

Modeling the probable growth of slums by using Geoinformatics

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Abstract

In both territorial and demographic terms, the world is becoming more and more urban. The consequence of urbanization in most of the developing countries, is characterized by informality, illegality and unplanned settlements in cities. The extension of slums in developing countries is a product of 20th and 21st century urban growth. A worldwide consensus on poverty has acknowledged slums and the living conditions of slum dwellers as a major challenge faced by humanity. Hence, it is essential to locate and map the slums for proper planning and improve their living conditions. In the present paper, an attempt has been made to study the growth of slums by using GIS and RS techniques. The study area selected for this analysis is Pune city. Seven criteria were selected along with land use layer (restricted to slum use), which made the model more reasonable and effective. Each criterion is processed with a specified method and forms one criterion layer. These criterion layers are regarded as the initial conditions in the CA generation courses. They are weighted equally in the probability analysis of MCE in ArcGIS. The probability layer is finally added with neighborhood map to get the final output. The results are very much similar to the ground reality. More than 85% of slums are concentrated in the zone of more and most favourable zones. Remaining 15% of slums are in less and least favourable zones. The area available for future growth also calculated and it shows that almost 35% of area for further slum growth can take place in this zone in the light of ongoing urbanisation. The results pertaining to slums are essential for future planning and sustainable management of available resources.

Keywords: Contourlet transform; Maximum likelihood detector; Multiplicative image watermarking.

Introduction

In both the territorial and demographic terms, the world is becoming more and more urban. The city and its current mutant forms such as urban agglomerations, and metropolization (Ascher, 1995, 2000), were and are at the heart of the restructuring of human societies. Urbanisation is a relentless process, which has come to stay and has to be factored into all our developmental thinking and development processes. Urban centres drive economic growth, scale economies, increased productivity and the concentration of specialised skilled workforces. The urban primacy in the economic field goes hand in hand with internal disparities and more and more precarious urban centres owing to the growth of slums. The problem of informal settlements is of significant importance and has similar cause's worldwide (Charalabos Ioannidis *et al.*, 2009). The extension of slums in developing countries is a product of 20th and 21st century urban growth and represents the very essence of the Third World City. The slum is not only a manifestation of mismanagement (Boly Jean Claude, 2006), but also lack of urban planning

in the developing countries of Asia, particularly in India.

Slums have come to form an integral part of the phenomena of urbanization in India. The slum expansion is due to the pressure of the population mostly on un-used, un-protected and un-suitable government land. Without finding appropriate solutions to the housing problems of a majority of urban dwellers, public and private decision makers will not be able to meet the challenges of sustainable urban development.

There is a need to study slum from the perspective, of cities which are not capable of supplying enough housing for the masses through proper planning. We the urban dwellers/urban planners cannot just ignore the 40-60 percent of the city population living in slums, while planning for the city development, (Slums: A outlook of Researchers, 2009). During the last few years the growth of slums in the urban areas, especially in the big cities, has become a major problem for the planners and policy makers. It has been estimated that between 25 and 70 percent of urban dwellers in

the developing countries live in irregular settlements (Durand-Lasserve & Royston, 2002). The total number of slum dwellers in the world increased by about 36 percent during the 1990s, and in the next 30 years from 1990's the global number of slum dwellers will increase to about two billion if no concerted action to address the challenge of slums is taken (UN Habitat, 2007).

To have an idea of problems of slums, the planners and policy makers should have an appropriate data. As cities in the developing countries prepare to take on the range of challenges posed by the slums, it is essential that key knowledge about these measures be organized and disseminated in a format that can be readily used to create the momentum necessary for policy changes, national level programs, regulatory reforms and city level projects. In this juncture, the role of Geoinformatics is crucial in the form of remote sensing data for slum mapping (Ujjwal Sur, 2004; Turkstra, 2008; Kohli.D, 2011) and GIS for modeling and together in decision making. Hence an attempt has been made to map and model the probable growth of slums of Pune, the third largest city of India in terms of Slum population.

