# Spatial Growth of Informal Settlements in Delhi;

# An Application of Remote Sensing

by

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# ABSTRACT

Slum development and growth is quite popular in developing countries. Many studies have been done on what social and economic factors are the drivers in establishment of informal settlements at a single cross-section of time, however limited work has been done in studying their spatial growth patterns over time.

This study attempts to study a sample of 30 informal settlements that exist in the National Capital Territory of India over a period of 40 years and identify relationships between the spatial growth rates and relevant factors identified in previous socio-economic studies of slums using advanced statistical methods.

One of the key contributions of this paper is indicating the usefulness of satellite imagery or remote sensing data in spatial-longitudinal studies. This research utilizes readily available LANDSAT images to recognize the decadal spatial growth from 1970 to 2000, and also in extension, calculate the BI (transformed NDVI) as a proxy for the intensity of development for the settlements.

A series of regression models were run after processing the data, and the levels of significance were then studied and compared to see which relationships indicated the highest levels of significance. It was observed that the change in BI had a higher strength of relationships with the change in independent variables than the settlement area growth. Also, logarithmic and cubic models showed the highest R-Square values than any other tested models.

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# CHAPTER 1. INTRODUCTION

## 1.1 Problem Statement

Informal settlements have been a subject of study for many centuries. From the days of early English literature, mentions of slums and squatters can be found time and again. Often related to crime, poverty and lack of public services (UN, 2006), slums and squatter settlements have become a challenging issue for urban planning in many parts of the world. These problems are, however, predominant in developing countries, especially in fast growing South Asian and South American nations like India and Brazil.

The biggest issue that developing countries face is rural-urban migration, which gives birth to poverty stricken squatter settlements that tend to become permanent, establishing themselves as unmovable communities with adverse planning implications. Apart from social and economic factors, weak urban regulatory framework and political appeasement of the constituencies also contribute to formation of squatter colonies and their eventual perpetuation into permanent slums.

This study, however, focuses on validating the relationships between the location choice and spatial growth of slums, and quantifiable and observable factors such as water availability, accessibility to public transit and jobs, identified as relevant in earlier studies on the subject of squatter settlements in New Delhi. The unique contribution of this study is use of spatial data available from satellite images for obtaining a better understanding of slum formation, which perhaps may not be possible otherwise, given the data constraints in the developing countries.

## 1.2 Context of New Delhi

The urban population in India has grown from 78.9 million in 1961 to 286 million in 2001, and is estimated to double by 2025. Delhi, the capital of the Republic of India is one of the fastest growing urban megapolises in the world. In the 2001 census the population of the city was recorded at 13.78 million, which is a 4.36 million increase from the 1991 census. 62% of the population growth during 1990-2000 has been due to natural increase and 38% due to in-migration (Chakrabarti, 2001). Although the relative contribution of in-migration to this growth has declined, the absolute number of migrants has increased over the years.

Delhi's population has grown by 221.57% over the last twenty years. No other city in the world has witnessed similar growth, which is unprecedented both in its scale and magnitude (Chakrabarti, 2001). Much of this growth has been influenced by poverty induced migration from different parts of the country, particularly from neighboring states, in search of livelihood. Unending streams of poor villagers have swamped into the city and have found shelter in numerous squatter/informal settlements. According to an estimate prepared by the Society for Development Studies (Chakrabarti, 2001), the rate of growth of squatter population in Delhi during 1981-1994 was four and a half times more than the non-squatter population. The  squatter population grew by 13.2% per annum as compared to the 2.9% per annum growth in non squatter population.

New Delhi, has been facing growth in informal settlements since the partition of India in 1947. After independence of India, its capital experienced a large scale migration of refugees from the erstwhile state of Punjab which was divided between India and Pakistan. This trend was further accentuated by migration of rural population to the Territory of Delhi which was managed by the federal government as the National Capital Territory (NCT). In order to more efficiently deal with migration and the related challenged of urban management and resource demand, the region was later extended to establish the National Capital Region (NCR) which included  parts of the adjoining states.  Today, the NCR. the urban agglomeration of Delhi includes 33578 square kilometers of area (NCT is 1483 square Km) and 13,782,976 people living in the Union Territory of Delhi.

A newly formed republic, India, did not have the resources or the technical experience to plan its new urban developments. As a result, migrants created their own settlements in vacant lands throughout the city and its peripheries. Migrants from the west settled on the western edge of the city and migrants from the east settled on the east side of the river Yamuna. Till date these settlements are predominantly inhabited by the same cultural groups that established them a half century ago.

In 1962, New Delhi formulated its first 20 year master plan. However, during the 15 years after independence till the master plan was formulated, these unplanned (informal) settlements flourished to become large established communities with their own neighborhood facilities and commercial centers. Even after the master plan came into effect, the issues relating to its implementation and enforcement continued as the already established communities were unwilling for any de-stabilization of lifestyles, even with a promise for improved living conditions in future. The constraints posed by earlier unorganized settlements in implementation of the master plan allowed further unplanned growth of these settlements.

In 1980, the second master plan for New Delhi was prepared and operationalized and it recognized for the first time the existence of unauthorized settlements in the NCT (Kundu 2003). Multiple efforts were made to remove, relocate and rehabilitate the people living in the squatter settlements, but the population of these communities had grown manifold over the years, thus changing the ground conditions from when the plan was originally created and making it almost impossible to implement master plan proposals. Efforts continued throughout the 80s and the 90's but the growth of these settlements turned out to be too rapid for the government to control. By 2000, the issue and the population had gotten so big that the government decided to legalize these settlements and accept their existence and to just plan from that point on, instead of attempting any further relocation/rehabilitation procedures. The third master plan, approved in 2006 (with a 2020 horizon) identifies over 1500 unauthorized settlements in the NCT-Delhi and regularizes them. In a newer scheme, the master plan proposes to fix these existing settlements and provide them with proper electricity, sewer and water connections, proper road networks etc.

Today (census 2001), more than half of Delhi lives in some kind of informal settlement. The worst form is the slums and squatter settlements, also known as Jhuggi Jhonpri clusters, that accommodate about 2.5 million people. Another form is the resettlement colonies which came up to accommodate above 1 million slum dwellers, the legally notified slum areas (mainly Old Delhi) that houses more than 2 million people in a highly congested and dilapidated environment, the unauthorized colonies that have come up without government approval and the Villages that have been engulfed by urbanization (Urban Villages) where slum like conditions prevail in the absence of provisions for basic services.

## 1.3 Relevance of GIS and Remote Sensing in Urban Studies

GIS proves to be one of the most effective tools for spatial analysis. Several studies have been conducted on New Delhi and other affected areas globally on the subject of squatter settlements however not much has been done developing a model which analyzes the importance of each factor that affects the location choice of informal settlement dwellers. Also, this study uses remote sensing as a source of secondary information in a data constrained environment and shows its effectiveness. Remote sensing provides immediate ground truths to planners in terms of built up area and intensity of development, which can potentially help with the planning and implementation process. Different procedures of analyzing satellite images can expose even what materials the houses in a neighborhood are made of, their building heights, road networks, intensity of vegetation etc. However, for advanced information, more detailed and expensive (high resolution) satellite imagery would be required.

For the purpose of this study, freely available Landsat images have been used to identify spatial growth and intensity of development from the year 1970 to 2000. Since India did not have civilian satellites recording its urban growth until the recent past, other remotely sensed data such as Landsat by the US had to be used. The Landsat program was initiated in 1972 by the USGS and NASA with the objective of keeping records of land cover. There have been significant changes (new additions and improvements) to the satellite systems, however basic land cover information is available from 1972 onwards. Other information, like population, jobs, transport network information etc were collected from the census database, master plan projections and existing travel network information websites. Given that there are no piped water connections, one of the principal hypotheses of this study is that the ground water levels influence the decision of settlers. The groundwater information was acquired from the Central Ground Water Board (CGWB) and the Delhi Jal Board (DJB) who maintain historical records of the ground water levels in the NCT-Delhi. Recent advances in technology show use of satellite images to also acquire data on underground geology and other micro level information.

## 1.4 Research Background and Literature Review

This portion of the study highlights previous works done on informal settlements and the causes and implications of their existence and growth on urban planning and the urban fabric in general. This study has two key elements to it (1) Squatter Settlements and (2) Remote Sensing as a source of data. The first half of this chapter explores the factors that create environments of informal settlement development and the location choice of informal settlers, based on previous studies. The second part discusses remote sensing techniques which have been applied to the study of slums and which ones would prove to be more useful for the purpose of this study.

### 1.4.1 Squatter Settlements/Informal Settlements

The definitions of informal settlements vary depending on context from country to country, based on either their physical, social or legal characteristics. In most cases the legal character of a settlement is the decisive factor in classifying establishments as squatter (Loayza, 2009). Equally often these illegal establishments are accompanied by dilapidated physical living conditions and occupied by people of similar social and economic background.

Cases of informal settlements have been observed throughout the world, including in developed countries like the United States in the 1920's. During the great depression many shanty towns formed throughout the nation on encroached government land due to increased numbers of homeless people and the economic downturn. These squatter settlements were popularly called 'Hooverville', named after the president at the time Herbert Hoover, who allegedly created the bad economic environment. Favelas in Brazil, Colonias in Mexico, Gecekondus in Turkey and Jhuggi Jhonpdis in India are all popular examples of studied informal settlements.

In the Indian context, particularly in the case of Delhi, there are five categories of informal settlements; Slums, Resettlement Colonies, Notified Slums, Unauthorized Colonies and Urban Villages (Chakrabarti, 2001; Kundu, 2003) based on their tenurial security. Slum is the most basic classification based on the construction materials used and the living conditions. Slums, also referred to as *Jhuggi Jhompdi clusters* (JJC) tend to be relatively smaller in size, ranging from approximately 0.2-1 sq km. There are approximately 1080 slum clusters in the capital according to a survey conducted by the Municipal Corporation of Delhi (MCD) -1994, which contain approximately 4,80,000 households. Resettlement Colonies are temporary relocation measures for slum dwellers on the outskirts of the city which house around 2,16,000 households. Resettlement Colonies were formed under the Slum Clearance and Improvement Act of 1956 and provide 18 sq m plots to relocated slum households at a price of Rs. 5,000 (USD 106) per plot. Resettlement Colonies, although planned, suffer from an immense lack of infrastructure such as water supply, sewerage, drainage, electricity, schools etc. Urban Villages are the villages that have been surrounded by urbanization over the years and have experienced exponential growth in land values but inadequate growth in infrastructure availability.

This study focuses on the last two types of informal settlements; Notified Slums and Unauthorized Colonies. These are the largest among the five categories of informal settlements and have experienced the most growth over the years, therefore making it simpler to measure spatial growth using historical satellite imagery. Notified Slums are settlements that have been declared as slum areas under the Slum Clearance Act, 1956 due to dilapidation, overcrowding, faulty arrangement and design and lack of ventilation, etc. Lastly, Unauthorized Colonies are settlements that have illegally changed the land use from agriculture to residential or any other building mass. This is the most common case in Delhi, especially during 1980-90 due to heavy residential demand and sudden land value increases in the capital (Kundu, 2003).

Most literature that attempts at understanding informal settlements concludes that they come up due to larger economic opportunity present in the metropolitan areas. The United Nations Economic Commission for Europe (UNECE) in a study dated 2007 suggests that poverty and social ostracism are the primary causes of informal settlements in most nations. The report goes on to say that governments around the world grapple with fiscal deficits and therefore promote and subsidize industrial sectors in major cities that can revitalize the economy, which in turn leads to mass rural-urban migration in search of better jobs. This shift of government investments significantly reduces the public budget for rehabilitation of urban areas, thus impairing the ability of governments to effectively address the problem of informal settlements.

Although governments have implemented policies to provide housing for the urban poor, their efforts have proved futile. According to Housing the Urban Poor (UNECE, 2007), several governments have pursued anti-urbanization policies. They have evicted people from informal settlements, razed the housing, and sent the dwellers back to the countryside. These measures fail to stem the tide of urban migration. Other tactics have included subsidized public sector housing and incentive schemes for private real estate developers to move down market. As their options dry up, governments have resorted to a "blind-eye" approach. They furnish basic services to informal settlements and only evict squatters if they need the land.

In Delhi's case, an overwhelming majority of the city's migrant population has found employment in the growing informal sector of the city's economy. The growth and diversification of the informal sector, its flexibility and decentralized scale of operation, its competitiveness and capacity to absorb large manpower and to support the formal sector, both in trading and manufacturing activities is responsible for the high GDP growth of Delhi. Apart from providing low cost labor for manufacturing and trade, a large segment of migrant workforce is engaged in non-basic jobs (self-employment) like maid servants, watchman, street cobbler, barber, tailor, washer man, rickshaw pullers and private tutors. Many migrants engage in construction jobs such as construction laborer, blacksmith, electrician, carpenter and locksmith due to large number of new developments happing in the metropolitan region.

The National Economic Census (NSSO, 2000) finds that almost 50% of the migrants from rural areas occupied the above mentioned self-employment jobs. The remaining either occupy formal jobs or are unemployed. The government is reluctant to take effective counter measures against rural-urban migration due to the immense contribution of the migrants value-addition services to the gross national product.

In summation, the economic interests of governments lead to development of such policies that increase economic opportunities of individuals in metropolitan areas, thus providing an incentive for migration to the rural population in search of better sources of livelihood. Also, due to higher government investments in urban areas to develop and support infrastructure like schools, hospitals, it becomes somewhat necessary for the rural population to migrate in order to have a better quality of life. Since migrant affordability of formal residences is very low, they have to create more affordable informal settlements on unoccupied government land. Public budgets for enforcement tend to be relatively lower compared to investments in inducing industrial growth, thus making it easy for the development and growth of informal settlements. Another interesting fact which is worth mentioning is that in the political process, the vote bank of the informal settlements is resulting in the promotion of a populist political culture. This has been acknowledged in context of developing countries, particularly India, by the United Nations Center for Human Settlements - Habitat. Arif Hasan (Hasan,1998) suggests that it is in the interest of political leaders to see growth in informal settlements because the infrastructure demands of squatters can be met with relative more ease as compared to the demand of formal settlers, therefore ensuring temporary public satisfaction at lower costs.

Upon studying the causes of informal settlement growth, in the context of this study, the next step is to research the factors affecting a migrant's location choices. A study done by the 'Development Research Group' of the World Bank in Washington D.C. (Kapoor, 2004) suggests that there are primarily three location specific characteristics that households are willing to pay relative premiums for intra-city differentials. Employment opportunities (Jobs), levels of public service and amenities, and socio-demographic composition of the neighborhood community. The study then sub classifies socio-demographic composition of neighborhoods into social and kinship networks measured by sharing common language and religion and similarities in educational attainment.

The importance of commuting or transport costs is motivated by Alonso (1964) and Mills (1967) who demonstrate how residential choices are defined by the relationship between relative expenditures on commuting and land consumption. They modeled the metropolitan area as a "mono centric city" - That is, the metropolitan area has a central business district (CBD) at its center to which each household commutes. Taking a bid-price approach to household location decisions where commuting or travel costs are capitalized in the bid-price for land, locations closer to the CBD are more valuable than those at the periphery. In these bidding and sorting models, households maximize their bid-price offer for housing subject to the constraint that such payments leave the household no worse off than any other alternative. If the demand for land is income elastic, then richer households will be better off by purchasing land that is further from the CBD and are offset by the increase in travel or commuting costs.

In our model we consider a polycentric environment, i.e. many CBDs in a city to which residents need to travel for work. We also consider commuting convenience by measuring distance to the nearest bus stop, since this is the most common mode of transport used by the urban poor in Delhi. Tiebout's (1956) model of fiscal competition brings into play the role of local public services in the location decisions of households. In this model, communities or jurisdictions provide public services (which are financed by local taxes) to their residents. In making a residential location choice, a household will shop across communities and choose the one that provides the composition and level of public services that best satisfy the household's demand. If expenditures on public goods increases with income, then household in the same community will tend to have similar incomes (McGuire 1974; Berglas 1976; Wooders 1978). In the aggregate, this may lead to sorting based on preferences and demand for locally financed public services.

