UGB itself (Horn, 2009; Sim et al., 2016).

In the case of Bangladesh, although operating in a decentralized structure of urban governance, there is a disproportionate power dynamic between the central and the local government. While the survey indicates that the respondents perceive the central and local government to have a similar level of influence on the adoption and implementation of UGB policies, with 47.37% and 42.11% of the respondents indicating local and central governments as having a high influence on UGB adoption and implementation process for Chattogram respectively (Table 15), City Corporations such as Chattogram despite being an autonomous entity, lack the financial and political independence to undertake large scale policies or programs such the UGB (Huq, 2015). These city corporations are largely dependent on central government and donor agencies for financial support and lack the institutional power necessary to formulate and enact the policies independently (Huq, 2015). Furthermore, the central government has been seen to try to consolidate political power and exert partisan control over these local urban governing bodies (Huq, 2015; R. Karim, Former Chief Town Planner of the Chattogram City Corporation, personal communication, February 2021). As a result, for the successful inception of a potential UGB for Chattogram, it would first require strong coordination as well as strong political goodwill with the central government to ensure political and financial support for the policy. A lack of such political backing for the policy from the central government is likely to lead to a failure in launching a UGB for Chattogram (Sabrin & Kamal, 2014).

Moreover, even after the policies have been formulated, there have been many instances where these policies have not been implemented at all at the local level (Ferdousi & Qiu, 2013; Institute of Governance Studies, 2012). While a part of this lack in implementation of policies has been due to issues such as budgetary constraints, others have resulted from systemic shortcomings of urban governance in Bangladesh that is highlighted by poor collaboration and insufficient coordination between different bureaucratic and policy actors (Panday & Jamil, 2011; Sabrin & Kamal, 2014). There is a clear deficiency in inter-organizational and intra-organizational coordination and cooperation between different ministries and amongst different levels of governing bodies responsible for formulation and implementation of the policies within an overlapping jurisdiction (Panday & Panday, 2008). A major reason for this has been the lack of explicit rules or any formal or informal agreements for coordination and cooperation amongst these governing bodies and within their departments (Panday & Jamil, 2011; Sabrin & Kamal, 2014). This has brought on several different issues such as ill-defined responsibilities, differences in the method of operation, deficiency in delivery of public services to the citizenry, and absence of accountability and enforcement within the city corporation to name a few (Panday & Panday, 2008; Sabrin & Kamal, 2014).

It is evident from the survey that there is much concern amongst the stakeholders regarding the insufficient coordination and collaboration between various bureaucratic entities, and policymakers leading to policy and regulatory issues for the potential adoption and implementation of the UGB. While 42.11% of the respondent have indicated that this lack of coordination will have a high impact on the UGB adoption and implementation, 52.63% have indicated it as having a medium impact and only 5.26% have indicated it as having a low impact (Table 14). With the current situation in Bangladesh, collaboration and coordination problems that have plagued the previous implementation of UGB in developing countries are also likely to be an issue when considering a potential UGB for Chattogram. As such, the success of this potential UGB would be highly dependent on the effectiveness and efficiency of intra-organizational and inter-organizational coordination between various planners, government actors, and non-government agencies involved in formulating and implementing these policies. Better coordination and linkages amongst the governing and policy-making bodies would not only aid in identifying and addressing common problems within the jurisdiction through the creation of supporting policies but would also provide joint venture opportunities, standardized work procedures, and a larger pool of resources and expertise to draw from (Siddiqui, 1994). These collaborations would further provide a stronger voice to the individual city corporation to garner more power and resources from the central government (Siddiqui, 1994). All of these are crucial considerations for the successful implementation of a potential UGB in Chattogram and would aid in mitigating some of the pitfalls faced by other countries during their implementation of UGB.

4.5.4 Institutional Capacity

With regards to the various considerations relating to the potential adoption of UGB for Chattogram, such as policy and regulatory consideration and greater engagement of stakeholders, it is also necessary to build the institutional capacity of the various parties, such as the policymakers and implementors, involved in undertaking this large-scale multidimensional project. In the past, some of the notable lapses in UGB implemented in the developing countries have been in part due to the lack of institutional capacity (Al-Hathloul & Mughal, 2004; Long et al., 2013). These lapses have resulted in poorly formulated, incompletely delineated, and incompetently implemented policies resulting in an inefficient UGB. For Saudi Arabia, technical limitations and institutional deficiencies resulting from a shortage of trained planners and surveyors were a major concern in the initial UGB formulation process (Al-Hathloul & Mughal, 2004). These issues were further exacerbated due to the lack of up-to-date maps, current census data, and land ownership information; all of which contributed to a poor delineation and implementation of UGB (Al-Hathloul & Mughal, 2004; R. Karim, Former Chief Town Planner of the Chattogram City Corporation, personal communication, February 2021; Zahid, 1996). In a similar case, the initial implementation of UGB in China and Albania also suffered as a result of inadequacies of planners using an outdated centrally-planned economic architecture based system that lacked the range of data and methodology necessary for evidence-based UGB delineation (Abitz, 2006; Long et al., 2013).

