# ASSESSMENT OF POPULATION AT HAZARD RISK

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**MASTER OF PHILOSOPHY**

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21 July 2011

## *CERTIFICATE*

*I, **Tarun Prakash Meena**, do hereby declare that the dissertation entitled '**Assessment of population at hazard risk**' for the degree of **Master of Philosophy** is my bonafide work and may be placed before the examiners for evaluation.*

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Dedicated To

My Parents

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# INTRODUCTION

## 1.1 Introduction:

India's average population density is of 382 people per square kilometer as (2011 census provisional results). On an average, 57 more people inhibit every square kilometer in the country as compared to a decade ago. Whereas it was some 250 people per square mile in 1941 (103 people per square kilometer) was only moderately high, being less than the average densities of most western European countries or of such eastern Asiatic countries as Japan, Korea, the Philippines, or Java. Now, only Bangladesh has population density more than that of India. However, those parts of India with level, moist alluvial soils have among the highest densities of population in the world. About a third of India-mainly the Northern Plains and the Coastlands- has relatively excellent resources of level land, soil, and water and supports over two-thirds of the entire population. Another third of India-comprising chiefly the upland areas of the Indian Plateau-has moderately good resources of soil and water and supports most of the remaining third of the population. Only isolated spots in that third of India comprising the Highland Rim and the Thar Desert are of much value or support more than a meager population.

Hoffman, 1943[1] stated that these great inequalities in the pattern of India's resources are relatively permanent and will probably always determine the main pattern of rural population distribution. Possible modifications through landscape alteration, drainage, irrigation, clearance, and the use of artificial fertilizers are relatively small, expensive, and generally most feasible in or near the fringes of the present population concentrations. The later statement seems to be synchronized with New Economic Geography (NEG) report of World Bank, which highlighted emergence of new economies in large urban agglomerations.

India's diverse physiographic landscape is no exception to various kinds of natural disaster. About 4,250,320 people killed in droughts from 1900 to 2011, about 70,000 killed in 93 events of flooding, about 1, 80000 killed in 154 events of cyclones and damage of billons of household's property (CRED International Disaster Database). Thus, the estimation of the population exposed to natural hazards is based on proxies of their physical footprint such as flooded regions or watersheds. Satellite hazard footprints, combined with population and disaster impact data, can provide an impact assessment of higher precision. There is

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[1] Lawrence A. Hoffman (1943), Main Population Concentrations. The Geographical Journal, Vol. 111, No. 1/3 , pp. 89-100

requirement to combine such data using GIS methods and compare these estimates with those obtained using others.

Until now, assessment of population at risk is generally attempted at some administrative unit say districts or village. But within that unit no further information is available regarding number of people living in per square kilometer and prevailing land use and land cover. This is big limitation while processing various kinds of datasets in geographic information systems, since other overlapping datasets derived from remote sensing satellites regarding hazards are in raster format. So, a requirement was felt to generate grid based raster population dataset, which can be globally processed in case of natural disasters for mobilization of resources and rescue operations.

Researchers have been developing a number of techniques for mapping globally variations of parameters within countries. As these techniques have become more sophisticated, and the capacity of computers to handle very large datasets with great speed has increased, the interest in developing methods for distributing population data to the grid cells of GIS maps has also increased. Initially, GIS specialists tended to direct their efforts towards establishing the coordinates of coastlines and country boundaries, and generating georeferenced datasets for physical and environmental variables that could be derived from high-resolution aerial photography and satellite imagery. Less effort was directed towards the development of georeferenced socio-economic datasets, mainly because such data is collected by censuses and surveys and compiled for political or administrative units, and direct interpolation techniques to estimate the spatial distribution of socio-economic variables are still lacking.[2]

Despite these limitations, improvements in the quality and accessibility of georeferenced environmental data have generated growing demand for more accurate and up-to-date spatial information about the global distribution of population variables. This demand has been driven by two different concerns within the development community. One relates to the interest of demographers, sociologists and urban planners in mapping urbanization processes and defining the location and socio-economic characteristics of urban populations and population at hazard risk with more precision. The first issue to be addressed has been the problem of definition. Somewhat surprisingly, despite the importance of urban growth for

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[2] Deichmann, U. 1996a. Asia medium resolution population database documentation. Database documentation and digital database prepared in collaboration with UNEP/GRID Geneva for the UNEP/CGIAR Initiative on Use of GIS in Agricultural Research, National Center for Geographic Information and Analysis, University of California, Santa Barbara, (available also at http://www.na.unep.net/globalpop/asia/index.php3).

development processes worldwide, there is no commonly accepted definition of what constitutes an urban area, and no commonly accepted spatial characterization of urban areas. The methods used to enumerate urban and rural populations differ from one country to another, and these national differences are reflected in the global population statistics maintained by the United Nations.

This study attempts to assess the relevance of raster population datasets in the events of natural hazards and to generate and compare patterns relating to urban agglomerations and population densities. For assessment, LandScan, 2008 raster population datasets from Oak Lab is attempted along with census datasets; hazards raster footprints and remote sensing datasets derived built-up for urban areas. Since, there is hardly any study on Indian region, so evaluation of raster population data is first attempted at various levels, namely state, districts and wards. Then assessment of population at risk because of natural hazards is attempted.

The principal goal of this dissertation is to address the first task of, which is to "assess the strengths and weaknesses of existing data, methods (e.g., gaps in spatial and thematic coverage, counting individuals, proxy measures such as those derivable from Earth observations), and tools for estimating population living under risk conditions." Because the we was charged with the overall task of better identifying populations at risk—groups that are susceptible to the impact of natural or human-induced disasters- we recognize that there are three critical elements of the data, each of which is a scale issue: spatial scale (how far below the national level can estimates be derived?); temporal scale (for how recent a time period can estimates be made?); and risk scale (how detailed are the available population characteristics of living, place of accommodation and shelter?).

### 1.2 Conceptual framework:

Population data is very important for decision making for government. Census is carried out every decade. "*Census* is the procedure of systematically collecting, compiling, evaluating, analyzing and publishing demographic, economic and social data pertaining to all persons in the country or in a well-limited territory for a specific period of time"[3]. Census of India carried out Population counts every decade since 1872. Though the Precision is very high, the cycle is long and the cost is high, therefore every method of population estimation which is less costly and short is worthy studied.

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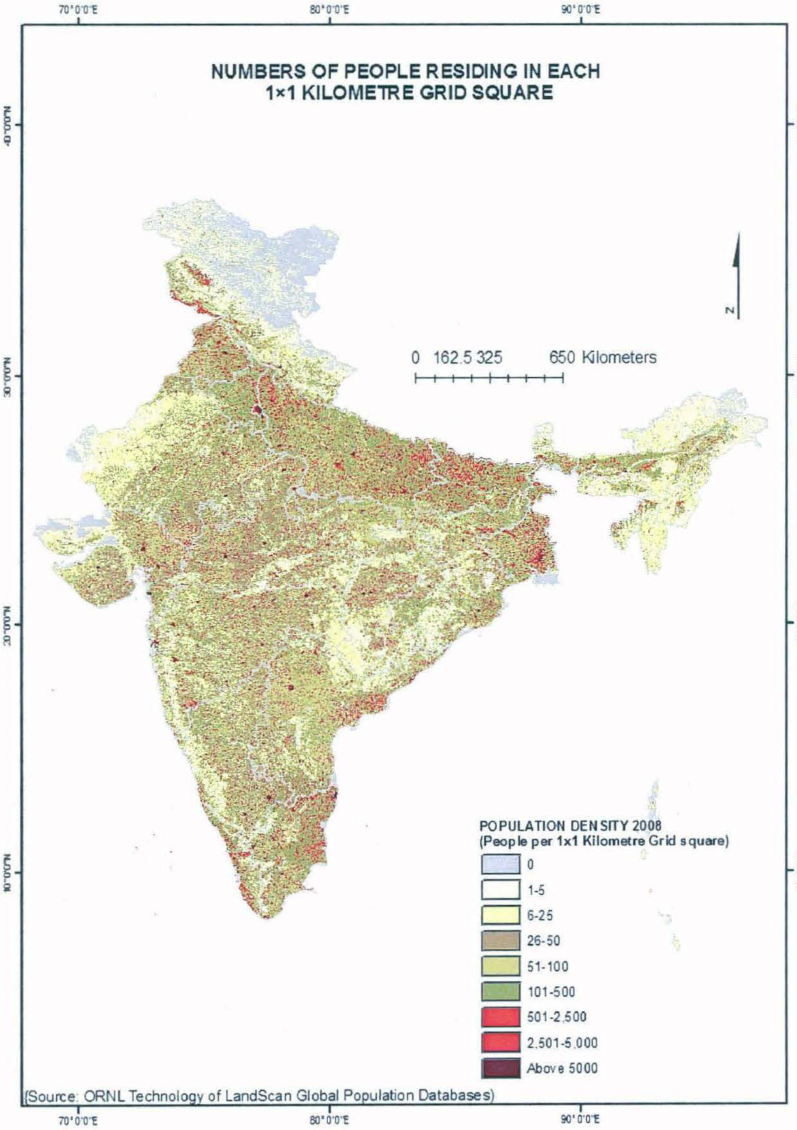
[3] Shepard, Jon; Robert W. Greene (2003). Sociology and You. Ohio: Glencoe McGraw-Hill. pp. A–22. ISBN 0078285763

Geospatial data can be most simply defined as *information that describes the distribution of things upon the surface of the earth*. Also known as spatial data or geographic information it is the data or information that identifies the geographic location of features and boundaries on Earth, such as natural or constructed features, oceans etc. Spatial data is usually stored as coordinates and have semantic topology. Spatial data is often accessed, manipulated or analyzed through Geographic Information Systems. The nature of Geospatial data relationships are important to understand within the context of complex systems like earth system or urbanisation processes. In India there is large possibility and scope as well as need of Geospatial datasets. India is highly populated country as well in India; there is a lack of skilled. Census of India also provides this data but it is in tabular format, which is not easy to understand, do sorting and classifying. Therefore we need a database which can easily be communicated and understood.



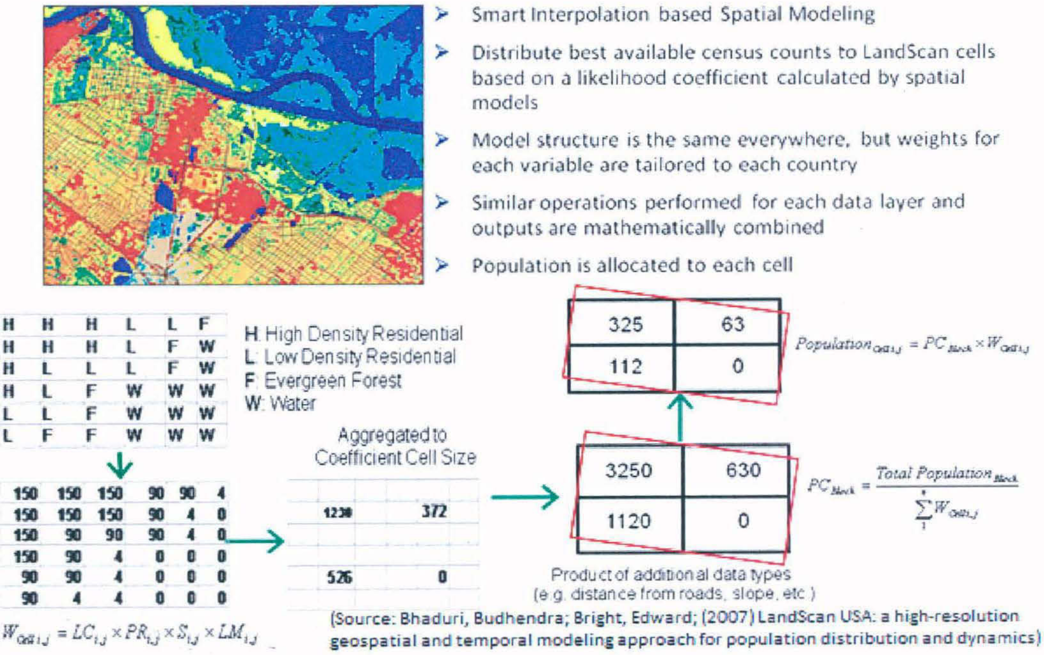
(Source: ORNL Technology of LandScan Global Population Databases)

Figure No.1: LandScan 2008: Population Distribution of India

People tried to estimated population using remote sensing since emergence Geographic Information Science and Remote Sensing. But the initial step is forwarded by *Wang H. H,* (1990) who estimated population in Gulou district of Nanjing Land using density algorithm method, but sampled region is difficult to select in this method. *Wang Faceng* (1990) pointed out method for estimation urban population using multispectral imagery, using density algorithm. *Langford et al.* (1991) derived population using Landsat TM imagery, but regionally derived model method failed in global application. *Flowerdew* and *green* (1992) estimated population density using areal interpolation. *Sautton P* (1998) modelled population density with Night-time satellite imagery. *Landford et al* (1994) and *Lin Z J et al* (2001) modelled population density by means of GIS using density algorithm method[4].

### 1.2.1 What is LandScan datasets?

LandScan Global Population Databases are the world's finest population distribution data generated at ORNL lab. Its raster data with grid resolution of 1 km, it is decomposed vector data into raster grid format. It means administrative vector unit containing some value decomposed into raster, but while doing so other population proxy variables are captured by using high resolution remote sensing data, land use data, transport network data and other ancillary data explained below.



- Smart Interpolation based Spatial Modeling
- Distribute best available census counts to LandScan cells based on a likelihood coefficient calculated by spatial models
- Model structure is the same everywhere, but weights for each variable are tailored to each country
- Similar operations performed for each data layer and outputs are mathematically combined
- Population is allocated to each cell

| | | | | | |
|---|---|---|---|---|---|
| H | H | H | L | L | F |
| H | H | H | L | F | W |
| H | L | L | L | F | W |
| H | L | F | W | W | W |
| L | L | F | W | W | W |
| L | F | F | W | W | W |

H: High Density Residential
L: Low Density Residential
F: Evergreen Forest
W: Water

| | | | | | |
|---|---|---|---|---|---|
| 150 | 150 | 150 | 90 | 90 | 4 |
| 150 | 150 | 150 | 90 | 4 | 0 |
| 150 | 90 | 90 | 90 | 4 | 0 |
| 150 | 90 | 4 | 0 | 0 | 0 |
| 90 | 90 | 4 | 0 | 0 | 0 |
| 90 | 4 | 4 | 0 | 0 | 0 |

$W_{Cell\,i,j} = LC_{i,j} \times PR_{i,j} \times S_{i,j} \times LM_{i,j}$

Aggregated to Coefficient Cell Size

| | |
|---|---|
| 1238 | 372 |
| 526 | 0 |

| | |
|---|---|
| 3250 | 630 |
| 1120 | 0 |

Product of additional data types (e.g. distance from roads, slope, etc.)

$PC_{Block} = \frac{Total\ Population_{Block}}{\sum_{1}^{n} W_{Cell\,i,j}}$

| | |
|---|---|
| 325 | 63 |
| 112 | 0 |

$Population_{Cell\,i,j} = PC_{Block} \times W_{Cell\,i,j}$

(Source: Bhaduri, Budhendra; Bright, Edward; (2007) LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics)

Figure No.2: Preparation of LandScan Database

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[4] Min, Lu An; Cheng-ming, Li; Zong-jian, Lin (2002) "Modeling middle urban population density with Remote Sensing Imagery"

In above figure it is the smart interpolation which show how the LandScan being prepared with help of different nation datasets and other databases based on spatial modals. Modal structure is the same everywhere, but weights for each variable are tailored to each country. Similar operations performed for each data layer and output are mathematically combined then allocated to each cell. The *probability coefficient is based on slope, proximity to roads, land cover, nighttime lights, and an urban density factor.*

$$\boxed{WCellij = LCij + PRij + PRRij + Sij + LMij + PRKSij + SCHij + PRSNij + ARPTij + WTRij}$$

*(where LC, Weight for Land Cover; PR, Weight for proximity to roads; PRR, Weight for proximity to rail roads; S, Weight for slope factor; LM, Weight for landmark polygon feature; PRKS, Weight for parks, SCH, Weight for K-12 schools, PRSN, Weight for prisons; ARPT, Weight for Airports; and WTR, Weight for water bodies.)*[5]

A geographic information system (GIS) is essential for conflation of diverse input variables, computation of probability coefficients, allocation of population to cells, and reconciliation of cell totals with aggregate (usually province) control totals. Remote sensing is an essential source of two input variables-land cover and nighttime lights-and one ancillary database-high-resolution panchromatic imagery-used in verification and validation of the population model and resulting LandScan database.