In the case of informal settlements, often households are not able to afford to pay these local taxes to receive these local public services like open space maintenance, road maintenance etc, therefore choosing to settle with similar households under similar unwelcoming conditions. Over time differences can also be seen among informal settlements, where some appear to be more organized than others due to the affordability/ability to pay such local taxes of the households.

For the simplicity of the study we do not consider jobs like house cleaner, laundry person etc that the slum dwellers/informal settlers do in residential areas near their dwellings. We only consider Jobs at CBDs that are identified by the Master Plans for Delhi as a source of local public services and employment. Also, upon data research there appears to be no available record of informal jobs occupied by the study settlement dwellers in Delhi.

The third component of location choice, as suggested by the World Bank study (Kapoor, 2004) is individual preferences for community composition. This is most famously articulated in the works of Thomas Schelling (1969, 1971, 1978) whose models of social interaction show that microeconomic forces such as discriminatory individual preferences or behavior lead to aggregate phenomena such as sorting and segregation. The model implies that people are willing to pay differential premiums to live near others who share common socio-economic or demographic characteristics. These characteristics include religion, class, language, educational attainment, and duration of stay and tenure in the city. Another paper by Lall et al.(2004) argues that social interaction and participation tend to increase with cultural, ethnic or economic homogeneity. In other words, individuals have an aversion to heterogeneity if it implies that they will be forced to associate with people who are not like themselves. The "cost" of participation in neighborhood activities, therefore, is higher in more diverse communities.

For our study, we do not analyze the social homogeneity or diversity of such informal settlements, as it would require significant primary data collection. However, Jha et al. (2002) and the recent New Delhi slum census do provide anecdotal evidence that these informal settlements are predominantly occupied by people of similar ethnic backgrounds.

Water has been a big concern for the urban poor. Many studies have been done to understand the water demands of informal settlement dwellers and the quality of water they have access to. New Delhi has a very high water stress. Water Stress is defined as the proportion of water intake to the inventory of water resources (UN, 2006).

None of the illegal slums and colonies in Delhi have any underground drainage, and only 3 percent had underground sewerage (Zehra, 2000). The drinking water quality in these colonies has been found to be bad time and again, and the water supply, none to very sporadic. Broken hand pumps and lack of piped connections result in women having to travel long distances to fetch water or slums withdrawing water from the ground (Baviskar, 2000). This implies that the poor, often without knowledge and ability to filter the supplied water, are the most vulnerable to receiving non-potable water and, hence, most vulnerable to water-borne diseases.

Residents attempt to fill the gap between demand and supply by using coping mechanisms, such as storing water, stealing water from private connections, using water from place of employment (construction sites and private homes) and paying for water from private tankers.

The primary hypothesis which was investigated in this study is that the ground water availability is one of the big factors for the urban poor to choose their residential location. It would be interesting to explore this idea since not much has been done to find a correlation between spatial growth of settlements and the ground water availability. Delhi avails surface water from the Yamuna, Bhakra storage and Ganges river. Surface water supplied to Delhi is approximately 1150 MCM (million cubic meters). 290 MCM of groundwater is available per year. Ranney wells and tube-wells are included in this. Delhi's ground-water level has gone down by about eight meters in the last 20 years at the rate of about a foot a year (Rehman and Netzband, 2007). A national survey conducted by the World Bank in 2006 found that only 40 percent of the households in Delhi have a 24-hour water supply, and approximately 25-percent have only 4 hours of service. The duration of water supply is the least reliable in slum communities (Truelove, 2001). Zehra's (2000) paper indicates that slums located near water treatment plants have better access to potable water. Currently, there are no water treatment plants located in South, North or West Delhi. The slum localities in these regions have access to only 35-40 liters per capita per day of water.

### 1.4.2 Remote Sensing Applications in Urban Studies

Satellite data are increasingly considered to be an essential data source for the appraisal of urban environments as they provide timely and valuable information for analyzing the natural and constructed landscape. Unfortunately these landscapes are composed of diverse materials (concrete, asphalt, metal, plastic, glass, shingles, water, grass, shrubs, trees, and soil) and arranged in complex ways, which produce spectral responses that are difficult to interpret (Jensen and Cowan, 1999). This is usually the result of land cover variability in close proximity which produces a variety of reflectance characteristics that the satellite detects. The resulting image pixels are then comprised of different proportions of grass, trees, buildings, and roads, which can be difficult to differentiate (Forster 1985; Welch 1980).

Adding to this difficulty in the case of most Asian cities, the patterns of development are significantly different from North American cities. Street layouts, buildings and structural materials, along with the size, amount and type of vegetation, make analysis of these places more complex.

A study done at the Stockton College, New Jersey (Thomson, 2001) attempted to identify informal housing clusters in Metropolitan Bangkok using remote sensing techniques, in light of the data constraints posed by a developing country. The study coupled the use of Landsat ETM images with aerial imagery to increase accuracy of land cover assessment for a more recent cross section of time. Dr. Curtis used three sets of data: three sets of panchromatic aerial photos, a base map of the congested communities (developed from aerial photography) and Landsat ETM image, to accurately map the informal housing. The study concluded with realizing the constraints of using multispectral image classification for distinguishing a variety of urban land cover and the inaccuracies associated with it, especially when the size of a pixel is larger than an individual dwelling.

Another study done at Ruhr University, Germany (Netzband, 2010) attempts to map slum areas in different locations over the world using Remote Sensing (RS) data obtained from newer high resolution IKONOS, QuickBird, Cartosat and World View satellites. The researcher suggests that 0.6m resolution imagery from QuickBird was ideal for an accurate spatial assessment of informal housing areas. The study also explores the possibilities of Urban Structure Type (UST) assessments using RS data.

There are many similar studies that identify/map informal housing or slum clusters in different parts of the world. However, these studies only look at slums with a more current perspective with the use of expensive higher resolution imagery. This thesis intends to use historical remote sensing data to look at the same slums over a period of forty years and identify factors influencing growth, using freely available lower resolution historical Landsat Images.

## 1.5 Literature Review Summary

This chapter documents studies about informal settlements, their sub categories and their differences. It goes on to present the causes of their creation and subsequent growth. Several studies on Delhi's informal sector were consulted and a good context for our case study was gathered and presented. Key finding from the background research on Delhi was that almost 50% of the current population is living in some type of informal settlement, thus making it very important to study these settlement's growth with a historical perspective.

Upon identifying reasons for development and growth, the literature tried to explore the factors affecting location choices of these squatters. Several factors from different research studies were identified such as Jobs (location of CBDs for formal jobs, temporary construction jobs for new development, support non-basic jobs like cobbler, tailor, maid servant near new developments), accessibility to transit services, social and economic character of the migrant population. None of the traditional studies identify ground water as a relevant factor in determining location choice of squatters. Since the primary hypothesis for this study is that ground water plays a crucial role in location choice due to lack of piped water access, an attempt was made at exploring the water situation in informal settlements in Delhi. It was found that these settlements do not receive piped water through government sources and cope with their ever increasing demand for potable water by digging community wells and withdrawing water from the aquifers.

Lastly, works on use of remote sensing for urban mapping were consulted to test the applicability of such tools to this study. Most work done with remote sensing in urban areas is not often a means to model growth, but merely stops at mapping and identification of problem areas. This study attempts to use remote sensing as a tool to measure spatial growth and intensity over time to be used as the dependent variable.

## 1.6 Research Framework and Scope

This study is limited to a sample of 30 informal settlements within the National Capital Territory of Delhi, India. The data used are from official sources for the same years as the analyzed satellite images. The time frame of analysis was limited from the years 1970 to 2000 due to the unavailability of satellite images prior to 1970 and census data after 2000 during the data collection phase.

This research develops a settlement level database for a set of explanatory variables with readings for 1970, 1980, 1990 and 2000, and also the change in each of the variables over 10 years. With the use of this database, it tries to study the relationships between change in explanatory variables and the dependent variables, and also realize the strengths of these relationships.

The study explores the following research questions:-

- Is the level of ground water affecting the location choices of people in New Delhi, since informal settlements do not have access to piped water?
- How is spatial growth of settlements affected by change in public transit access and development investments in the settlement proximity?
- Is spatial growth or intensity of growth more relevant when studying informal settlements in the context of New Delhi?

## 1.7 Justification for the Study

There have been many studies done on the subject of slums and squatter settlements throughout the world, ranging from the socio-economic aspects to the political influences on their evolution and. Many studies have identified factors that abet growth of these settlements and discussed their qualitative implications and causes. The focus of these studies has been South-East Asia, Brazil, Mexico and Mumbai, India. Also, there has been limited attempts at doing a quantitative spatial analysis of these settlements.

This research attempts to do a quantitative analysis of informal settlement growth in the North Indian context and test the relevance and applicability of previous work for New Delhi. It also studies the growth of slums with a longitudinal perspective, which has not been adequately explored in previous studies. One of the key contributions of this study would be to show the applications of readily available historical satellite images and remote sensing data to urban studies.

# CHAPTER II. METHODOLOGY

## 2.1 Conceptual Framework

This study tests the hypothesis that the spatial growth rate of informal settlements is related to the accessibility to employment opportunities, ground water availability, distance to public transit facilities and population growths, data on these variables would be needed.

Most information on the independent variables has been acquired from several government agencies like the Survey of India, Census of India, the Delhi Jal Board, and the Delhi Development Authority. Information on settlement growth is derived from Landsat images..

Collected and processed data is analyzed using SPSS software for different degrees and levels of significance of relationships between different variables. Finally, the expected results would be compared to the derived results to see if they support our hypotheses.

The 2020 Delhi Master Plan identifies over 1500 informal settlements that exist in the NCT. This study took a sample of 30 settlements from different districts of New Delhi, attempting to ensure uniform representation. The criteria of selection were:

- More settlements from bigger districts (weighted sampling), and

- Settlements were identifiable and distinguishable in all of the available satellite images (specially in the 80m resolution 1970 Landsat MSS image)

## 2.2 Dependent Variables

Our primary dependent variable for this research is the decadal change in settlement area. This is derived from processing and digitizing the available Landsat images from the USGS archives. Upon processing and digitization (at a later stage), it was found that some settlements reached build-out and did not grow in size (Fig 2.2.1.1 to Fig 2.2.1.3). Therefore, another dependent variable was chosen to study the intensity of development within these settlements. Given the data constraints posed by primitive satellite data only NDVI could be used as a proxy indicator of the intensity of development, with the assumption that vegetation is inversely related to the intensity of development. This assumption should hold true since most land, currently under informal settlement occupation, has been gradually converted from agricultural land according to previous studies reported earlier.

This section will explain in detail what information was required for the two dependent variables and how it was acquired/calculated.

### 2.2.1 Settlement Size/Area

This study uses satellite images as a source of information on settlement size. The images were acquired from United States Geological Survey (USGS). This study used LANDSAT MSS and LANDSAT TM images from the year 1970 to 2000, since no other satellite images were available for the 1970-1990 time period of the study.

Raw data were processed using the ERDAS Imagine software to generate images in TIFF format. These images contained bands 1 to 4 of satellite data, which were then used to calculate the area of settlements by importing the images into ArcGIS and digitizing the outer boundary of built up space for each of the four sample years.

In some cases, where settlement boundaries were not clearly visible, different band combinations were used to get a clearer approximation of the outer settlement boundary. After digitization of extent of settlements, ArcGIS function 'Calculate Geometry' was used to calculate the area for each settlement. The maps below show the settlement outer boundaries for the years 1970 to 2000.

