An Empirical Geometric Model for City Expansion

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***Abstract*—** This paper represents an empirical geometric modeling to visualize the different scenarios of possible spatial growth of a city and its surrounding region. The major areas are modeled with simple functional form with two dimensional expansion rates and the cumulative growth of neighborhood areas shows the complex dynamics of city expansion. Different plausible scenarios are considered for the Bangalore region, India as a test case using the proposed methodology. This methodology helps understand the evolution of different city structures, and identify forces that may have led to it and indicate the need for policy directives to modifications thereof.

***Keywords*—** Spatial Growth, Geometric Model, City expansion, Scenario Generation, Policy

I. INTRODUCTION

The primacy of very large cities, the very wide dispersion in city sizes, the stability of the hierarchy between cities over decades or even centuries, and the role of urbanization in economic development are all particularly interesting qualitative features of urban structure worldwide. With the high urbanization trends, especially in the developing world, the spatial expansion of the urban built-up area and the dynamics associated with it has become a hotspot in the research community [1-9]. The spatial expansion characteristics of urban built-up area, in order to reveal its dynamic mechanism from socioeconomic and other aspects, requires the thematic information of urban construction land in different periods. [10-12]. New Economic Geography (NEG) models emphasize the current need for analysis in the support for cumulative causation argument. The importance of localization economies [13] has been observed like the jute and textiles industries of Kolkata and Mumbai, respectively.

Recent development literature suggests existence of circular and cumulative relationship between current developments and future development. It highlights the importance of spatial distribution of economic activity has a great impact on the persistence of low development levels-low relative income, standard of living, health standards, literacy and longevity [14]. Analysis of spatial organization of economic activity, with increasing research on externalities, increasing returns to scale and imperfect spatial competition have regained interest recently[11],[12],[15]. These models argue that the geographic barriers to interaction, helping in specialized labor supply, and facilitating into exchange, technology diffusion, and other positive spillovers that reinforce each other, is enhanced by improved accessibility. It has also emphasized the importance of localization economies, dynamic externalities due to specialization and geographical concentration. The inter-industry linkages have also enhanced and made the localization processes become more efficient. Urbanization economies benefit from access to specialized financial and professional services, inter-industry information transfers and availability of infrastructure. Diverse range of input-output linkages also enhances the development process. However it should be noted that localization economies, input output linkages and urbanized economies are not mutually exclusive. Different spatial economies interact with each other and it difficult to separate out cause and the impact [14]. The institutional and social aspects of location theories are important and they suggest that the most decisions are based on perceptions and characterized by imitation, inertia and cumulative causation. These decisions are efficient since cumulative causation reduce the cost of decision making.

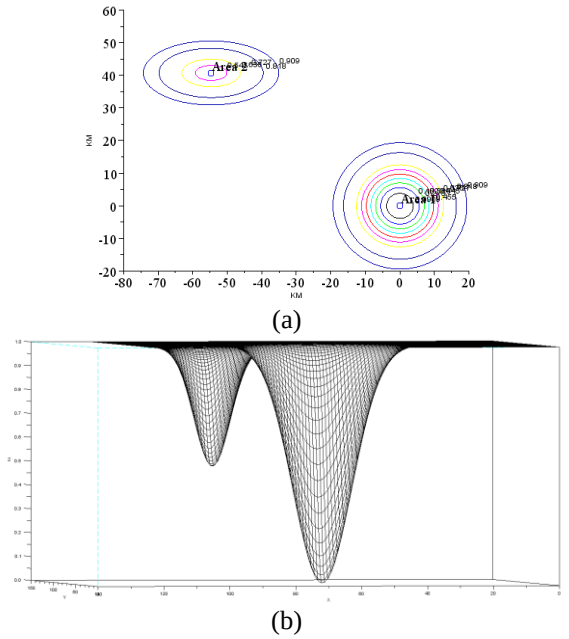
This approach is not merely a static equilibrium or comparative statics of traditional economic analysis. It has a dynamic perspective, focusing on process and linkages. As we use computation, we need to go beyond social science in the traditional sense and see how social scientists' and technologists' views complement, inform, and evolve with each other [15, 16].