When considering adoption and implementation of new policies, such as the UGB for Chattogram, the ability of the government to enact these policies and the overall success in the implementation of these policies is highly dependent on the readiness and the professionalism of the policymakers and implementers (Hill, 1992). For Bangladesh however, reports have indicated major lapses in institutional capacities resulting in undersupply of technically qualified manpower, vague definitions of institutional responsibilities, operation practices and accountability, the lack of policy enforcement, bureaucratic failures, and apparent administrative weaknesses within the local governing bodies (Ferdousi & Qiu, 2013; Panday & Jamil, 2011, 2011). Cross-referencing this with the results from the survey, 65% of the respondents have indicated the lack of institutional capacities with regards to proper implementation of UGB as being a major concern and 65% of the respondents have also indicated UGB not being properly enforced in Chattogram as being a major concern (Table 14). Taking this into consideration, an effective formulation of UGB for Chattogram would require strengthening of in-house technical, administrative and managerial capacities for the Chattogram City Corporation. Due diligence, in the form of detailed policy analysis associated with the formulation of UGB and other supporting policies would need to be conducted, while keeping in mind the concerns and suggestions of the citizenry within Chattogram. Additionally, evidence-based formulation of UGB would necessitate up-to-date information on factors such as land cover change, population growth as well as data based on public participation and on-the-ground grassroots level surveys.

The donor community has made noteworthy progress in terms of creating these institutional capacities of government, non-government agencies, and local institutions, through technical assistance, training, and financial support (Ferdousi & Qiu, 2013). However, these aids have generally come with donor conditionalities and policy prescriptions that have not always been conducive or effective in terms of their implementation (Institute of Governance Studies, 2012). The formulation, implementation, and most importantly continued support and success of the potential UGB in Chattogram would require building in-house expertise not only through donor aid but through creating institutional linkages to think tanks, universities, and other professional civil society organizations to address these needs (Aminuzzaman, 2013).

4.5.5 External Influences

External influences from private corporations, influential figures, and external donor agencies are an inevitable part of any policymaking process particularly in developing countries and undoubtedly is also a major consideration when examining the potential adoption of UGB for the City of Chattogram. Past use of UGB in developing countries has experienced a variety of external influences that have contributed to inefficiencies in the delineation and implementation of the UGB. For example, in Saudi Arabia, external pressures from influential citizens with high-level government connections have led to the creation and subsequent exploitation of loopholes within the system. These loopholes have allowed for the creation of vast built-up areas outside of the designated UGB (Mubarak, 2004). Similarly, in Albania, these influences from the social and political elite have led to UGB being misused as a method to segregate the poor citizenry outside the boundary (Pllumbi, 2013). Whereas in Chile, the external influences from the business elite in the policymaking process and pressures for economic development have been responsible for the growth of the city being driven by a select group of companies and political interests (Hölzl & Nuissl, 2014). This has instigated the assimilation of vast amounts of surrounding areas into the UGB without much investigation or oversight (Zegras & Gakenheimer, 2000). All of which have been detrimental to the achievement of the core goal of urban growth management set out during the adoption of UGB.

For Bangladesh, the policymaking process has been highly impacted by several external actors. Among these, donor agencies/countries, development partners, and non-profit organizations (International and National Non-Governmental Organization) have had a big influence on the policy formulation and implementation process (Aminuzzaman, 2013; Shakil et al., 2016). Over the last few decades, even though there has been a drastic decrease in Bangladesh's dependency on foreign aid, the influences from development partners and donor agencies/countries have played a significant role in the policymaking process of the country (Institute of Governance Studies, 2012). These donor agencies have been crucial in providing research, technical assistance, and consulting support in the policy formulation and implementation process (Aminuzzaman, 2013), but the criticisms have stemmed from aid conditionalities and contingent policy prescriptions suggested by the donors (Institute of Governance Studies, 2012). Although the respondents of the survey have indicated the donor's agencies and NGOs would have a low (57.89%) to a medium (21.05%) level of influence on the adoption and implementation of UGB policies for Chattogram (Table 15), past experiences related to NGO donor influences and policy interventions have garnered mixed but largely negative feedback on the policy interventions imposed by the donors. These criticisms have included policies being overly ambitious (Ferdousi & Qiu, 2013) with a large number of conditionalities put into place (M. M. S. Khan & Sharma, 2001), policy recommendation being overtly general and direct transfers from the West (Dolowitz & Marsh, 2000), and policy prescriptions completely failing to acknowledge the local realities and the political landscape of the country (Swapan, 2016). Although more recently, the donor community has increasingly acknowledged the political challenges along with challenges in good governance in Bangladesh when considering policy formulation and implementation, these initiatives have not always come to fruition (Institute of Governance Studies, 2012). Nonetheless, donors are a crucial part of policymaking and implementation processes in Bangladesh (Aminuzzaman, 2013). Particularly for a large policy undertaking such as the UGB, in addition to financial assistance, donor support in areas such as technical research for the project, improvement of participatory policymaking process, and building institutional capacities of the government, non-government and local agencies will be pivotal. These donor inputs, however, will need to be conducted with consideration to the drawbacks that have been associated with the currently prevalent aid practices suggested by the Paris Declaration (Bissio, 2013; Sjöstedt, 2013).