Fig. 2.2.1.1 Settlement Boundaries for North West Delhi

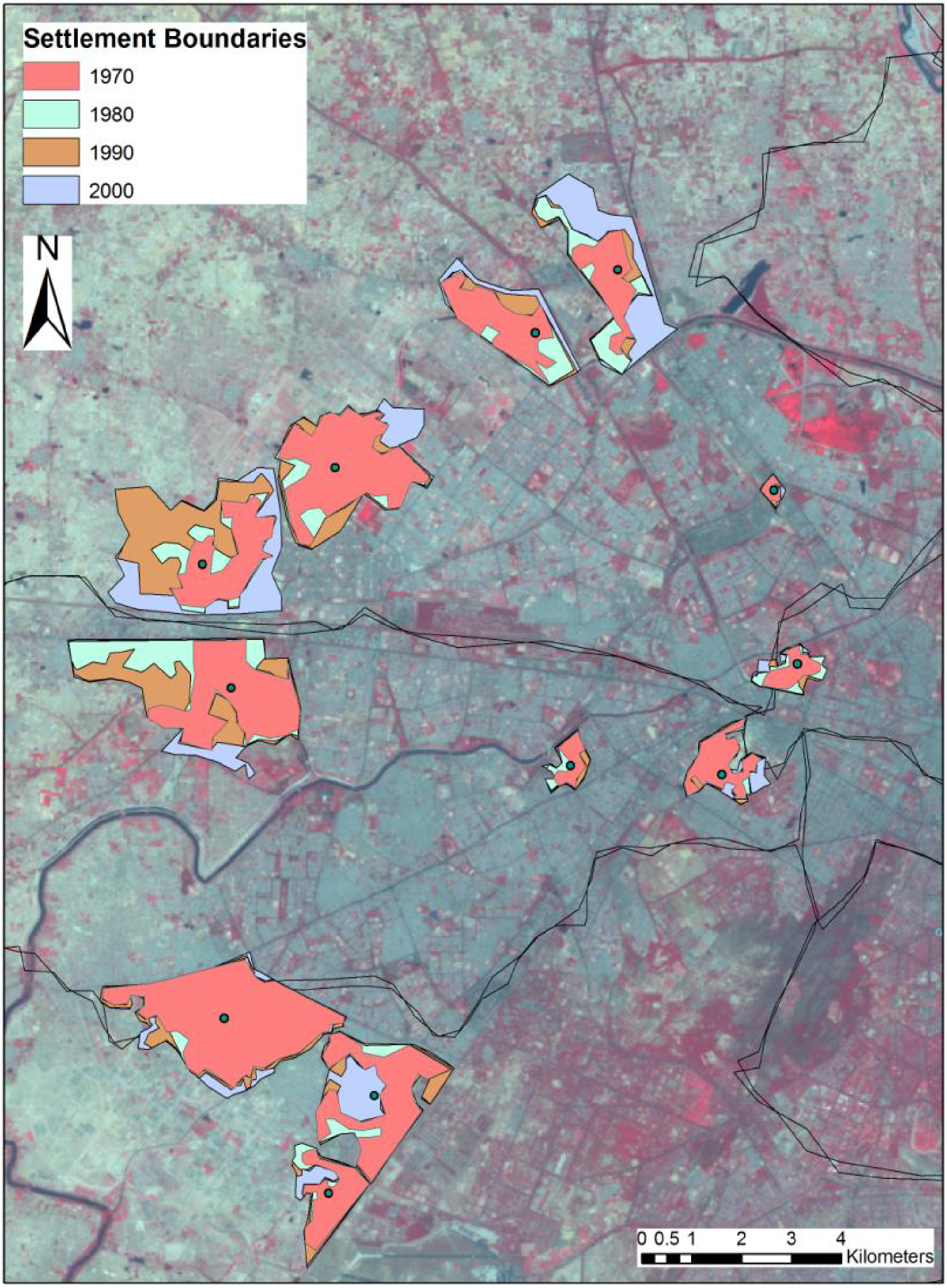


Fig. 2.2.1.2 Settlement Boundaries for South Delhi

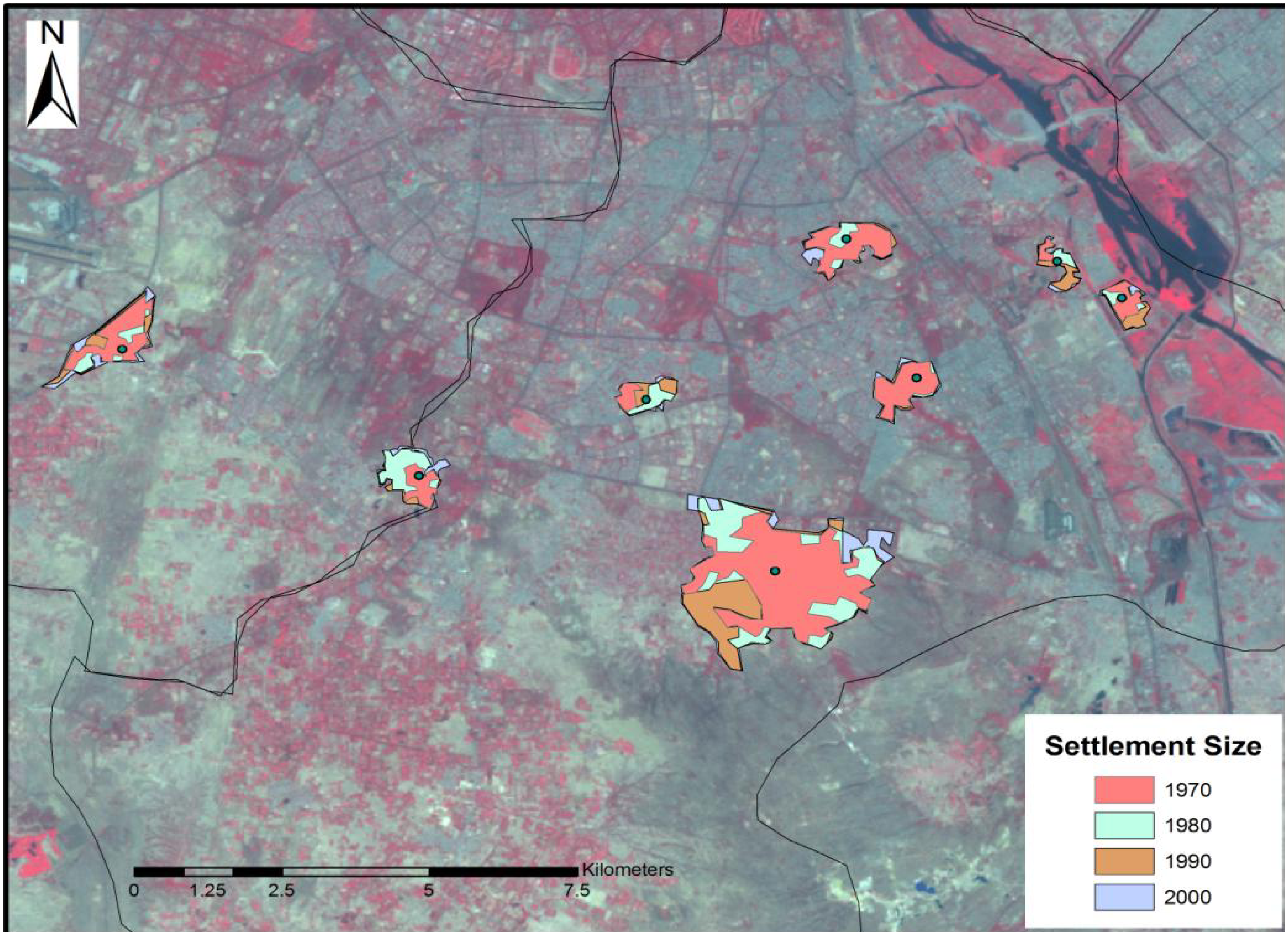


Fig. 2.2.1.3 Settlement Boundaries for East Delhi

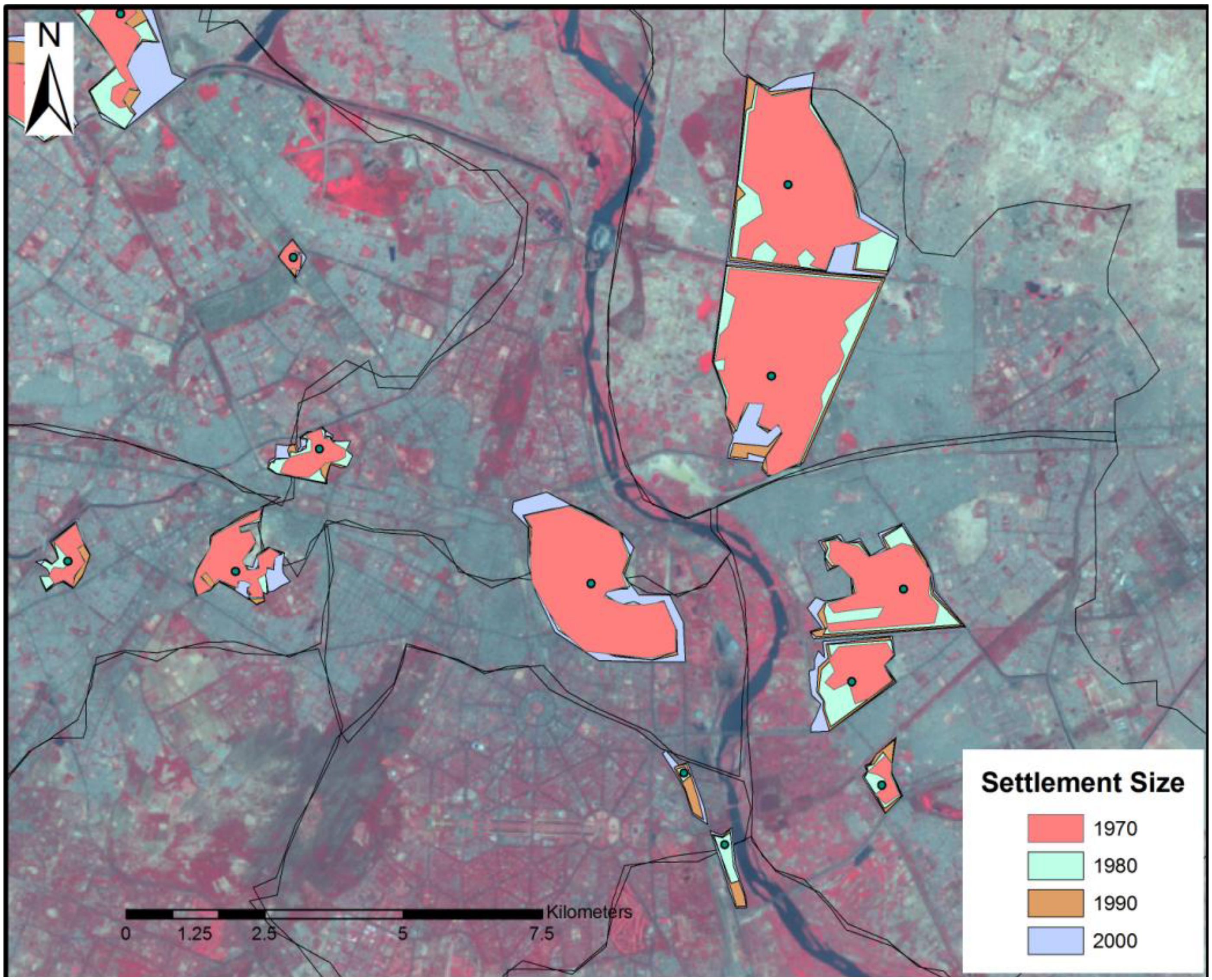


Table 2.2.1.1 Area of Settlements from 1970-2000, in square kilometers.

| Area of Settlements | | | | |
|---|---|---|---|---|
| | **1970** | **1980** | **1990** | **2000** |
| **Pandav Nagar** | 0.2113 | 0.3455 | 0.4532 | 0.488 |
| **Indraprastha Slums** | 0 | 0.0363 | 0.175 | 0.297 |
| **Mahipalpur** | 0.6761 | 0.8614 | 1.0647 | 1.3101 |
| **Uttam Nagar** | 5.8793 | 6.0292 | 6.5802 | 7.0088 |
| **Nayagaon** | 6.079 | 6.8203 | 7.2715 | 7.7892 |
| **Shahabad** | 1.8314 | 2.3325 | 2.7009 | 3.1468 |
| **Roshanpura** | 4.3711 | 4.4412 | 4.4926 | 5.4924 |
| **YamunaPushta** | 0 | 0.1695 | 0.273 | 0.3799 |
| **Laxmi Nagar** | 0.8831 | 1.3718 | 1.5274 | 1.8344 |
| **Sagarpur/Dabri** | 2.7283 | 3.097 | 3.4656 | 4.4101 |
| **Palam Gaon** | 1.1777 | 1.3212 | 1.536 | 1.8328 |
| **Najafgarh** | 3.6879 | 4.2316 | 4.8163 | 5.2641 |
| **Sangam Vihar** | 3.7216 | 5.1848 | 6.3449 | 6.8904 |
| **Makanpur** | 1.7692 | 2.086 | 2.1561 | 2.3299 |
| **Shaheen Bagh** | 0.2241 | 0.2833 | 0.4132 | 0.472 |
| **Okhla Vihar** | 0.0642 | 0.1498 | 0.2973 | 0.3475 |
| **Gobindpuri** | 0.6348 | 0.6792 | 0.7089 | 0.7695 |
| **Bengali Colony** | 1.3423 | 2.1975 | 2.5864 | 4.6868 |
| **Lakshmi Park** | 3.4606 | 5.0044 | 6.9838 | 7.4742 |
| **Garhi** | 0.6618 | 0.8201 | 0.9 | 0.962 |
| **Malviya Nagar** | 0.1365 | 0.2922 | 0.465 | 0.4985 |
| **Vasant Vihar Slums** | 0.2843 | 0.6917 | 0.7564 | 0.8727 |
| **Nehru Vihar** | 5.0095 | 6.1023 | 6.4521 | 7.1978 |
| **Patel Nagar** | 1.0441 | 1.1279 | 1.2232 | 1.4949 |
| **Sudarshan Park** | 0.3566 | 0.4795 | 0.5813 | 0.6227 |
| **Krishna Vihar** | 2.1227 | 2.8124 | 5.8008 | 7.8076 |
| **Shastri Nagar** | 0.483 | 0.7175 | 0.8026 | 0.9011 |
| **Azadpur** | 0.1285 | 0.1285 | 0.1496 | 0.1875 |
| **Krishna Nagar** | 2.1946 | 2.8124 | 3.0837 | 3.3702 |

### 2.2.2 Settlement development intensity proxy - NDVI

This study uses Normalized Distribution Vegetation Index (NDVI) as a proxy variable for Building Intensity/Development Intensity. Base assumptions behind using NDVI as a proxy for building intensity is that people occupy the vacant lands in between developments in these informal settlements resulting in a decrease in vegetation levels over time and the settlements do not have any exposed soil component to their associated imagery pixels. Ridd's vegetation-impervious surface-soil model (Ridd, 1996) suggests that each pixel value is a mixture of these three components. Assuming the exposed soil component for the pixel is zero, one can say that decline in vegetation would mean increase in impervious surfaces or building intensity. NDVI was however transformed to represent built up index using the following method:

**Positive Vegetation Index = 1 + NDVI**

**Veg (0-1) = (1 + NDVI)/2**

**Built = 1 - (1 + NDVI)/2 , Assuming soil component = 0**

ERDAS Imagine software was used to convert the satellite images into NDVI images. The NDVI function of the software was used for this. Further, the settlement boundaries were overlaid on the NDVI image and an average NDVI value for the entire settlement was calculated using the Area of Interest (AOI) function of Imagine software.

There are more accurate indices available that represent intensity of growth, like the Building Intensity Index (BII). However, these were not used since the study works with old Landsat-MSS images that do not have the necessary band information to calculate these advanced indices. Fig 2.2.2.1 Shows the NDVI calculations output for Delhi.

Fig 2.2.2.1 NDVI Map for New Delhi

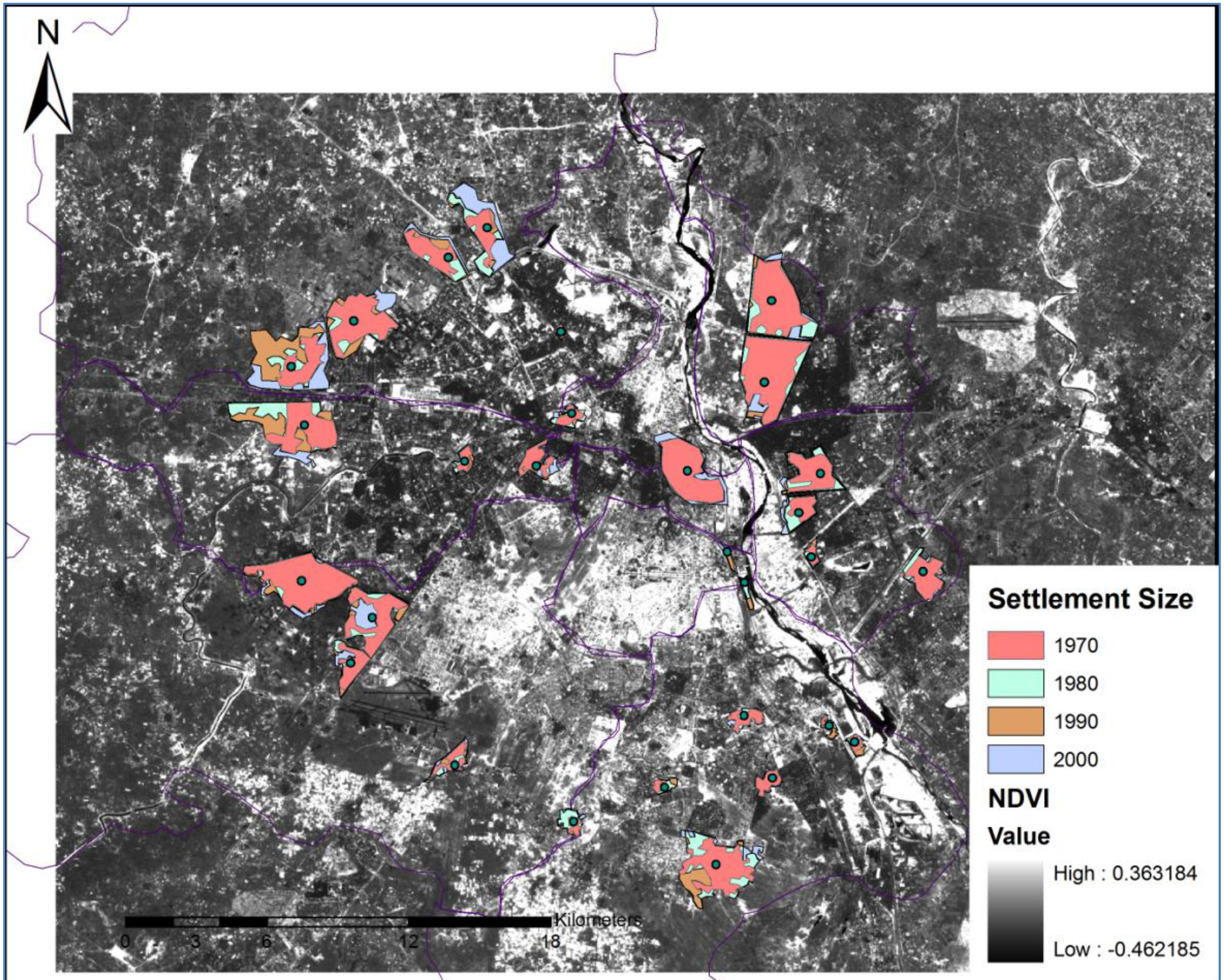


Table 2.2.2.1 Average NDVI value for Settlements from 1970-2000, and transformed built up index (BI)