The Oak Ridge National Laboratories developed LandScan in 2008 in order to overcome the limitations of GPW, and originally in response to a demand for distributed population data that would show emergency workers where populations were likely to be concentrated in the event of a disaster[6]. It was subsequently updated in 2000, 2001 and 2002[7]. LandScan was conceived as an effort to capture ambient population, more than decennial population counts. The difference between ambient and resident population is not significant as the results are quite coarse in all available population density maps.

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[5] Bhaduri, Budhendra; Bright, Edward; (2007) LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics; GeoJournal (2007) 69:103–117; DOI 10.1007/s10708-007-9105-9; Springer Science+Business Media B.V. 2007

[6] Dobson, J.E., Bright, E.A., Coleman, P.R., Durfee, R.C. & Worley, B. A. 2000. LandScan: a global population database for estimating populations at risk. Photogrammetric Engineering and Remote Sensing. 66(7): 849–857.

[7] Oak Ridge National Laboratory (ORNL) LandScan Global Population Database, 2008 (Downloaded in March 2011) (available at www.ornl.gov/sci/gist/landscan/landscan2002/index.html)

The LandScan methodology consists in an automated procedure to allocate population data to 30 arc-second cells, which correspond to approximately 1 square kilometre at the equator. The population estimates used as inputs are based primarily on aggregate data for second order administrative units compiled by the International Programs Center of the US Bureau of Census and represent the most recent census information for each country. These population counts are allocated to the individual 30 arc-second cells through a 'smart' interpolation method that assesses the relative likelihood of population occurrence in cells on the basis of road proximity, slope, land cover, and Nighttime Lights. Probability coefficients are assigned to every value of each input variable, and a composite probability coefficient is calculated for each LandScan cell. The coefficients for all regions are based on the following factors, Roads, weighted by distance from major roads, Elevation, weighted by favourability of slope categories, Land cover, weighted by type with exclusions for certain types, and Nighttime Lights of the World, weighted by frequency. The resulting coefficients are weighted values, independent of census data, which can then be used to apportion shares of actual population counts within any particular area of interest. Coefficients vary considerably from country to country even within different regions of the same country.

### 1.2.2 LandScan Data Description:

The input variables used to estimate the ambient population (mobile population, say population at a location in day and night) of each grid cell are: Census Information, Administrative Boundaries, land cover, imageries coastline and Other Spatial Data (roads, slope, populated places, night-time lights, exclusion areas, urban density factor)[8].

***Table No. 1: LandScan 2008 Data Description***

| *Population* | *Road* | *Rail Roads* | *Land cover/ land use* | *Slope* | *Academic institutions* | *Prisons* | *Hospitals* | *Business employment* | *Imagery* |
|---|---|---|---|---|---|---|---|---|---|
| Census Polygons | VMAP | 1:100K national railway network | Geocover | DTED | Department of Education | National Jail Census | American Hospital Association (AHA) | Info USA | Earth-Viewer |
| Tract-to-tract worker flow | GDT Dynama | | MODIS State GIS | Elevation Data | ESRI | | | Dunn and Bradstreet | Terra Server |
| BLS quarterly updates | TIGER; | | National Land Cover Data | | GDT | | | | Google Earth |

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[8] LandScan: http://www.ornl.gov/sci/landscan/index.shtml

### 1.2.3 Utility and purpose of Global Population Database:

LandScan allows quick and easy assessment, estimation, and visualization of population at risk. It also provides high resolution night time (residential) as well as daytime population distributions for some parts of the world. Demographic (age, race, sex) and socioeconomic characteristics are integrated with population data to allow easily integration with risk and impact assessment models in GIS environment, and Critical component of emergency planning and management, Rapid risk assessment, Evacuation planning, consequence assessment, mitigation planning and implementation.

## 1.3 Literature Review:

Estimation of the population has been a long process adopted by various empires and dynasties for planning and recruitment of soldiers for military. Its considered a an important variable for planning at various level and even for disbursement of funds for socio economic development. During colonial period British administration stated regular enumeration of people since 1872. Some earliest studies are for population distribution in India is by Hoffman, 1943 and Arthur Geddes, 1941.

In absence of raster population data for processing and analysis in GIS environment, its difficult to plan for population mobilisation at risk and emergency resource mobilisation for rescue operation. Thus it is very important to do a focussed literature review. It has been divided into following subsection.

LandScan is a new Information dataset, therefore not much literature is available on this it is a dataset which is produced by the Oak Ridge National Laboratories (ORNL), distributes national populations by land cover category, according to a model with assumed coefficients for population occurrence in each type of land cover. Although there is lack of literature on this theme, still what is available to us is worth looking. Some of them are orientated towards how LandScan being calculated how it is being done at what level it provides datasets what are the utilities of these. Secondly, Literature focused on Population Modelling and estimation of Population at risk. Some other ancillary Literatures are also available which can be useful in my study such as poverty estimation, Spatial Population distribution etc.

LandScan World's Finest Population Distribution Data, by ORNL Technology of LandScan Global Population Databases. It is the world's most accurate and reliable, geographically based, time-of-day population distribution model and databases. LandScan Developed by the

Distribute best available *census counts to LandScan cells based on a likelihood coefficient calculated by this model and Model structure is the same everywhere, but weights and scores for each variable are tailored to each region.* Budhendra Bhaduri (2007).

Census of India, which reports population counts by census Wards (smallest polygonal unit), Tehsil (aggregated Wards), and Districts (aggregated Tehsils). At the highest resolution (Ward level), a *uniform population distribution is assume*d and the population values are typically an attribute of the block (polygon) 'centroids'( Budhendra Bhaduri, Edward Bright, Phillip Coleman, and Marie L. Urban 2004). Similarly, population values for Above Ward levels are reported at the centroids of the block group and tract polygons.

### 1.3.1 Global Population Database and Census Data:

*Lawrence A. Hoffman; (1948)*[i] One of the pioneer of population distribution studies in this study his case study is on India. He studied the Indian population and try to explain the spatial structure of Indian population. He termed his study as India: Main population concentration where his main focus is on India regions based on which population of India is distributed spatially, population density, concentration of cities and towns, communal concentration and population increase over five decades (1891-1941). Though Pakistan and Bangladesh also included in his study but still his study has a great importance in population studies in India and its Historical perspective.

*Kees Klein Goldewijk (2005)*[ii] started with the notion of that large parts of the original land cover have been altered (e.g., deforestation), leading to extra emissions of GHG's to the atmosphere and enhancing global climate change. The spatial and temporal aspects are still not very well known. More and more global integrated environmental assessments concerning global sustainability require long time series of global change indicators, of which population is an important one. This study presents an update of the geo-referenced historical population maps for the period 1700–2000, part of the History Database of the Global Environment (HYDE), which can be used in integrated models of global change and/or global sustainability.

High-resolution population distribution data are critical for successfully addressing important issues ranging from socio-environmental research to public health to homeland security, since scientific analyses, operational activities, and policy decisions are significantly influenced by the number of impacted people according *Budhendra Bhaduri et el. (2007)*[iii]. Dasymetric modeling has been a well-recognized approach for spatial decomposition of census data to increase the spatial resolution of population distribution. In this paper, author have discuss the development of LandScan USA, a multi-dimensional dasymetric modeling approach, which has allowed the creation of a very high-resolution population distribution data both over space and time. At a spatial resolution of 3 arc seconds (*90 m), the initial LandScan USA database contains both a night time residential as well as a baseline daytime population distribution that incorporates movement of workers and students. Challenging research issues of disparate and misaligned spatial data and modeling to develop a database at a national scale, as well as model verification and validation approaches are illustrated and discussed. Initial analyses indicate a high degree of locational accuracy for LandScan USA distribution model and data. High-resolution population data such as LandScan USA, which describes both distribution and dynamics of human population, clearly has the potential to profoundly impact multiple domain applications of national and global priority.

*Tian Xiang Yuea et el. (2005)*[iv] in their study, on the basis of introducing major data layers corresponding to net primary productivity (NPP), elevation, city distribution and transport infrastructure distribution of China, surface modelling of population distribution (SMPD) conducted by means of grid generation method. A search radius of 200 km is defined in the process of generating each grid cell. SMPD not only pays attention to the situation of relative elements at the site of generating grid cell itself but also calculates contributions of other grid cells by searching the surrounding environment of the generating grid cell. Human population distribution trend since 1930 in China is analysed. The results show that human population distribution in China has a slanting trend from the eastern region to the western and middle regions of China during the period from 1930 to 2000.

LandScan USA is a 90 m population distribution model that is used for a variety of applications, including emergency management. Models should have a measure of accuracy; however, the accuracy of population distribution models is difficult to determine due to the inclusion of multiple input datasets and the lack of quantifiable, observable (validated) data to confirm model output. Validated data enables quantification of: (1) overall model accuracy and (2) changes in model output at different levels of quality control. This article examines the effect of quality control for two national school datasets incorporated as input in LandScan USA for Philadelphia County, Pennsylvania; which had a local, validated school dataset available.

*Lauren Patterson et el. (2007)*[v] assessed spatial and attribute errors in large national datasets for population distribution models, which is a case study of Philadelphia county schools. At Oak Ridge National Laboratory a population model has been developed that incorporates national schools data as one of the model inputs. This paper evaluates spatial and attribute inaccuracies present within two national school datasets, Tele Atlas North America and National Center of Education Statistics (NCES). Schools are an important component of the population model, because they are spatially dense clusters of vulnerable populations. It is therefore essential to validate the quality of school input data. Schools were also chosen since a validated schools dataset was produced in geospatial format for Philadelphia County; thereby enabling a comparison between a local dataset and the national datasets. Analyses found the national datasets are not standardized and incomplete, containing 76 to 90 percent of existing schools. The temporal accuracy of updating annual enrollment values resulted in 89 percent inaccuracy for 2003. Spatial rectification was required for 87 percent of NCES points, of which 58 percent of the errors were attributed to the geocoding process. Lastly, it was found that by combining the two national datasets, the resultant dataset provided a more useful and accurate solution.

*Aarthy Sabesan et el. (2007)*[vi] in their study used Metrics for the comparative analysis of geospatial datasets with applications to high-resolution grid-based population data. Three sets of metrics, adopted or customized from geostatistics, applied meteorology and signal processing, are tested in terms of their ability to evaluate geospatial datasets, specifically two population databases commonly used for disaster preparedness and consequence management. The two high-resolution, grid-based population datasets are the following: The LandScan dataset available from the Geographic Information Science and Technology (GIST) group at the Oak Ridge National Laboratory (ORNL), and the Gridded Population of the World (GPW) dataset available from the Center for International Earth Science Information Network (CIESIN) group at Columbia University. Case studies evaluate population data across the globe, specifically, the metropolitan areas of Washington DC, USA, Los-Angeles, USA, and Houston, USA, and London, UK, as well as the country of Iran. The geospatial metrics confirm that the two population datasets have significant differences, especially in the context of their utility for disaster readiness and mitigation. While this paper primarily focuses on grid based population datasets and disaster management applications, the sets of metrics developed here can be generalized to other geospatial datasets and applications. Future research needs to develop metrics for geospatial and temporal risks and associated uncertainties in the context of disaster management.

*Budhendra Bhaduri, Eddie Bright, Veeraraghavan Vijayraj (2008)*[vii] stated that geospatial information is essential for quick and effective response during disaster and emergency situations. Because disasters and emergencies are always geographically defined and addressed, the decision making capability in emergency management requires spatio-temporal visualization of our environment, which in turn is empowered by geospatial information that is largely derived from earth observation or remote sensing data and spatial analyses using various Geographic Information System (GIS) based modeling and simulation tools. Consequently, remote sensing technologies are increasingly becoming nucleus to disaster preparedness, response, and recovery missions. Majority of disaster impact modeling and mitigation analyses programs take advantage of geospatial data and other surrogate data sets that are derived from the large volume of image data being produced and archived.

*Lauren Patterson et el. (2009)*[viii] discussed LandScan USA process were assessed to determine what level of quality control was required to have a statistically significant change of the model's population distribution. The typical level of quality control for LandScan USA resulted in 36% of schools being moved to the correct location and 20% of missing student enrollments were found, compared to 87% and 98% respectively for the validated dataset. The costs of increasing quality control resulted in a six-fold increase in labour time; however, the additional quality control did not produce statistically significant improvements in the LandScan USA model. Thus, typical quality control efforts for schools in LandScan USA produced a population distribution similar to the validated level of quality control, and can be applied with confidence for policy, planning, and emergency situations.

The entire population of an area is uniformly distributed over that area. In fact, non uniform distribution of human population is quite obvious from simple visual observation of any landscape. Before going to our final objective of population at risk estimation first we should know where the population is living? What is their distribution pattern? What is the population density? There are numerous studied done over population distribution all over the world such as studies by *Tian Xiang Yuea (2005), Ming-Dawa Su a (2010)* which mainly talked about distribution, Dasymetric pattern, density, there are lack of studies relating to application mainly in developing countries like India.

Thus after reviewing literature on LandScan we get a clear theme of our study which will be more application oriented rather than Dasymetric or distribution density of population representation, because there is lack of literature on applications of LandScan in developing countries.

### 1.3.2 Hazard assessment studies:

*Taranjot Kaur Gadhok, (2002)*[ix] in his study Floods in Delhihave described about the picture of Delhi in terms of occurrence of floods, their mitigation etc. In a study by *R. Sinha, G.V. Bapalu L.K. Singh, and B. Rath*[x] discusses the flooding problem in the Kosi river basin and presents an in-depth analysis of flood hydrology. They have integrated the hydrological analysis with a GIS-based flood risk mapping in parts of the basin. Typical hydrological characteristics of the Kosi river include very high discharge variability, and high sediment flux from an uplifting hinterland. Annual peak discharges often exceed the mean annual flood and the low-lying tracts of the alluvial plains are extensively inundated year after year. Their flood risk analysis follows a multi-parametric approach using Analytical Hierarchy Process (AHP) and integrates geomorphological, land cover, topographic and social (population density) parameters to propose a Flood Risk Index (FRI). The flood risk map is validated with long-term inundation maps and offers a cost-effective solution for planning mitigation measures in floodprone areas.

A summary report by *Proceedings of the Project Workshop(2004)*[xi] on the basis of synthesis of the ideas shared during the course of the five day workshop involving staff from Bangladesh, China, India and the US states that flood monitoring, forecasting and risk assessment represents only one extreme of the total water resource management picture. The other extreme is represented by drought and water shortages. Between these extremes are many competing requirements for water. Floods and droughts are not inherently disasters. They only become disasters when human populations are affected.

The India flood forecasting service was initiated by the Central Water Commission in 1958. A network of 157 flood forecasting stations was established in major and interstate river basins. Of these, 80 flood forecasting stations are on the Ganges and 27 are on the Brahmaputra. The steps in the flood forecasting and warning system are to 1) collect data, 2) transmit results, 3) analyze data and compute forecast, and 4) disseminate forecast. Data collected includes river water level, river discharge, rainfall and other precipitation. The data are transmitted using wireless, telephone, fax, satellite, telegraph and telex. The data are analysed and forecasts are computed using simple correlation, co-axial correlation, Muskingum method and successive routing through sub-reaches mathematical models. The accuracy of the flood forecasts is calculated and analyzed for each forecast station.