Corporations and business elites have been another influential actor within the policymaking and planning processes in Bangladesh (Huq, 2015). Since the establishment of the first parliament in 1973, politics and business in Bangladesh have been increasingly intertwined with policymakers and politicians being dominated by businessmen (Firoj, 2013). This injection of business personnel in politics and policymaking roles has led to business groups gaining an unfair competitive edge in the policymaking process (Ahmed, 2019). Additionally, business elites have been able to create favorable policy outcomes by pressuring key decision-makers through personal linkages and mutual personal financial benefits (Kochanek, 2000; Zafarullah & Siddiquee, 2001). These clientelistic and patronage politics specifically catered to corporations and business elites have in effect neglected the public needs, oppressed the voice of the citizenry in the policymaking process, and eroded the trust in these policies (Kochanek, 2000; Zafarullah & Siddiquee, 2001). With regards to policies related to UGB for Chattogram, the survey results show that 60% of the respondent indicated having high concerns with regards to the clientelistic and patronage politics impacting the adoption and implementation of UGB for the city (Table 14). As indicated previously, these influences from the private sector can have a large impact on the potential adoption of UGB for Chattogram and can sway the policies in favor of businesses. In the survey, when specifically inquired about the type of impact that these private companies, such as construction companies and real-estate developers, would have on the UGB policy, 50% of the respondents indicated that these companies are likely to have a high impact with regards to construction outside the designated UGB and 44.44% indicated that the companies would have high impact in terms of allocation of land in within the UGB for development as well as in terms of expansion and changes to the delineation of UGB itself (Table 16).

Table 16: Perception of respondents on the level of impact that private companies such as construction companies and real-estate developers have on UGB

	High	Medium	Low	None
Impact on the allocation of land for development within the UGB	44.44%	44.44%	11.11%	0.00%
Impact on the expansion or changes to the delineation of UGB	44.44%	50.00%	5.56%	0.00%
Construction outside the allocated urban growth boundary	50.00%	38.89%	11.11%	0.00%

Finally, political actors are another major influence in the policymaking process, particularly at the local level. As mentioned in the previous section, despite decentralization, due to the top-down process of governance in Bangladesh, the central government still has one of the most influential positions within the local urban governance structure (Sarker, 2006). The relationship between the central and the local government appears to be along the party lines with preferential treatment, such as the allocation of funds and distribution of benefits, given to those within the same political party (Kochanek, 2000). As such, they are capable of exerting disproportionate influence in the policymaking process through these political and financial pressures (Brinkerhoff & Goldsmith, 2002). Moreover, there have been many instances where policies that have been formulated are not implemented due to political opposition and erosion of political will at the central government level (Panday & Jamil, 2009).

Based on the current structure, successful adoption and implementation and of UGB for Chattogram and its supporting policies would be dependent on the political support and the political climate within the central government (R. Karim, Former Chief Town Planner of the Chattogram City Corporation, personal communication, February 2021). In the survey, 35% of respondents indicated the impact of political opposition on UGB as being a major concern, while

45% have indicated it as being a medium concern (Table 14). With the amount of influence that the central government has on the local policymaking process, it is also more than likely that the potential adoption of UGB, even if it was approved through the local policymaking process in Chattogram, would need to be favored by the central government for continued support. Finally, due to these external pressures from different actors, the final implementation of the UGB could likely be altered from what was initially proposed. Furthermore, if there is waning support from the central government, it may even result in possible shelving of the entire policy.

4.6 Discussion and Conclusion

The concept of Urban Growth Boundary (UGB) is still new in the context of Bangladesh, but it can be an effective way of moving forward with controlling the haphazard outward urban expansion to surrounding environmentally sensitive rural areas. With the complex nature of formulation and implementation of UGB intertwined with the economic realities, the social structure, and the political climate of Chattogram, this paper is a cautionary exploration on the key factors specific to the city of Chattogram that may influence or hinder the potential adoption of UGB for the city. The five considerations discussed in this paper are aimed at providing an initial overview of some of the prevalent issues that would need to be addressed for the potential application of UGB for the city of Chattogram. Furthermore, the responses of the planning professionals and academics along with the unstructured interview validate these postulations made through the literature regarding considerations for adoption and implementation of potential UGB for Chattogram and provide a deeper insight into specifics on these postulations that would aid in the implementation of the UGB while strengthening the overall findings from the literature review.