| | NDVI | | | | Built up Index (BI) | | | |
|---|---|---|---|---|---|---|---|---|
| | 1970 | 1980 | 1990 | 2000 | 1970 | 1980 | 1990 | 2000 |
| **Pandav Nagar** | -0.02 | -0.14 | -0.16 | -0.31 | 0.51 | 0.57 | 0.58 | 0.66 |
| **Indraprastha Slums** | 0.08 | -0.01 | -0.09 | -0.20 | 0.46 | 0.51 | 0.55 | 0.60 |
| **Mahipalpur** | -0.08 | 0.04 | -0.07 | -0.28 | 0.54 | 0.48 | 0.53 | 0.64 |
| **Uttam Nagar** | -0.09 | -0.09 | -0.13 | -0.32 | 0.55 | 0.55 | 0.57 | 0.66 |
| **Nayagaon** | -0.11 | -0.13 | -0.15 | -0.30 | 0.55 | 0.57 | 0.57 | 0.65 |
| **Shahabad** | -0.04 | -0.03 | -0.11 | -0.28 | 0.52 | 0.51 | 0.55 | 0.64 |
| **Roshanpura** | -0.18 | -0.21 | -0.22 | -0.32 | 0.59 | 0.61 | 0.61 | 0.66 |
| **YamunaPushta** | -0.01 | -0.01 | -0.12 | -0.28 | 0.50 | 0.51 | 0.56 | 0.64 |
| **Laxmi Nagar** | -0.05 | -0.16 | -0.17 | -0.29 | 0.53 | 0.58 | 0.58 | 0.64 |
| **Sagarpur/Dabri** | -0.05 | -0.13 | -0.13 | -0.30 | 0.53 | 0.56 | 0.57 | 0.65 |
| **Palam Gaon** | -0.06 | 0.03 | -0.11 | -0.26 | 0.53 | 0.49 | 0.56 | 0.63 |
| **Najafgarh** | -0.03 | -0.03 | -0.06 | -0.27 | 0.51 | 0.51 | 0.53 | 0.63 |
| **Sangam Vihar** | 0.02 | -0.02 | -0.12 | -0.29 | 0.49 | 0.51 | 0.56 | 0.64 |
| **Makanpur** | 0.00 | 0.03 | -0.07 | -0.28 | 0.50 | 0.49 | 0.53 | 0.64 |
| **Shaheen Bagh** | -0.07 | -0.10 | -0.14 | -0.32 | 0.53 | 0.55 | 0.57 | 0.66 |
| **Okhla Vihar** | -0.02 | -0.01 | -0.08 | -0.24 | 0.51 | 0.50 | 0.54 | 0.62 |
| **Gobindpuri** | -0.12 | -0.09 | -0.10 | -0.25 | 0.56 | 0.54 | 0.55 | 0.63 |
| **Bengali Colony** | -0.05 | -0.05 | -0.12 | -0.29 | 0.52 | 0.53 | 0.56 | 0.65 |
| **Lakshmi Park** | -0.11 | -0.13 | -0.18 | -0.30 | 0.56 | 0.56 | 0.59 | 0.65 |
| **Garhi** | -0.03 | -0.04 | -0.09 | -0.26 | 0.52 | 0.52 | 0.55 | 0.63 |
| **Malviya Nagar** | -0.10 | -0.15 | -0.23 | -0.35 | 0.55 | 0.57 | 0.61 | 0.68 |
| **Vasant Vihar Slums** | -0.03 | -0.09 | -0.14 | -0.32 | 0.51 | 0.55 | 0.57 | 0.66 |
| **Nehru Vihar** | -0.03 | -0.06 | -0.14 | -0.29 | 0.51 | 0.53 | 0.57 | 0.64 |
| **Patel Nagar** | -0.03 | -0.02 | -0.07 | -0.26 | 0.51 | 0.51 | 0.53 | 0.63 |
| **Sudarshan Park** | -0.01 | 0.00 | -0.03 | -0.14 | 0.51 | 0.50 | 0.51 | 0.57 |
| **Krishna Vihar** | -0.01 | -0.01 | -0.04 | -0.19 | 0.50 | 0.51 | 0.52 | 0.59 |
| **Shastri Nagar** | -0.06 | -0.06 | -0.10 | -0.15 | 0.53 | 0.53 | 0.55 | 0.58 |
| **Azadpur** | -0.02 | -0.03 | -0.09 | -0.16 | 0.51 | 0.51 | 0.54 | 0.58 |
| **Krishna Nagar** | -0.10 | -0.12 | -0.17 | -0.32 | 0.55 | 0.56 | 0.58 | 0.66 |

For analysis purposes, the new index (BI) was used instead of NDVI. This was done to create a positive index in order to get correct coefficient signs in the multivariate models.

## 2.3 Explanatory Variables

### 2.3.1 Employment Opportunities/Jobs

Since better employment opportunities was the most relevant factor associated with rural to urban migration found in the literature, this explanatory variable was crucial to this study. The Delhi Development Authority published a list of all central business districts in New Delhi as a part of their 2021 Master Plan. This list identifies all the Developed, Developing and Unplanned CBD's in the National Capital Territory and indicates the number of formal jobs offered in each location. The data were linked with the year of development from which the change in number of jobs at a decadal rate from 1970-2000 could be calculated.

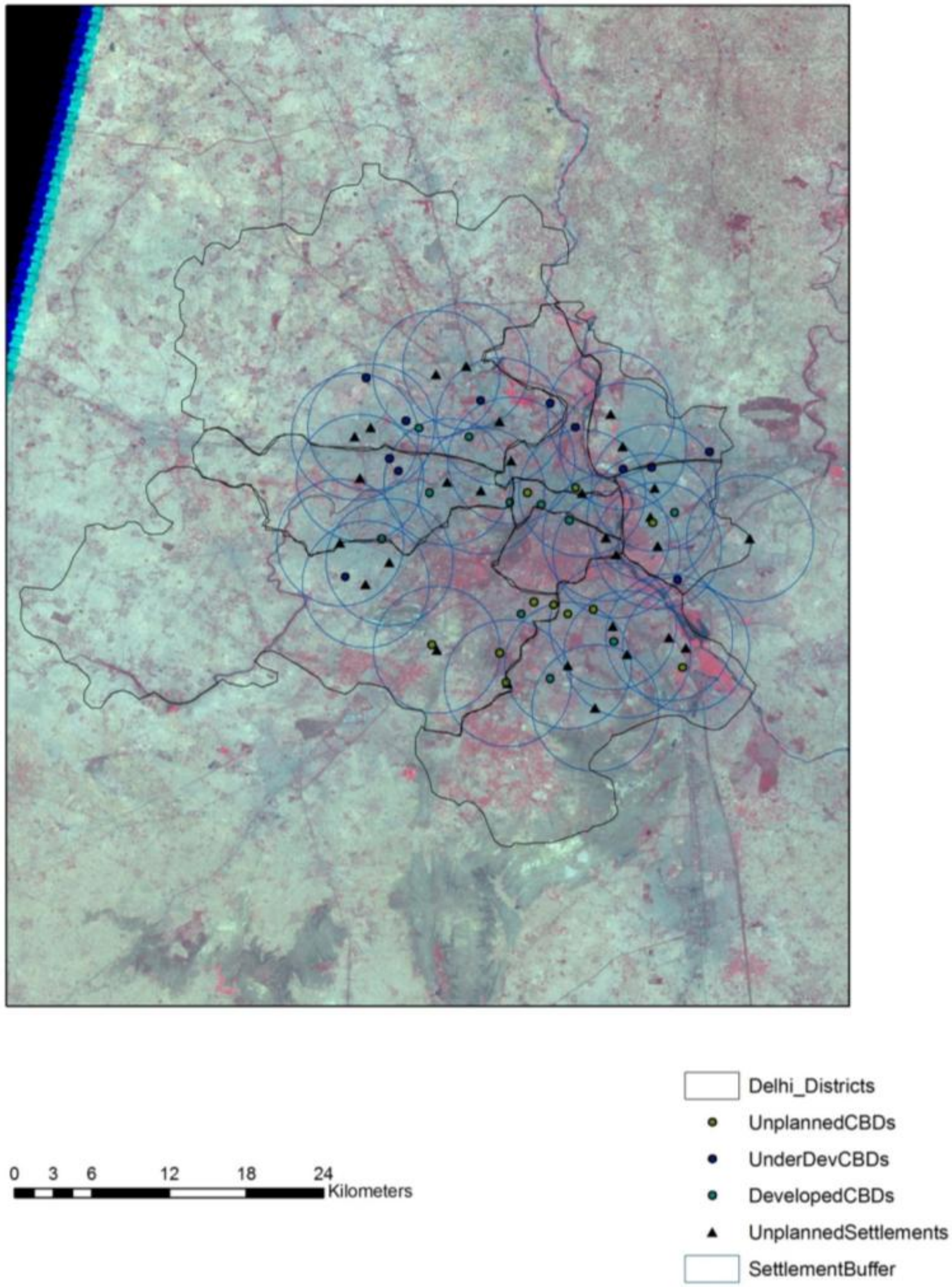
Further, the locations of these CBDs were mapped in ArcGIS and 5 kilometer buffers were drawn around them. This is the average distance a person in New Delhi travels to reach work (Mitra, 1994). Each settlement was individually analyzed and the number of jobs for each decade were calculated based on when the CBDs within the buffer became operational.

Table 2.3.1.1 shows the associated jobs to each of the relevant Central Business Districts in New Delhi and the year if its establishment. The map shows how buffers were drawn from each settlement for 5 kilometers to calculate the jobs with average work related travel distance from each settlement.

Table2.3.1.1 Jobs in Central Business Districts

| Name of CBD | Year Built | Jobs | Area (SqKm) |
|---|---|---|---|
| Lajpat Nagar | 1950 | 6400 | 1.6 |
| INA Market | 1970 | 850 | 0.2 |
| Sarojini Nagar | 1980 | 900 | 0.2 |
| Munirka | 1990 | 1200 | 0.1 |
| Mehrauli | 1990 | 650 | 0.3 |
| Chandni Chowk | 1950 | 22000 | 1.1 |
| Mahipalpur | 1990 | 300 | 0.4 |
| Laxmi Nagar | 1980 | 7200 | 1.5 |
| Karol Bagh | 1980 | 5600 | 0.4 |
| South Extension | 1990 | 1800 | 0.5 |
| Nehru Place | 1980 | 12000 | 0.3 |
| Rajendra Place | 1990 | 3500 | 0.1 |
| Bhikaji Cama Place | 1990 | 4200 | 0.2 |
| Janakpuri | 1990 | 5200 | 0.1 |
| Preet Vihar | 1990 | 1800 | 0.1 |
| Shivaji Place (Raja Garden) | 1980 | 2600 | 0.2 |
| Jhandewalan | 1980 | 7200 | 0.3 |
| Netaji Subhash Place (Wazirpur) | 1980 | 4000 | 0.1 |
| Saket | 1990 | 2600 | 0.2 |
| Manglam Place (Rohini) | 2000 | 1600 | 0.3 |
| Connaught Place | 1950 | 18500 | 2.4 |
| Okhla Ind Area | 1970 | 17500 | 3.6 |
| Trans Yamuna (Shahdra) | 2000 | 2600 | 0.2 |
| Rohini | 1990 | 3400 | 0.1 |
| Piragarhi | 1990 | 3200 | 0.1 |
| Paschim Vihar | 2000 | 1800 | 0.1 |
| Shalimar Bagh | 1990 | 1600 | 0.1 |
| Dheerpur Extension (Jahangirpuri) | 2000 | 340 | 0.1 |
| Majnu ka Tila | 1980 | 650 | 0.1 |
| Dilshad Garden | 2000 | 2200 | 0.2 |
| Shastri Park ( Shahdara) | 2000 | 1600 | 0.1 |
| Mayur Vihar | 1990 | 1200 | 0.2 |
| Rohini Ph-III, IV & V | 2000 | 4500 | 0.4 |
| Dwarka | 1990 | 6500 | 0.2 |

Fig 2.3.1.1 Buffer analysis for jobs within 5 kilometers of each settlement




Since this study analyzes how decadal spatial growth is impacted by the change in our explanatory variables, the decadal change in the number of jobs was calculated by using the difference in number of jobs (ΔJobs) between subsequent decades.

### 2.3.2 Ground Water Levels

There is anecdotal evidence that ground water has been playing a vital role in the growth of these informal/unplanned settlements. By observing the growth of settlements in different parts of the city, it is clear that settlements on the east are growing at a faster rate than the settlements on the west. To support this hypothesis, knowledge of ground water levels becomes vital. Several agencies were contacted to obtain this historical information, however ground water was not realized as a crucial subject until early 1980s, thus making available records of ground water levels intermittent. Certain reasonable assumptions were made like the ground water level in 1968 was used for 1970.

The ground water maps were overlaid on the settlement locations to note which depth zone individual settlements overlapped with each decade. Also, it was realized that the ground water level for each settlement at the beginning of a decade would be more pivotal in people's location choice than the change in ground water levels during the decade. Hence, in the decadal change table the absolute value of ground water depth was used instead of the change in ground water depth.

Table 2.3.2.1 shows the changes in ground water level over the past 40 years for the sample settlements:

Table 2.3.2.1 Ground Water Depth in Meters below surface

| Ground Water Depth in Meters below surface | | | | |
|---|---|---|---|---|
| | **1970** | **1980** | **1990** | **2000** |
| **Pandav Nagar** | 2 | 6 | 12 | 15 |
| **Indraprastha Slums** | 7 | 10 | 16 | 30 |
| **Mahipalpur** | 3 | 5 | 8 | 11 |
| **Uttam Nagar** | 3 | 5 | 9 | 10 |
| **Nayagaon** | 3 | 8 | 13 | 17 |
| **Shahabad** | 5 | 5 | 9 | 15 |
| **Roshanpura** | 4 | 6 | 13 | 21 |
| **YamunaPushta** | 11 | 11 | 17 | 26 |
| **Laxmi Nagar** | 3 | 5 | 8 | 9 |
| **Sagarpur/Dabri** | 5 | 7 | 11 | 13 |
| **Palam Gaon** | 5 | 7 | 11 | 12 |
| **Najafgarh** | 3 | 5 | 11 | 12 |
| **Sangam Vihar** | 20 | 18 | 18 | 22 |
| **Makanpur** | 3 | 5 | 9 | 9 |
| **Shaheen Bagh** | 3 | 7 | 10 | 12 |
| **Okhla Vihar** | 3 | 8 | 10 | 12 |
| **Gobindpuri** | 5 | 7 | 12 | 16 |
| **Bengali Colony** | 5 | 7 | 10 | 14 |
| **Lakshmi Park** | 10 | 10 | 16 | 22 |
| **Garhi** | 5 | 8 | 12 | 18 |
| **Malviya Nagar** | 20 | 22 | 26 | 30 |
| **Vasant Vihar Slums** | 20 | 22 | 20 | 30 |
| **Nehru Vihar** | 6 | 7 | 12 | 18 |
| **Patel Nagar** | 8 | 12 | 18 | 24 |
| **Sudarshan Park** | 8 | 12 | 18 | 24 |
| **Krishna Vihar** | 12 | 14 | 22 | 28 |
| **Shastri Nagar** | 8 | 12 | 18 | 24 |
| **Azadpur** | 8 | 10 | 16 | 20 |
| **Krishna Nagar** | 3 | 7 | 8 | 9 |

### 2.3.3 Public Transit Access

Public transit is one of the key factors that urban poor consider whilst choosing residential location. Most informal settlement dwellers use buses in New Delhi for their transit needs. In recent past, the emergence of the Delhi metro in 2005 has caused a slight shift from bus use to metro use, however, historically speaking buses have been the primary mode of transport for the poor.

In this study public transit access is measured as the distance to nearest bus stop from the centroid of sampled informal settlements. This information was gathered from the Delhi Transport Corporation's (DTC) archival maps showing their growth in bus coverage. Measurements were taken from the known locations of the centroids of study settlements to the nearest bus stops for the years 1970, 80, 90 and 2000. These numbers (in kilometers) were also used as absolute values since the distance to a bus stop is more explanatory of the proximity to public transit as compared to the change in distance, i.e., a settlement with less change in distance could possibly still be closer to a bus stop than a settlement with a greater change over a decade.

Table 2.3.3.1 shows the change in proximity to bus stops for each sampled settlement.