*Jan de Leeuw et. al. (2010)* [xii] in their study; The Function of Remote Sensing in Support of Environmental Policy discussed about limited awareness of environmental remote sensing's potential ability to support environmental policy development constrains the technology's utilization. Paper reviews the potential of earth observation from the perspective of environmental policy. A literature review of "remote sensing and policy" revealed that while the number of publications in this field increased almost twice as rapidly as that of remote sensing literature as a whole (15.3 versus 8.8% yr−1), there is apparently little academic interest in the societal contribution of environmental remote sensing. This is because none of the more than 300 peer reviewed papers described actual policy support. The potential, actual support, and limitations of earth observation with respect to supporting the various stages of environmental policy development have also been discussed. Examples are given of the use of remote sensing in problem identification and policy formulation, policy implementation, and policy control and evaluation. While initially, remote sensing contributed primarily to the identification of environmental problems and policy implementation, more recently, interest expanded to applications in policy control and evaluation. Study concludes that the potential of earth observation to control and evaluate, and thus assess the efficiency and effectiveness of policy, offers the possibility of strengthening governance.

### 1.2.3 Urban studies:

*Jerome E. Dobson et el. (2000)*[xiii] in their study discussed LandScan Global Population Project which produced a world-wide 1998 population database at a 30- by 30-second resolution for estimating ambient populations at risk. Best avail-able census counts were distributed to cells based on prob-populaability coefficients which, in turn, were based on road proximity, slope land cover, and night-time lights. Landscan1998 has been completed for the entire world. Verification and Validation were conducted routinely for all regions and more extensively for Israel, Germany, and the south-western United States. Geographic information systems (GIS) were essential for conflation of diverse input variables, computation of probability coefficients, allocation of population to cells, and reconciliation of cell totals with aggregate control totals. Remote sensing was an essential source of two input variables-land cover and night-time lights-and one ancillary data base-high-resolution panchromatic imagery--used in v & v of the population model and resulting LandScan database.

*Yongzhong Tian, Tianxiang Yue, Lifen Zhuc and Nicholas Clinton (2005)*[xiv] investigated the correlation between land cover data and other factors that affect population distribution. The results show that land cover data contain sufficient information to infer population distribution and can be used independently to model the spatial pattern of population density in China. China's population distribution model (CPDM) was developed based on land cover data to calculate population density in China at 1 km resolution. For cells in rural areas, population probability coefficients were calculated based on weighted linear models, the weights of land cover types being derived from multivariate regression models and on a qualitative order of land types in 12 agro-ecological zones. For cells in urban areas, a power exponential decay model based on city size and the distance from urban center was employed to calculate population probability coefficients. The models were validated in sampled cells using ancillary population data. The validation shows the mean relative error of estimated population to be 3.13 and 5.26% in rural and urban areas, respectively. Compared to existing models, the accuracy of CPDM is much higher at cell, county and province scales.

*Silvana Amaral et el. (2005)*[xv] in their study on estimating population and energy consumption in Brazilian Amazonia using DMSP night-time satellite data, described a methodology to assess the evidence of human presence and human activities in the Brazilian Amazonia region using DMSP/OLS night-time satellite sensor imagery. It consists on exploring the potential of the sensor data for regional studies analysing the correlation between DMSP night-time light foci and population, and the correlation between DMSP night-time light foci and electrical power consumption. DMSP/OLS imagery can be used as an indicator of human presence in the analysis of spatial–temporal patterns in the Amazonia region.

*S. I. Hayl, A. M. Noor, A. Nelson, and A. J. Tatem, (2005)*[xvi] in their study Human population totals are used for generating burden of disease estimates at global, continental and national scales to help guide priority setting in international health financing. The analysis presented in the paper tests the accuracy of five large-area, public-domain human population distribution data maps against high spatial resolution population census data enumerated in Kenya in 1999.

*Fang Qiu, Kevin L. Woller, and Ronald Briggs(2003)* [xvii] modeled population growth from 1990 to 2000 in the north Dallas-Fort Worth Metroplex using two different methods: a conventional model based on remote sensing land-use change detection, and a newly devised approach using GIS-derived road development measurements. These methods were applied at both city and census-tract levels and were evaluated against the actual population growth. It was found that accurate population growth estimates are achieved by both methods.

*Guiying Li and Qihao Weng (2005)*[xviii] by Using Landsat, ETM Imagery to Measure Population Density in Indianapolis, Indiana, discussed that remote sensing techniques have been previously used in urban analysis, settlement detection, and population estimation. This research explores the potentials of integration of Landsat ETM data with census data for estimation of population density in City of Indianapolis, Indiana. Spectral signatures, principal components, vegetation indices, fraction images, textures, and temperature were used as predictive indicators. Correlation analysis was used to explore the relationships between remote sensing variables and population, and stepwise regression analysis was then used to develop models for estimating population quantities. Two sampling schemes (non-stratified versus stratified sampling) were compared. It was found that the integration of textures, temperatures, and spectral responses substantially improved the accuracy of estimation. Stratification of the population into three categories of low-, medium-, and high-densities and development of different models for individual population density category provided better estimation results than a non-stratified scheme. The total population for City of Indianapolis was estimated to be 832,792 in 2000 yielding an accuracy of 96.8 percent.

*Xiao Hang Liu, Keith Clarke, and Martin Herold (2006)*[xix] in their study the correlation between census population density and Ikonos image texture was explored. The spatial unit for the analysis was census blocks with homogenous land-use. Ikonos image texture was described using three methods: the gray level co-occurrence matrix (GLCM), semi-variance, and spatial metrics. Linear regression was conducted to explore the correlation between image texture and population density. It was found that although correlation exists, its degree varies depending on the method used to describe image texture. The highest correlation is given by the spatial metrics method. Result suggests that the correlation between texture and population density is not strong enough to predict or forecast residential population. However, image texture does provide a base to refine census-reported population distribution using remote sensing. High-resolution satellite images therefore have the potential to support "smart interpolation" programs to estimate human population distribution in areas where detailed information is not available.

*Magnus Bengtsson, Yanjun Shen and Taikan Oki (2006)*[xx] presented a dataset covering three global population forecasts for the period 1990 2100 at 0.5-degrees resolution. The basis for these forecasts is the SRES scenarios developed for the IPCC climate-modeling framework. In addition, a gridded dataset of urban and rural populations for the period 1990-2050 is presented. To illustrate how the datasets can be used, future changes in population density and urbanization were analyzed for some of the world's major river basins. This analysis shows that the population density in the Ganges basin, which is already very high, is likely to increase considerably. The highest future increase rates were found in some African and Middle-Eastern basins. The population dataset for 2015 was compared with one previously published gridded dataset. The comparison shows some differences in population density, mainly in small, highly urbanized coastal river basins, while for large basins, the two datasets agree fairly well.

*Christopher D. Elvidge et el. (2009)*[xxi] prepared a global poverty map and produced at 30 arcsec resolution using a poverty index calculated by dividing population count (LandScan 2004) by the brightness of satellite observed lighting (DMSP night time lights).

*Anil Cheriyadat et el. (2007)* [xxii] tried to automate human settlement mapping by utilizing ORNL's high performance computing capabilities. Their algorithm employs gray-level and local edge-pattern co-occurrence matrices to generate texture and edge patterns. Areas of urban land cover correlate with statistical features derived from these texture and edge patterns. They have parallelized their algorithms for implementation on a 64-node system using a single instruction multiple data programming model (SIMD) with Message Passing Interface (MPI) as the communication mode. The early results are promising, pointing towards future large-scale classification of human settlements at high-resolution.

*David R. Rain E John F. Long E Michael R. Ratcliffe (2007)*[xxiii] discussed that measures of the effects of population pressure on the landscape using traditional methods for classifying urban territory are inadequate. Their paper examines comparative urbanization measures among three case studies: the Pearl River Delta in Guangdong Province of China, the Indian state of Kerala, and the southern part of Florida in the United States. It proposes a measure based on the distribution of local population densities, taking advantage of the detailed data on small area populations and land area available in modern censuses and model-derived population databases such as LandScan, and the increasing potential of spatial analysis using geographic information systems (GIS). Examined with a similar set of thresholds, the resulting density distributions offer the potential to show better the ecological effects of population than do traditional measures.

*Marcia Caldas de Castro (2007)*[xxiv]'s study reviews demographic studies that specifically addressed space with spatial statistical models, and that focused on fertility, mortality, migration, and population models. Additionally, it summarizes different spatial datasets and software freely available, as well as the challenges that exist for the development of spatial demography applications.

*Ramita Manandhar , Inakwu O. A. Odeh and Tiho Ancev (2009*[xxv]*)* in their study have checked Accuracy of Land Use and Land Cover on the basis of Classification of Landsat Data. Classifying remote sensing imageries to obtain reliable and accurate land use and land cover (LULC) information still remains a challenge that depends on many factors such as complexity of landscape, the remote sensing data selected, image processing and classification methods, etc. The aim the paper was to extract reliable LULC information from Landsat imageries of the Lower Hunter region of New South Wales, Australia. The classical maximum likelihood classifier (MLC) was first applied to classify Landsat-MSS of 1985 and Landsat-TM of 1995 and 2005. The major LULC identified were Woodland, Pasture/scrubland, Vineyard, Built-up and Water-body. By applying post-classification correction (PCC) using ancillary data and knowledge-based logic rules the overall classification accuracy was improved from about 72% to 91% for 1985 map, 76% to 90% for 1995 map and 79% to 87% for 2005 map. The improved overall Kappa statistics due to PCC were 0.88 for the 1985 map, 0.86 for 1995 and 0.83 for 2005. The PCC maps, assessed by McNemar's test, were found to have much higher accuracy in comparison to their counterpart MLC maps. The overall improvement in classification accuracy of the LULC maps is significant in terms of their potential use for land change modelling of the region.

*Rajesh Bahadur Thapa and Yuji Murayama's (2009)*[xxvi] study on Kathmandu Valley, Nepal: Remote Sensing and Spatial Metrics Approaches, examines the spatiotemporal pattern of urbanization in Kathmandu Valley using remote sensing and spatial metrics techniques. The study is based on 33-years of time series data compiled from satellite images. Along with new developments within the city fringes and rural villages in the valley, shifts in the natural environment and newly developed socioeconomic strains between residents are emerging. A highly dynamic spatial pattern of urbanization is observed in the valley. Urban built-up areas had a slow trend of growth in the 1960s and 1970s but have grown rapidly since the 1980s. The urbanization process has developed fragmented and heterogeneous land use combinations in the valley. However, the refill type of development process in the city core and immediate fringe areas has shown a decreasing trend in the neighborhood distances between land use patches, and an increasing trend towards physical connectedness, which indicates a higher probability of homogenous landscape development in the upcoming decades.

*Kwasi Appeaning Addo (2010)'s*[xxvii] study states that urban farming, practiced by about 800 million people globally, has contributed significantly to food security and food safety. The practice has sustained livelihood of the urban and peri-urban low income dwellers in developing countries for many years. Its popularity among the urban low income is largely due to lack of formal jobs and as a means of adding up to household income. There is increasing need to sustainably manage urban farming in developing nations in recent times. Population increase due to rural-urban migration and natural, coupled with infrastructure developments are competing with urban farming for available space and scarce resources such as water for irrigation. Lack of reliable data on the extent of urban/peri-urban areas being used for farming has affected developing sustainable policies to manage urban farming in Accra. Using ground based survey methods to map the urban farmlands are inherently problematic and prohibitively expensive. This has influenced accurate assessment of the future role of urban farming in enhancing food security. Remote sensing, however, allows areas being used as urban farmlands to be rapidly established at relatively low cost. This paper will review advances in the use of remote sensing technology to develop an integrated monitoring technique for urban farmlands in Accra.

*Gunter Zeug 1 and Sandra Eckert (2010)*[xxviii] in their study based on Spatial Built-up Patterns: The Sana'a, Yemen, have stated that in light of rapid global urbanisation, monitoring and mapping of urban and population growth is of great importance. Population growth in Sana'a was investigated for this reason. The capital of the Republic of Yemen is a rapidly growing middle sized city where the population doubles almost every ten years. Satellite data from four different sensors were used to explore urban growth in Sana'a between 1989 and 2007, assisted by topographic maps and cadastral vector data. The analysis was conducted by delineating the built-up areas from the various optical satellite data, applying a fuzzy-rule-based composition of anisotropic textural measures and interactive thresholding. The resulting datasets were used to analyse urban growth and changes in built-up density per district, qualitatively as well as quantitatively, using a geographic information system. The built-up area increased by 87 % between 1989 and 2007. Built-up density has increased in all areas, but particularly in the northern and southern suburban districts, also reflecting the natural barrier of surrounding mountain ranges. Based on long-term population figures, geometric population growth was assumed. This hypothesis was used together with census data for 1994 and 2004 to estimate population figures for 1989 and 2007, resulting in overall growth of about 240%. By joining population figures to district boundaries, the spatial patterns of population distribution and growth were examined. Further, urban built-up growth and population changes over time were brought into relation in order to investigate changes in population density per built-up area. Population densities increased in all districts, with the greatest density change in the peripheral areas towards the North. The results reflect the pressure on the city's infrastructure and natural resources and could contribute to sustainable urban planning in the city of Sana'a.

*Christopher N.H.Doll , ShonaliPachauri (2010).*[xxix] estimated rural populations without access to electricity in developing countries through night-time light satellite imagery. Paper investigates the extent to which electricity access can be investigated using night-time light satellite data and spatially explicit population datasets to compare electricity access between 1990and2000.

*Ming-Dawa Su et el. (2010)*[xxx] in their study proposed a multi-layer multi-class dasymetric (MLMCD) framework to better redistribute the regionally aggregated population statistics into smaller areal units and reveal more realistic spatial population distribution pattern. The Taipei metropolitan area in Taiwan was used as a case study area to demonstrate the disaggregation ability of the proposed framework and the improvements to the traditional binary or multi-class dasymetric method. Assorted data, including remote sensing images, land use zoning, topography, transportation and accessibility to facilities were introduced in different layers to improve the redistribution of aggregated regional population data.

### 1.4 Statement of problem:

Now a day when micro and accurate data is needed for planning and policies, Census data cannot be considered as the only source to get all information related demography. New techniques have emerged with time to fill the gaps in population data provided by Census of India. Many countries are using this as an important information provider for the population distribution and risk assessment. But in India till now it is not that much popular. That is why there is need to compare data of Census with LandScan so that correctness of this source can be proved. At the same time LandScan data gives minor information about spatiality of population so it can also be used in the assessment of various aspects. To be relevant, '*population at risk*' is the most crucial subject of this population estimation source in this period of climate change and its impacts as floods and sea level changes. So the study moves to study the area from the frame of reference of Multi level Modelling of population concentration including knowledge of where the population is located and Estimation of population living in risk prone areas using LandScan: Global Population Dataset and Census Information.

### 1.5 Objectives:

The major objectives are as follows:

1. Evaluation of Global Raster Population Database and Census of India Population Database at State and district level.
2. Determining variation in the distribution of populations and to evaluate differentials in terms of population estimates in selected Mega cities at ward level.
3. Assessment of urban population distribution and agglomeration density at ward level.
4. Assessment of Population at hazard Risk

Above given objectives together would provide a frame to understand the scenario of population concentration over the grid cell space, and the last objective which is application oriented which becomes the backbone of study and policy formation.

### 1.6 Research Questions:

To study the area from the frame of reference of *Multi level Modelling of population concentration including knowledge of where the population is located and Estimation of population living in risk prone areas using LandScan: Global Population Dataset and Census Information* the following questions being examine are:

1. LandScan population estimates are equal to Census/official population estimates,
2. Population estimates are somewhat weaker in Urban Areas than Rural areas and population estimates alter with the change in topography.

### 1.7 Databases:

The study is mainly based on secondary data information and facts available from different sources. The major required sources are as follows:

- *Demographic Data:* The original census data comes from Indian population by county in 2011 *(Census of India, 2011)*. These data are available as an attribute of the administrative polygons at the different levels. Census administrative polygons consider population and other indicator as uniformly distributed in the polygon which is not possible in real world. Here for this study require census data of:
    - General population tables (A Series): to compare state level population with the LandScan population count at macro level and look for data accuracy.
    - Primary census abstract tables (PCA): used to estimate number person and houses to estimate *population at risk.*
- *LandScan and Geospatial data:* Global Population Database by ORNL Technology of LandScan.
- Survey of India provides Geo spatial data, to fulfil research requirement of spatial data is provided by Survey (Air) and Delhi Geo-spatial Data Centre, New Delhi.
- *Data of Land cover and DEM:* Digital data (LANDSAT Satellite Imageries) for land use classification will be taken from Earth Science Data Interface at the Global Land Cover Facility (GLCF) and Digital elevation model dataset will be from U.S. Geological Survey's (USGS) Earth Resources Observation System (EROS) Data Center. The slope data were derived from the DEM and Shuttle Radar Topography Mission (SRTM).