Figure 1 Study area

Pune the city, selected for the study of Slum growth is one of the fast developing urban agglomerations in Asia and ranks eight at national level (Census of India, 2001). Pune city lies between latitudes 18°25'N and 18°37'N and longitudes between 73°44'E and 73° 57'E and it covers an area of 244 sq.km (Fig. 1). It has grown two fold over the past two decades in terms of population, and area (Shekhar, 2004). Due to phenomenal increase in population, largely on account of inward migration from rural areas, Pune's slum population also has grown by many folds since 1991. As per the secondary information collected from Pune Municipal Corporation, there are 564 slums in Pune city, of which 353 are declared and 211 undeclared slums (ESR, 2006, 2007, 2008). But as per information from Shelter Associates (1998), an NGO working on Pune Slums the total number of slums is 447 (253 declared, 113 undeclared, 9 partly declared, 8 in process of rehabilitation and 64 not recorded). Differences in these statistics further emphasise the need for appropriate methodology for slum identification and mapping (Joshi Pratima *et al.*,

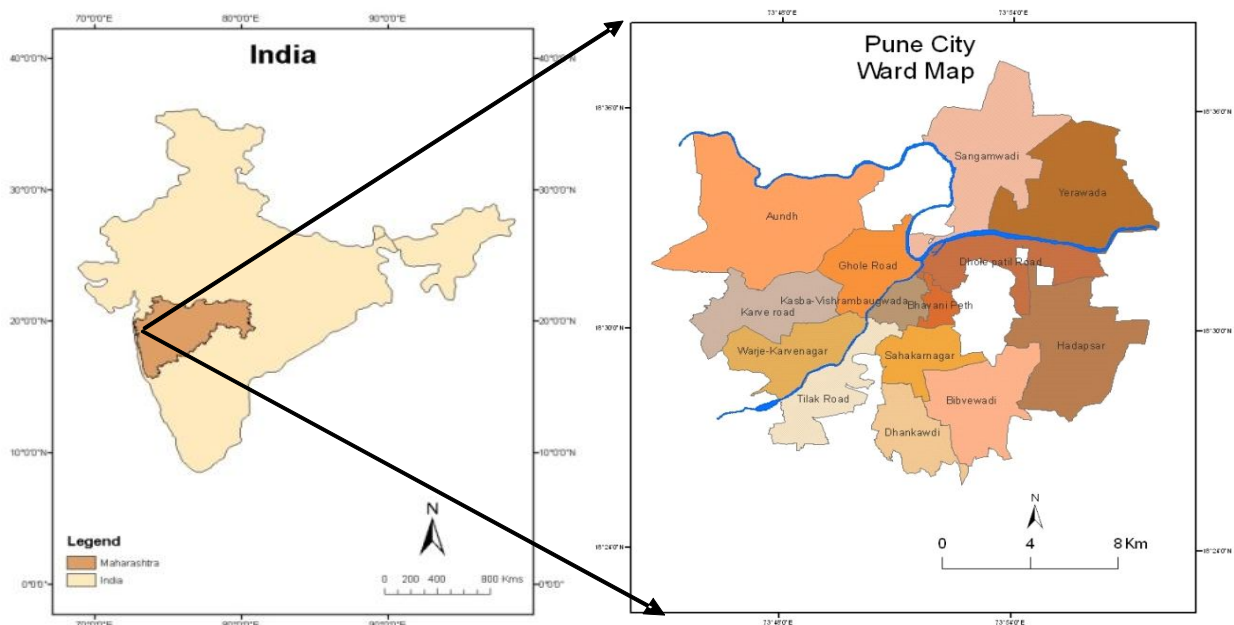


Fig.1. Study area

1998; Sinanda Sen *et al.*, 2003).

Materials and methods

Data base consists of both Spatial and aspatial data from different sources. Satellite data from high-resolution commercial earth imaging satellite such as Quick bird (Digital Globe), Topographical maps of Survey of India 47F/14 and 47F/15 surveyed in 1979-80 and other secondary data includes Pune Municipal Corporation's Environmental status reports and census data.

The methodology part includes defining the slum conditions, classification of image (with restricted land use / land cover categories such as slums, hill slopes and barren land), selection of factors (which supports the growth of slums), development of model in Arc GIS environment and finally comparing the results (model output) with the existing slums.

Definition of Slum

The first step is to quantify and locate the slum population and is to develop an operational definition of the term "slum". Experts at an UN-HABITAT meeting held in 2002 agreed on the following definition: "A slum is a contiguous settlement where the inhabitants are characterized as having inadequate housing and basic services" (UN Habitat, 2003). A slum is often not recognized and addressed by the public authorities as an integral part of the city. This is one of the reasons why little data on slum dwellers can be found. Further to add, the definitions of slum vary from country to country, and even within the country. The lack of a common definition, that clearly defines, identifies, and signifies the main points of commonality and diversity, among the slum areas coupled with rapid dynamic growth of slums, are commonly recognized as the main obstacle in the monitoring of the growth of these areas as well as the planning and upgrading their conditions.