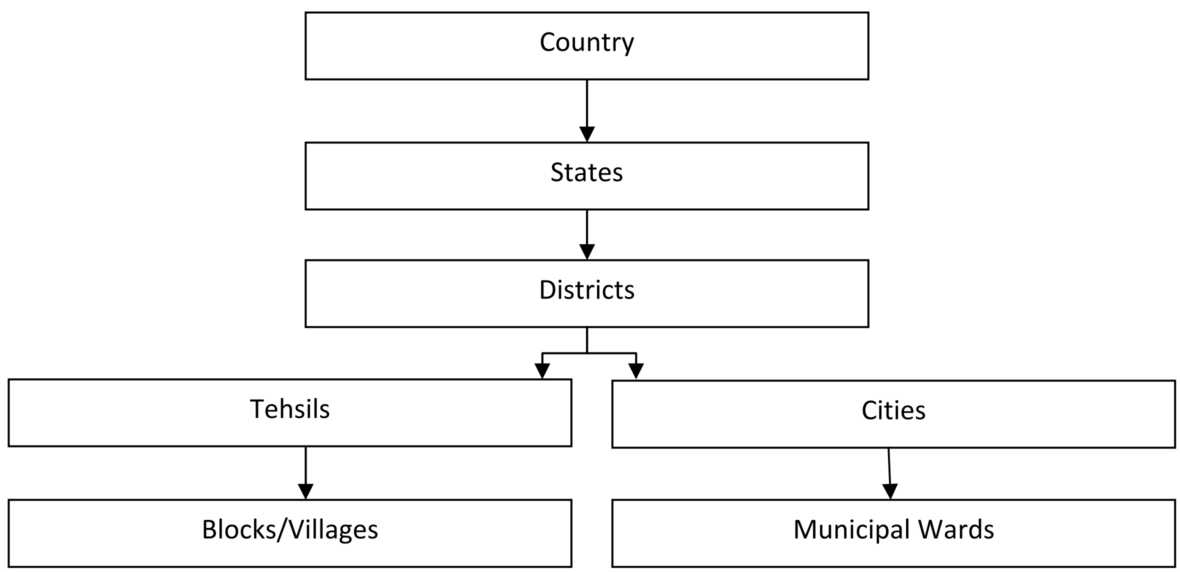
Table 2.3.3.1 Distance to the Nearest Bus Stop from Settlement Centroid

| Distance to Nearest Bus Stop | | | | |
|---|---|---|---|---|
| | **1970** | **1980** | **1990** | **2000** |
| **Pandav Nagar** | 2 | 2 | 0.6 | 0 |
| **Indraprastha Slums** | 0.5 | 0.5 | 0 | 0 |
| **Mahipalpur** | 3 | 1.5 | 0.3 | 0 |
| **Uttam Nagar** | 4 | 2 | 0.5 | 0 |
| **Nayagaon** | 4.5 | 3.2 | 1.5 | 0.5 |
| **Shahabad** | 4 | 4 | 2.5 | 2 |
| **Roshanpura** | 0.5 | 0 | 0 | 0 |
| **YamunaPushta** | 0.2 | 0.2 | 0 | 0 |
| **Laxmi Nagar** | 0.5 | 0.5 | 0 | 0 |
| **Sagarpur/Dabri** | 6 | 4 | 3 | 1 |
| **Palam Gaon** | 7 | 5 | 4 | 1 |
| **Najafgarh** | 12 | 10 | 7 | 4 |
| **Sangam Vihar** | 6 | 6 | 3 | 1 |
| **Makanpur** | 3 | 3 | 1.5 | 0.5 |
| **Shaheen Bagh** | 2.8 | 2.1 | 1.7 | 0.5 |
| **Okhla Vihar** | 2.5 | 2.2 | 1.5 | 0.2 |
| **Gobindpuri** | 2.8 | 2.8 | 1.8 | 0.8 |
| **Bengali Colony** | 1.26 | 1.26 | 1.26 | 1.26 |
| **Lakshmi Park** | 1.26 | 1 | 1 | 0.5 |
| **Garhi** | 4.2 | 2.5 | 1.5 | 0 |
| **Malviya Nagar** | 2.2 | 2 | 1.2 | 0 |
| **Vasant Vihar Slums** | 2.2 | 2.2 | 1.6 | 0.5 |
| **Nehru Vihar** | 2.47 | 1.8 | 1.2 | 0 |
| **Patel Nagar** | 1.78 | 1.3 | 0.8 | 0 |
| **Sudarshan Park** | 1.05 | 0.5 | 0.5 | 0 |
| **Krishna Vihar** | 4.15 | 3.2 | 2.2 | 1.2 |
| **Shastri Nagar** | 2.4 | 2 | 1.4 | 0.6 |
| **Azadpur** | 0.28 | 0.28 | 0 | 0 |
| **Krishna Nagar** | 2.7 | 2 | 1.2 | 0.4 |

2.3.4 Population Statistic

The first Indian census was conducted in 1951 with assistance from the Soviet Union, after the India-Pakistan partition in 1947. India has continuously conducted decadal censuses from that point onwards. The Census of India (COI) has been historically collecting data in urban areas and presenting it by settlement name, ward number, tehsil and district names. However, due to the dynamic nature of these unplanned settlements, it becomes very difficult to compare census data at settlement levels. Fig 2.3.4.1 shows how the Indian administrative system is divided.

Fig 2.3.4.1 Indian Administrative Hierarchy




The left branch of the flowchart indicates the federal levels of administration and the right side shows the state levels of administration. Each level has its political significance. Blocks/Villages and Tehsils ensure grass roots representation at the national level, whereas municipal wards and cities ensure representation at the state levels. In case of smaller cities, the tehsil boundary can be larger than the city. However, the case of Delhi is interesting since Delhi is a City-State.

Census information can be aggregated at any of the levels in the flowchart. Tehsil was chosen as unit of study since it was the lowest administrative level at which the political boundaries have remained stable during the period of study (1970-2000). Choice of tehsil as unit of population helped in making available consistent and comparable data over a period of time.

Preparing data for this variable required two steps;

(1) Identifying which tehsil each of the study settlements was in from the Survey of India.

(2) Recording tehsil populations for the study years from the Census of India.

Table 2.3.4.1 shows the tehsil population for the study settlements in Delhi.;

Table 2.3.4.1 Population of the Tehsil containing the sample settlement

| Population of Tehsil Containing Settlement | | | | |
|---|---|---|---|---|
| | **1970** | **1980** | **1990** | **2000** |
| **Pandav Nagar** | 62,143 | 70,035 | 106,033 | 205,492 |
| **Indraprastha Slums** | 6,072 | 7,214 | 23,529 | 31,474 |
| **Mahipalpur** | 42,154 | 45,357 | 46,264 | 65,603 |
| **Uttam Nagar** | 86,451 | 98,813 | 175,888 | 396,803 |
| **Nayagaon** | 38,122 | 46,573 | 127,611 | 399,169 |
| **Shahabad** | 16,255 | 17,347 | 18,388 | 21,128 |
| **Roshanpura** | 97,546 | 109,085 | 178,900 | 382,024 |
| **YamunaPushta** | 32,445 | 34,735 | 40,293 | 55,846 |
| **Laxmi Nagar** | 66,122 | 74,426 | 130,247 | 288,367 |
| **Sagarpur/Dabri** | 86,451 | 94,352 | 105,674 | 186,621 |
| **Palam Gaon** | 86,451 | 94,352 | 105,674 | 186,621 |
| **Najafgarh** | 72,112 | 74,895 | 145,686 | 172,645 |
| **Sangam Vihar** | 36,247 | 40,404 | 58,990 | 114,736 |
| **Makanpur** | 41,654 | 45,248 | 54,750 | 96,635 |
| **Shaheen Bagh** | 71,225 | 76,388 | 88,611 | 152,676 |
| **Okhla Vihar** | 71,225 | 76,388 | 88,611 | 152,676 |
| **Gobindpuri** | 71,225 | 76,388 | 88,611 | 152,676 |
| **Bengali Colony** | 27,461 | 28,795 | 41,596 | 52,487 |
| **Lakshmi Park** | 42,932 | 46,847 | 52,145 | 68,374 |
| **Garhi** | 63,114 | 68,251 | 76,714 | 135,401 |
| **Malviya Nagar** | 32,412 | 36,165 | 51,210 | 104,263 |
| **Vasant Vihar Slums** | 22,440 | 24,118 | 27,645 | 44,532 |
| **Nehru Vihar** | 82,514 | 90,039 | 101,204 | 178,928 |
| **Patel Nagar** | 74,692 | 85,343 | 167,784 | 442,279 |
| **Sudarshan Park** | 74,692 | 85,343 | 167,784 | 442,279 |
| **Krishna Vihar** | 41,551 | 45,406 | 56,213 | 102,590 |
| **Shastri Nagar** | 27,512 | 28,849 | 42,119 | 64,214 |
| **Azadpur** | 12,124 | 13,448 | 17,641 | 28,464 |
| **Krishna Nagar** | 66,122 | 74,426 | 130,247 | 288,367 |

### 2.3.5 Major Development Events during the Decade

Major development events are an indicator of how much government or private funding went into an area, for creating infrastructure like roads, bridges and residential complexes, which in turn create employment opportunities and/or make the area more desirable to live in.

A variable that captures the amount of money invested in an area would be ideal, however it became very difficult to obtain the investment quantities for these development events. This study, therefore, disregards the financial cost of development and considers just the number of development events within 5 kilometers of each settlement during the decade. Development events were identified as events that potentially involved an estimated investment of Rs. 50 Crores (USD 10 Million) or higher, based on the researcher's judgment.

The study also considers the development events at the time the work was initiated instead of the time at which a project culminated. This is because there are many construction jobs that are created during the length of project development that attract rural-urban migrants to move into nearby cheaper informal residential areas. This explanatory variable tries to capture that aspect of settlement growth.

Table 2.3.5.1 shows the number of development events during each of the 3 study decades:

Table 2.3.5.1 Number of Major Development Events within 5 Kms of each settlement

| | 1970-1980 | 1980-1990 | 1990-2000 |
|---|---|---|---|
| **Central-Roshanpura** | 0 | 9 | 5 |
| **East-Krishna Nagar** | 2 | 8 | 7 |
| **East-Laxmi Nagar** | 3 | 13 | 9 |
| **East-Makanpur** | 20 | 8 | 4 |
| **East-Pandav Nagar** | 6 | 11 | 8 |
| **New Delhi-Indraprastha Slums** | 2 | 3 | 5 |
| **New Delhi-YamunaPushta** | 4 | 6 | 4 |
| **North East-Nayagaon** | 1 | 5 | 4 |
| **North East-Nehru Vihar** | 3 | 5 | 7 |
| **North West-Azadpur** | 1 | 5 | 5 |
| **North West-Bengali Colony** | 4 | 2 | 6 |
| **North West-Lakshmi Park** | 3 | 5 | 8 |
| **North West-Shahabad** | 0 | 5 | 3 |
| **North West-Shastri Nagar** | 4 | 7 | 12 |
| **South-Garhi** | 5 | 12 | 7 |
| **South-Gobindpuri** | 6 | 4 | 7 |
| **South-Malviya Nagar** | 3 | 9 | 6 |
| **South-Okhla Vihar** | 12 | 7 | 6 |
| **South-Sangam Vihar** | 0 | 1 | 4 |
| **South-Shaheen Bagh** | 7 | 6 | 8 |
| **South West-Mahipalpur** | 2 | 2 | 3 |
| **South West-Najafgarh** | 0 | 0 | 20 |
| **South West-Palam Gaon** | 1 | 2 | 19 |
| **South West-Sagarpur/Dabri** | 1 | 2 | 23 |
| **South West-Vasant Vihar Slums** | 0 | 5 | 5 |
| **West-Krishna Vihar** | 6 | 7 | 6 |
| **West-Patel Nagar** | 7 | 8 | 8 |
| **West-Sudarshan Park** | 4 | 6 | 8 |
| **West-Uttam Nagar** | 0 | 2 | 15 |

### 2.3.6 Percentage of district land under structured/formal development

This factor was developed out of curiosity, at a later stage, to statistically test whether structured/planned development increases the rate of growth or decreases the rate of growth of informal settlements. Arguments exist that support both positive and negative impacts of formal development on growth of informal settlements. For example, increase in planned development creates service sector employment opportunities for proximate informal settlements, however, the desirability of informal settlements near planned developments is low, so planned development tends to bring the nearby informal settlements into view of the enforcement agencies, which limit their growth.

Table 2.3.6.1 shows the change in percentages of land, in districts corresponding to each settlement, over the four study years:

Table 2.3.6.1 Percent Formal/Structured Development

| Percent Formal/Structured Development | | | | | |
|---|---|---|---|---|---|
| | **District Name** | **1970** | **1980** | **1990** | **2000** |
| **Pandav Nagar** | East | 22.00% | 26.00% | 37.00% | 42.00% |
| **Indraprastha Slums** | New Delhi | 68.00% | 72.00% | 86.00% | 86.00% |
| **Mahipalpur** | South West | 12.00% | 22.00% | 32.00% | 39.00% |
| **Uttam Nagar** | West | 17.00% | 28.00% | 32.00% | 37.00% |
| **Nayagaon** | North East | 13.00% | 18.00% | 22.00% | 26.00% |
| **Shahabad** | North West | 4.00% | 8.00% | 12.00% | 14.00% |
| **Roshanpura** | Central | 48.00% | 62.00% | 62.00% | 68.00% |
| **YamunaPushta** | New Delhi | 68.00% | 72.00% | 86.00% | 86.00% |
| **Laxmi Nagar** | East | 22.00% | 26.00% | 37.00% | 42.00% |
| **Sagarpur/Dabri** | South West | 12.00% | 22.00% | 32.00% | 39.00% |
| **Palam Gaon** | South West | 12.00% | 22.00% | 32.00% | 39.00% |
| **Najafgarh** | South West | 12.00% | 22.00% | 32.00% | 39.00% |
| **Sangam Vihar** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Makanpur** | East | 22.00% | 26.00% | 37.00% | 42.00% |
| **Shaheen Bagh** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Okhla Vihar** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Gobindpuri** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Bengali Colony** | North West | 4.00% | 8.00% | 12.00% | 14.00% |
| **Lakshmi Park** | North West | 4.00% | 8.00% | 12.00% | 14.00% |
| **Garhi** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Malviya Nagar** | South | 12.00% | 16.00% | 18.00% | 22.00% |
| **Vasant Vihar Slums** | South West | 14.00% | 22.00% | 32.00% | 39.00% |
| **Nehru Vihar** | North East | 13.00% | 18.00% | 22.00% | 26.00% |
| **Patel Nagar** | West | 17.00% | 28.00% | 32.00% | 37.00% |
| **Sudarshan Park** | West | 17.00% | 28.00% | 32.00% | 37.00% |
| **Krishna Vihar** | West | 17.00% | 28.00% | 32.00% | 37.00% |
| **Shastri Nagar** | North West | 4.00% | 8.00% | 12.00% | 14.00% |
| **Azadpur** | North West | 4.00% | 8.00% | 12.00% | 14.00% |
| **Krishna Nagar** | East | 22.00% | 26.00% | 37.00% | 42.00% |

## 2.4 Research Procedures

After using GIS and Microsoft Excel to properly structure the database, the statistical analyses were conducted in two steps:

- Bivariate regression analyses to test the type of relationships that exist between each dependent variable and the explanatory variables. This step showed whether the relationship was linear, exponential, cubic and also gave the researcher the statistical significance of each type of relationship.
- Multivariate regression analyses to see how the independent variables independently and collectively explain the variation in change in settlement growth.

The bivariate analyses is important as it informs the multivariate analyses. Our multivariate analysis is based on the following function:

**ΔArea or ΔNDVI = β1*Distance to Nearest bus stop + β2*Major Development Events +β3*Ground Water Level at the start of Decade+β4*ΔJobs+β5*ΔTehsil Population +β6*ΔPercent of Planned Development + Constant**

## 2.5 Expected Results

Table 2.5.1 outlines the different relationships that needed to be statistically tested and expected results.

Table 2.5.1 Hypotheses to be statistically tested

| Variables | | **Major Dev Events** | **Jobs** | **Ground Water** | **Distance to Bus Stop** | **% of organized Dev** | **Tehsil Pop** |
|---|---|---|---|---|---|---|---|
| **Area and BI** | Expected Strength | ++ | +++ | +++ | ++ | + | ++ |
| | **Logic** | Development Events provide temporary construction jobs, and later provide permanent informal jobs. This leads to more people moving in. | CBD jobs provide steady sources of income. Proximity to CBDs gives more options to informal settlers. | Ground water is used as a primary source of water since piped water is not given to informal settlements. Higher water table means more people. | Proximity to public transit would increase the desire to live in certain areas. Informal settlers normally have low vehicular ownership rates. | Increase in organized development brings more infrastructure into the area, possibly making the places more desirable to live in. However, it is also possible that restictions on informal growth be put when an area is planned. | Growth rate of tehsil would reflect growth of settlements in it. |

After the analysis phase, results would be added to this table to study if our hypotheses were supported.

# CHAPTER III: ANALYSIS

This chapter discusses the results of the two step analysis conducted for this study. The first step deals with bivariate analyses between each explanatory variable and the two dependent variables to identify the type of relationship and the strength of relationships. The second section details the results of multivariate analyses using all the explanatory variables to explain the change in our two dependent variables.