- *Ancillary data:* Other data include Administrative Boundaries, topographic sheet, railways, highways, rivers, and cities location. They will be taken from the database Survey of India at different scales in *Arc Info* coverage format. Then data regarding disaster and population at risk will be take from National Institute of disaster management, Ministry of Home Affairs; Government of India and National Disaster Management Authority (Data for Risk assessment).

## 1.8 Methodology:

Methodology in any case is like a key which apparently reveals and discloses the complexities of any kind of problems. In order to shift the complexities and draw inferences, various cartographic statistical and GIS techniques have been applied according to the objectives:

- *Modelling based on land cover*: Land is a synthesis of many natural and social factors which have acted in concert for long periods of time.[9] Land cover is highly correlated with many factors affecting population distribution; it is a good proxy for estimating the characteristics of population distribution. This study determines the feasibility of modelling population density by means of land cover. data. Therefore Population concentration analysis methods:

- *Concentration of population includes distribution and density of population* calculated using LandScan Dataset at grid cell level
    - Comparison of Census data and LandScan population counts considering administrative boundaries as indicator common.
    - Growth pattern and changes population concentration and Spatial changes in population at grid cell level and at different administrative levels.

- *Population at Risk* assess based on census and LandScan data for risk prone areas using *Normalization Procedure, Mapping on a categorical scale and Regression method*

- *Controlling total population at the county Scale:* Administrative polygons at the county scale are the minimum mapping units available at a countrywide scope at present, and therefore represent the best country level population data. Quantification of total

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[9] (Zhang, 1997), Modeling population density using land cover data Yongzhong Tian a,b,*, Tianxiang Yue a, Lifen Zhuc, Nicholas Clinton d

population by rural area and urban area at the county scale therefore avoids the reallocation of population between different counties and between rural and urban areas. Population probability coefficients were normalized in rural and urban areas of counties in order to make use of the best national level population data.

  - *Modelling rural area and urban area separately:* Urban and rural areas were treated separately due to the difference of affecting factors between rural and urban areas on population distribution. This separation was necessary to avoid mistakes such as over or under estimation of population density within rural or urban grid-cells.
  - *Zone Modelling for Mega cities:* Significant geographic differences of natural, social, economic and historical factors have resulted in different characters of land use in different regions. Modelling in relatively homogeneous zones can reduce effects of these differences on population distribution. The model was implemented in *homogenous zones* in an effort to minimize population estimate error resulting from the geographic disparity in the factors affecting population. Method of Estimation population at Risk will be calculated by population count living in areas under Risk i.e. flood, water logging, etc.

  Therefore her we have used simple statistical method to make our data use full for use by these methods here we tried to make our element in indicators.

- *Cartographic methods:* Cartographic methods are the second main component of analysis of phenomena. The maps explain and interpret the data and also adopt cartographic methods to translate the tabular form of data into quantitative visual/ graphical form. Here we will use the different cartographic methods to prepare maps because our data type is different and on the basis data type we will use the visual variable to represent the theme:
  - LandScan data is capable of detecting and measuring a variety of element relating to the population, such as the Distribution, Density, Location, Texture, Form, and Spread etc. There are various techniques estimate accuracy, (Using of GIS Software's namely Arc-view, ERDAS Imagine, for Map making better analysis of study area),
  - Using Satellite Imageries and toposheet of study area for Land use change detection.

Natural and manmade disasters place vast populations at risk, often with little or no advance warning. Consider the following examples:

*Natural Disaster:*

- Flood due Kosi river course change many cities threatened in Bihar, India 2008,
- Most recent heavy rain causes overflowing water in Yamuna River in Delhi, submerged low ling areas and risk of *flood 2010.*

*Manmade Disaster:*

- An industrial plant releases hazardous chemicals into the atmosphere, as a Union Carbide plant did in Bhopal, India in 1984,
- A nuclear power plant releases radiation, as Chernobyl did in 1986,
- Toxic gases spread from a terrorist's bomb, as sarin did in Tokyo, Japan 1994.

These examples represent global threats to local places, and geographic information is essential for quick and effective response. How will the contaminant be dispersed? Where will it go? How many people are at risk? Who are they? Where are they? Here we will try to deal with these questions ahead using GIS software's.

- *GIS*: It is fundamental methodology used for visual representation of data of analysis of data. It contains the characteristics of both above methods it consist no. methods and software' here we will use Arc-GIS and ERADAS for our purpose, and for *Population Density Calculation at grid cell level we will use ArcMap and Spatial Analyst extension.*

ArcView with the Spatial Analyst extension was used to derive population distributions for sub-national administrative areas and generate histograms of distributed population. Data subsets will be created to speed processing time by converting grid values to integers. The legend editor was employed to set a common set of population density categories for all study sites. The map calculator will be taken to divide the population of each selected area by the actual area in the Area Grid. Population density classes were subsequently modified to adjust for latitudinal variation etc.

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*Chapter No. 2*

# Analogical association between Global Raster Population Database and Census of India Population Database

## 2.1 Introduction

Global Population increase and climate change is receiving increasing attention, not only from the scientific community but also from policy makers. As research progresses, it is becoming clear that large-scale changes of the global climate system would seriously affect large numbers of people in various ways. Fundamental for the estimation of the extent of such impacts is population forecasts and predictions of changes in human habitation patterns. Demographic changes are also of prime concern for studies of human impacts on their local environments. The impact of large-scale climatic changes on humans (through for example Sea level Change) and the impact of humans on the local and regional hydrology (through Flood). Population changes, including the spatial distribution of people, are therefore essential for assessments of future water resources, in addition to climatic and hydrological parameters[1].

Population maps have a long history, but the recent development of powerful computers and software in combination with the increasing availability of various kinds of remote sensing data has led to a growing research activity in this area. In the last few decades several efforts to generate grid maps of population have thus been seen. On the global scale, Dobson, Bright, Coleman, Durfee, and Worley (2000) developed a global population dataset in 30 arc-seconds resolution (LandScan). The LandScan dataset is made by a model, which distributes sub national census data to grids by using various remote sensing data. The newest version of LandScan (2008) is available on the Internet.[1]

A ***Census*** is the procedure of systematically acquiring and recording information about the members of a given population. It is a regularly occurring and official count of a particular population. Census provides the information about their households (e.g. number of members, water & electricity supply, ownership of land, vehicles, computers and other assets and services), social, economic status as well as the total population is counted and statistics related to individuals are collected. The *decennial census* of India is the primary source of information about the demographic characteristics of the population of India. The 2011 census will be one of the largest censuses in the history of mankind. As we know the last census was held in 2001 this 10 year gap is very large in terms of R&D therefore we need

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[1] Magnus Bengtsson, Yanjun Shen, Taikan Oki; (2006), SRES-based gridded global population dataset for 1990-2100, Population and Environment, Vol. 28, No. 2 (Nov., 2006), pp. 113-131

some alternative measure to estimate the population for these gap years. Here we try to compare the LandScan dataset with the Census of India Provisional Population Total 2011.

The ***LandScan*** data set is a worldwide population database compiled on a 30" X 30" Latitude/longitude grid (approx. 1km x 1km). Census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients, which are based on proximity to roads, slope, land cover, night-time lights, and other data sets. Data is available by continent and for the world in a number of formats. Which is easy to excess and user friendly, as well as more accurate as compare to other datasets (e.g. GPW, AfriPop, GRUMP etc). Therefore we need to compare the LandScan with accurate existing census dataset.

### 2.2 LandScan comparison with existing Census dataset:

India is one of the earth's four major population concentrations, with an area and population equal to that of Europe (exclusive of the Soviet Union) or to that of agricultural China. It is as large in area as humid eastern United States, but has nearly four times the population. India's average density of some 250 people per square mile is only moderately high, being less than the average densities of most western European countries or of such eastern Asiatic countries as Japan, Korea, the Philippines, or Java. However, those parts of India with level, moist alluvial soils have among the highest densities of population in the world[2].India is among the most rural of the larger countries, with 90 per cent of the population living in some villages and small towns. Only 10 percent of India's 1.2 billion live in the 7956 cities and towns of 10,000 inhabitants and over. With the development of a modern, integrated transport system, urban growth is tending to concentrate in the more accessible of the larger cities and towns. Accuracy assessment of large scale population datasets is always challenging due to the use of all geographically specific datasets to produce the population dataset, leaving little independent data for testing. However, simple comparison tests with existing gridded population datasets were undertaken.

The *2008 version of LandScan* is the most widely used population datasets, and were acquired and compared to the newly created dataset (*Census of India, 2011*), given the differing spatial dataset. To make the comparisons possible, population datasets were adjusted to the same year calculating *Exponential Growth Rate* (2008) meters spatial

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[2] Lawrence A. Hoffman; (1948) India: Main Population Concentrations; The Geographical Journal, Vol. 111, No. 1/3 (Jan. - Mar., 1948), pp. 89-100.

resolution. Different methods were used to compare the Census population and LandScan datasets.[3]

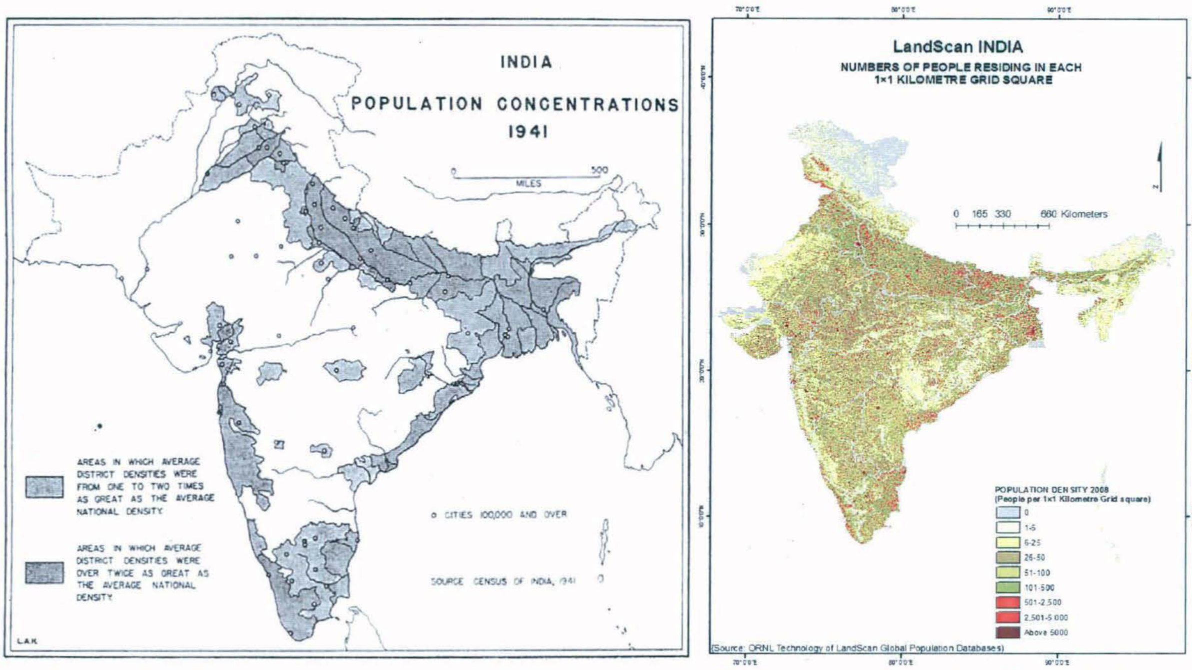

Figure No.3: Population concentrations in 1941 (Lawrence A. Hoffman; (1948) and LandScan 2008: Population Distribution

Firstly, predicted population totals per State (district level for Costal districts of India) were having been compared to the census population estimates for the year 2008. The two population datasets were adjusted to 2008 for this calculation. The LandScan dataset was unsurprisingly near perfect here, as the population data were matched (approximately) to Census population estimates in the modelling procedure. However, the aim is to observe how far away the LandScan datasets is from these most contemporary estimates. $R^2$ (0.999) were extracted and differences in population estimates per state/district were mapped.

Secondly, grid-based differences between datasets have been measured. Unit level absolute differences were mapped and plotted to explore tendencies in these differences.

Thirdly, the numbers of people predicted in towns and settlements with known population size have been compared. In order to allow the calculation of population predicted in small

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[3] Catherine Linard, Victor A Alegan, Abdisalan M Noor, Robert W Snow, Andrew J Tatem;(2010); A high resolution spatial population database of Somalia for disease risk mapping; Linard et al. International Journal of Health Geographics 2010, http://www.ij-healthgeographics.com/content/9/1/45

settlements (smaller than 1 km), the LandScan datasets were for this comparison. ($R^2$) between predicted and observed population in towns and settlements were extracted. Finally, the impact of the choice of population dataset on estimates of the population at risk (PAR) has been tested of flood and Sea level Rise in coastal areas of India. The LandScan and Census datasets were overlaid on the map of sea level change for the year and PAR estimates were extracted.

Perhaps the simplest way to group information about India is in four major regions: the Highland Rim, the Northern Plains, and the Coastlands and Uplands of the Indian Plateau

This regional system is adapted from that by Dudley Stamp, and is based partly on geological structure, partly on topography, partly on climate and soil, and partly on present human use.

### 2.3 Comparison between Census and LandScan Population counts:

The resulting 2008 gridded population dataset of India at 30" X 30" Latitude/longitude grid (approx. 1km x 1km) resolution is presented in figure. This figure shows that in the majority of area is showing that the LandScan population is estimated to be lower than census population[4]. There is only 4 People per 1×1 Kilometer grid square difference between Census and LandScan, i.e. people per square kilometre or in *Demographic* terms Population Density. Population densities are higher around the biggest cities – *Delhi (10465) and Chandigarh (10446)* and along the Northern belt (Gangatic plain) of India. As following table shows that highest population density is in lower Gangatic plain of the total population is concentrated in 2 major states of India i.e *Bihar (1102), and West Bengal (1029).* The Population density of people living is lower in the North Eastern states because major part of the area around Assam is mountainous, where population density is are relatively less. The Southern states are also showing the signs of low Population with some exceptions i.e *Kerala(859), Tamil Nadu(555).*

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[4] Bhaduri, Budhendra et el. 2007. Urban, LandScan USA: a high-resolution geospatial and temporal modelling approach for population distribution and dynamics. GeoJournal (2007) 69:pp. 103–117.