Successful adoption of UGB for Chattogram would be dependent on a well-formulated holistic approach to UGB complemented by supporting policies that work synergistically to address issues related to unmanaged urban growth within the city. As indicated by the literature review and validated by the survey, there is currently a lack of specific and dedicated policies to dictate urban growth management and to support the establishment of such policies in Chattogram. Adoption of UGB in Chattogram would provide the robust forward-looking framework aimed at restricting and directing the rate of future urbanization and urban expansion. Moreover, it would serve as a planning structure upon which other planning tools and regulations dedicated to good urban governance and essential supporting policies could be formulated. This would also require the development of technical, administrative, and managerial capacities among pertinent institutions involved in the policymaking process, as well as the creation of best practices for urban governance strategies. As clientelistic/patronage politics and enforcement are indicated as major considerations from the survey, adoption of potential UGB would also require strong bureaucratic oversight, accountability, and enforcement mechanisms to prevent encroachments and urban buildup outside of the delineated boundary. Additionally, active coordination and collaboration between various government, non-government, and donor institutions cutting across the central and local levels would also be necessary. While the donor community and NGO were not indicated as being a vital component from the survey, they would be essential in providing financial and technical assistance in this process.

The urban planning and policymaking within the current governance structure of Bangladesh is seen to be influenced by large corporations and private businesses and without much incorporation of critical inputs from the citizenry. As a vital component in a holistic approach to the formulation and implementation of an effective UGB for Chattogram, a push towards greater integration of inputs from the citizenry, stakeholders, and civic engagement particularly at the grassroots level would be needed. Finally, the long-term success of UGB in Chattogram can only be achieved if there is political support, particularly at the topmost level, along with a favorable policy climate. These considerations listed in this study is only the tip of the iceberg. There are many additional topics related to the establishment of UGB in Chattogram that must be further explored and should be analyzed in depth. As these considerations directly impact the potential use of UGB for the city of Chattogram, further research into this individual topic prior to the formulation of UGB is essential so that appropriate evidence-based policy solutions can be implemented for the successful adoption of UGB for Chattogram.

CHAPTER V: CONCLUSION

The rapid rate of urban growth currently seen in Bangladesh has been accompanied by a haphazard and chaotic development of built-up urban areas. This unregulated and uncontrolled expansion of the urban footprint can largely be attributed to the lack of effective urban planning and regulations. This has raised major concerns regarding the continued sustainability of the urban expansion of cities in Bangladesh. In this dissertation, I explore the concept of sustainable urban expansion for cities in Bangladesh. Specifically, I examine the unevenness of urban expansion occurring between the larger and mid-to-smaller sized cities in Bangladesh and propose the adoption and implementation of UGB, as an urban planning framework with a focus on sustainable urban expansion of the cities. Considering the current haphazard and unregulated nature of rapid urban growth, particularly in larger cities in Bangladesh, the application of UGB within these cities would provide the policy base necessary to restrict and direct the development of built-up urban areas within the city.

Chapter I of the dissertation provides a brief introduction and history of UGB and its implementation around the world. Specifically, it highlights the limited use of UGB within developing countries and subsequently, the limited availability of research on the application of UGB within these countries. However, results from the examination of the literature reveal a gradual resurgence in interest in the application of UGB within developing countries. This has been indicated by the increased adoption of UGB in various cities within these countries, spearheaded by countries such as China, Saudi Arabia, and South Africa, and an upsurge in the literature examining the application of UGB in the developing world. Chapter II specifically focuses on examining the growth of the city of Chattogram as well as evenness in the distribution of both the population of the city and the built-up urban footprint of the city. This is done by comparing the rank-size distribution of the cities and municipalities in Bangladesh. While the population data for various municipalities from the past three years used in this research was obtained from the decennial census, the extent of built-up urban areas for these municipalities was derived from Landsat satellite images using Google Earth Engine. Results from the comparison rank-size distribution of these urban growth statistics reveal a rapid expansion of the built-up urban footprint occurring in the biggest cities, compared to the relatively low levels of increase in built-up urban areas in small and mid-sized cities and municipalities, where most of the population growth has been seen. This highlights the spatial inequalities in urban development and the unsustainable levels of urban expansion occurring within the big cities in Bangladesh such as Chattogram. Furthermore, the findings from the study emphasize the need for spatially explicit urban growth restriction strategies such as the UGB to address the unregulated expansion of built-up urban areas of the city.