Before discussing actual statistical analysis, it would be interesting to look at how the values of NDVI and Settlement area have change for our sample of settlements over the past 40 years. The graph showing change in settlement areas (Fig 3.1) does not show any conclusive observations however the NDVI graph (Fig 3.2) suggests that almost all informal settlements show signs of converging to a similar level of NDVI by the year 2000. This indicates that the settlements are reaching similar levels of intensity of development or are potentially reaching build out. This is an expected phenomenon because scarcity of land  in one settlement would lead to people switching location choice to other settlements due to budget constraints, until all settlements reach a very similar developmental state.

Fig 3.1 Change in area over time (Y-axis in sq. km.)

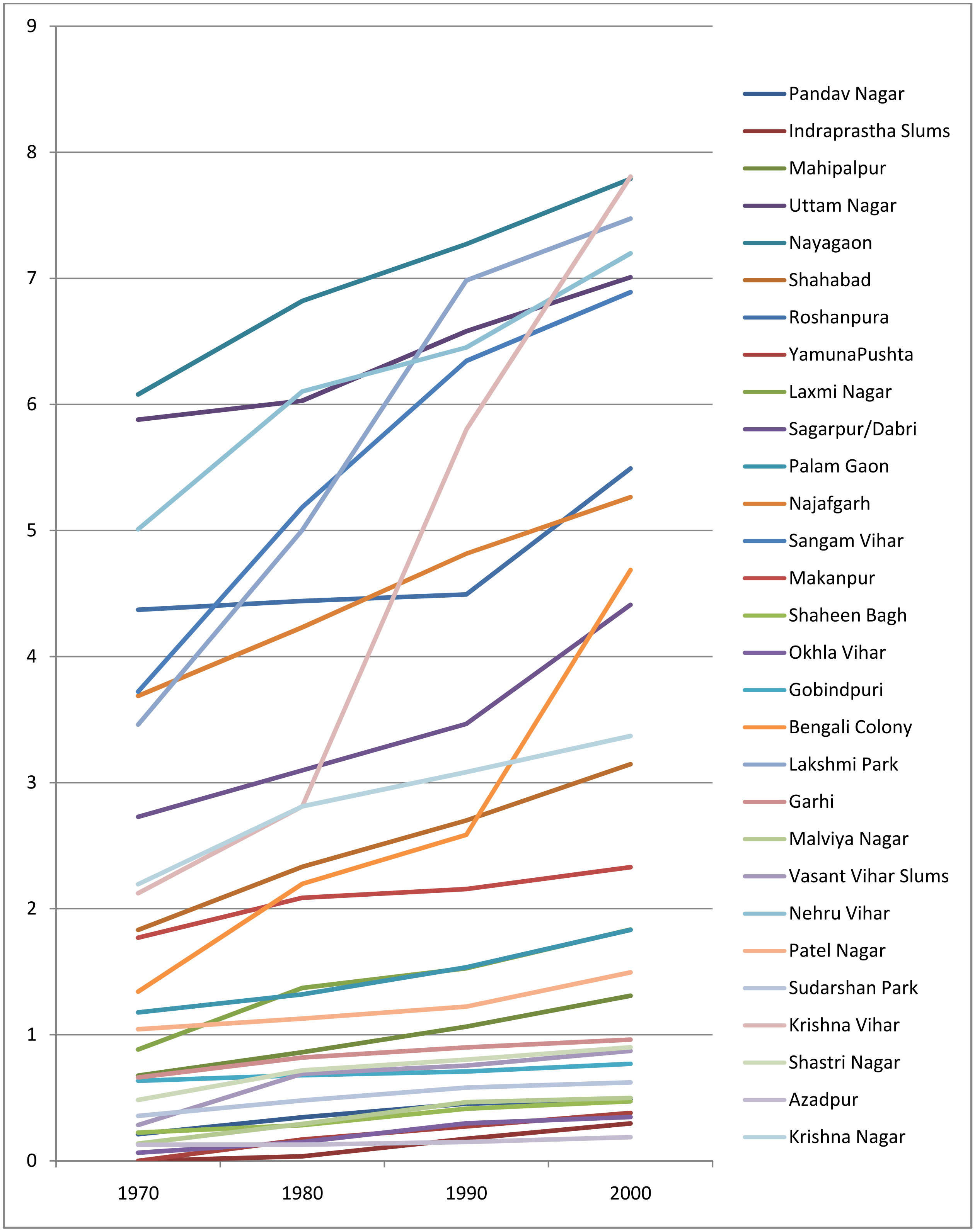
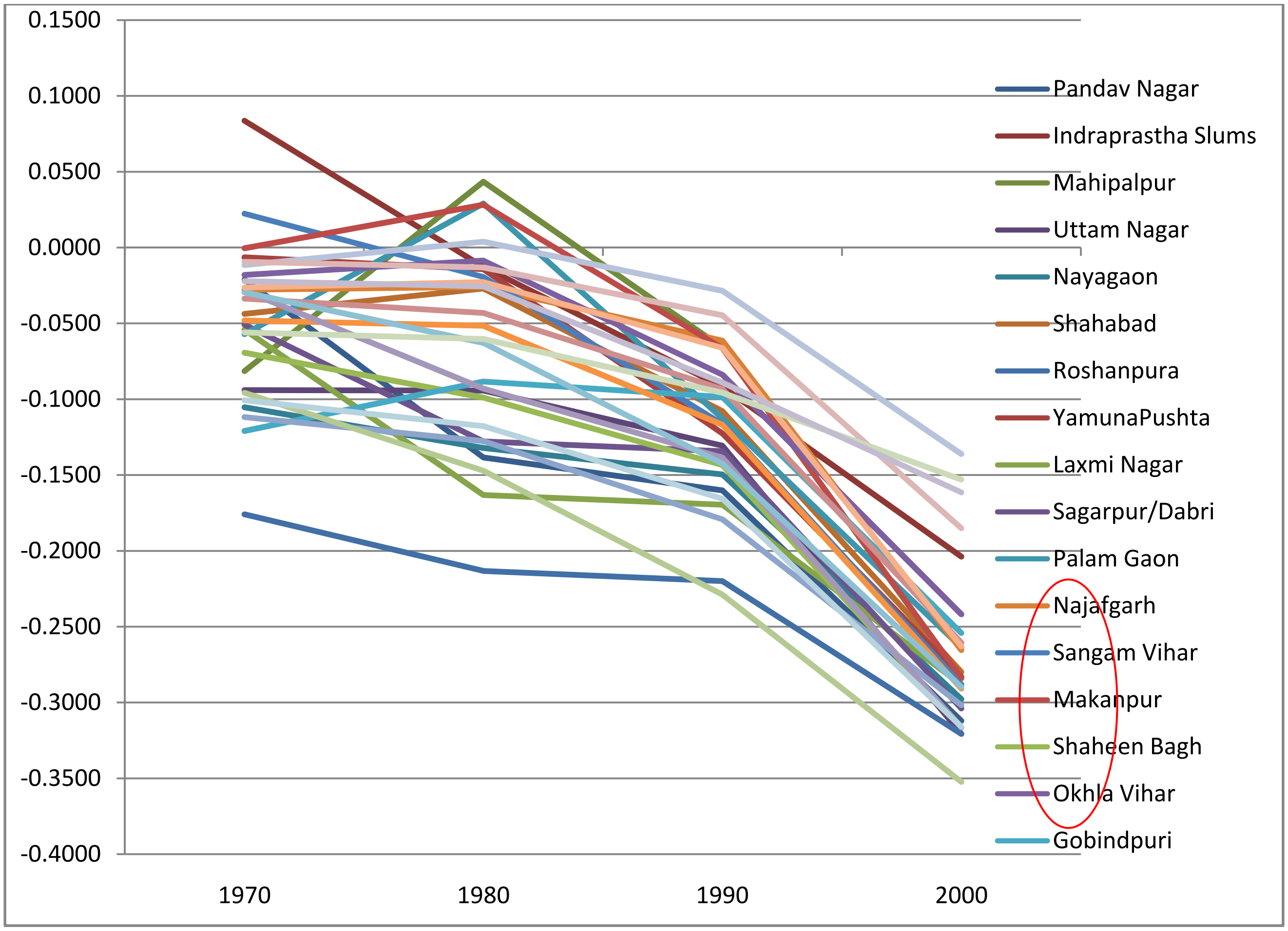


Fig 3.2 Change in NDVI over time



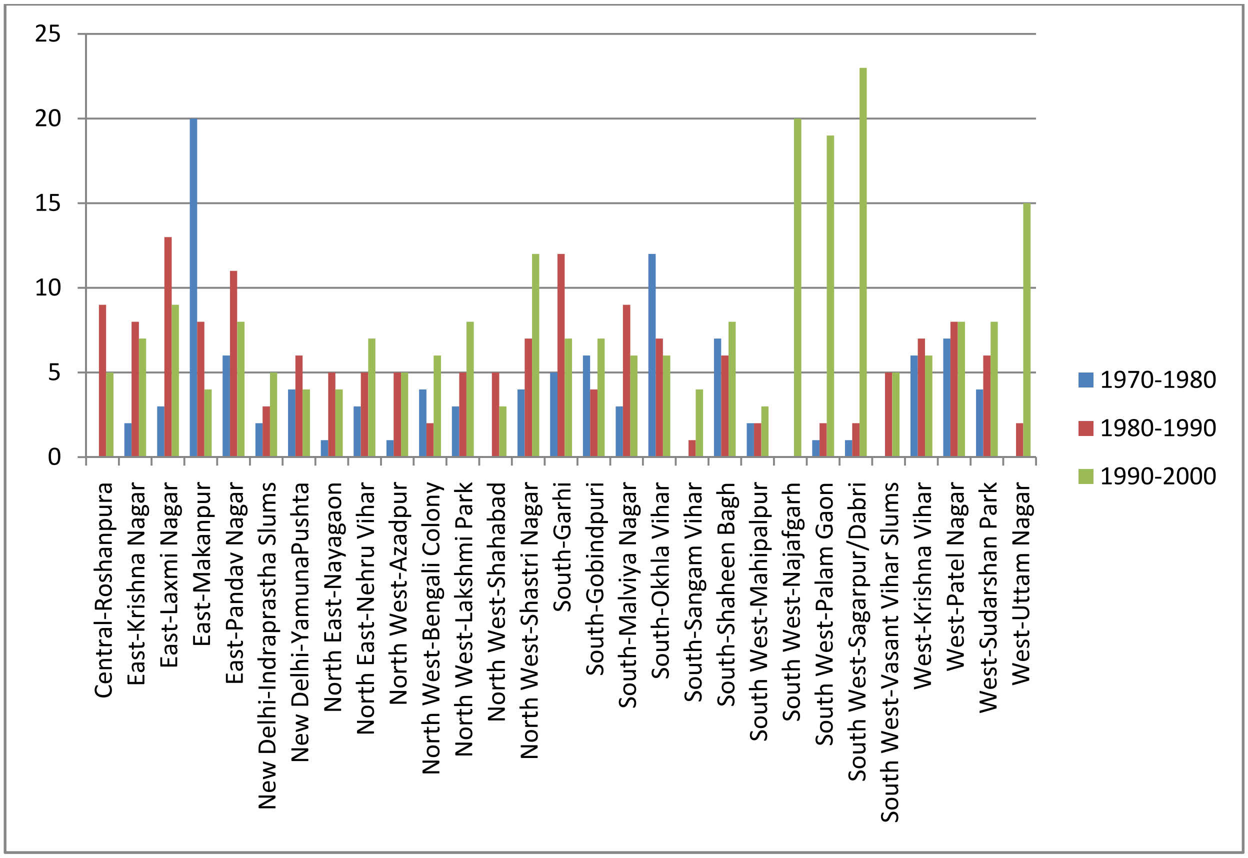
## 3.1 Bivariate Analysis

### 3.1.1 Major Development Events

The graph below shows the development events within 5 kilometers of the study settlements over three decades. A development event was defined as any government initiated project with an estimated cost of over Rs. 50 Crores (USD 10 million).

Certain interesting observations can be made by looking at this graph. *The first is that East Delhi saw the most government initiated growth in the 1970s and 1980s. Secondly, development focus shifted to the southwest in the 1990s.* This is because East district is across the river Yamuna and the government realized the growth potential on the other side of the river in the late 1960s. Several bridges were made in the 70s that provided direct access to central Delhi from the other side of the river.

Fig 3.1.1.1 Major Development Events near sampled settlements




The next step was to study the relationship between Major Development Events and NDVI and Area. A curve fit analysis was done on SPSS which showed the following results:

Table 3.1.1.1 Relationship with Change in Area

| Equation | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .004 | .360 | 1 | 85 | .550 | .446 | -.008 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .021 | .890 | 2 | 84 | .415 | .554 | -.045 | .002 | |
| Cubic | .037 | 1.069 | 3 | 83 | .367 | .453 | .030 | -.009 | .000 |

The independent variable is Major Dev Events within 5 Kms.

Table 3.1.1.2 Relationship with Change in BI

| Equation | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .065 | 5.935 | 1 | 85 | .017 | -.051 | -.004 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .076 | 3.468 | 2 | 84 | .036 | -.039 | -.008 | .000 | |
| Cubic | .121 | 3.819 | 3 | 83 | .013 | -.016 | -.025 | .003 | -8.168E-5 |

<u>Findings</u>

One can see that the significances of Development events is higher when regressed against BI or the intensity proxy compared to change in settlement area. Also, highest levels of significance can be seen in the linear and cubic regressions.

### 3.1.2 Change in Jobs

Similar analysis was done for jobs at CBDs within 5 kilometers of each of the study areas. Since the purpose of this study is to find the relationship between change in intensity of development and change and spatial size of settlements with independent variables, the delta values were tested first for potential relationships and their strengths.

Table 3.1.2.1 Relationship with Change in Area

| Equation | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .003 | .227 | 1 | 85 | .635 | .422 | -6.079E-6 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .021 | .903 | 2 | 84 | .409 | .381 | 3.509E-5 | -3.084E-9 | |
| Cubic | .022 | .630 | 3 | 83 | .598 | .372 | 5.366E-5 | -6.448E-9 | 1.375E-13 |

The independent variable is Change in Jobs within 5 Km.

Table 3.1.2.2 Relationship with Change in BI

| Equation | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .081 | 7.517 | 1 | 85 | .007 | -.089 | 4.543E-6 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .082 | 3.744 | 2 | 84 | .028 | -.088 | 3.539E-6 | 7.520E-11 | |
| Cubic | .082 | 2.478 | 3 | 83 | .067 | -.089 | 4.868E-6 | -1.654E-10 | 9.835E-15 |

The independent variable is Change in Jobs within 5 Km.

