

Thesis Summary

1. Introduction

Rapid, unplanned, and uncontrolled urbanization and urban sprawl is one of the most concerning issues adversely affecting the wellness and health of cities around the globe. The mass migration of the population towards the urban cores for opportunities and prospects of socio-economic prosperity and well-being has manifested in unprecedented developmental initiatives to meet the ever-increasing demands. Indeed, it has put tremendous weight on the capabilities and capacities of these cities to sustainably meet expectations. This consequently has led to the problem of urban sprawl. Urban sprawls are the proliferations of urban cores extending towards peripheries, engulfing vast expanses of land and consistently breaching urban-rural boundaries and orders.

Urban sprawl is characterized by density, continuity, concentration, clustering, centrality, nuclearity, proximity, development type, and indistinct urban-rural boundaries. Depending on the influences of the specified characteristics, urban sprawls can be categorized into the following types: leapfrog, ribbon, low-density single-use, exurban, and edge cities.

Some of the known causes for urban sprawl include greater opportunities for socio-economic advancement, pursuit of enhanced quality of life, escalating desire for affordable housing, presence of abundant cheap land for expansion in suburban areas, availability of transportation facilities, infrastructural initiatives, socio-economic differentiation and lifestyle preferences, regulations and policies, unsustainable urban plans and inadequate institutional coordination, institutional incentives, technological advancements and their outreach, and the impact of globalization.

The consequences of urban sprawl are multifaceted, affecting the social, environmental, institutional, health, and economic stability of the urban landscape. Social concerns include unregulated population growth, social pollution, scarcity of resources, social stratification, deteriorating social relationships, and quick access to important services.

Environmental concerns include escalated land consumption, environmental degradation, noise, air, water, and soil pollution, climate change, loss of natural resources, deteriorating water quality, elevated environmental risks, degradation of arable land, reduction of forested land and waterways, and escalated reliance on non-renewable natural resources. Institutional concerns include uncontrolled infrastructural development, unregulated and spontaneous urbanization, increased energy consumption, and the creation of urban heat islands. Safety and security concerns include critical resource management and hindrances to regulating and orchestrating growth. Health concerns include sedentary lifestyle and initiation of health disorders resulting from pollution. Likewise, economic concerns include inflation, the increased cost of infrastructure, and the increased cost of essential commodities.

2. Study Area

Sikkim officially became part of India on May 16, 1975, as its 22nd state, as represented in Figure 1 a) Sikkim is a land where nature peacefully coexists in harmony with rich culture, tradition, and aspiration for development leading to economic prosperity. Sikkim initially had four districts, namely East Sikkim, North Sikkim, South Sikkim, and West Sikkim, as represented in figure 1 b) These four districts were further subdivided into 16 subdivisions. As per the latest development, Sikkim now has 6 districts, namely Mangan, Gangtok, Pakyong, Namchi, Soreng, and Gyalshing. North Sikkim District is now Mangan, South Sikkim District

is now Namchi, Gangtok and Pakyong have been carved out of East Sikkim District, and Soreng and Gyalshing have been carved out of West Sikkim District for administrative ease.

The four districts of Sikkim, namely East Sikkim, North Sikkim, South Sikkim, and West Sikkim, occupy areas of size 954 sq km, 4226 sq km, 750 sq km, and 1166 sq km, respectively. Geographically, North Sikkim is the largest district as per the area, followed by West Sikkim, East Sikkim, and South Sikkim, respectively. Altitude-wise, North Sikkim lies in between 610 meters in the lower areas to over 8,585 meters at the highest peak, East Sikkim is located at an altitude of 1145 meters to 2619 meters, South Sikkim lies in between 400 meters to 2,000 meters, and finally West Sikkim lies in between 400 meters to 2500 meters.

The four districts are well connected with an extensive road network among the four districts, East Sikkim is the best connected by air and land, as it is in close proximity to Pakyong Airport and has well-established interstate connectivity. Located at the farthest distance are the North and West districts.

Over the years, Sikkim has undergone tremendous transformation and has emerged as one of the focal points for study. Urban sprawl has resulted in the loss of productive agricultural lands and open green spaces, the loss of surface water bodies, and the depletion of groundwater. Therefore, there is a need to study, understand, and quantify the urban sprawl.

Considering geographical landscape, favorable weather, availability of resources, affordability, and reachability, East Sikkim stands as the most preferred of the four districts in terms of administration, business, finance, industries, tourism, education, public work, and avenues for public health. Further, the majority of East Sikkim has a well-established water supply

network, sewerage network, waste disposal provision, and well-established power network, making it an ideal choice.