Chapter III of the dissertation delves further into the application of UGB for Chattogram. Specifically, the chapter focuses on examining the novel approach to the delineation of UGB for the city using SVM supervised machine learning algorithms. Here, freely available data and data derived from it (the extent of built-up urban areas calculated from Landsat images) from the last three decades was used to simulate the future extent of built-up urban areas for 2040, and based on it, the delineation of UGB for Chattogram was performed. While the delineation of the boundary is an important start to the adoption and implementation process of the UGB, the success of the UGB policy is highly dependent on other external factors associated with the policy. Chapter IV of the dissertation investigates five of these key considerations specific to the city of Chattogram that would need to be addressed for successful adoption and implementation of the UGB. This is performed through the review of policies and past academic/non-academic literature along with examining the perceptions of the stakeholders on the past and future urban growth of Chattogram and their concerns regarding the use of urban growth restriction policies such as UGB for the city. The findings produced from this study, while highlighting the need for urban growth restrictions for Chattogram, provide a robust framework necessary to adopt and implement a forward-looking UGB strategy aimed at sustainable urban expansion for the city of Chattogram. Additionally, while this study particularly focuses on the city of Chattogram, a similar methodological approach could potentially be implemented for other cities in Bangladesh to promote sustainable urban expansion of these cities.

However, there are still several limitations within the study that would need to be addressed to create a complete plan for the actual deployment of UGB in Chattogram or any other city in Bangladesh. Future research would need to focus on obtaining detailed socio-economic data for the city and incorporating the data as an integral part of the UGB. This information would allow for planners and policymakers to identify areas within the city where additional resources would need to be injected to encourage the uniform provision of amenities and services within the city. Moreover, while this research does incorporate stakeholder inputs regarding UBG in the form of an online survey of planners' and academics' perceptions, moving forward with the adoption of UGB for Chattogram would call for a more comprehensive survey of the citizens of Chattogram to ascertain their needs and expectations with regards to UGB for the city. Furthermore, if established, the UGB would need to be assessed periodically and the delineated boundary would need to be revised based on any updated information available. Additionally, for the UGB to be truly successful, the use of improved data for delineation and inputs from the stakeholders would need to be reinforced by supporting policies, specifically addressing these issues that have been highlighted in the research. Finally, one of the biggest hurdles to the actual realization of the UGB for Chattogram, or any other policy in any other city, would be the political climate and political backing of the policy. Regardless of all the available research and recommendations provided for the adoption of the UBG, there would need to be an active political will and support for these projects targeted at sustainable urban expansion such as the UGB for it to proceed forward.

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APPENDIX A: SELECTED LITERATURE DISCUSSING REAL-LIFE USE OF UGBS IN DEVELOPING COUNTRIES

Country	City	Research	References
China	Beijing	Examined the effectiveness of urban construction boundary for Beijing using satellite images between 1983 to 2005 and highlighted some of the frustrations that were faced in the implementation process	(Hao-ying Han et al., 2009)
China	Beijing	Provided a general overview of implementation and impact of different growth containment policies used in Beijing between 1990 and 2000	(P. Zhao et al., 2009)
China	Beijing	Examined the performance of various urban containment strategies used in Beijing and discussed the dilemmas associated with implementation of these containment strategies between 1990 and 2000	(P. Zhao et al., 2010)
China	Beijing	Assessed the performance of urban containment strategies in Beijing between 1990 and 2009 and highlighted some of the critical issues involved	(P. Zhao, 2011)
China	Beijing	Investigated the effectiveness of initial implementation of UGBs in Beijing and the subsequent problems associated with it. Additionally, it proposed a methodology of UGB delineation using cellular automata.	(Long, Han, Lai, & Mao, 2013)
China	Beijing	Examined the effect of land use and land use control policies on transportation use. Additionally, it highlighted some of the challenges associated with these compact land development policies	(P. Zhao, 2013)
China	Beijing	Investigated the effectiveness of urban construction boundary for Beijing during two planning periods between 1983 and 2005 and argued for changes in the comprehensive master plan for more efficient application of UGB	(Lai & Han, 2014)
China	Hangzhou	Evaluated the effectiveness of urban growth control boundary within the comprehensive land use plan and highlighted some of the underlying reasons behind the challenges	(L. Zheng, 2014)