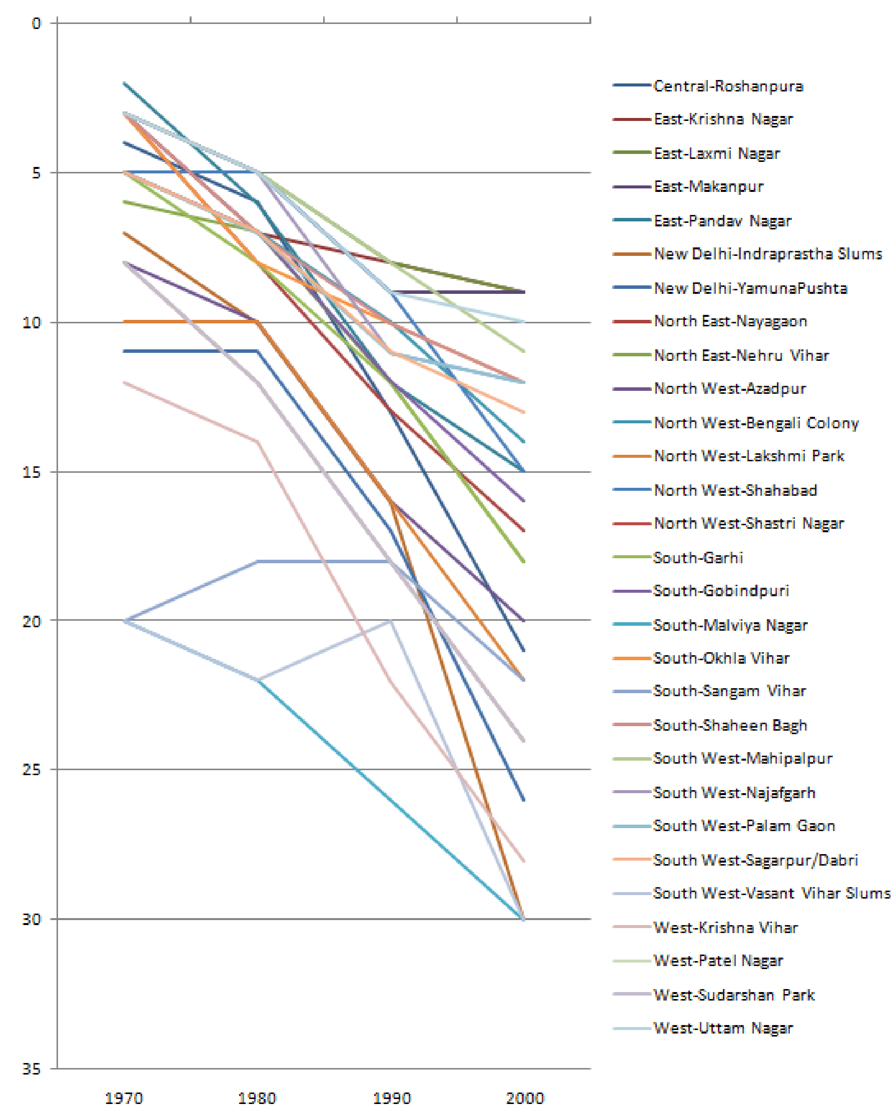
<u>Findings</u>

The analysis shows that jobs have a more significant relationship with BI than they do with the area. The association also seems to be linear in nature.

3.1.3 Ground Water Depth below Surface

Ground water is one of the key elements which would be tested in this study. The hypothesis is that people tend to develop informal settlements or existing informal settlements flourish in locations where ground water levels are higher due to lack of piped potable water access.

Fig 3.1.3.1 Ground Water Variation (in meters below surface) from 1970-2000



From the graph we can see that the slope is highest for Indraprastha Slums, which are located close to the Yamuna river bank in the central part of the city. The ground water levels changed to 30 meters below ground level in 2000 from 7 meters in 1970. A constant decline can be seen in all cases with a lower decline rate in the eastern settlements. This is because East Delhi falls on both the Yamuna and Ganga flood plains, and has sub-surface characteristics that permit higher aquifer recharge rates[1].

Table 3.1.3.1 Relationship with Change in Area

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .021 | 1.854 | 1 | 85 | .177 | .264 | .014 | | |
| Logarithmic | .023 | 2.011 | 1 | 85 | .160 | .112 | .136 | | |
| Quadratic | .028 | 1.211 | 2 | 84 | .303 | .123 | .044 | -.001 | |

Table 3.1.3.2 Relationship with Change in BI

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .163 | 16.518 | 1 | 85 | .000 | -.023 | -.005 | | |
| Logarithmic | .210 | 22.598 | 1 | 85 | .000 | .044 | -.055 | | |
| Quadratic | .242 | 13.437 | 2 | 84 | .000 | .044 | -.019 | .001 | |

Findings

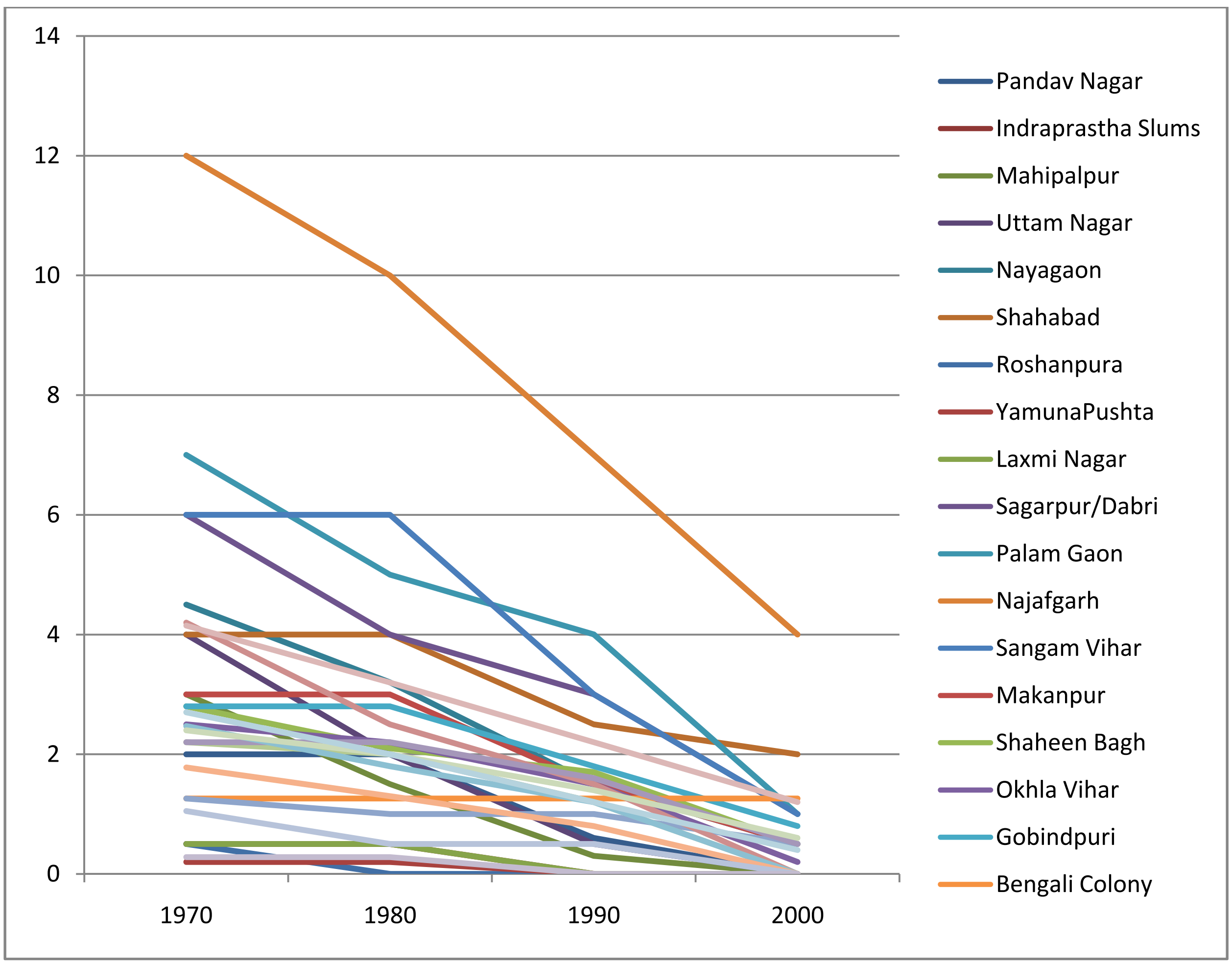
Upon doing the curve fit tests to identify bi-variate relationship between Area change, BI change and ground water levels at the start of the decade, results show highest significance in a logarithmic relationship with area change.

[1] http://rainwaterharvesting.org/index_files/water_level_fluct.htm

3.1.4 Distance to Nearest Bus Stop

The next variable to be studied is distance to public transit access (Bus Stops). The graph below shows the changes in distance from the centroid of study settlements to the closest bus station over a period of 40 years.

Fig 3.1.4.1 Distance (in kms) to Bus Stop Change from 1970-2000



Since there is a huge demand for public transport by the lower income population of New Delhi, the Delhi Transit Corporation and the State Transit Authority have made constant effort to increase both frequencies and coverage of the bus transport network. This is clearly visible in the above graph as a constant decline in the distance one has to travel from settlements to bus stops occurs in all cases. It is interesting to note that improvements in public transit accessibility for settlements further away from the center was less apparent than settlements closer to the center. Some examples would be settlements towards the north like Bengali colony.

The tables below show the results of a curve fit test done for distance to bus stop.

Table 3.1.4.1 Relationship with Change in Area

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .029 | 2.536 | 1 | 85 | .115 | .304 | .043 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .039 | 1.685 | 2 | 84 | .192 | .238 | .098 | -.006 | |
| Cubic | .039 | 1.113 | 3 | 83 | .349 | .231 | .109 | -.009 | .000 |

Table 3.1.4.2 Relationship with Change in BI

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .061 | 5.561 | 1 | 85 | .021 | -.093 | .008 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .069 | 3.117 | 2 | 84 | .049 | -.101 | .015 | .000 | |
| Cubic | .074 | 2.221 | 3 | 83 | .092 | -.108 | .026 | -.004 | .000 |

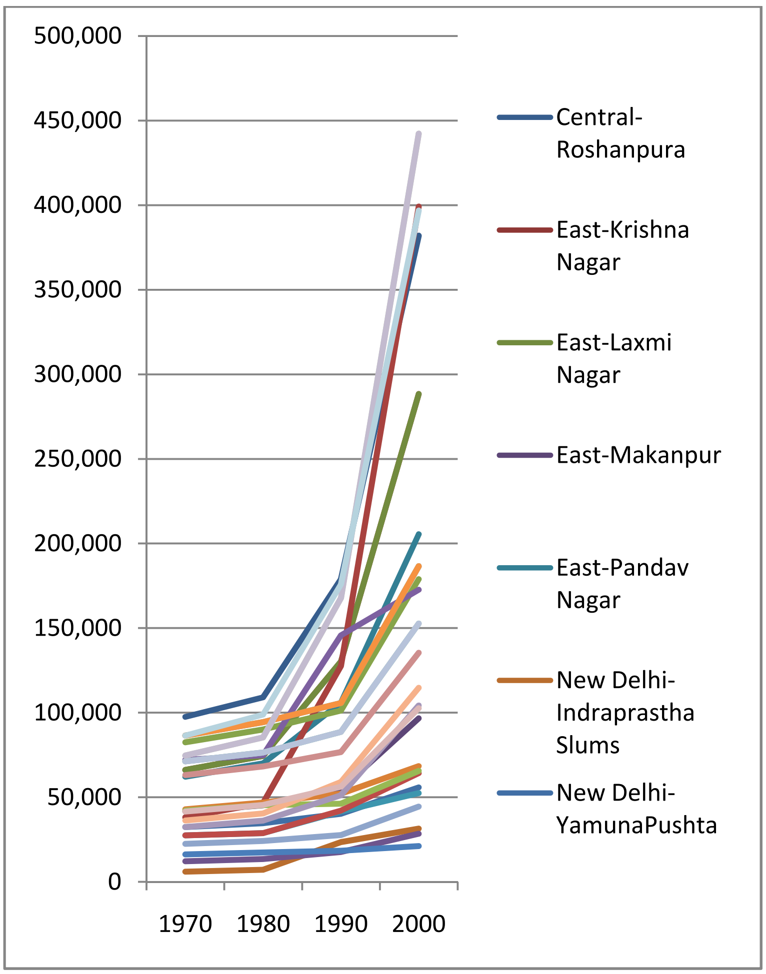
Findings

Significances are again higher in relationship with intensity. Linear relationship has the highest level of significance in the BI analysis.

3.1.5 Change in Tehsil Populations

This line chart plots the population of the Tehsil that the settlement belongs to.

Fig 3.1.5.1 Tehsil Population growth trends



The graph clearly shows that the growth rate of eastern settlements has been significantly higher as compared to settlements in other parts of the city, specifically during 1980 to 2000.

Table 3.1.5.1 Relationship with Change in Area

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .001 | .089 | 1 | 85 | .766 | .413 | -2.751E-7 | | |
| Logarithmic | .001 | .090 | 1 | 85 | .765 | .515 | -.012 | | |
| Quadratic | .002 | .077 | 2 | 84 | .926 | .424 | -9.576E-7 | 2.931E-12 | |
| Cubic | .008 | .221 | 3 | 83 | .881 | .456 | -4.608E-6 | 5.115E-11 | -1.330E-16 |

Table 3.1.5.1 Relationship with Change in BI

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .162 | 16.4 | 1 | 85 | .000 | -.056 | -4.627E-7 | | |
| Logarithmic | .228 | 25.1 | 1 | 85 | .000 | .150 | -.023 | | |
| Quadratic | .198 | 10.3 | 2 | 84 | .000 | -.045 | -1.085E-6 | 2.671E-12 | |
| Cubic | .217 | 7.67 | 3 | 83 | .000 | -.038 | -1.969E-6 | 1.435E-11 | -3.221E-17 |

Findings

One can see that the significances of tested relationships between spatial growth of settlements and the increase in Tehsil population are negligible as opposed to stronger relationships between Tehsil population growth and the settlement's building intensity (BI). Logarithmic appears to be the best fit.

### 3.1.6 Change in Percentage of Structured Development

The tables below show the results for curve fit tests between change in percentage structured development and change in area and change in BI.

Table 3.1.6.1 Relationship with Change in Area

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .008 | .695 | 1 | 85 | .407 | .474 | -.012 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .008 | .346 | 2 | 84 | .708 | .465 | -.010 | .000 | |
| Cubic | .055 | 1.620 | 3 | 83 | .191 | .158 | .156 | -.021 | .001 |

Table 3.1.6.2 Relationship with Change in BI

| | Model Summary | | | | | Parameter Estimates | | | |
|---|---|---|---|---|---|---|---|---|---|
| Equation | R Square | F | df1 | df2 | Sig. | Constant | b1 | b2 | b3 |
| Linear | .047 | 4.154 | 1 | 85 | .045 | -.097 | .004 | | |
| Logarithmic | . | . | . | . | . | .000 | .000 | | |
| Quadratic | .048 | 2.132 | 2 | 84 | .125 | -.091 | .002 | .000 | |
| Cubic | .064 | 1.885 | 3 | 83 | .138 | -.067 | -.011 | .002 | -5.258E-5 |

<u>Findings</u>

BI has higher levels of significance in relationship with changes in percentage structured development, as compared to the actual change in area. Linear form is the best fit.

### 3.1.7 Correlation between Settlement Area and BI

In context of this study, it is interesting to look at whether the Intensity and Settlement Area are closely correlated. Logic suggests that where intensity increases more the growth in area would be less. The correlation analysis suggests that Settlement Area and BI are negatively related, which is to be expected. However, the level of significance is substantially low.

Table 3.1.7.1 Correlation between Change in Area and Change in BI

| | | Change in Area of Settlement SQKM | Change in NDVI |
|---|---|---|---|
| Change in Area of Settlement SQKM | Pearson Correlation | 1 | -.038 |
| | Sig. (2-tailed) | | .724 |
| | N | 87 | 87 |
| Change in NDVI | Pearson Correlation | -.038 | 1 |
| | Sig. (2-tailed) | .724 | |
| | N | 87 | 87 |

After studying and analyzing each variable individually, the next step is to see how the independent variables together effect our dependent variables. For the next step, this study uses multiple regression modeling to identify any multivariate relationships that determine the changes in growth and intensity of informal settlements in New Delhi.

## 3.2 Multivariate Analysis

One of the primary objectives of this thesis is to study the impact of changes in our independent variables on the change in settlement spatial growth or intensity. For this, it is required to do a multivariate regression analysis using the Δ values (change during decade) instead of the absolute values for the four cross sections of time. To examine the influence of the independent variables on settlement growth, several multivariate regression models were estimated. These included (1) a model explaining change in area and intensity values (2) models explaining absolute values of spatial extent and intensity of settlements over time.