For the purpose of Slum Census, the census of India, 2001 defined the slum as the areas broadly constituted of:-

1. All specified areas notified as 'Slum' by State/Local Government and UT Administration under any Act.
2. All areas recognized as 'Slum' by State/Local Government and UT Administration which may have not been formally notified as slum under any Act.
3. A compact area of at least 300 populations or about 60-70 households of poorly built congested tenements, in unhygienic environment usually with inadequate infrastructure and lacking proper sanitary and drinking water facilities.

Based on these characteristics the slums are identified and mapped in this study with the help of high resolution data. Much work is now being done on using VHR imagery for urban mapping, but most of it is focused on cities in the developed world and on general topographic and land use and land cover mapping. Although, slum identification and mapping has received relatively little attention until recently, much can be learnt by examining the general developments on urban remote sensing and the limited studies that deal specifically with slums.

A number of general conclusions were drawn on the aspects of slum diversity:

1. There is no universal model of a slum in a physical sense that would allow the development of a standard method for all the slum identification and mapping. Although, certain variables are likely to be important, in most situations, and the parameter settings will certainly always require local tuning.
2. The diversity of slum conditions is such that even within one city many different manifestations of slums may be found, each of which may require specific methodological adjustments for identification and mapping.
3. It is necessary to understand the nature of building construction (characteristics such as size, materials, shape), the nature of other objects (such roads, health and social service facilities, open space), the characteristics of the site conditions (such as location in urban area, slope, natural vegetation, hazards), as well as the slum development process itself.

4. Slum development is a process that can take several different forms. Slums can develop through the gradual degradation of formal housing and social filtering processes. Slums can also develop through a variety of informal housing development processes (example; incremental and structured, incremental and unstructured, sudden and structured, sudden and unstructured). Each form has its own distinctive characteristics.





5. The development stage of a slum area (infancy, consolidation, maturity) must be considered when deciding how it is to be identified and mapped from VHR images. The development of slum identification and mapping methods will need to explicitly consider how slum characteristics may change according to the development stage of the slum (EGM, 2008, UN Habitat, 2008).

Slum identification

Satellite data can be considered as an essential data source for the appraisal of urban environments as they provide valuable and timely information for interpreting the landscape (Forster, 1985; Welch, 1982).

In terms of methods for identifying and mapping slums by using VHR images, the foremost conclusion is visual interpretation performed by the interpreters familiar with local conditions provides a flexible and a useful approach to slum mapping though it does have shortcomings for repetitive surveys of very large cities due to difficulties in controlling quality over time and between interpreters.

Some of the visual and qualitative indicators which were used for slum identification include:

-  Haphazard, high density building pattern
-  Proximity to natural and technological hazards such as Flood prone areas
-  Structure, size and condition of road network
-  Proximity to public services (health, education, open space, public transport).

Developing a Slum model

Modeling the urban slum growth pattern is a prerequisite to understand this complex process. A model is an abstraction of reality that is used to

understand complex relationships. Research into the understanding, representation and modeling of this dynamic system has a long tradition in Geography and Planning (Batty, 1994). The study on, "Remote sensing and urban growth models – Demands and perspectives by Martin Herold *et al.*, (2002), demonstrated the potential of a combined remote sensing and modeling approach. Cellular Automata (CA) are simple, spatial, processing models which have close associations with the complexity theory and have been employed in the exploration of a diverse range of urban phenomena (Clarke & Gaydos, 1997; White & Engelen, 1997; Wu & Webster, 2000; Ward *et al.*, 2000; Yan Liu, 2001; Cheng & Masser, 2003; Anuj Kumar Singh, 2003; Shekhar, 2006), generally to investigate ideas about how real urban systems operate, but from a controlled experimental environment within the computer software.

As per the principles of Cellular Automata, the state of the cell itself and the states of its neighbouring cells at a previous time step determines the state of a cell in the urban fuzzy set. If a cell has strong propensity for development and it can get support for such development from its neighborhood, then development will occur to that cell. However, not all the cells in the urban system are developing at the same time or at the same speed. Variation of the state of cells and factors such as the geographic conditions of the cell and its neighbouring cells, socio-economic status, planning and government policies can have significant impacts on such development, resulting in variation in the urban development in space and over time.