China	Beijing	Evaluated the effectiveness of urban growth boundary of Beijing from 2005 to 2010 using a variety of data on human mobility data	(Long et al., 2015)
China	Changzhou City	Highlighted some of the recent developments related to the latest iteration of UGBs in China and used GIS and used the SLEUTH model to identify urban growth boundaries for the Changzhou City	(P. Jiang et al., 2016)
China	Hangzhou	Examined the evolution of urban form in China including the use of UGB and suggested a novel framework for urban sprawl control in Hangzhou	(Y. Wu et al., 2017)
Saudi Arabia	Nationwide	Investigated limitation and implementation of urban and regional planning process within KSA which included the "Nitag Omrani" project for the delineation and definition of urban growth boundaries for 100 Saudi towns and cities	(Zahid, 1996)
Saudi Arabia	Nationwide	Discussed the methodology used in the adoption of urban limits in KSA and evaluated its impact in Saudi cities	(Al-Hathloul & Mughal, 2004)
Saudi Arabia	Riyadh	Traced the overall changes in management structure and development activities of Riyadh up to 2004 including the implementation of UGB	(Garba, 2004)
Saudi Arabia	Riyadh	Inspected the use of UGB fop the city of Riyadh and highlights the social-political and cultural factors resulting in inefficiencies associated with the sprawl	(Mubarak, 2004)
Saudi Arabia	Jeddah	Provided a qualitative review of the urbanization process of Jeddah and outlines the historical evolution of the urban planning including UGB that have been used for growth management	(Gadou & Quazi, 2009)
Saudi Arabia	Jeddah	Examined the effectiveness of urban planning strategies implemented in Jeddah since 1963 to 2005 including the use of UGB	(Baesse, 2012)
Saudi Arabia	Dammam	Presents an analysis of unsustainable urban growth practices occurring in Dammam and suggests polices on urban sustainability for the region	(Abou-Korin & Al-Shihri, 2015)
Saudi Arabia	Riyadh	Evaluated the implication of UBG of Riyadh while particularly focusing on the its impact on reduction of traffic congestion	(Aldalbahi & Walker, 2015)
Saudi Arabia	Nationwide	Report highlighted the reforms intended for the new the National Spatial Strategy under the vision 2030 plan, including challenges to the current UGB and key changes to the policy that would need to be addressed for a more efficient UGB policy	(FSCP, 2016)

Saudi Arabia	Nationwide	Provided an overview of the chronological implementation process of different phases of UGB in KSA	(UN Habitat, 2016)
Saudi Arabia	Riyadh	Discussed different development plans that have been implemented in in Riyadh from 1967 to 2016	(Al-Hathloul, 2017)
Saudi Arabia	Riyadh	Examined the change in urban growth for Riyadh between 2005 and 2015 using satellite imagery while discussing the impact of the most current implementation of UGB of Riyadh	(Alkhayyal, 2017)
Saudi Arabia	Riyadh	Studied the urban planning practice implemented in Riyadh and provided information on first, second and future implementation of UGBs for Riyadh	(Alshebli, 2018)
Chile	Santiago	Reviewed the scope of "Plan Regulador", a of a Chilean policy instrument used to control physical urban growth and detailed the historical and current implementation of UGB in Santiago	(Jirón & Padzerka, 1999)
Chile	Santiago	Investigated the consequences of new urban policies of 1979 particularly focusing on the access to land, segregation and social integration	(Sabatini, 2000)
Chile	Santiago	Explored the implications of 1979 deregulation of UGB in Santiago	(Smolka & Sabatini, 2000)
Chile	Santiago	Examined the challenges and the potentials of urban growth management polices within the context of a developing country particularly focusing on Santiago	(Zegras & Gakenheimer, 2000)
Chile	Santiago	Investigates the urban planning of Santiago from 1960 to 2004	(Poduje, 2006)
Chile	Santiago	Traced the pattern of urban development in Santiago particularly focusing on residential segregation influenced by changes in policy and planning	(Peters, 2009)
Chile	Santiago	Studied the changes in land market and social housing in Santiago up to 2010 within the context of changing policies	(Trivelli & Limitada, 2010)
Chile	Santiago	Evaluated the reason behind the difference in densities within Santiago using regression analysis	(Aquino & Gainza, 2014)
Chile	Santiago	Highlighted the characteristics of public policy and spatial planning in Santiago and examined the conditions that facilitate or hamper the implementation of these policies	(Hölzl & Nuissl, 2014)

Chile	Santiago	(McCawley, 2015)	(McCawley, 2015)
Albania	Nationwide	Provided a critical summary of major provisions in Albanian law concerning city planning	(Jacobs & Craig, 1997)
Albania	Tirana	Discussed the urban growth of Tirana while stressing on the specific of land tenure, land access and private property systems	(Felstehausen, 1999)
Albania	Tirana	Examined the devleopmennt of Tirana within the context of a post-socialist city and its impact on socialist planning structures such as yellow lines that have been implemented	(Abitz, 2006)
Albania	Nationwide	Documented the progress made in establishment of land and property markets and ownership rights, administration, regulation and laws governing them while highlighting some of the associated conflicts	(Valletta et al., 2006)
Albania	Nationwide	Reported on the issues related to rapid urbanization and decentralization and actions required in order to address these issues	(The World Bank, 2007)
Albania	Tirana	Provided a city profile for Tirana focused on the physical, economic, social and environmental problems and issues related to its post-communist transformation into a market economy	(Pojani, 2010)
Albania	Shkodër	Investigated the spatial transformations that occurred in the peri-urban area of Shkodër city after 1990 and examined the impact of these transformations on the community and on land use	(Rustja, 2011)
Albania	Nationwide	Examined the spatial planning approach of the territorial planning in Albania, identified the challenges associate with it and provided recommendation	(Allkja, 2012)
Albania	Tirana	Analyzed the problems and trends associated with sustainable development of Tirana and investigated potential urban forms that might be feasible in the local context	(Pllumbi, 2013)
Albania	Tirana	Explored the urban growth of Tirana in the socialist and post-socialist periods and the associated ideologies that dictate the regulations governing the urban growth of the city	(Dino et al., 2016)
Albania	Nationwide	Discussed the post-communism changing urban landscape of Albania using three factors – access to public space, demographic movement and the role of international community in the urbanization process	(Prato, 2016)