Table No.2: State level Comparison between Census of India, 2011 and LandScan2008

| State | state code | Geographic Area | 2001 | 2011 | Average Annual Exponential growth (2001-2011) (1/10) | Exponential growth (2001-2011) for 8 Years (8/10) | Population 2008 ((EGR/100)*Pop )+Pop) | LandScan 2008 | Difference | Percent Difference | Density 2001 (Pop/Area) | Density 2011 (Pop/Area) | Density 2008 (Pop/Area) | Landscan Density (L_Pop/Area) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Jammu & Kashmir* | 1 | 222236 | 10069917 | 12548926 | 2.55 | 17.61 | 11842888 | 16371475 | -4528587 | 27.66 | 45 | 56 | 53 | 74 |
| *Himachal Pradesh* | 2 | 55673 | 6077248 | 6856509 | 1.62 | 9.65 | 6663807 | 6803667 | -139860 | 2.06 | 109 | 123 | 120 | 122 |
| *Punjab* | 3 | 50362 | 24289296 | 27704236 | 1.80 | 10.52 | 26845493 | 27171102 | -325609 | 1.20 | 482 | 550 | 533 | 540 |
| *Chandigarh* | 4 | 114 | 900914 | 1054686 | 3.39 | 12.61 | 1014493 | 1190767 | -176274 | 14.80 | 7903 | 9252 | 8899 | 10,446 |
| *Uttarakhand* | 5 | 53331 | 8479562 | 10116752 | 1.76 | 14.12 | 9677106 | 9305722 | 371384 | -3.99 | 159 | 190 | 181 | 174 |
| *Haryana* | 6 | 44212 | 21082989 | 25353081 | 2.47 | 14.75 | 24193721 | 23549020 | 644701 | -2.74 | 477 | 573 | 547 | 533 |
| *Delhi* | 7 | 1483 | 13782976 | 16753235 | 3.81 | 15.61 | 15934853 | 15519328 | 415525 | -2.68 | 9294 | 11297 | 10745 | 10,465 |
| *Rajasthan* | 8 | 342239 | 56473122 | 68621012 | 2.49 | 15.59 | 65275428 | 63012262 | 2263166 | -3.59 | 165 | 201 | 191 | 184 |
| *Uttar Pradesh* | 9 | 241005 | 166052859 | 199581477 | 2.30 | 14.71 | 190484733 | 184581718 | 5903015 | -3.20 | 689 | 828 | 790 | 766 |
| *Bihar* | 10 | 94180 | 82878796 | 103804637 | 2.50 | 18.01 | 97805691 | 93274731 | 4530960 | -4.86 | 880 | 1102 | 1038 | 990 |
| *Sikkim* | 11 | 7096 | 540493 | 647688 | 2.85 | 14.47 | 618725 | 631103 | -12378 | 1.96 | 76 | 91 | 87 | 89 |
| *Arunachal Pradesh* | 12 | 83743 | 1091117 | 1382611 | 2.33 | 18.94 | 1297794 | 1347064 | -49270 | 3.66 | 13 | 17 | 15 | 16 |
| *Nagaland* | 13 | 16579 | 1988636 | 1980502 | 4.97 | -0.33 | 1982115 | 1950416 | 31699 | -1.63 | 120 | 119 | 120 | 118 |
| *Manipur* | 14 | 22327 | 2388634 | 2721756 | 2.63 | 10.44 | 2638114 | 2546620 | 91494 | -3.59 | 107 | 122 | 118 | 114 |
| *Mizoram* | 15 | 21081 | 891058 | 1091014 | 2.56 | 16.20 | 1035376 | 965609 | 69767 | -7.23 | 42 | 52 | 49 | 46 |
| *Tripura* | 16 | 10486 | 3191168 | 3671032 | 1.46 | 11.21 | 3548798 | 2996874 | 551924 | -18.42 | 304 | 350 | 338 | 286 |
| *Meghalaya* | 17 | 22429 | 2306069 | 2964007 | 2.62 | 20.08 | 2769123 | 2260997 | 508126 | -22.47 | 103 | 132 | 123 | 101 |
| *Assam* | 18 | 78438 | 26638407 | 31169272 | 1.73 | 12.57 | 29985868 | 30166682 | -180814 | 0.60 | 340 | 397 | 382 | 385 |
| *West Bengal* | 19 | 88752 | 80221171 | 91347736 | 1.64 | 10.39 | 88556859 | 89592468 | -1035609 | 1.16 | 904 | 1029 | 998 | 1,009 |
| *Jharkhand* | 20 | 70614 | 26909428 | 32966238 | 2.09 | 16.24 | 31279675 | 29903648 | 1376027 | -4.60 | 381 | 467 | 443 | 423 |
| *Orissa* | 21 | 155707 | 36706920 | 41947358 | 1.48 | 10.68 | 40625755 | 41018504 | -392749 | 0.96 | 236 | 269 | 261 | 263 |
| *Chhatisgarh* | 22 | 135039 | 20795956 | 25540196 | 1.66 | 16.44 | 24214728 | 23297491 | 917237 | -3.94 | 154 | 189 | 179 | 173 |
| *Madhya Pradesh* | 23 | 308087 | 60385118 | 72597565 | 2.18 | 14.74 | 69282923 | 67176313 | 2106610 | -3.14 | 196 | 236 | 225 | 218 |
| *Gujarat* | 24 | 196024 | 50596992 | 60383628 | 2.03 | 14.15 | 57754478 | 56000109 | 1754369 | -3.13 | 258 | 308 | 295 | 286 |
| *Daman & Diu* | 25 | 112 | 158059 | 242911 | 4.42 | 34.38 | 212397 | 316202 | -103805 | 32.83 | 1411 | 2168 | 1896 | 2,823 |
| *Dadra & Nagar Haveli* | 26 | 491 | 220451 | 342853 | 4.65 | 35.33 | 298337 | 228255 | 70082 | -30.70 | 449 | 698 | 608 | 465 |
| *Maharashtra* | 27 | 307609 | 96752247 | 112372972 | 2.04 | 11.97 | 108336965 | 106373566 | 1963399 | -1.85 | 315 | 365 | 352 | 346 |
| *Andhra Pradesh* | 28 | 275068 | 75727541 | 84665533 | 1.30 | 8.93 | 82486477 | 84949709 | -2463232 | 2.90 | 275 | 308 | 300 | 309 |
| *Karnataka* | 29 | 191971 | 52733958 | 61130704 | 1.59 | 11.82 | 58967308 | 58924253 | 43055 | -0.07 | 275 | 318 | 307 | 307 |
| *Goa* | 30 | 3702 | 1343998 | 1457723 | 1.39 | 6.50 | 1431333 | 1392688 | 38645 | -2.77 | 363 | 394 | 387 | 376 |
| *Lakshadweep* | 31 | 32 | 60595 | 64429 | 1.59 | 4.91 | 63569 | 26789 | 36780 | -137.30 | 1894 | 2014 | 1987 | 837 |
| *Kerala* | 32 | 38863 | 31838619 | 33387677 | 0.90 | 3.80 | 33048662 | 34636512 | -1587850 | 4.58 | 819 | 859 | 850 | 891 |
| *Tamil Nadu* | 33 | 130058 | 62110839 | 72138958 | 1.06 | 11.97 | 69547927 | 69792750 | -244823 | 0.35 | 478 | 555 | 535 | 537 |
| *Pondicherry* | 34 | 492 | 973829 | 1244464 | 1.87 | 19.62 | 1164874 | 1178768 | -13894 | 1.18 | 1979 | 2529 | 2368 | 2,396 |
| *Andaman & Nicobar Islands* | 35 | 8249 | 356265 | 379944 | 2.39 | 5.15 | 374605 | 277559 | 97046 | -34.96 | 43 | 46 | 45 | 34 |
| *India* |  | 3277884 | 1027015247 | 1210233322 | 2.39 | 13.13 | 1161261000 | 1148730741 | 12530259 | -1.09 | 313 | 369 | 354 | 350 |
| *(Sources: Calculated from provisional Population Totals, Census of India- 2011)* |  |  |  |  |  | Correlation | 0.999 |  |  |  |  |  |  |  |

# Density of Population

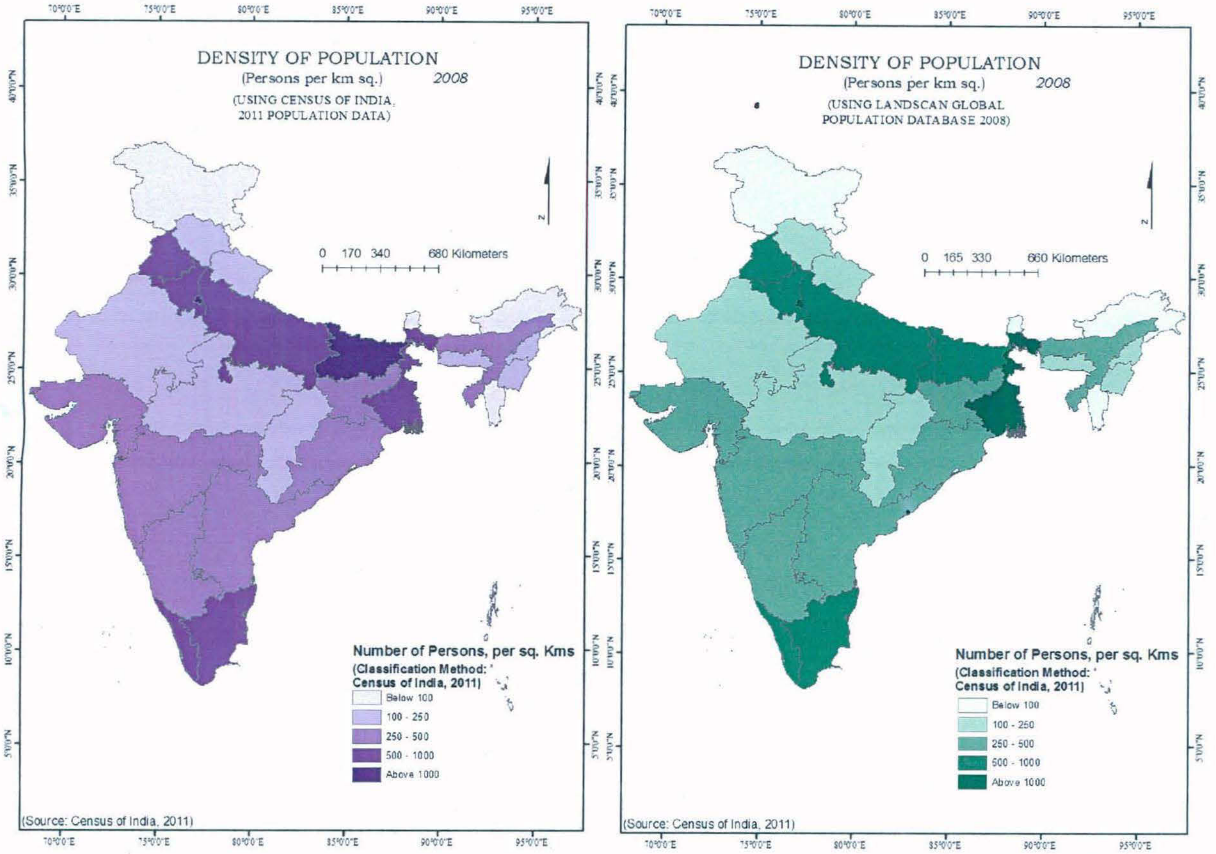
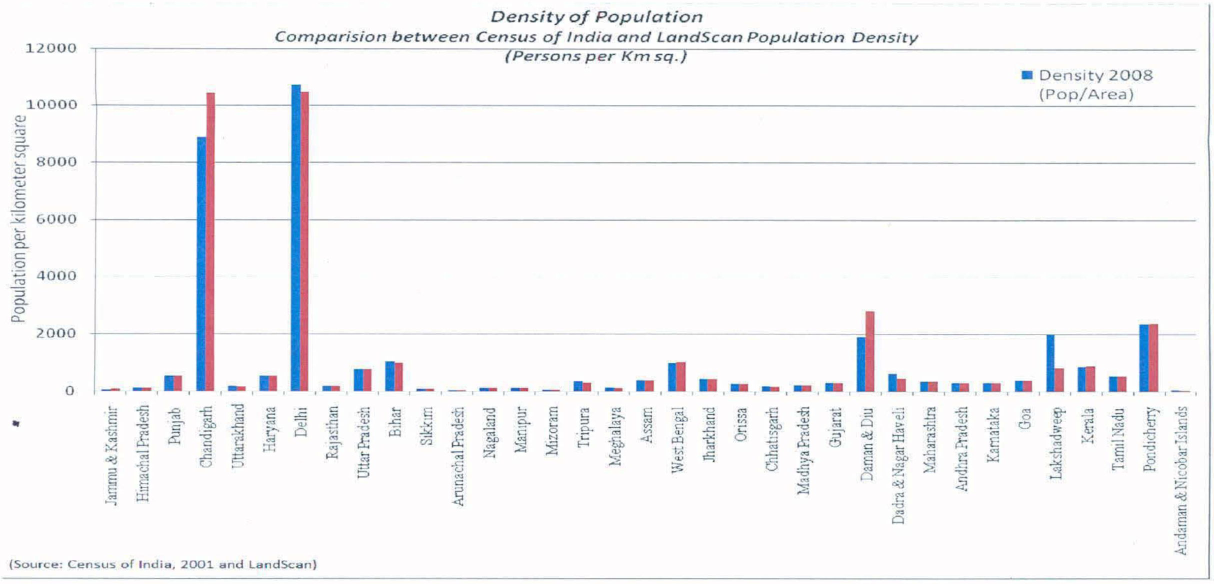


Figure No.3:

1) Census of India, 2011 population data: Density of Population in India, 2008
2) LandScan population database 2008: Density of Population in India, 2008

The Percentage difference between census population and LandScan Population is just (-1.09%) negligible which we will discuss ahead. Here for Density of population classes have been taken from Census 2011. Based on which above maps have been prepared. Map show that at the state level is very less or almost nil difference between Census population and LandScan Counts. Only the exception is West Bengal and Bihar. In terms of density the population is mainly concentrated in northern plains (Ganga-Brahmaputra) of India. As well as some remarkable population density is also shown by southern states of India.

As we move to next graph we will see the root level condition of Population density condition in Indian states. Union territories are showing very high density (Delhi, Chandigarh, Lakshadweep, Pondicherry, Dadra & nagar Haveli, Daman & Diu) as compare to all states of India the only exception is Andaman and Nicobar which is comparatively less. Arunachal Pradesh and Jammu & Kashmir are the states where the Density of Population is negligible due to their physical conditions and Political situation (for Jammu & Kashmir).



(Source: Census of India, 2001 and LandScan)

Figure No.4: Relationship between LandScan and national Census in Population Density

When it comes to population concentration The population of India, at 1210.2 million, is almost equal to the combined population of U.S.A., Indonesia, Brazil, Pakistan, Bangladesh and Japan put together (1214.3 million). Table shows that50 % of the total population is located in 5 major states of India i.e. Utter Pradesh (16.56), Maharashtra (9.48), Bihar (8.38), West Bengal (7.64) and Andhra Pradesh (7.04). The percentage of people living is lower in the North Eastern states because major part of the area around Assam is mountainous, where population densities are relatively less. The Southern states are also showing the signs of low population, but the large populations of Andhra Pradesh. The total population in 2011 is 1,21,01,93,422 and in 2008 is estimated to be 1,16,12,61,000 where the LandScan population approximately equal to that is 1,14,87,30,741.