There are various conditions under which the change (transition) from one state to another state can take place. For instance, if a cell has propensity for development but it cannot get sufficient support from its neighbourhood, development could be slowed down. This slow development can also occur if the cell is located in a high terrain or a steep slope area. With the support of transportation networks, development might be expedited. Cells, which are sited in water bodies, such as lakes or rivers, cannot be developed. Therefore, for the

development of a cell at a certain time depends on the condition of a cell itself and the conditions of cells in its neighbourhood. These conditions can be either physical, socio-economic, or institutional or the combinations of any or all (Yan *et al.*, 2001)

Selecting the factors: In applying cellular models to urban development, transition rules must reflect significant factors that influence the slum growth and consequently can comprise a range of geographical and economic factors (Shekhar, 2006). Factors were identified through a review of pertinent literature, as well as through consultation with experts in the field. These can be divided into factors that can be assessed by their relative suitability and factors that are either suitable or unsuitable. But in this model factors were assessed by their relative suitability for slum growth.

Location	Number of Hutments
River banks	5142
Along Nallahs* and canals	19670
Hill and Hill slopes	11604
Roadsides and Gardens Meant for Public use	3584

In Pune city, the slums are scattered all over the city in various environmental conditions (Table. 1). Actually the existence of slums in various setup helped to decide various factors in the CA model. Slums frequently develop on hazardous sites where other development is not possible. In India, majority of the slums are located next to the linear features such as roads and canals (Fig.2). Industries also attract slum development due to employment possibilities of such locations (Davis, 2007; Neuwirth, 2005; Kohli *et al.*, 2011). These sites and situations (locations) helped to select the factors for evaluating the site for slum development in the CA model.

Cellular Automata may be represented by a set of simple production rules while its outcome may mimic a very complex system (Firebaugh, 1998). With the factors, which influence the development, the core part of the model, where this change should take place is defined by using the concept of

Cellular Automata. In this model, cellular automata can be represented as quadruple as follows:

$$(USNT) \dots\dots\dots (1)$$

Where U is Universe (cell space or lattice); S is set of all possible states which a cell can attain, N is neighborhood of a cell, and T is a set of transition rules.

Cell space (or lattice) is fixed as an area under study and in reality it can't be in a regular square shape. Cells representing a subset of geographical area have attributes which include both geophysical and socio economic. The land use type is represented as state of a cell. Principally, any cell should be able to attain any one of the states, but considering some ground realities the number of states available is restricted. The transition rules were made to address all the factors responsible for different growth processes. In the spatial domain they are associated with natural and human related parameters responsible for different growth/decay processes at local, regional and Global level. This information can be modeled to find the suitability of a particular land use say, slum for each cell, using Multi Criteria Evaluation (MCE).

$$S^{t+1}_{xy} = f(S^t_{xy})$$

State of cell (S) at xy (Location of the cell) in a time t+1 is the function of status of the cell at xy in time t (Shekhar, 2006).

In this study the Base map for neighbourhood analysis was prepared with 3 states (Land use / land cover) such as Hill slopes, barren Land and Slums. The conversion of one state to another state will take place only among these three in a linear direction and the conversion of any cell is possible only to Slum. Hence, suitable transition rules were set to run a CA model in the GIS environment.

Transition rule 1

If the status of the cell is “Z” in time t, then in time t+1, it will remain as “Z” only if the cell is surrounded by all “Z” cells in its neighbourhood (Z can be slum, Hill slope and barren land in this study). Such as:

If the status of the cell is Slum in time t, then in time t+1, it will remain as slum only if the cell is surrounded by (Majority) slum cells in its neighborhood.



Fig. 2. Location of Slums in Pune

If the status of the cell is Hill slope in time t, then in time t+1, it will remain as Hill slope only if the cell is surrounded (Majority) by Hill slope cells in its neighborhood.

If the status of the cell is Barren land in time t, then in time t+1, it will remain as Barren only if the cell is surrounded (Majority) by barren cells in its neighborhood.

Transition rule

If the status of the cell is Hill slope in time t, then in time t+1, it will change into Slum if the cell is surrounded (Majority) by Slum cells in its neighborhood.

If the status of the cell is Barren in time t, then in time t+1, it will change into Slum if the cell is surrounded (Majority) by Slum cells in its neighborhood.

If the status of the cell is Slum in time t, then in time t+1, it will change into Slum if the cell is surrounded (Majority) by suitable cells (hill slope or barren) in its neighborhood.

To apply these rules in the neighbourhood analysis, Moore’s Neighbor was selected (3x3 matrix) and Majority option was used in the neighborhood analysis from Spatial Analyst tool. The output is the neighborhood map (N).

The final score should be the integration of the suitability scores obtained by the factors and the neighborhood influence. Therefore, the probability of the cell for Slum growth can be represented as

$$F_{sc} = P + N \dots\dots\dots (2)$$

Where Fsc is the final score of a cell, P is the Probability map score and N is the neighborhood influence map.