Albania	Nationwide	Evaluated the problems associated with urban development of Albania and highlighted some of the major problems associated with it	(Mane, 2017)
South Africa	Cape Town	Investigated the Metropolitan Spatial Development Framework for Cape Town, highlighted some of the issues associated with it and explored the options available to address these issues	(Watson, 2002)
South Africa	Gauteng	Detailed the origin and evolution of Gauteng urban edge and highlighted some of the concerns associated with it	(Britz & Meyer, 2006)
South Africa	Gauteng	Studied the rational behind implementation of urban edge in Gauteng, its delineation and provided recommendations on the improvement of these urban edges	(Horn, 2009)
South Africa	Western Cape	Provided a manual for the Provincial Spatial Development Framework for Western Capen	(PGWC, 2009)
South Africa	Gauteng	Examined the history and implementation of the Gauteng Urban Edge	(Horn, 2010)
South Africa	Nationwide	Provided a simplified spatial development framework guideline	(Department of Rural Development and Land Reform, 2011)
South Africa	Cape Town	Reviewed the UGB for Cape Town for 2010, listed key lessons learned regarding and outlined adaptation strategy for developing countries at the local level	(Sinclair-Smith, 2014)
South Africa	Nationwide	Provided and overall view of spatial planning policies implemented in South Africa and evaluated its influence in urbanization of South African cities	(Du Plessis & Boonzaaier, 2015)
South Africa	Johannesbu rg	Examines the management of urban growth for Johannesburg while examining the effectives of UGB and the strategies and framework associated with it	(Jackson, 2015)
South Africa	eThekwini	Explores the evolution of urban edge in eThekwini between 2002 and 2013 and its evolution into Urban Development Lines	(Sim et al., 2016)
South Africa	Western Cape	Investigated the spatial planning tools applied for land use management for Western Cape province	(Wylie, 2016)

South Africa	Gauteng	Provided detailed description of Gauteng’s spatial development framework up to year 2030	(Gauteng Planning Division, 2017)
South Africa	Cape Town	Evaluated outcomes and policy decisions leading to the termination of Urban Edge in Cape Town	(Horn, 2018)
South Africa	Western Cape	Examined the effectiveness of urban edges in various cities in Western Cape through the application of Urban Sprawl Index	(Horn & Van Eeden, 2018)

APPENDIX B: SELECTED LITERATURE DISCUSSING POSSIBLE/HYPOTHETICAL USE OF UGBS IN DEVELOPING COUNTRIES

Country	City	Research	References
China	Xi'an	Examined the possible use of growth management strategy such as UGB for Quito, Ecuador; Hyderabad, India and Xi'an China	(The World Bank, 2008)
China	Beijing	Delineated UGB using constrained cellular automata while taking into consideration a variety of spatiotemporal factors for urban growth simulation for Beijing	(Long et al., 2009)
China	Beijing	Provided a comparison between the Urban Construction Boundary in Beijing and similar urban containment policy in the Xinyi district of Taipei	(L. G. Wang et al., 2014)
China	Jinan	Implemented the Weight of Evidence (WOE), a statistical method based on a log-linear form of Bayes' theorem, to delineate UGB for the Jinan, China	(X. Zheng & Lv, 2016)
China	Changzhou	Used GIS techniques and SLEUTH to delineate UGB and tested the UGB model using empirical data for the Changzhou,	(P. Jiang et al., 2016)
China	Xinzhuang	Utilized the Conversion of Land Use and its Effects at Small regional extent or CLUE-S model for demarcation of UGB for the town of Xinzhuang and provided a simulation of urban growth after the implementation of UGB	(R. Zhou et al., 2016)
China	Nationwide	Reviewed the use of cellular automata as simulation tool to assist in urban and regional planning in China including its use for delineation of UGB	(X. Li et al., 2017)
China	Changzhou	Utilized the SLUETH model to delineate the urban development boundary for Changzhou and the InVEST model to evaluate the quality of ecological space area of interest	(J. Liu et al., 2017)
China	Yiwu and Qingtian	Simulated the impact of different urban growth management strategy based on different driving modes for urban growth impacting economic development, migration and land conservation	(W. Wang et al., 2017)