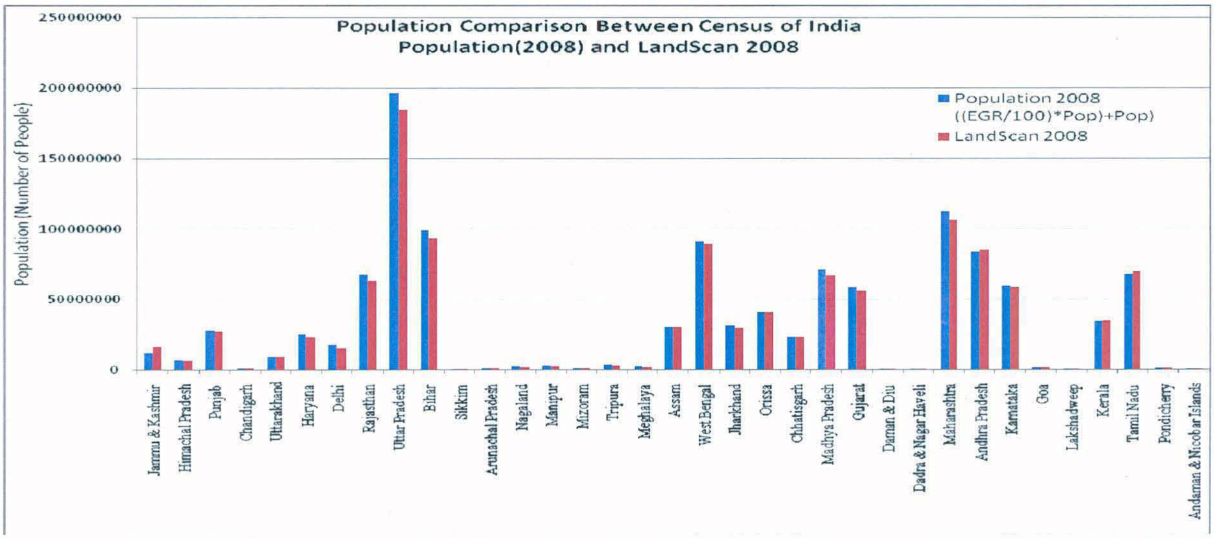
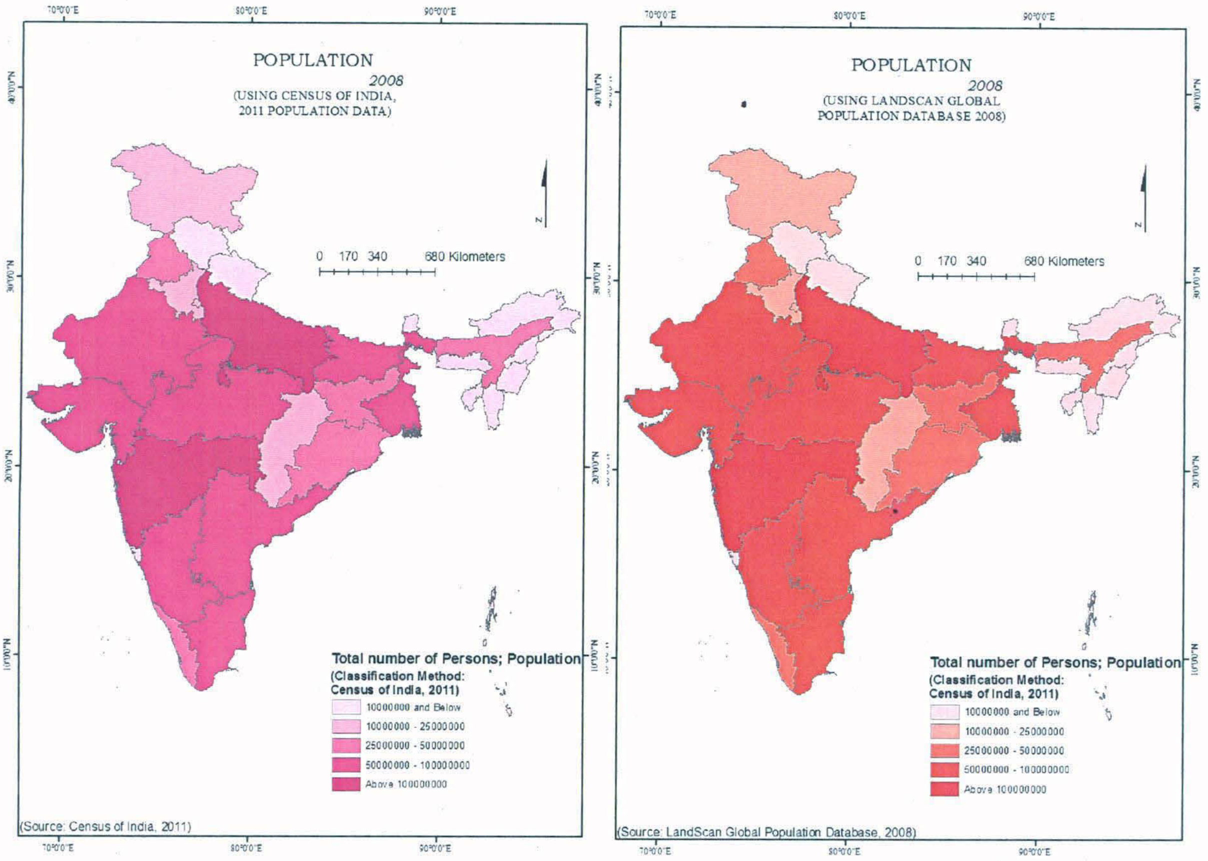


Figure No.5: Comparison between LandScan and national Census in absolute Population

# Population



(Source: Census of India, 2011)

(Source: LandScan Global Population Database, 2008)

Figure No.6:

1) Census of India, 2011 population data: Population in India, 2008
2) LandScan population database 2008: Population in India, 2008

The same methodology have been followed here as applied in above analysis.. Number of Population classes for both the maps have been constructed based on census. As we look at the maps we find that there no difference between both the datasets but when we look into the graph given shows the percentage difference value as well as variation in Population amongst states. Comparison with existing datasets Figure shows a visual comparison between the Census and LandScan datasets. In the LandScan dataset, the construction methodology means that population is concentrated into a few major urban areas and shows scattered population clusters in rural areas.

In the LandScan dataset, the construction methodology means that populations are clustered around roads and less concentrated in villages and towns, but more diffuse in rural areas. The total population per district predicted by the LandScan dataset is closer to the Census estimates than the any other dataset, though overall $R^2$s values are relatively high in LandScan. Value of 'R' varies between -1 to +1. The value + or -1 indicates a perfect positive or perfect negative correlation. Here in our case value is near perfect positive correlation which shows that LandScan data at the state level solve our purpose.

| Model | R | R Square ($R^2$) | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .998 | .998 | .998 | 1487597.041 |

*Census Data 2008 Predictors: (Constant), LandScan 2008*

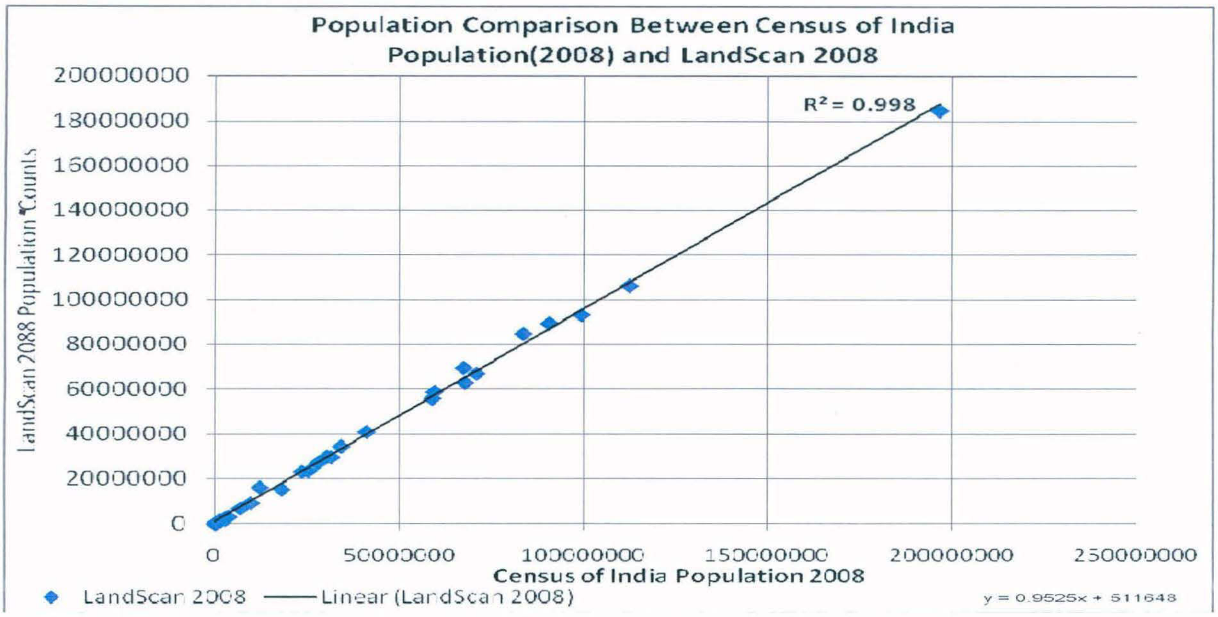


*Figure No.7: Correlation between Census of India and LandScan population database 2008*

As shown in figure, LandScan overestimates population counts compared to the Census estimates in most of the districts, where as it underestimates these population counts in many districts, principally in Northern, Southern and North Eastern India. The total population also differs the LandScan estimated there to be 1,25,30,259 on people living in India in 2008. Grid-based difference measures led to interesting insights on where the differences between datasets are the most significant. Figure shows that, for the large majority of pixels, the absolute difference between LandScan and Census is lower than **4** person per 1 × 1 km grid square[5]. For these pixels with very low differences, the human population density is generally close to zero. However, the absolute differences can be much higher in more densely and extreme sparsely populated places. The urban extent of major cities such as Delhi, Mumbai (large cities) strongly influenced the results. The urban extents of the LandScan dataset are generally smaller, resulting in significantly higher population densities in city centres. In more sparsely regions, such as the Leh Ladakh, Thar, Arunachal Pradesh, and Kachh Region

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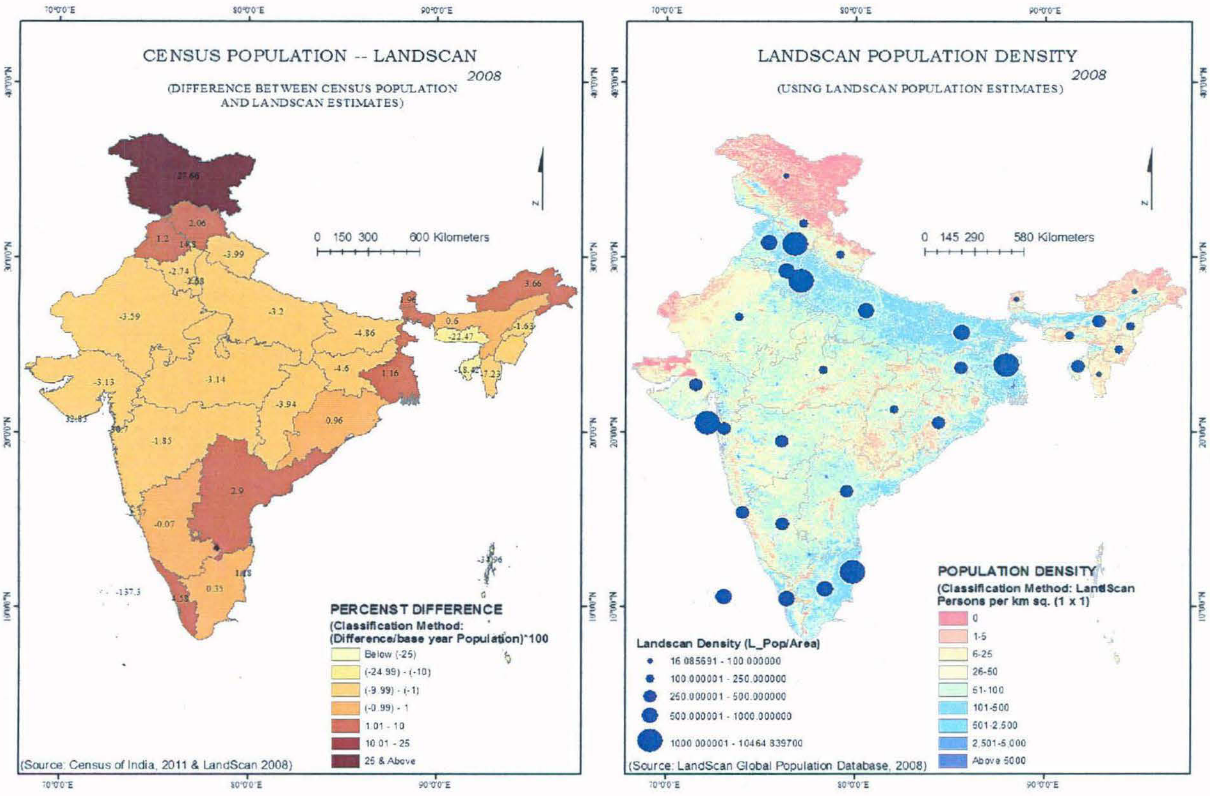
[5] Magnus Bengtsson, Yanjun Shen, Taikan Oki; (2006);A SRES-based Gridded Global Population Dataset for 1990-2100; Population and Environment, Vol. 28, No. 2 (Nov., 2006), pp. 113-131

of the India, the main difference between the datasets is that more villages and small towns are represented in the LandScan dataset. The LandScan dataset shows some higher density pixels, mainly along only the major roads. Figure shows the relationship between absolute differences and LandScan population counts.

The comparison of population numbers predicted in settlements with independent settlement size estimates showed a better adjustment for LandScan (Pearson correlation = 0.999; $R^2$ = 0.999).

**Percentage Difference**



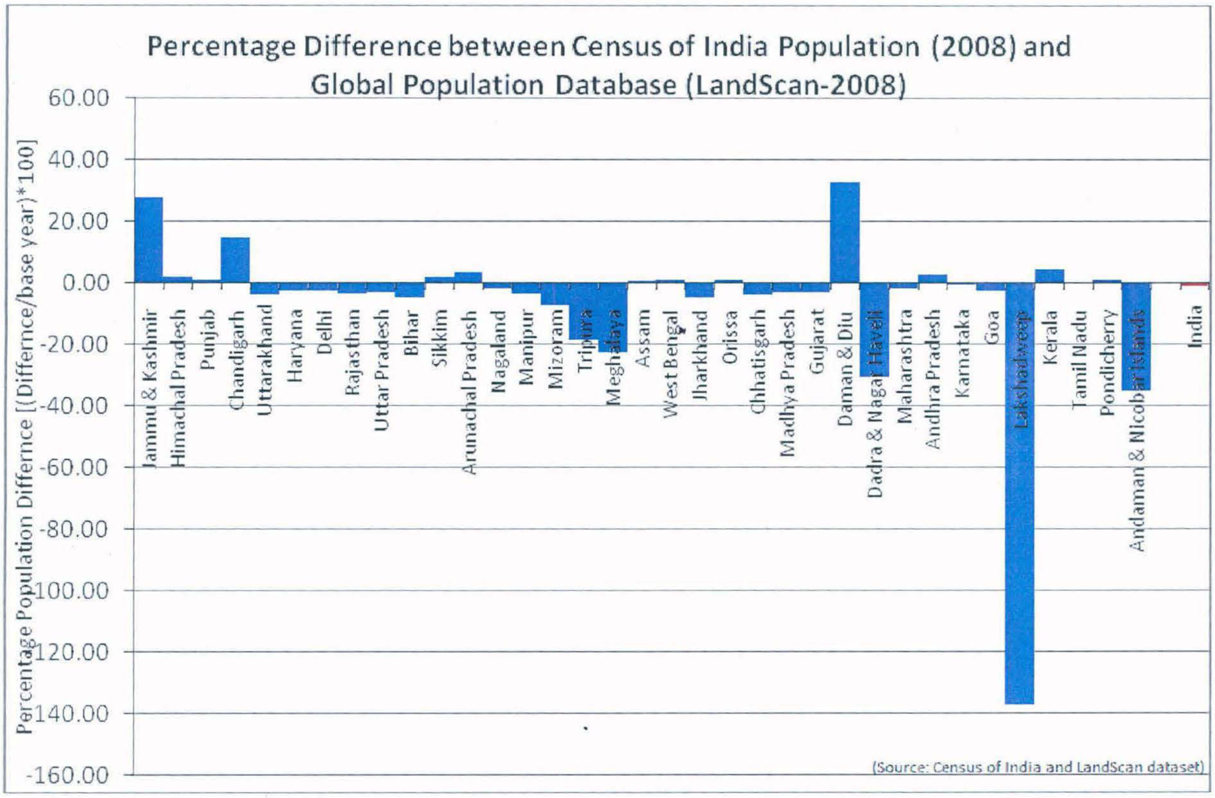
(Source: Census of India, 2011 & LandScan 2008)

(Source: LandScan Global Population Database, 2008)

Figure No.8:

1) Difference between Census of India, and LandScan population estimates 2008
2) LandScan Population density 2008

When we come to percentage difference between census population and LandScan population estimates it finally show the trend of difference at micro level. This tells us that amongst all states showing different patten due to the methodology of LandScan data preparation, there are some inbuilt errors. Although states like Uttar Pradesh, Bihar, Jharkhand, Rajasthan, Madhya Pradesh, Chhattisgarh have a very high population but due to night-light imageries which they have used for data preparation population is underestimated. Where in Mountainous states like Jammu and Kashmir, Chandigarh, Himachal Pradesh, Arunachal Pradesh the population is overestimated. Sothern states of India are also over rides the population due to their infrastructural development.