Since the last seven decades, East Sikkim (represented in figure 1 c)) has been experiencing tremendous transitions in population and all spheres of socio-economic growth due to the creation of opportunities in governmental institutions, industries, business enterprises, tourism, and projects of public interest. It has been observed that these opportunities for socio-economic prosperity are not uniformly distributed across the various districts of the state. It may be due to the geopolitical dynamics, ease of accessibility to resources, favorable climatic conditions, reachability, investment strengths & certainty of returns, suitability for habitation, and many more.

East Sikkim in particular has experienced unprecedented growth; some of the influential causes could be,

- it accounts for approximately 46% of the total state's population.
- it has Gangtok, the capital of the state, as one of its prime centers.
- it has the headquarters of all the governmental offices, banking institutions, private ventures, and start-ups.
- it serves as the business capital, a hub for financial institutions, and a commercial center that caters to a wide variety of macro as well as micro businesses.
- it caters to the hospitality and tourism industry as it is one of the premier tourist destinations of the state.
- it serves as a center for academic institutions, including the majority of schools, colleges, and universities.
- it serves as a hub for the majority of health institutions, government/private.

- it hosts pharmaceutical industries, power projects, and other avenues of commerce.
- it has become an urban hotspot for infrastructural projects to cater to increasing residential needs of the population.

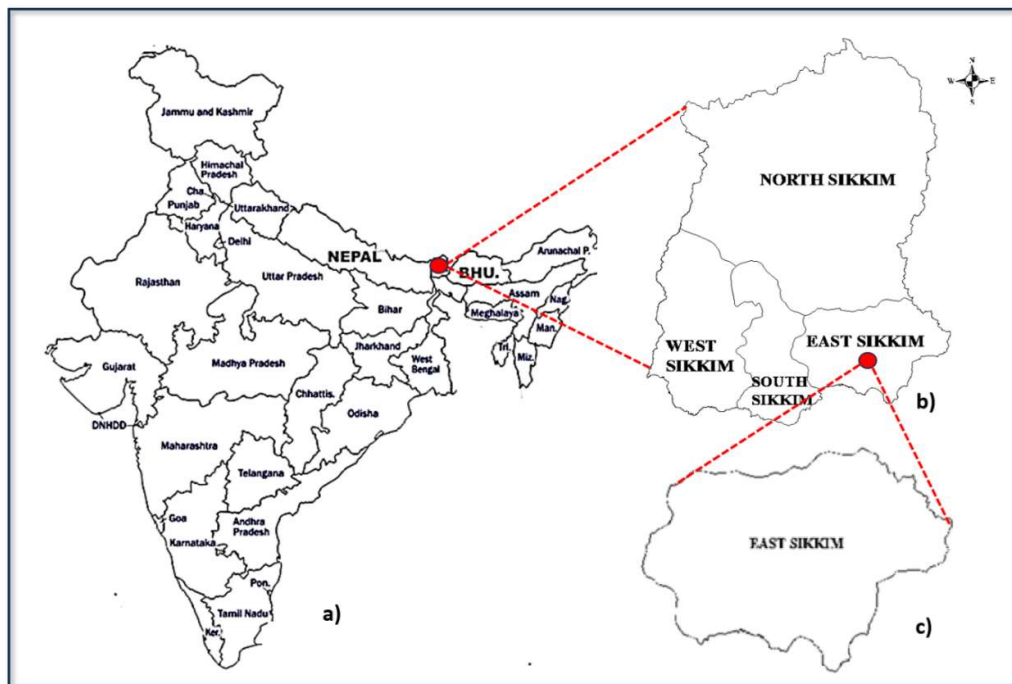


Figure 1: a) Map of India b) Map of Sikkim c) Map of East Sikkim

3. Scope of the research work

The primary scope of this study is to examine and understand the trends in urban sprawl and its extent in the East Sikkim District (Gangtok District and Pakyong District) of the State of Sikkim, India. Further, the study also aims at identifying urban hotspots for analyzing temporal changes. Eventually, the research also extends its scope to identifying and examining various demographic and developmental factors that are critical to triggering such advancements.

Attainment of the aforementioned work is strategized through

- analysis of temporal remotely sensed satellite dataset for building an understanding of trends of urban sprawl and its progression over years
- identification of hotspots for understanding growth in urban sprawl.
- exploring classified temporal demographic data and other critical factors that would explicitly or implicitly have a causal relation with the growth in urban sprawl

4. Problem definition

With the scope of work defined, the problem statement for the research work is

“Study of Sprawl Pattern for Deriving bases for Urban Planning”

5. Research Objectives

The objectives of the research initiative are:

Objective 1:

- classification of temporal satellite images using supervised, unsupervised, and hybrid techniques
- perform accuracy assessment of the various classification techniques
- suggest a favorable approach based on the results of the accuracy assessment.