After framing the transitional rules, on the basis of visual interpretation and necessary field survey, the slum location map within the municipal boundary area was prepared (Fig. 3). The classified land cover map with

limited land cover categories such as hill slopes and barren land was prepared in Erdas Imagine environment. As slum growth can be speedup or slowed down by a number of factors such as topographical conditions, transportation networks, socio-economic status as well as planning and human decision making behaviour. Therefore, after preparing those base maps, suitable factors were selected for MCE analysis.

Multi-criteria evaluation (MCE) is a widely used methodology to handle land suitability evaluation (Tiwari *et al.*, 1999). Integration of multi-criteria evaluation and GIS is becoming popular now-a-days (Makropoulos & Butler, 2005; Malczewski & Rinner, 2005; Boroushaki & Malczewski, 2008) in a natural and social research. It is primarily concerned with how to combine the information from several criteria to form a single index of evaluation. With the help of MCE, all the candidate cells (those available for probable slum development) can be given a score on the basis of weightage of the factors.

The derivation of Suitability map (For probable growth) comprises three steps:

- Selection of criterion:

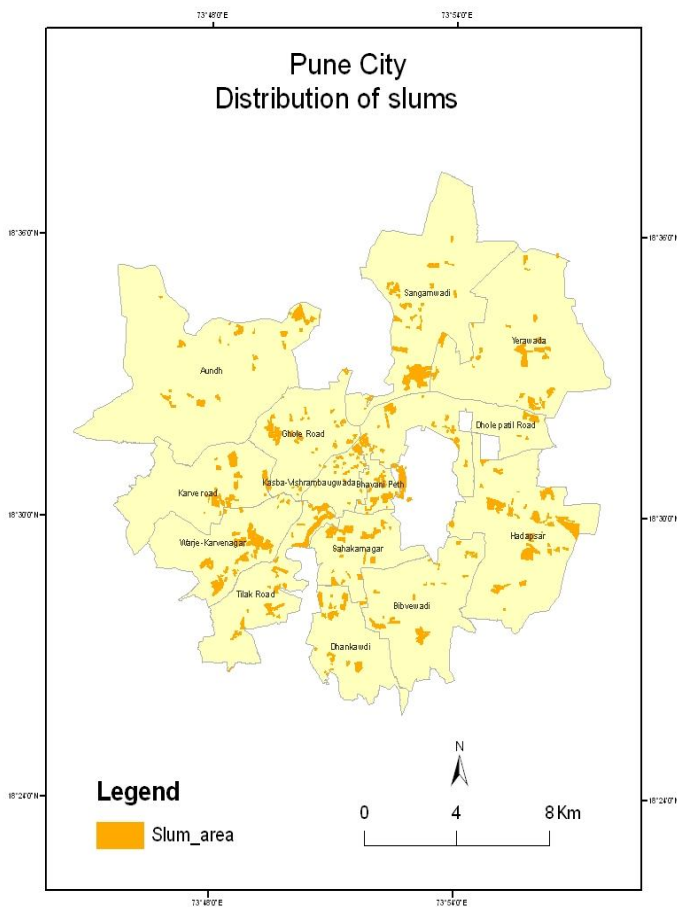


Fig.3. Slum map of Pune (Result of Visual

Seven criteria have been chosen which include Distance from River, Distance from canal, Distance from Railway line, Distance from Road, Distance from industry, Slope and relief features.

- Generation of criterion maps
- The criterion maps are generated by using ArcGIS model builder (Fig. 4)
- Probability classification

This study used the suitability classes for probable growth based on a fuzzy logic. As slum growth can speedup or slowed down by a number of factors such as topographical conditions, transportation networks, socio-economic status as well as planning and human decision making behaviour, based on a fuzzy logic control, the pattern of slum development can be modified using a number of linguistic variables (Shekhar, 2006) such as “The Most”, “Moderate”, “less”, and “the least” and so on to achieve different scenarios of

growth. The linguistic variables are based on the final score calculated by using the formula 2.

If the probability score of a cell is 1, the state of which is regarded shows the least for slum growth, very less growth will take place. If the suitability score of a cell is 2, the state of which is regarded as less suitable for slum growth then slow growth will take place. If the suitability score of a cell is 3, the state of which is regarded as much appropriate for slum growth, more growth will take place. If the suitability score of a cell is 4, the state of which is regarded as very much appropriate for slum growth shows that most of slum growth will take place.