In an attempt to understand the future of urbanization on a spatial scale, the paper looks at different scenarios that can emerge based on the absorption capacity of the cities, vis-a-vis others. Absorption capacity may be defined as the power of the city to provide employment options, and satisfy other socio-economic needs like healthcare, education, social safety, and also the ability to satisfy the urban aspirations of the rural populace. Bangalore has the high absorption capacity, due to the presence of skilled workforce needed for the IT boom that emerged globally in the 1990s, and cascaded into need for other services and thus more job options, and opportunities for urban migrants from other states and also for the rural migrants. The process begins by identifying forces that may impact the spatial transformation. The inter-linkages between the forces and the resultant impact based on certain leverage points or stimuli create diverse scenarios about how the future could evolve. Scenarios help expand our thinking about both the opportunities and constraints that the future might hold. It

helps to explore various alternative dynamics that might inhibit, alter, or further current trends. Together, a set of scenarios captures a range of future trajectories, good and bad, anticipated and surprising; but always plausible. It is to be understood that scenarios are not predictions, rather, they are thoughtful hypotheses that allow us to imagine, and then to rehearse, different trajectories in order to better design policies that are more robust.

II. Model Description

For computational simplicity the centre of an area can be considered at (x_i, y_i) where i = 1,2,...,n. Here i -represents the i-th area and n is the total number of areas under consideration. Though due to different expansion rate some of the areas may not exist at time t = 0, (and also in some time period) but from theoretical point of view, we can consider those area as an area with x and y directional growth is zero at that time (and also in that time period). Hence from algebraic simplicity let consider each area contains a 'growth-time-factor' (g_i). Since the city has radial-outward expansion, for simplicity let assume the expansion rate in x and y direction as $e_{x(i)}$ and $e_{y(i)}$, respectively. Hence in this computational framework, any area can be represented as $[x_i, y_i, g_i, e_{x(i)}, e_{y(i)}]$ and the growth of the area at any time step can be represented as, $G_i(x_i, y_i, g_i, e_{x(i)}, e_{y(i)})$ for some function G. Here (x_i, y_i) can be considered as the centre of area, around which the area is evolved and depends on the geographic information of the area. The expansion rate $e_{x(i)}$ and $e_{y(i)}$ depends on the socio-economic condition and the absorption capacity of the area. The growth time factor g_i depends on the time dependent evolution or historical information of the area.



(a)

(b)

Fig 1. (a) shows the two dimensional reprentation and (b) shows the three dimensional representation of expansion of two areas. Area 1 has equal expansion rate in both direction where as Area 2 has non equal expansion rate. The differen growth time factor of two areas are shown in (b)

Using the proposed functional relationship, a schematic diagram of two areas is represented in fig 1(a). As shown in the figure, the different concentric circular (in case of Area 1) and elliptical path (in case of Area 2) represents the expanding behavior of the area at different time step. In is interesting to see that, in case of area 1 (see fig 1(a)) the x and y directional expansion are considered equal (i.e. $e_{x(i)} = e_{y(i)}$) and hence shows the concentric lines of different time step as a circle; while in case of area 2, due to different expansion rate in x and y, the concentric lines at different time step are elliptical.

Fig 1(b) shows the three dimensional representation of the expansion considering the z-axis as the time scale. As shown in the figure 1(b), the x and y directional expansion of area 2 is zero for initial time period while the expansion of area 2 exists. The z-directional slice at different time step of the three dimensional representation (fig 1(b)) produces the two dimensional representation fig 1(a). For simple representation of the expansion we have considered the circular or elliptical expansion but in reality different functional form can be considered. An interesting behavior of this representation is that, if two areas are comparatively close to each other the expansion of one area affects the other and the cumulative representation shows the actual expansion of the areas as a whole. For more areas a complex dynamics occurs between each of the areas and brings complex growth pattern. To visualize the complex growth pattern in different area expansion, we have considered a real time geographic scenario and the proposed modeling procedures are applied to view different future plausible growth patterns.