Objective 2:

- identify the seed points for investigating the extent of sprawl
- considering temporal satellite data determine sprawl around each of the seed points
- determine the growth in sprawl

Objective 3:

- identify all the critical factors directly or indirectly influencing sprawl
- quantify all of these factors for building the statistics
- determine temporal trends wherever there are substantial evidences for analysis

Objective 4:

- Predict the changes in land cover classes obtained from classification of temporal satellite images
- Predict the change in the density of the clusters obtained through Seed-Based clustering
- Predict the change in distribution of population participation
- Predict the change in distribution of household participation

6. Some of the inferences

In regards to attainment of **objective 1**, Maximum Likelihood, ISODATA and their combination were selected as representatives for supervised, unsupervised, and hybrid classification approaches and applied to the sample satellite images to determine its effectiveness with which it identifies various classes. User accuracy, producer accuracy, error of omission, error of commission, kappa, and overall accuracy were evaluated for determining the performance. Based on the observations, Maximum likelihood classifier was found to be the most suitable candidate. There after the same was applied to the temporal satellite images for identifying the various classes. Considering the results from the accuracy evaluation, it has been noted that the maximum likelihood classifier produced the highest overall accuracy in comparison to the other two approaches. The maximum likelihood classifier attained a best accuracy average of 93.25%, with a minimum of 91.00%. In contrast, the ISODATA classifier achieved a best accuracy average of 74%, with a minimum of 70.25%. The hybrid classifier recorded a best accuracy average of 90.50%, with a minimum of 87.5%. Correspondingly, the optimal Kappa statistics produced by the maximum likelihood classifier is .8738, the ISODATA classifier is .6878, and the Hybrid classifier is .8379, respectively.

In light of the results obtained, the decision was made to utilize the outcomes from the maximum likelihood classifier for further research and analysis of the classified images. The classified images will be subsequently compared with the demographic data. The results obtained from this chapter are utilized for further analysis in subsequent chapters.

In regards to attainment of **objective 2**, the results obtained by applying the Maximum Likelihood classifier on the temporal satellite images were considered as input based on the results of the accuracy assessments. Thereafter, for the analysis of urban sprawl, only the portion of the classified image representing urban sprawl was extracted for further analysis. Eight seed points, namely Gangtok, Pakyong, Lingtam, Rhenock, Singtam, Tumin, Sajong, and Rangpo, were selected for performing guided clustering based on some empirical study. The research leveraged the capabilities of seed-based clustering using Mahalanobis distance for determining the clusters around the eight seed points across the temporal data. It can be inferred from the analysis of the output obtained from the execution of these processes that in the last 24 years, urban sprawl around Gangtok, Pakyong, Lingtam, Rhenock, Singtam, Tumin, Sajong, and Ranipool has increased by 125.60%, 9.69%, 31.68%, 4.96%, 8.42%, 206.69 %, and 71.79%, respectively, with an increase in area coverage of more than 3.12 sq km, 1.79 sq km, 1.24 sq km, 0.88 sq km, 1.31 sq km, 0.78 sq km, 1.20 sq km, and 1.65 sq km respectively. It was further inferred that places like Gangtok, Tumin, and Ranipool have experienced tremendous growth in the past 24 years, whereas Pakyong, Lingtam, Rhenock, Singtam, and Sajong are fast emerging as urban hubs.

In regards to attainment of **objective 3**, the research initiative has unveiled some critical and concerning issues explicitly responsible for the progression of urban sprawl in the East Sikkim district of the State of Sikkim. Most importantly the disproportionate rate of increase in urban population of East Sikkim. The urban population of the district is growing at a steady rate of

7.11%, whereas the rest of the districts are cumulatively growing at 6.88%, rural population is growing at 3.54% and the state is growing at 4.5% annually. It has been determined that the urban population of the East Sikkim contributes maximum which is estimated around 83.7% to the total urban population of the state. It has been observed that there has been an unprecedented increase of 338% in the number of urban households in East Sikkim District with an average share of 84.69% from 1981 to 2022. In contrast there is a marginal increase in the urban households in rest of the districts with an average increase of 127%. There are several factor that has led to the increase of the population some of which are 100.00% of administrative headquarters, 33.79% of schools, 69.57% colleges, 41.18% universities, 32.61% of health institutions, 79.82% of hotels, 45.75% of homestays, 29.41% of power projects, 70.00% of government projects, 75.00% of pharmaceutical companies, 50.00% distilleries, 50.00% breweries and 70.00% manufacturing industries has been established in the East Sikkim District disproportionately over burdening it causing a toll on public infrastructure. The result was further substantiated by the inferences drawn from processing of remotely sensed data from 2000 to 2023.