Results and Discussion

Over the last decade, Cellular Automata (CA) and their application in Urban Modeling have been rapidly gaining favour among urban researchers. This is because of the ability of cellular automata, ‘to model and to visualize complex spatially distributed processes’ (Takeyama an & Couclelis, 1997). The present work applies CA to MCE, in combination in ArcGIS environment to model the probable growth of slums.

Seven criteria have been chosen which include Distance from River, Distance from canal, Distance from Railway line, Distance from Road, Distance from industry, Slope and relief features. These seven criteria maps were prepared by using Arc GIS and these maps were again reclassified according to the suitability for the probable growth of slums (Table. 2).

Once the maps were reclassified according to their suitability the weightage was added to the factors. Among the factors such as relief, slope, river, canal, road, railway line and industry, except canal, were given equal influence to support the growth of slums, whereas, the canal had been given little more weightage, assuming that close to the water facility has less vulnerability and might attract more slum dwellers.

Thus the weightage was decided and then the model was allowed to run. The map which resulted after running the model is shown in Fig 5. It has

Table 2: Suitability Scores

Rank	4 (Most)	3 (Moderate)	2 (less)	1 (Least)
Relief	Less than 600m	600-650m	650-700m	700m & above
Slope	Less than 4 °	4-8 °	8-12 °	Above 12 °
Canal	Less than 1120m	1120- 2240m	2240-3360m	Above 3360m
Road	Less than 850m	850-1700m	1700-2550m	Above 2550m
River	Less than 1220m	1220-2440m	2440-3660m	Above 3660m
Rly Line	Less than 1620m	1620-3240m	3240-4860m	Above 4860m
Industry	Less than 1470m	1470-2940m	2940-4410m	Above 4410m

four classes of favourable sites for slum development. Such as 4 - Most favourable site for slum growth, 3- Moderately favourable site for slum growth, 2 - Less favourable site for slum growth and 1 - Least favourable site for slum growth.

The percentage of slum area is less in *most favourable zone* in comparison with percentage of slum area in *moderately favourable zone*. This may be due to the following reasons

- Difficult to extract slums in the central part of the (old) city from the Satellite Image
 - Mostly affected by flood, therefore shifted to other areas (Zone for moderately favourable development) under Slum renewal schemes by Local administration & NGOs.
- (i) There is not much land for expansion of old slums in the central part; whereas the slums in the more favourable zone got enough space for expansion. (ii) Therefore more growth must have taken place in this zone.

After the creation of suitable area maps, the next part is preparation of neighborhood analysis map. By using Spatial Analyst-Neighborhood-Focal statistics-Majority option, the land use map with selected classes was run in the model. The barren land and the hill slopes are considered for possible areas of slum growth. Once the neighborhood map was created, it was added with suitable areas for probable slum growth in order to