III. Plausible Growth of Bangalore, India – Different Scenarios

Bangalore is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India. It has been identified as the country's 'Silicon Valley' and it is one of the technological innovation hubs with a score of 13 out of a maximum of 16 [1](United Nations Development Programme, 2001). However, with all the hype about growth in IT and IT based industries, Bangalore also houses numerous other leading commercial and educational institutions, and industries like textiles, aviation, space, biotechnology, etc. Of late, the development and growth in Karnataka has been concentrated in and around Bangalore due to various reasons, the major one is the "absorption capacity" of the city. The absorption capacity of Bangalore is high due to the fact that other cities, in Bangalore do not have adequate absorption capacity.

The scenarios depict that the interactions of the absorption capacities of the different cities, pose different evolution patterns of cities. As they grow in size, the original monocentric structure of large metropolises with time tends to dissolve progressively into a polycentric structure. Historical business center with low level of amenities, increasing car ownership, cheap land, flat topography, and street design may

[1] Almost on par with San Francisco (USA), while Silicon Valley (USA) is number 1 with a score of 16.

accentuate the tendency towards poly-centricity. Other forces that might inhibit poly-centricity could be commercial center with high level of amenities; rail based public transport, radial primary road network, and difficult topography preventing communication between suburbs [17].

The models above implicitly assume that the growth function is highly dependent on the socio-economic and political advantage of the cities. If the other city in the Bangalore region is at a relative disadvantage, then the advantaged city growth engulfs the land surrounding it and in the long time the nearby cities become a part of the larger metropolitan area, as is the case with Yelahanka, and Whitefield a major center of the polycentric Bangalore, in Scenario 1. Scenario 1 depicts the high absorption capacity of Bangalore and also Mysore. Bangalore engulfs its surrounding cities, and Mandya (20 km away), a relatively disadvantaged city in terms of absorption capacity becomes a part of Mysore urban agglomeration. Similarly, the interaction of the absorption capacities of Ramanagaram and Kanakpura, help form the Ramanagaram- Kanakpura-Channapatna urban agglomeration. However, in scenario II, Mandya and Tumkar have some absorption capacity and prevent itself from being a part of Mysore or Bangalore, respectively. However, Magadi town, approximately same distance from Bangalore to Tumkur at 20 km, becomes a part of the Bangalore urban region (spreading 80 km east-west) as it fails to grow by itself. Scenario III highlights the primacy of Bangalore in the region and shows the plausibility of the formation of a mega urban agglomeration. The wide range of economic opportunities has always been the driving force for high densities, area morphology, infrastructure demand and climate change. The characteristics, relativity of different components and their influence on each other, socio – economic and environmental factors are critical in the dynamic process. The dynamic restructuring process in an area with the past, present and future components is a complex process and may or may not be identical. This has implications for land conservation, energy consumption, and natural resource use.

IV. POLICY IMPLICATIONS

Urbanization in India over the past half century has resulted in high levels of concentration of population and activities in large cities. The costs of excessive concentration (inadequate infrastructure facilities, congestion and time lost to long commutes, traffic accidents, health costs due to exposure to high levels of air and water pollution) stem from underdeveloped institutions and human resources for urban planning and management. The form of urbanization in India has resulted in a massive deterioration of quality of life for millions of Indians, with that number likely to increase dramatically going forward. According to estimates, the states of Punjab, Gujarat, Tamil Nadu, Karnataka and Maharashtra will be more than fifty-percent urbanized [18].

As an immediate consequence of this growth in the last decade, there has also been great pressure on infrastructure and resources like water supply, energy, public transportation, land, etc. These three probable future evolutions of cities that highlight the primacy of Bangalore will have a great impact on the economic and environmental performance of the city/city region. Currently, most Central infrastructure funding policies in India favour the bigger cities, due the urgent nature of the problems, and also the ability to generate funds. Redistribution of investment is recommended to develop strong economic base and increase the 'absorption capacity' of urbanization for small and medium city neglected so far so that migration flows are directed to small and medium cities. Alleviating excessively high urban concentration requires investments in interregional transport and telecommunications to facilitate deflection of economic activities from the mega cities. It also requires fiscal decentralization, so that smaller cities can reach out to fiscal resources and provide the services needed to compete with the mega cities for industry and population. The urban aspirations (higher standard of living), of the smaller towns and rural areas need to be understood and reflected in policy and planning.