### 3.2.1 Multivariate Regression for Absolute Values

Table 3.2.1.1 Multivariate Regression for Absolute Settlement Area Values

**Model Summary[b]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .391a | .153 | .115 | 2.1819010 |

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 1.045 | .648 | | 1.613 | .110 |
| | Jobs within 5 Km | -2.327E-5 | .000 | -.140 | -1.350 | .180 |
| | Ground Water Zone (Depth in Meters) | .024 | .032 | .070 | .731 | .466 |
| | Distance to nearest Bus Stop | .252 | .116 | .219 | 2.164 | .033 |
| | Percentage of Planned development in District | .000 | .013 | -.008 | -.073 | .942 |
| | Tehsil Population | 9.482E-6 | .000 | .353 | 3.820 | .000 |

Table 3.2.1.2 Multivariate Regression for Absolute BI Values

**Model Summary**[b]

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .679[a] | .461 | .437 | .03880159 |

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .524 | .012 | | 45.477 | .000 |
| | Jobs within 5 Km | 2.243E-7 | .000 | .061 | .732 | .466 |
| | Ground Water Zone (Depth in Meters) | .002 | .001 | .302 | 3.971 | .000 |
| | Distance to nearest Bus Stop | -.006 | .002 | -.231 | -2.867 | .005 |
| | Percentage of Planned development in District | .000 | .000 | -.053 | -.628 | .532 |
| | Tehsil Population | 2.500E-7 | .000 | .418 | 5.665 | .000 |

a. Dependent Variable: BI

Findings

The BI model has a significantly higher R-Square value compared to the Area model. This indicates that our factors explain actual BI values in the study settlements better than they explain the size of settlements.

Subsequent models also tested for non-linearities in the relationships. This was expected to improve the model parameters given our earlier analysis of bivariate relationships that suggested many of the relationships were indeed non linear.

3.2.2 Multivariate regression for change values

Table 3.2.2.1 Multivariate Regression explaining Change in Settlement Area

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .276[a] | .076 | .007 | .5260494 |

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .250 | .212 | | 1.180 | .242 |
| | Dist to Nearest Bus Stop at Start of Decade | .055 | .029 | .219 | 1.911 | .060 |
| | Major Dev Events within 5 Kms | -.007 | .013 | -.059 | -.518 | .606 |
| | Ground Water Zone (Depth in Meters) at start of decade | .016 | .011 | .167 | 1.423 | .159 |
| | Change in Jobs within 5 Km | -1.785E-6 | .000 | -.015 | -.136 | .892 |
| | Change in Tehsil Population | -1.245E-7 | .000 | -.015 | -.126 | .900 |
| | Change in Percentage of DDA development in the District | -.014 | .016 | -.102 | -.881 | .381 |

Findings

In the first model (Table 3.2.2.1) we see that only Distance to public transit has a reasonable level of significance in determining the change in an informal settlement's size. The other factors are not at an acceptable level of significance. Also the R-Square value is very low. In addition, the scatter plot indicated the presence of Heteroscedasticity[2] in the data. Table

3.2.2.2 Multivariate Regression explaining Change in BI

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .565[a] | .320 | .278 | .03032259 |

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | .015 | .011 | | 1.348 | .181 |
| | Change in Percentage of DDA development in the District | .000 | .001 | -.071 | -.729 | .468 |
| | Change in Tehsil Population | 1.593E-7 | .000 | .277 | 2.842 | .006 |
| | Change in Jobs within 5 Km | -1.341E-6 | .000 | -.168 | -1.779 | .079 |
| | Major Dev Events within 5 Kms | .001 | .001 | .136 | 1.414 | .161 |
| | Ground Water Zone (Depth in Meters) at start of decade | .002 | .001 | .274 | 2.750 | .007 |

a. Dependent Variable: Change in BI

[2] An irregular scattering of values in a series of distributions; accompanied by a comparable scatter of variances.

Findings

The second model (Table 3.2.2.2) which studies the impact of change in various factors on BI has a relatively higher R-Square value and the levels of significance of the dependent variables are also reasonable. Change in jobs and planned development have a negative impact on the built intensity (BI) of informal settlements.

After observing the results from the bivariate analyses, it was seen that in most cases the relationship between change in area and the explanatory variables was not linear, or in other words the significance for non linear relationships was higher. Therefore, it was necessary to do a log-log model, where natural logs of the change in area were regressed against the logs of the explanatory variable values. The next section discusses the results for this analysis.

### 3.2.3 Log-Log Model

Considering the results from bivariate analyses conducted on the dataset, it was a possibility that the relationships between Change in Area and Change in other variables is not a linear relationship. In order to build a model that explores this scenario logarithms of the change in independent variables were regressed with the logarithm of change in area. The advantage of doing this is that taking logarithms changes an exponent relationship between original variables into a linear relationship between the logarithms. The results are as follows:

Table 3.2.3.1 Multivariate Regression explaining Log of Change in Area

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .527[a] | .278 | .200 | .433038158504762 |

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -8.320 | 4.267 | | -1.950 | .057 |
| | Log of Change in Tehsil Pop | 1.191 | .687 | .274 | 1.732 | .090 |
| | Log of Dist to Bus Stop | .431 | .181 | .338 | 2.386 | .021 |
| | Log of Ground Water | .144 | .269 | .081 | .536 | .595 |
| | Log of Major Dev | -.405 | .206 | -.301 | -1.966 | .055 |
| | Log of Change in Jobs | .000 | .060 | .000 | -.005 | .996 |

Findings

One can see that the significances are higher in the log-log model as compared to the model that studies the absolute figures of change (Model 2A). The R-Square also is substantially higher in this case. All coefficients except Major Development Events are positive, which means with more planned development events, growth of informal settlements is limited.

### 3.2.4 Semi Log Model

The Semi-Log Model is similar to the log model, however it takes non logarithmic values for ground water level, distance to bus stop and change in percentage developed area for regression.

Table 3.2.4.1 Semi Log Regression for Change in Area

**Model Summary**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .463[a] | .214 | .116 | .4610814472 |

**Coefficients**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -7.943 | 4.131 | | -1.923 | .060 |
| | Ground Water Zone (Depth in Meters) at start of decade | .004 | .013 | .042 | .275 | .785 |
| | Dist to Nearest Bus Stop at Start of Decade | .057 | .034 | .269 | 1.644 | .107 |
| | Log of Major Dev | -.409 | .235 | -.295 | -1.743 | .088 |
| | Log of Change in Tehsil Pop | 1.149 | .650 | .274 | 1.767 | .084 |
| | Change in Percentage of DDA development in the District | -.012 | .018 | -.098 | -.698 | .489 |
| | Log of Change in Jobs | .010 | .064 | .024 | .156 | .877 |

a. Dependent Variable: Log of Change in Area

The semi log model shows a lower R-Square value compared to the log-log model.

## 3.3 Analysis Summary

Upon comparing and studying the results of the bivariate analysis we see that some of our hypotheses were correct. However, it is interesting to note that BI has a stronger relationship with each of our explanatory variables than area of settlements. This is an interesting finding and one can say *that there is more densification that occurs in these informal settlements than the actual settlement spatial expansion*. The table below gives a consolidated look at the results from all the bivariate analyses.

Table 3.3.1 Consolidated results from the bivariate analyses

| ` | | | Major Dev Events | Jobs | Ground Water | Distance to Bus Stop | % of Structured Dev | Tehsil Pop |
|---|---|---|---|---|---|---|---|---|
| HYPOTHESIS | Area and Intensity NDVI | Expected Strength | ++ | +++ | +++ | ++ | + | ++ |
| | | Logic | Development Events provide temporary construction jobs, and later provide permanent informal jobs. This leads to more people moving in. | CBD jobs provide steady sources of income. Proximity to CBDs gives more options to informal settlers. | Ground water is used as a primary source of water since piped water is not given to informal settlements. Higher water table means more people. | Proximity to public transit would increase the desire to live in certain areas. Informal settlers normally have low vehicular ownership rates. | Increase in organized development brings more infrastructure into the area, possibly making the places more desirable to live in. However, it is also possible that restictions on informal growth be put when an area is planned. | Growth rate of tehsil would have a direct impact on growth of settlements in it. |
| Statistical Results | Area | Sig | 0.367 | 0.409 | 0.16 | 0.115 | 0.191 | 0.765 |
| | | Relationship with highest significance | Cubic | Quadratic | Logarithmic | Linear | Cubic | Logarithmic |
| | NDVI | Sig | 0.013 | 0.007 | 0 | 0.021 | 0.045 | 0 |
| | | Relationship with highest significance | Cubic | Linear | Linear/Log/Quadratic | Linear | Linear | Linear/Log/Quad/Cubic |

The table indicates that BI is linearly related to most of our explanatory variables, whereas Area is related to different variables with different degrees of exponent.

Table 3.3.2 Consolidated results from multivariate analyses

| | | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
|---|---|---|---|---|---|---|---|
| | | **Absolute Values** | | **Decadal Change Values** | | **Log Values** | **Semi Log** |
| **ND** | | Area | BI | ΔArea | ΔBI | Log(ΔArea) | Log(ΔArea) |
| **R - Square** | | **0.153** | **0.461** | **0.076** | **0.328** | **0.278** | **.114** |
| Jobs | Coeff(Sig) | -.14(.18) | - .061(0.466) | -.015(.892) | .173(.071) | 0(.996) | .024(.87) |
| Ground Water | | .07(.466) | -.302(0) | .167(.159) | -.261(.011) | .081(.595) | .04(.78) |
| Bus Stop | | .219(.033) | .231(.005) | .219(.06) | .096(.329) | .338(.021) | .26(.1) |
| Tehsil Population | | .353(0.0) | -.418(0) | -.015(.9) | -.26(.01) | .274(.09) | .27(.08) |
| Planned Development | | -.008(.942) | .053(.532) | -.102(.381) | .053(.59) | - | -.098(.48) |
| Major Development Events | | - | - | -.059(.606) | -.13(.182) | -.301(.055) | .02(.87) |

The above table gives a consolidated view of results from the six multivariate models that this study tested. Model 2 has the highest R-Square value, which is a regression of the absolute figures for all variables regressed against average settlement BI values at particular points of time.

BI models have a higher R-Square value in general when compared to similar models with area as the dependent variable. This indicates that even as a whole, our explanatory variables explain intensity of growth better than they explain the settlement expansion.

# CHAPTER IV: DISCUSSION AND CONCLUSIONS

## 4.1 Introduction

This study examined the factors affecting the growth of informal settlements in New Delhi from the period 1970-2000. It tested the hypotheses that ground water is a significant factor when lower income population choose their residential location, whether intensity of growth or spatial expansion is more prevalent in the case of New Delhi and what changes occur to both when public transit access is improved and developmental investments occur in close proximity to informal settlements. The hypotheses were tested by statistically analyzing the absolute values and the decadal change values of all variables, using bivariate and multivariate regression modeling.

## 4.2 Expected Findings and Results

The first question asked in this study is the importance of ground water availability to informal settlers given that these settlements lack piped water. The results show that Ground water is relatively significant in determining the spatial growth of settlements and extremely significant in determining the intensity of development within settlements. This supports our initial hypothesis. Another interesting thing to note would be the coefficients of ground water in table 3.3.2, which indicate that if the ground water levels increase, the intensity and area of settlements both increase. However, intensity increases faster than area. This is also what was expected before conducting statistical testing, and the relative strength of relationship is also in accordance with anticipated result, thus supporting our null hypothesis.

Second, one can see from the bivariate analysis results that proximity to bus stops is of much higher significance as compared to the availability of jobs nearby and close developmental investments. From this observation, one may say that as long as there is good public transit access or bus access, people do not mind distance between place of work and place of residence in New Delhi. Also, in almost all cases the intensity of development is better related to our explanatory variables. Intensity shows linear relationships with most explanatory variables whereas area shows more complex relationships like cubic, quadratic and log.

Thirdly, from the multivariate analysis we note that the BI models have a higher R-Square value than any other models. This indicates that the intensity of development is the more relevant variable that is explained by the independent variables used in this study. Available data and personal observations suggest spatial expansion reaches peak after a certain time in New Delhi while density keeps increasing. This is due to the spatial constraints imposed by planned development. This argument can also be statistically reinforced by considering the negative coefficient of both decadal change and the absolute value of percent planned development in the district .

Several other interesting observations were found during the course of this research, like the intensity levels of all settlements reaching very similar values towards the end of the forty year study period, indicating saturation levels, and the growth focus shifting towards southwest Delhi in the 90s as compared to east Delhi in the 70s and early 80s. The ground water table has gradually been falling throughout the city, however eastern part of Delhi has seen a lower decline rate due to higher ground water recharge areas. Although ground water has played a crucial role in the past growth of these settlements, it may not be a major determinant for future growth due to regularization of these informal settlements and undergoing provisions for piped water. One can speculate that current property prices (affordability) would determine which settlements grow more than other factors.

Greater strength of the log-log model and semi log model indicates that there exists a multiplicative effect of our explanatory variables in determining the change in area of such urban informalities.

## 4.3 Planning Implications

Planners in India have struggled to develop a policy for controling the growth of informal settlements throughout the country, particularly in the capital. By understanding the dynamics of informal growth planners can improve their chances of predicting accurately where and how such settlements will grow and thereby develop appropriate plans to accommodate this growth. Factors like water and public transit access prove to be very important inthe migrants' location decisions. Therefore, plans should carefully consider the implications of transportation and water delivery improvements for settlement growth.

Ground water levels play a substantial role in the growth of informal settlements in Delhi. Settlements in the east have flourished due to easier access to aquifer water as opposed to the settlements in the west. The lack of piped water to informal settlements is partly responsible for the exponential groundwater withdrawal rates. Although the government provides water to residents by withdrawing from the groundwater, outlawing private wells and ensuring access to each home through pipes would enable better planning and control of water supply.

Lack of proper enforcement has led to rapid unchecked growth in Delhi over the past 40 years. Remote Sensing proves to be a cheap and effective tool to keep track of spatial growth and intensities of developments over large areas. The utility of such tools needs to be realized by enforcement and planning agencies in developing countries. In Delhi's case, it is evident that building intensity has higher significance in explaining growth than spatial extent of informal settlements. More carefully focused policies, accompanied by proper enforcement, is needed to check unlawful densification of irregular settlements.

## 4.4 Limitations of the Study

There are several factors where this study is limited. The most significant one is the assumption that is made to derive BI from NDVI values. This is due to the use of historical satellite imagery, which does not provide the researcher with necessary information to calculate better indicators of intensity of development that newer satellite images do. The second limitation is the spatial resolution of freely available satellite images. Images used for this study range from 80m to 30 m resolution. This would still be considered very coarse resolution for any urban spatial study. Newer QuickBird imagery has a 0.6m resolution and provides a higher level of accuracy when measuring the spatial extent of growth and development. Newer advancements in technology also enable users to determine the building materials used in construction of houses in slum clusters and informal settlements. This has been done in several cases studying the Favela clusters of Rio de Janeiro, Brazil and slum clusters of Mumbai and Bangkok.

Lastly, although the Census of India is a very good source of population figures, these data are not available at every level of spatial aggregation. This study would have had a clearer picture of density if population numbers were available at settlement level. However, approximation was required and due to the dynamic nature of political boundaries in New Delhi, choosing a standard and consistent unit of measurement becomes quite challenging. Although this study used Tehsil boundaries as the unit of population measurement, each tehsil comprises multiple settlements (in some cases even above 20 settlements). It would have been statistically worthwhile to find a system of approximation to calculate individual settlement populations.

## 4.5 Contributions of the Study

Despite its limitations, the study makes use of historical satellite imagery for the purpose of spatial analysis. It reiterates the usefulness of remote sensing in urban studies. It also shows how readily available low cost/free images can be applied for important research to an acceptable level of efficiency. This study is also one of the very few done to longitudinally study the growth of informal settlements over a period of 40 years. Also, it identifies New Delhi as one of the problem areas and shifts focus from more popular areas of research in India like Mumbai.

Lastly and most importantly, it shows how to do spatial analyses in a data constrained environment that developing nations like India pose on to academic researchers.

## 4.6 Future Work

There is lot of work still to be done to further this research. One of the key subjects which this study does not consider is the impact of political environment and influences on the growth of informal settlements in India. It is a known fact globally that slum clusters are the biggest vote banks that exist in an urban setting. This suggests a high desire of politicians to see an increase in the population living in such conditions. Also, the expectations and demands of these informal residents is much more basic and easier to meet by politicians as compared to the demands from formal dwellers.

Applying newer technology to study particular and more recent cross sections of time may also expose other relevant scientific factors that determine growth of informal settlements. The sample of this study comprised both settlements that were restricted and unrestricted by rigid planned development. It would be interesting to take more samples and study them in two separate categories.

It is a known fact that intensity and spatial growth both influence each other and spatial growth occurs first up to a threshold and then intensity kicks in. To some extent this intensity and spatial growth dynamic could possibly be better explained in a Simultaneous Equation Modeling system due to the back and forth nature of most urban development drivers of growth, which this study also does not do.

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