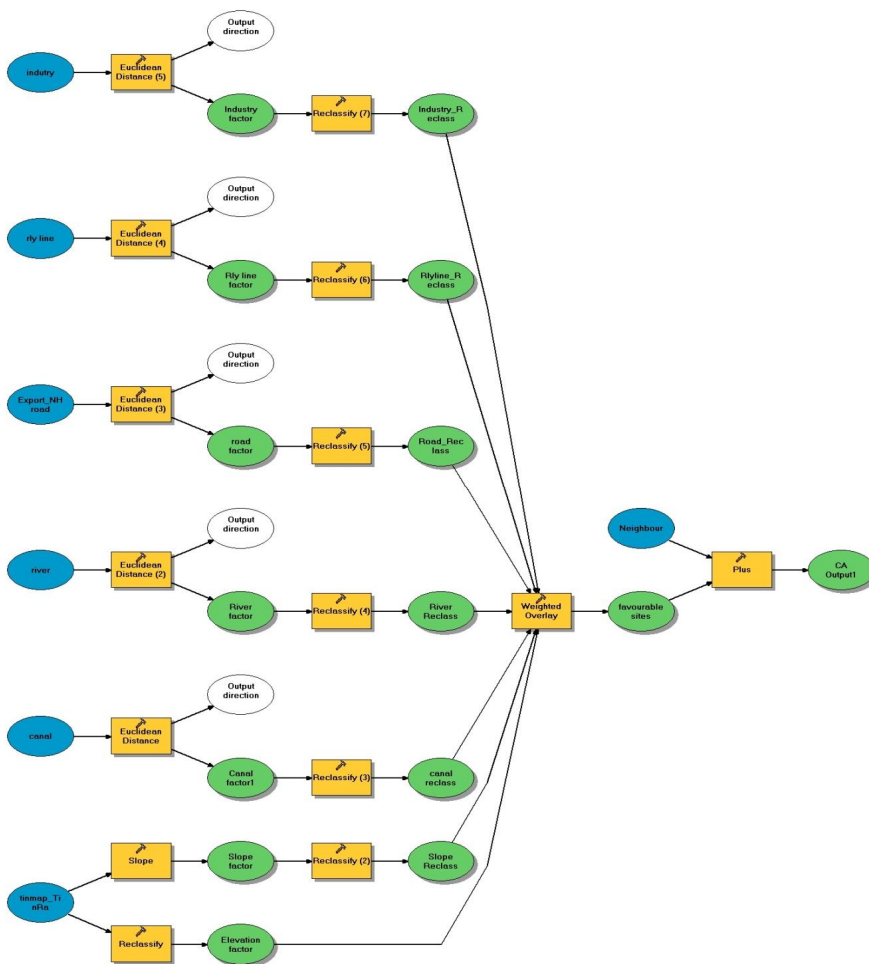


Fig. 4: Model development in Arc GIS Model Maker

Table 3: Degree of fitness

Degree of fitness	Area under Probable area for Slum growth(Sq.Km)	Area of existing Slums (Sq.Km)	Area available for Future growth (Sq.Km)
Most favourable	8.67	1.55	7.12
Moderately Favourable	35.99	6.84	29.15
LessFavourable	19.77	1.56	18.21
Least favourable	3.40	0.07	3.33

are tabulated to understand the number of area (vulnerable area of future slum development) is available for probable growth. More than 85% of slums are concentrated in the zone of more and most favourable zones. Remaining 15% of slums are in less and least favourable zones. The area available for probable future growth had been calculated (Table. 3) and it shows that almost 37% of area for further slum growth is found under zones of more and most favourable area of slum growth in the light of ongoing urbanisation.

Fig.7 shows that, “Most” and “More” growth of slums can take place in Barren land use and less growth of slums can take place in hill slopes. This is mainly because of environmental conservation, in the neighborhood analysis the hill slopes are given less value. Even then the hill slopes have to be taken care as such as it is mostly preferred for slums. These two land use/land cover categories have undergone lot of changes during the last two decades. Therefore, it has more choices for future growth too.

Conclusion

As a new attempt to model the growth of Indian Slums, this work introduced CA concept into site Probability evaluation for Slum growth. It integrated CA with MCE and GIS, and explored a new method of suitability simulation in Slum modeling. Seven criteria selected along with land use conversion restrict layer, have made

the model more reasonable and effective. The analysis of this study mainly focused on probable areas as these areas have highest choice for slum growth. The limitation of this study lies in the fact that, in the application of the model, there are still some uncertainties associated with the selection of