It thus becomes imperative that urbanization be strategized on a regional scale, so that the balance between environmental resources like land, forests, and water usage patterns along with services like energy, housing and transport and other infrastructure are optimized, ensuring a sustainable and inclusive development process.

It is therefore urgent that we try to mitigate and adapt to the impacts of the high rate of anticipated urbanization in India. We need to maintain/increase our high rate of economic growth, and at the same time we need to relook and plan development. For a comprehensive strategy at the regional scale that provides form for sustainable emergent systems, it is imperative to link economic planning with, spatial/regional planning [16]. In view of this, development of a regional urbanization strategy linked to low – carbon development plans for cites is vital for a comprehensive look at urban planning and service delivery. We need to diffuse the population pressure and resultant infrastructure gridlock of our mega cities, and at the same time revitalize the small cities and towns and prepare it to absorb the wave of urbanization. It is also important to be cognizant of the land use conflicts between urban development, agricultural land, and environmentally sensitive areas. Long term comprehensive development planning must include whole urban regions and a comprehensive urban sector perspective rather than sector-by-sector intervention. These should include innovative financing schemes such as public–private partnerships, domestic and foreign investments, new revenue sources through taxation reforms, levying of user charges, and new credit schemes.

V. CONCLUSION

This paper represents an empirical geometric model based approach to visualize different scenarios of futuristic plausible expansion of city. The complex spatial dynamics of city evolution is modeled as cumulative functional form of expansion of different areas. The proposed methodology is used to model the probabilistic growth of Bangalore, India and its nearby cities as a test case and highlight the need understanding spatial evolution and the need for urban policy directives to modify these patterns for sustainable and livable

cities. The actual expansion rate considering the socio-economic forces is under the future development of the proposed methodology.