Percentage Difference between Census of India Population (2008) and Global Population Database (LandScan-2008)

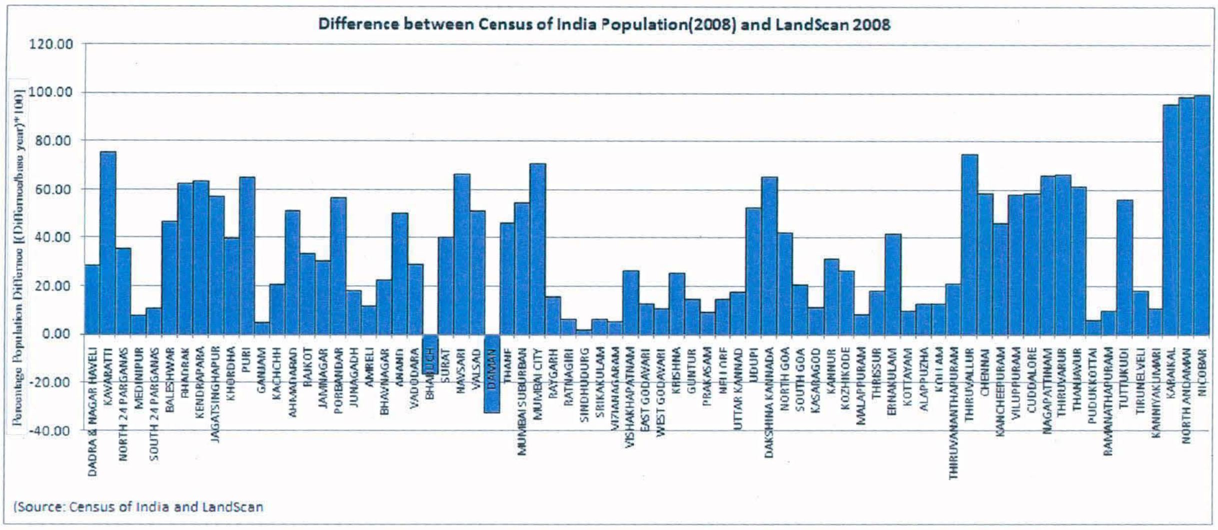
(Source: Census of India and LandScan dataset)

Figure No.9: Percentage difference between Census of India and LandScan population estimates

Based on above we can say that LandScan is the most accurate and reliable, geographically based, time-of-day population distribution model and databases ***Allows quick and easy assessment, estimation, and visualization of population at risk*** Provides high resolution night-time (residential) as well as daytime population distributions Is a critical component of emergency planning and management, rapid risk assessment, evacuation planning, consequence assessment, mitigation planning and implementation.

## 2.4 Comparison between Census and LandScan Population counts:

In terms of population-supporting capacity, there is considerable difference between the Coastlands of the Plateau and the Uplands. In having relatively favourable topography, soil, rainfall, and accessibility, the Coastlands are much like the Northern Plains. Nearly a fifth of the Indian population lives in these coastal strips, which comprise little more than a tenth of the total area. The Coastlands have an area and population similar to that of Japan or to that of pre-war Germany. Together, the Coastlands and the Northern Plains have two-thirds of the entire Indian population in only a third of the total area. The Uplands of the Indian Plateau comprise the third major region of India. These upland areas have a larger aggregate population than the Coast lands, but their average density is only two-fifths as great. The Uplands are equal in area and population to Eastern Europe (between Germany and Italy on the west and the Soviet Union on the east). Certain alluvial valleys among the Uplands, and parts of the Deccan upland plains, carry as dense a population as the lowland plains. These Uplands, particularly along the eastern and north-eastern edges, hold most of India's known mineral wealth, especially her coal, iron, and ferroalloy minerals.

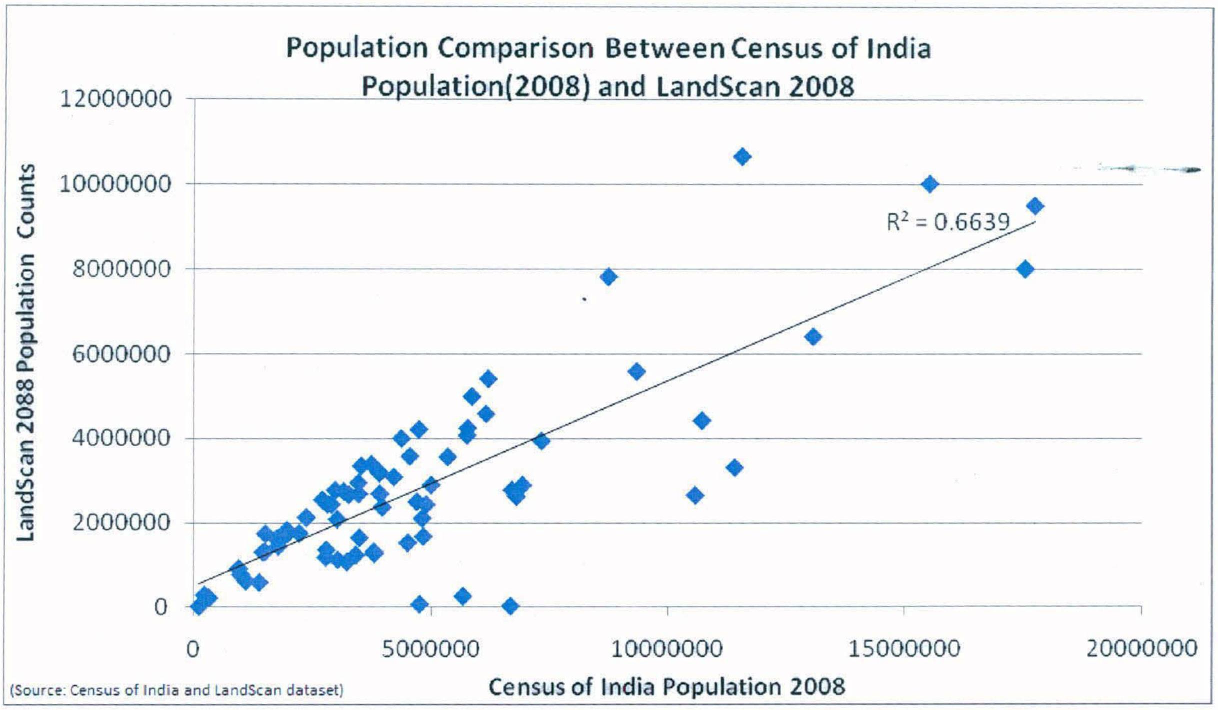


(Source: Census of India and LandScan

Figure No.10: Percentage difference between Census of India and LandScan population estimates in Coastal districts of India

Demographically, probably the least important of the major Indian regions is the Highland Rim which includes, generally speaking, all the northern highlands over 1000 feet in elevation. Although comprising nearly a quarter of the total area of India, these highlands support only a twentieth of the total population, and most of this is concentrated in a few valleys and basins adjacent to the Northern Plains. The southern part of the Western Coastlands (the Kerala and Konkan coasts) and the northern part of the Eastern Coast lands (the Northern Circars coast) each have about as many people as the entire Highland Rim, although each has only a tenth of its area. Geographically, the importance of the Highland Rim lies in its influence on India's climate, for it shelters the country from the out blowing winter winds of the continental interior, it probably affects the system of monsoonal rainfall, and it provides orographic rainfall for the irrigation systems of the Indus Plains and the upper Ganges Plains.

In figure, where the percentage difference between the population by census of india and the population estimation by Landscan can be look at, depicts a very perceptible fact that in all the coastal districts population estimated by landscan is less than the census population. This pattern is opposite to the pattern which has been observed in Megacities where landscan Population estimation in coastal districts is more than the census population. There are variations within districts in terms of the difference between two measures of population. Popular districts like Karaikal, North Andaman, Nicobar and Mumbai city have experienced higher difference between two estimations. There are two districts of Bharuch and daman which have negative difference means LandScan population more than census population against the general pattern in coastal districts.



(Source: Census of India and LandScan dataset)

Figure No 11: Correlation between Census of India and LandScan population database 2008 in Coastal districts of India

A more general pattern to observe the above fact further clearly has been presented in figure. As stated earlier both the population measures have a great difference as they rarely falls on the line of equal distribution. Higher $R^2$ value proves the fact statistically. As population size increase the difference also increases although it's an obvious fact but needed to be known to realize that having big population size districts have great difference when compared with less populated cities.

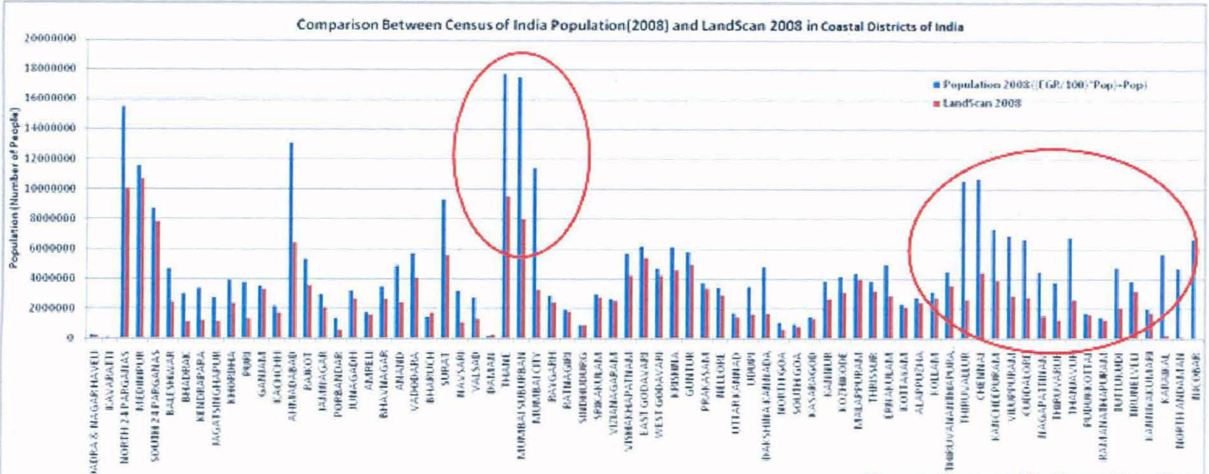
*Table No.3: Comparison between Census of India, 2011 and LandScan2008 in Coastal districts of India*