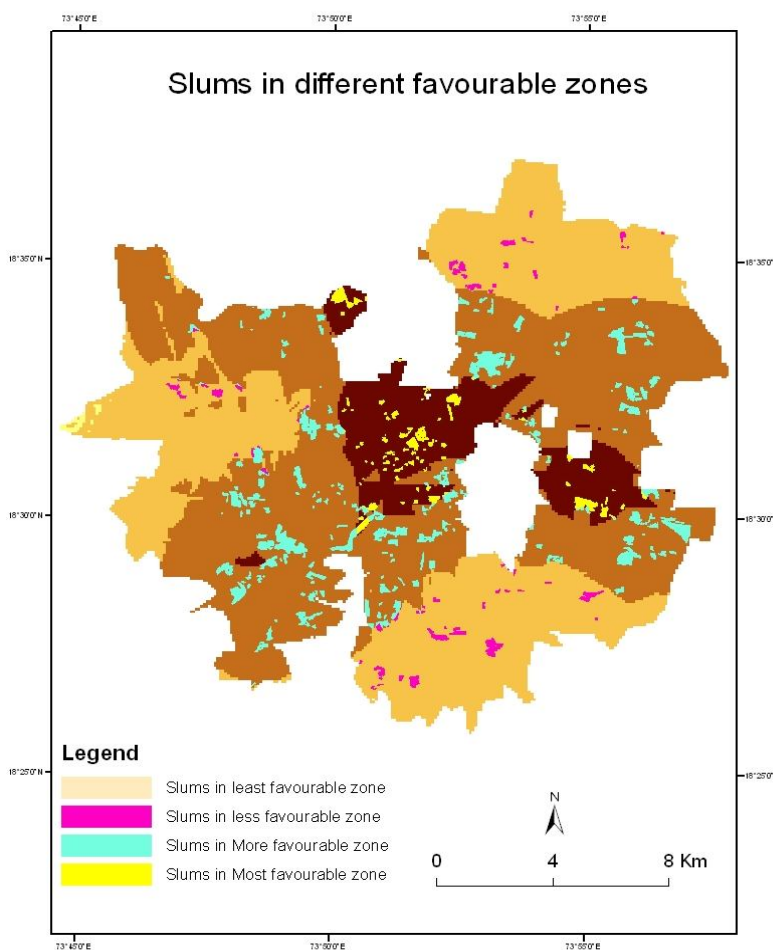


Fig.5: Result first output of model

get the final score map. By using spatial analyst – Math- Plus, these two raster maps were added to get the final map (Fig. 6) which will show the probable areas for the growth of slums in near future. Then the existing slums map was overlaid on this final map and the number of area of slums lying under each zone was calculated. The results

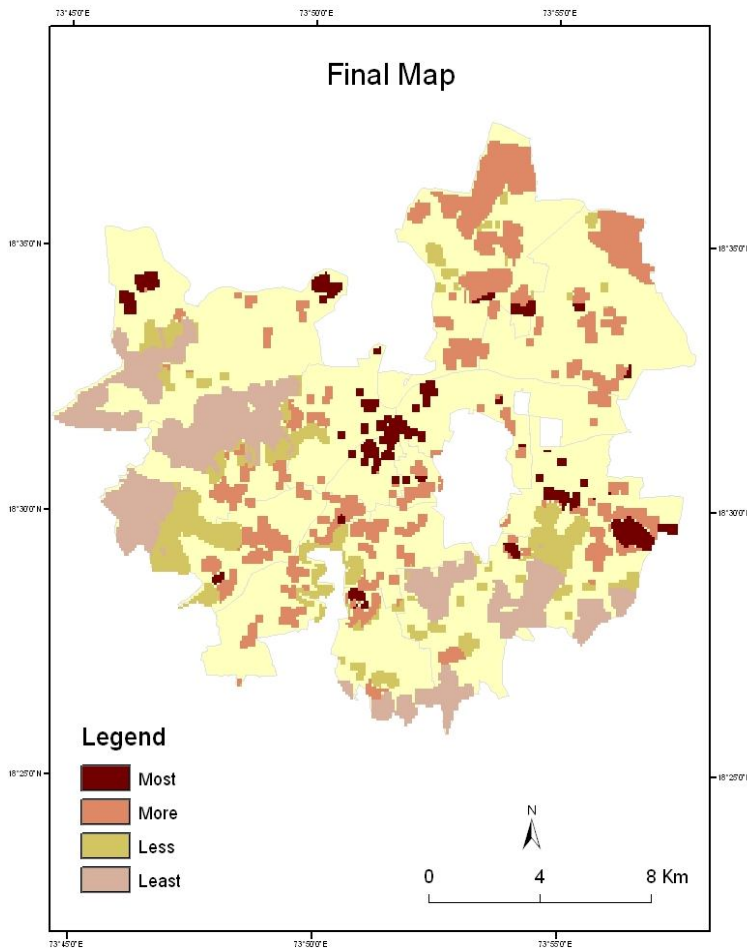


Fig.6: Result - Final output of model

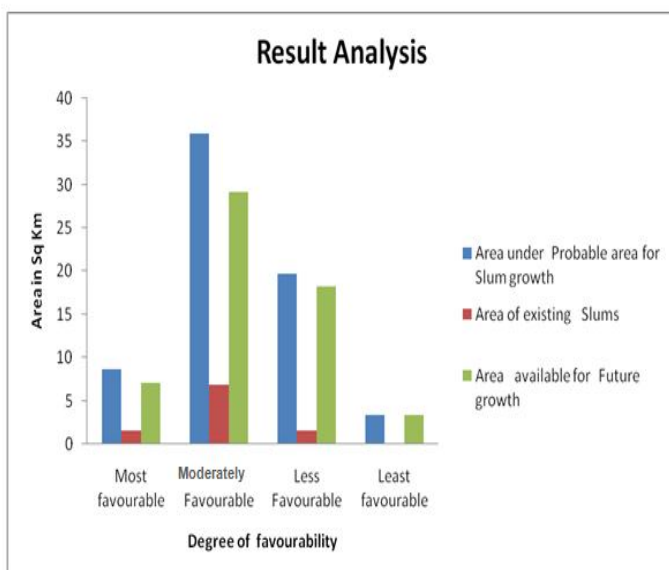


Fig. 7: Results of CA and MCE

factors and related weightage given to them. In combination with experts' participation and field investigation, special attention should be paid to the determination of parameter values in future work.

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