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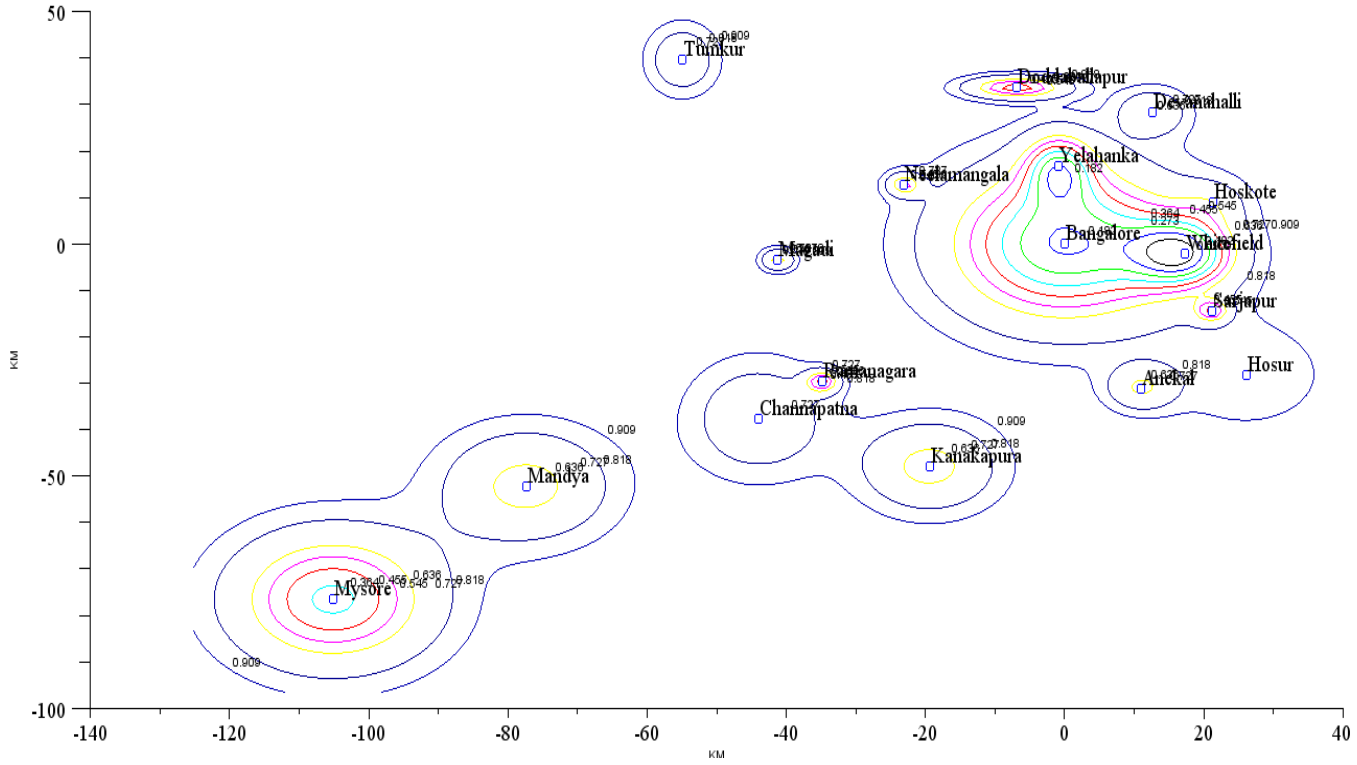