China	Qin-Ba mountain region	Used concepts and methods of fractal theory for the demarcation of urban growth boundaries for the mountain cities of Quinling and Bashan	(Yu et al., 2017)
China	Ningbo	Used a land suitability evaluation method in conjunction with cellular automata-based methodology for the delineation of UGB for Ningbo	(Q. Zheng et al., 2017)
China	Lhasa	Examined the application of smart growth and UGB theory for lanbd use planning in Lhasa	(Z. Li, 2017)
China	Xinbei	Applied remote sensing, GIS and SLEUTH for delineation of UGB with a particular focus examining its impact in accordance with China's farmland preservation, ecological protection and housing development policies for the high-tech manufacturing area of Xinbei	(Zhuang et al., 2017)
China	Changsha-Zhuzhou-Xiangtan	Used the ant colony optimization (ACO) algorithm for creation of UGB for core study area of Changsha-Zhuzhou-Xiangtan while incorporating planning intervention in the process	(Ma et al., 2017)
China	Wuhan	Examined the delineation of UGB for the city of Wuhan using UBEM approach, which consists of using the radial method used in calculating the length from the centroid to the boundary and the calculation of extension pressure on the UGB using a select set of variables	(He et al., 2018)
China	Heilongjiang	Created a quantitative model for the municipal administrative areas for the Heilongjiang Province which specific focus on ecology, agriculture production and living spaces in the model	(Y. Zhao et al., 2018)
China	Zhuhai	Implemented multiple models and methods for delineation of UGB with a particular focus on the use of rigid and elastic boundary within a special economic zone for Zhuhai	(B. Zheng et al., 2018)
China	Hangzhou	Explored the application of green infrastructure assessment based constrained cellular automata model for the delineation of future 2020 UGB for Hangzhou with goals targeted at conservation of valued ecological areas	(Y. Li et al., 2019)
China	Guangzhou, Foshan, Dongguan, Zhongshan, Shenzhen.	Implemented a patch based cellular automata for the delineation of UGB while putting in place the economic and ecological constrains of the region	(Y. Chen et al., 2019)
El Salvador	Santa Tecla	Conducted a cost benefit analysis of the application of urban containment policies including UGB for Santa Tecla City, El Salvador	(Bonilla, 2007)

Ecuador	Quito	Examined the possible use of growth management strategy such as UGB for Quito, Ecuador; Hyderabad, India and Xi'an China	(The World Bank, 2008)
India	Hyderabad	Examined the possible use of growth management strategy such as UGB for Quito, Ecuador; Hyderabad, India and Xi'an China	(The World Bank, 2008)
India	Kolkata	Used Ideal Urban Radial Proximity (IURP), to designate UGB for Kolkata	(Bhatta, 2009)
India	Nationwide	Assessed the application of UGB in for Indian cities as a defense against the ad-hoc and predatory urbanization occurring in India	(Mehta, 2011)
India	Siliguri	Proposed a delineation of flexible UGB for the Siliguri Municipal Corporation for 2020 using landsat images from 1990 to 2010 addedXX	(Chakraborti et al., 2018)
Iran	Tehran	Used distance dependent and distance independent rule based spatiotemporal models to predict future urban growth of Tehran and subsequently delineate the UGB	(Tayyebi, Pijanowski, & Pekin, 2011)
Iran	Tehran	Applied GIS and remotely sensed raster data with artificial neural networks to simulate urban expansion of Tehran and delineate the UGB	(Tayyebi, Pijanowski, & Tayyebi, 2011)
Israel	Nationwide	Evaluated the application of UGB along with other urban growth management policies based on a given set of goals for Israel	(Frenkel & Orenstein, 2012)
Malaysia	Iskandar	Used the GIS based Binary Urban Suitability Model for delineating urban growth limits for Iskandar Malaysia	(Ismail et al., 2018)
Serbia	Belgrade	Investigated the possible application of current urban development policies and urban land use tools such as UGB to manage the urban sprawl of Belgrade Metropolitan Area, Serbia	(Zeković et al., 2015)
South Africa	Buffalo City	Defined the urban edge for the city of Buffalo taking into consideration factors such as environmental impacts, infrastructure capacity and land use potential and provided recommendation for urban edge policy framework for the city	(Wanklin & Naidoo, 2007)

South Africa	Gauteng	Evaluated the implementation of urban development boundary as a planning tool for sustainable urban form for Gauteng city	(Cilliers & Schoeman, 2008)
Taiwan	Xianyi	Provided a comparison between the Urban Construction Boundary in Beijing and similar urban containment policy in the Xinyi district of Taipei	(L. G. Wang et al., 2014)
Taiwan	Taipei	Provided a theoretical examination of the impact of hypothetical urban construction boundaries on the behavior of developers Taipei, Taiwan	(Lai & Wang, 2016)