In regards to attainment of **objective 4**, Linear regression was used for predicting growth in population, household, and cluster density, whereas Dirichlet regression was used for predicting the growth in land use classes. The selection was based on the criterion of bound; specifically, for land use classes, regardless of their progression, the total number of pixels representing the district will always remain constant. This characteristic is one of the most significant achievements of Dirichlet Regression, as it consistently confines proportion contributions to 1. This technique can also be applied to the results obtained from seed-based clustering when the cluster size becomes unmanageable.

On applying predictive analysis to the land use classes obtained from classification of temporal satellite images, the results reflected that forest cover is expected to decrease by 7.09%, vegetation is expected to decrease by 0.06%, barren land is expected to decrease by 0.033%, and urban sprawl is expected to increase by 1.77%.

On applying predictive analysis to the outcome obtained from seed-based clustering, the results reflect that Gangtok, Tumin, and Ranipool are expected to experience an unprecedented increase of 157.83%, 384.86%, and 94.28%, respectively, and Pakyong, Lingtam, Rhenock, Singtam, and Sajong are expected to experience a marginal increase of 10.46%, 7.25%, 17.56%, 14.98%, and 0.66%, respectively.

On applying predictive analysis to the outcome of population estimation, the urban population of the state is predicted to reach 264,222 by 2052, of which 209,115 is predicted to be contributed by East Sikkim District, accounting for 79.14%. The contribution of all other districts to the urban population is predicted at 55,107, accounting for only 21%. The predicted percentage increase in the urban population of the entire state is estimated at 417.23%; likewise, for the East Sikkim District, it is predicted at 383.59%, and for the rest of the districts, it is predicted at 602.71%, with an average share of 200.9% per district. Therefore, it can be inferred that the percentage increase in the urban population of the East District is considerably higher compared to the other.

On applying predictive analysis to the outcome obtained from household estimation, the total urban household of the state is predicted to reach 72,011 by 2052, of which 58,166 is predicted to be contributed by East Sikkim District, accounting for 80.77%. The contribution of all other districts of the urban is predicted at 13844, accounting for only 19.22%. The predicted

percentage increase in the urban household of the entire state is estimated at 575.15%; likewise, for the East Sikkim District, it is predicted at 541.80%, and for the rest of the districts, it is predicted at 763.63%, with an average share of 254.54% per district.

6. Some Suggestive Measures

i) Promote and incentivize smart growth initiatives.

- Establish clear delineation of zones and promote investment initiatives.
- Implement stringent urban growth boundaries to manage urban expansion.
- Enforce policies and frameworks to ensure sustainable development.
- Advocate for mixed-use development projects
- Support ecologically sustainable practices.
- Develop initiatives centered around transit hubs to decrease dependencies.
- Enhance accessibility to fundamental necessities
- Encourage conservation and sustainable utilization of natural resources.
- Stimulate compact, clustered growth patterns
- Limit development in ecologically vulnerable regions.
- Establish conservation zones and curtail developmental projects.

ii) Strengthen the urban plan framework.

- Develop initial sustainable growth strategies.
- Enforce stringent zoning regulations
- Limit development initiatives to brownfields while conserving greenfields.
- Encourage green infrastructure in urban environments.
- Assign roles and responsibilities to urban residents.
- Construct a comprehensive road network and enhance commuting options to diminish reliance on automobiles.

iii) Rejuvenate existing urban spaces

- Advocate for sustainable infill development initiatives.
- Support the adaptive reuse of present and aging infrastructure.
- Design high-density affordable housing projects
- Enhance public services, including education, transportation, public health, and safety.

iv) Provide convenient and affordable public transport facilities.

- Enhance public transportation infrastructure and encourage its utilization.
- Establish an inexpensive and secure transportation network.
- Construct pedestrian pathways and advocate for their use.
- Promote healthy commuting options, such as cycling.

v) Raise public awareness

- Coordinate awareness activities.
- Inform the public about the advantages of sustainable development.
- Illuminate the expenses associated with urban sprawl.
- Encourage public involvement in the formulation of urban plans.
- Acknowledge sustainable initiatives

vi) Incentivize sustainable growth

- Offers subsidies for sustainable development
- Offers tax benefits for conservation initiatives