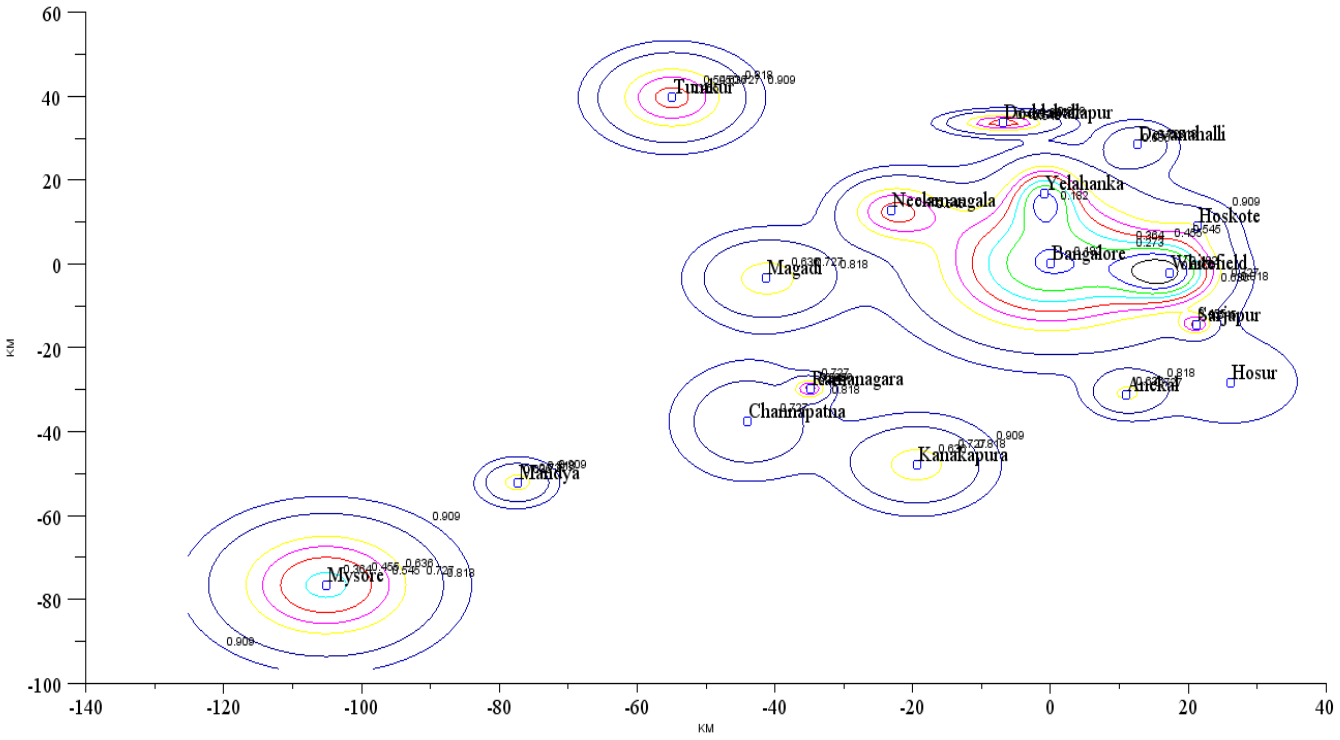
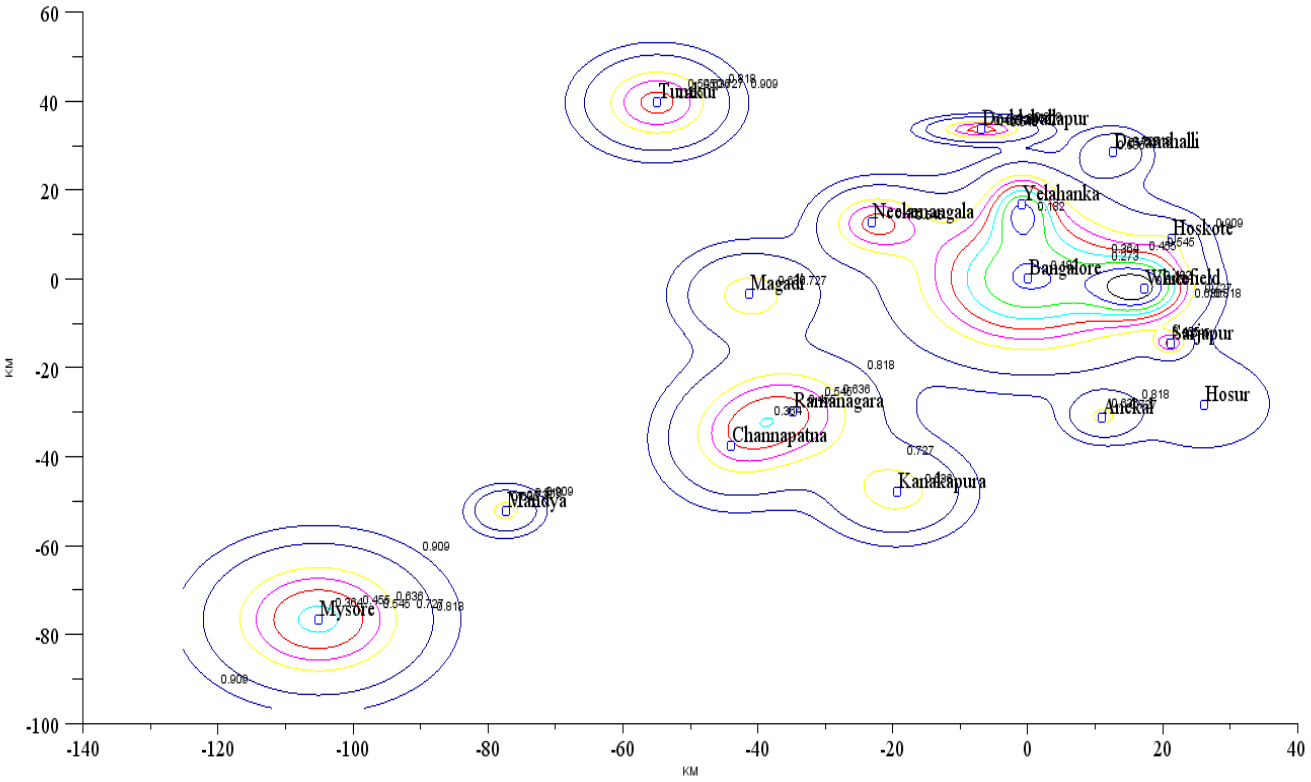


Scenario – I



Scenario – II



Scenario - III