| *INDIA* | *State code* | *Population 1991* | *Population 2001* | *Average Annual Exponential growth (1991-2001) (1/10)* | *Average Decadal Exponential growth (1991-2001) (10/10)* | *Exponential growth (1991-2001) for 8 Years (8/10)* | *Population 2008 ((EGR/100)*Pop)+Pop)* | *LandScan 2008* | *Difference* | *Percent Difference [(LandScan/ Census)*100]* |
|---|---|---|---|---|---|---|---|---|---|---|
| DADRA & NAGAR HAVELI | 26 | *126752* | 2,20,451 | 5.53 | 55.34 | 44.28 | 318057 | 228255 | 89802 | 28.23 |
| KAVARATTI | 31 | *22593* | 60,595 | 9.87 | 98.66 | 78.93 | 108420 | 26789 | 81631 | 75.29 |
| NORTH 24 PARGANAS | 1911 | *3551581* | 89,30,295 | 9.22 | 92.21 | 73.76 | 15517685 | 10032873 | 5484812 | 35.35 |
| MEDINIPUR | 1915 | *7510917* | 96,38,473 | 2.49 | 24.94 | 19.95 | 11561581 | 10676690 | 884891 | 7.65 |
| SOUTH 24 PARGANAS | 1918 | *4954653* | 69,09,015 | 3.32 | 33.25 | 26.60 | 8746813 | 7828942 | 917871 | 10.49 |
| BALESHWAR | 2108 | 389236 | 20,23,056 | 16.48 | 164.82 | 131.85 | 4690542 | 2506880 | 2183662 | 46.55 |
| BHADRAK | 2109 | 272711 | 13,32,249 | 15.86 | 158.62 | 126.90 | 3022830 | 1132011 | 1890819 | 62.55 |
| KENDRAPARA | 2110 | 172496 | 13,01,856 | 20.21 | 202.12 | 161.69 | 3406877 | 1245894 | 2160983 | 63.43 |
| JAGATSINGHAPUR | 2111 | 138937 | 10,56,556 | 20.29 | 202.87 | 162.30 | 2771345 | 1190932 | 1580413 | 57.03 |
| KHORDHA | 2117 | 464665 | 18,74,405 | 13.95 | 139.47 | 111.58 | 3965836 | 2381882 | 1583954 | 39.94 |
| PURI | 2118 | 221793 | 14,98,604 | 19.11 | 191.05 | 152.84 | 3789122 | 1324013 | 2465109 | 65.06 |
| GANJAM | 2119 | *2688242* | 31,36,937 | 1.54 | 15.44 | 12.35 | 3524310 | 3359776 | 164534 | 4.67 |
| KACHCHH | 2401 | *874650* | 15,26,321 | 5.57 | 55.68 | 44.54 | 2206195 | 1754568 | 451627 | 20.47 |
| AHMADABAD | 2407 | *1215127* | 58,08,378 | 15.64 | 156.45 | 125.16 | 13077924 | 6420301 | 6657623 | 50.91 |
| RAJKOT | 2409 | *1330156* | 31,57,676 | 8.65 | 86.45 | 69.16 | 5341626 | 3571274 | 1770352 | 33.14 |
| JAMNAGAR | 2410 | *932716* | 19,13,685 | 7.19 | 71.87 | 57.49 | 3013955 | 2093350 | 920605 | 30.54 |
| PORBANDAR | 2411 | 77039 | 5,36,854 | 19.41 | 194.14 | 155.31 | 1370661 | 593994 | 776667 | 56.66 |
| JUNAGADH | 2412 | *1615483* | 24,48,427 | 4.16 | 41.58 | 33.26 | 3262895 | 2676193 | 586702 | 17.98 |
| AMRELI | 2413 | *982933* | 13,93,295 | 3.49 | 34.89 | 27.91 | 1782176 | 1570122 | 212054 | 11.90 |
| BHAVNAGAR | 2414 | *1487186* | 24,69,264 | 5.07 | 50.70 | 40.56 | 3470865 | 2690596 | 780269 | 22.48 |
| ANAND | 2415 | 241930 | 18,56,712 | 20.38 | 203.79 | 163.03 | 4883770 | 2440909 | 2442861 | 50.02 |
| VADODARA | 2419 | *1761546* | 36,39,775 | 7.26 | 72.57 | 58.06 | 5752970 | 4083727 | 1669243 | 29.02 |
| BHARUCH | 2421 | *1217317* | 13,70,104 | 1.18 | 11.82 | 9.46 | 1499702 | 1746627 | -246925 | -16.46 |
| SURAT | 2422 | *1679779* | 49,96,391 | 10.90 | 109.01 | 87.20 | 9353458 | 5596895 | 3756563 | 40.16 |
| NAVSARI | 2424 | 162507 | 12,29,250 | 20.23 | 202.34 | 161.88 | 3219100 | 1080881 | 2138219 | 66.42 |
| VALSAD | 2425 | 418408 | 14,10,680 | 12.15 | 121.54 | 97.23 | 2782279 | 1367831 | 1414448 | 50.84 |
| DAMAN | 2502 | *35196* | 1,13,949 | 11.75 | 117.48 | 93.99 | 221045 | 293142 | -72097 | -32.62 |
| THANE | 2721 | *1855919* | 81,28,833 | 14.77 | 147.70 | 118.16 | 17734105 | 9515990 | 8218115 | 46.34 |
| MUMBAI SUBURBAN | 2722 | 2335817 | 85,87,561 | 13.02 | 130.20 | 104.16 | 17532043 | 8016695 | 9515348 | 54.27 |
| MUMBAI CITY | 2723 | 159355 | 33,26,837 | 30.39 | 303.86 | 243.09 | 11414084 | 3317491 | 8096593 | 70.94 |
| RAYGARH | 2724 | *1496176* | 22,05,972 | 3.88 | 38.83 | 31.06 | 2891157 | 2442798 | 448359 | 15.51 |
| RATNAGIRI | 2732 | *1406001* | 16,96,482 | 1.88 | 18.78 | 15.02 | 1951371 | 1829949 | 121422 | 6.22 |
| SINDHUDURG | 2733 | *769002* | 8,61,672 | 1.14 | 11.38 | 9.10 | 940106 | 922897 | 17209 | 1.83 |
| SRIKAKULAM | 2811 | *2030888* | 25,28,491 | 2.19 | 21.91 | 17.53 | 2971785 | 2779344 | 192441 | 6.48 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| VIZIANAGARAM | 2812 | *1747443* | 22,45,103 | 2.51 | 25.06 | 20.05 | 2695197 | 2557243 | 137954 | 5.12 |
| VISHAKHAPATNAM | 2813 | *1976509* | 37,89,823 | 6.51 | 65.10 | 52.08 | 5763524 | 4252785 | 1510739 | 26.21 |
| EAST GODAVARI | 2814 | *3460418* | 48,72,622 | 3.42 | 34.22 | 27.38 | 6206718 | 5422671 | 784047 | 12.63 |
| WEST GODAVARI | 2815 | *2789015* | 37,96,144 | 3.08 | 30.83 | 24.66 | 4732417 | 4222361 | 510056 | 10.78 |
| KRISHNA | 2816 | *2373879* | 42,18,416 | 5.75 | 57.49 | 45.99 | 6158666 | 4594154 | 1564512 | 25.40 |
| GUNTUR | 2817 | *2920299* | 44,05,521 | 4.11 | 41.12 | 32.89 | 5854664 | 5007112 | 847552 | 14.48 |
| PRAKASAM | 2818 | *2305264* | 30,54,941 | 2.82 | 28.16 | 22.53 | 3743073 | 3398327 | 344746 | 9.21 |
| NELLORE | 2819 | *1823198* | 26,59,661 | 3.78 | 37.76 | 30.21 | 3463105 | 2956371 | 506734 | 14.63 |
| UTTAR KANNAD | 2910 | *925744* | 13,53,299 | 3.80 | 37.97 | 30.38 | 1764380 | 1450521 | 313859 | 17.79 |
| UDUPI | 2916 | 76333 | 11,09,494 | 26.77 | 267.66 | 214.12 | 3485188 | 1652494 | 1832694 | 52.59 |
| DAKSHINA KANNADA | 2924 | 275168 | 18,96,403 | 19.30 | 193.03 | 154.43 | 4824953 | 1682069 | 3142884 | 65.14 |
| NORTH GOA | 3001 | *439200* | 7,57,407 | 5.45 | 54.49 | 43.60 | 1087604 | 628808 | 458796 | 42.18 |
| SOUTH GOA | 3002 | *250841* | 5,86,591 | 8.50 | 84.95 | 67.96 | 985242 | 782908 | 202334 | 20.54 |
| KASARAGOD | 3201 | *895282* | 12,03,342 | 2.96 | 29.57 | 23.66 | 1488023 | 1322328 | 165695 | 11.14 |
| KANNUR | 3202 | *1106251* | 24,12,365 | 7.80 | 77.96 | 62.37 | 3916968 | 2694703 | 1222265 | 31.20 |
| KOZHIKODE | 3204 | *1615444* | 28,78,498 | 5.78 | 57.77 | 46.21 | 4208730 | 3097656 | 1111074 | 26.40 |
| MALAPPURAM | 3205 | *2813876* | 36,29,640 | 2.55 | 25.46 | 20.37 | 4368840 | 4008737 | 360103 | 8.24 |
| THRISSUR | 3207 | *2017095* | 29,75,440 | 3.89 | 38.87 | 31.10 | 3900763 | 3193455 | 707308 | 18.13 |
| ERNAKULAM | 3208 | *1444059* | 30,98,378 | 7.63 | 76.34 | 61.07 | 4990671 | 2904811 | 2085860 | 41.80 |
| KOTTAYAM | 3210 | *1507353* | 19,52,901 | 2.59 | 25.90 | 20.72 | 2357481 | 2133248 | 224233 | 9.51 |
| ALAPPUZHA | 3211 | *1391607* | 21,05,349 | 4.14 | 41.40 | 33.12 | 2802678 | 2453968 | 348710 | 12.44 |
| KOLLAM | 3213 | *1961530* | 25,84,118 | 2.76 | 27.57 | 22.05 | 3153987 | 2751908 | 402079 | 12.75 |
| THIRUVANANTHAPURAM | 3214 | *1948407* | 32,34,707 | 5.07 | 50.69 | 40.55 | 4546513 | 3587143 | 959370 | 21.10 |
| THIRUVALLUR | 3301 | 76333 | 27,38,866 | 35.80 | 358.02 | 286.42 | 10583398 | 2659286 | 7924112 | 74.87 |
| CHENNAI | 3302 | 612137 | 42,16,268 | 19.30 | 192.98 | 154.38 | 10725343 | 4432018 | 6293325 | 58.68 |
| KANCHEEPURAM | 3303 | 411508 | 28,69,920 | 19.42 | 194.22 | 155.38 | 7329113 | 3952555 | 3376558 | 46.07 |
| VILUPPURAM | 3307 | 540693 | 29,43,917 | 16.95 | 169.46 | 135.57 | 6935032 | 2904988 | 4030044 | 58.11 |
| CUDDALORE | 3318 | 201070 | 22,80,530 | 24.29 | 242.85 | 194.28 | 6711166 | 2786316 | 3924850 | 58.48 |
| NAGAPATTINAM | 3319 | 118221 | 14,87,055 | 25.32 | 253.20 | 202.56 | 4499232 | 1536205 | 2963027 | 65.86 |
| THIRUVARUR | 3320 | 68981 | 11,65,213 | 28.27 | 282.68 | 226.15 | 3800304 | 1279684 | 2520620 | 66.33 |
| THANJAVUR | 3321 | 162757 | 22,05,375 | 26.06 | 260.64 | 208.51 | 6803840 | 2632024 | 4171816 | 61.32 |
| PUDUKKOTTAI | 3322 | *1136645* | 14,52,269 | 2.45 | 24.50 | 19.60 | 1736967 | 1636436 | 100531 | 5.79 |
| RAMANATHAPURAM | 3327 | *894252* | 11,83,321 | 2.80 | 28.01 | 22.41 | 1448473 | 1309830 | 138643 | 9.57 |
| TUTTUKUDI | 3328 | 118057 | 15,65,743 | 25.85 | 258.49 | 206.80 | 4803634 | 2116177 | 2687457 | 55.95 |
| TIRUNELVELI | 3329 | *1708656* | 28,01,194 | 4.94 | 49.43 | 39.55 | 3908985 | 3196622 | 712363 | 18.22 |
| KANNIYAKUMARI | 3330 | *1330240* | 16,69,763 | 2.27 | 22.73 | 18.19 | 1973423 | 1760244 | 213179 | 10.80 |
| KARAIKAL | 3404 | *83899* | 16,69,763 | 29.91 | 299.08 | 239.27 | 5664936 | 267980 | 5396956 | 95.27 |
| NORTH ANDAMAN | 3501 | *166498* | 16,69,763 | 23.05 | 230.55 | 184.44 | 4749412 | 78584 | 4670828 | 98.35 |
| NICOBAR | 3502 | *39208* | 16,69,763 | 37.52 | 375.16 | 300.12 | 6681131 | 34624 | 6646507 | 99.48 |
| **COASTAL INDIA** | | ***90333075*** | ***193597987*** | ***11*** | ***113*** | ***90*** | ***4834938*** | ***2850409*** | ***144870600*** | ***35*** |

***(Sources: Calculated from provisional Population Totals, Census of India- 2011)***

Apart from percentage difference in figure no. 12 the absolute numbers have been illustrated, showing the above discussed pattern more sharply. Junagadh, Amreli, Bhavnagar, Anand, Vadodara, Bharuch, Surat, Navsari, Valsad, Daman and Thane etc are some districts having less population at the same time less difference of two population estimations.



(Source: Census of India and LandScan

Figure No 12: Comparison between LandScan and national Census in absolute Population in coastal districts of India

Therefore, it can be stated that majority of the coastal districts reflected less population in landscan than the census records. The difference between the two is relatively high in densely populated districts while low in sparsely populated districts. The pattern is very opposite of Megacities of India which illustrated higher Landscan population when compared to the census population. The scatter plot depicts the comparison of population estimated using Landscan and population records of the Census. The line representing $R^2$ value is considered as the bench mark. The districts which marked less or no variation in population records of Landscan and Census fall on the line while the districts reflected relatively high Landscan estimated population than the census population fall below the line and districts with low Landscan estimated population than the census population lie above the line. The analysis depicts some interesting results. A very small number of coastal districts reflected the same population estimates by both Landscan and the census but a significant number of districts fall just above and below the benchmark line which implies that the landscan estimates of population are much close to the census records of population. Only a very small number of districts reflected major differences in population estimation by Landscan and census. The diagrammatic representation of the population estimates by Landscan and census also shows similar results. A significant number of coastal districts marked relatively low differences in Landscan population estimates to the census population records. Therefore, it can be stated

*Chapter No. 3*

# Variation in the distribution of populations and differentials in terms of population estimates in selected Mega cities at ward level.

### 3.1 Introduction

Population expansion in India has been very significant during the past decades. The urban population had doubled from 1901 to 1947 and it increased again six fold from Independence to 2001. One of the most talked about aspects of this growth is the emergence of three agglomerations that have exceeded 14 million inhabitants in 2007[1], thus belonging to the "megacities" of the world, as defined by the United Nations/ESA (World Urbanization Prospects). However, the challenge of Indian urbanisation must not be limited solely to these gigantic cities, but, on the opposite side, to the unclear stratum of localities, this category difficult to grasp statistically, wavering between urban and rural, and which constitutes one of the nation's identity issues : the small agglomerations.

The discussion ahead identified four megacities that experienced particularly high rates of population growth over specific periods before 2000, but no large city is expected to grow at a similarly high rate in the next 15 years so as to become a new mega-city. Indeed, most large cities have experienced moderate to low rates of population growth, particularly after their populations passed the 10 million mark. Urban agglomerations with over 10 million inhabitant.. Those with more than 10 million persons are referred to as mega-cities. The numbers of both large cities and mega-cities have been increasing, rising from 1 in 1981 to 3 in 2001 and to 6 in 2011. Over the next fifteen years a further 3 large urban agglomerations are expected to cross the 10 million population threshold to yield a total of 10 in 2021. Thus the number of large agglomerations almost tripled between 1981 and 1991, four time increase from 1981 to 2000, and is expected to grow by about half again in the short period between 2011 and 2021. Not only has the number of large urban agglomerations grown markedly, so has the number of people living in them. In 1981, just a small share of population lived in such large urban agglomerations. By 2001, that number had risen to 58 percent of total urban population of India and in 2021 it is expected to increase at the same pace in urban agglomerations of 10 million inhabitants or more.

Among large urban agglomerations, few are so large as to qualify as mega-cities. In 1981 there was only one, Mumbai, with more than 5 million inhabitants. By 1991 there were two such mega-cities. Mumbai and Calcutta in order of size, and by 2001, there is an increase of

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[1] Geopolis database, F. Moriconi-Ebrard (http://www.ifpindia.org/Built-Up-Areas-in-India-e-GEOPOLIS.html)

two more had emerged, making the total 4, of which 3 are in the Coastal region regions. In 2021 current projections put the number of megacities at 21, with 3 of the additions located in the Peninsular India.

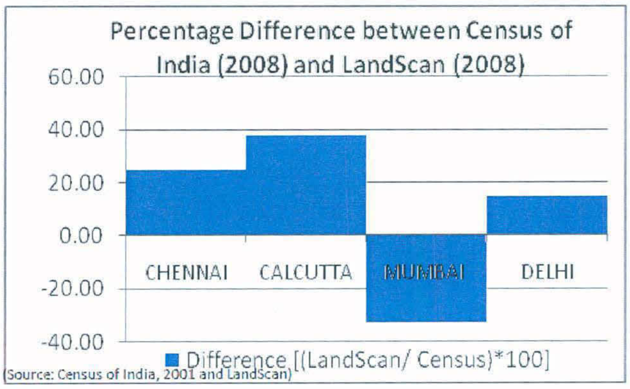
The evolution of population size for the 4 urban-agglomerations that are megacities in 2001 or that are expected to become mega-cities by 2011, It also presents estimates of average annual rates of growth during 1981-91, 1991-2001, and 2011-11. Calcutta in West Bengal had a higher rate of growth in 1981-1991. All other mega-cities experienced a boost of their growth rates between the two periods. The growth rates of most mega-cities are expected to continue increase further in 2001-2011 except for a slight increase in the growth rate of Calcutta City. That is, higher rates of growth prevailed in 2001-2011 than the ones expected to prevail in the future, partly because today's mega-cities had much smaller populations in 1981 than they have in 2001, and hence found it easier to sustain high rates of population growth over lengthy periods and present times.

*Table No.4: Comparison between Census of India and LandScan 2008 in Mega Cities of India*

| *WARDS* | *Annual Exponential Growth Rate (1991-2001)* | *Population 2008 ((EGR/100)*Pop)+Pop)* | *LandScan Population* |
|---|---|---|---|
| CHENNAI | 1.70 | 9865791 | 13155656 |
| CALCUTTA | 1.82 | 10386447 | 16695297 |
| MUMBAI | 2.62 | 24454755 | 18326187 |
| DELHI | 4.18 | 21106744 | 24704315 |

(Source: LandScan 2008 and Census of India)

Three of today's mega-cities had growth rates above 2 percent per year, Delhi at 4.1 per cent. In addition to Delhi; Mumbai and Calcutta growth rates above 2 per cent per year. Among those 3 urban agglomerations, only Mumbai had a population that surpassed 5 million in 1991. The rest had populations in the range of 2 million to 5 million inhabitants. That is, the highest rates of growth in 1991-2001 among future megacities were experienced by cities that were still of medium-size at the beginning of the period. The cities which had the highest growth rates in 1991-2001 among the mega-cities of 2011 are calcutta expected to have lower rates of



(Source: Census of India, 2001 and LandScan)

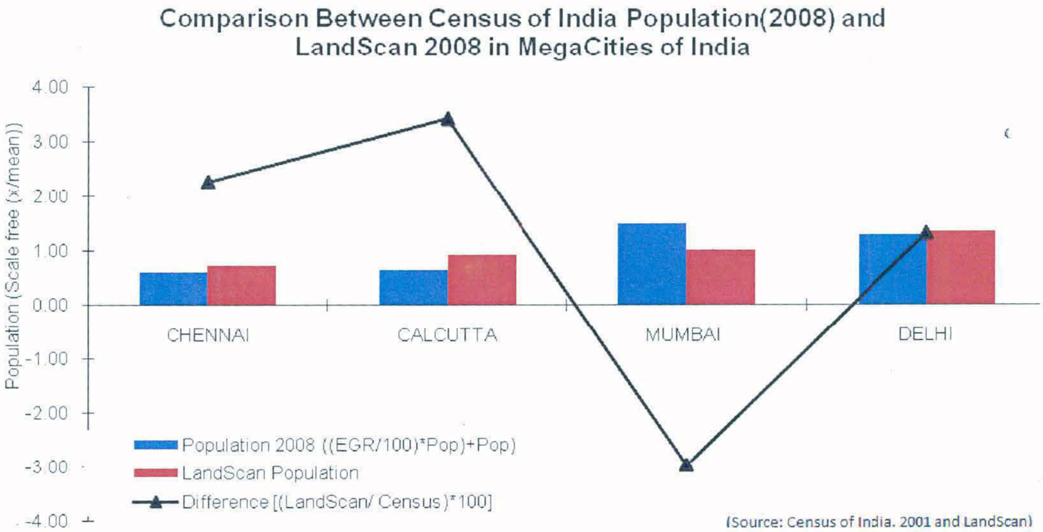
Figure No.13: Percentage difference between Census of India and LandScan population estimates in Mega cities (India) growth during 2001-2011. While other cities are anticipate growing at rates of only 1.8 percent to 4.1 percent per year Delhi, with Mumbai and Chennai growing with the pace of 4.1, 2.6 and 1.8 per year or more respectively. Nevertheless those rates are high considering that 3 more cities will attain mega-city status by 2011, with populations surpassing 10 million inhabitants.

LandScan tried to estimate the population of world where we all ready try to validate it at the state and district level in previous chapter now we will attempt on Wards of Mega cities. Unlike state and districts of India showing a very less amount of difference here at the micro level wards of mega cities are show is very different. LandScan population estimates here are very different from census population where there is a less amount of deviation at city level.

*Table No.5: Standardized difference between Census of India and LandScan population estimates in Mega Cities of India*

| *WARDS* | *Population 2008 ((EGR/100)*Pop)+Pop)* | *LandScan Population* | *Difference [(LandScan/ Census)*100]* |
|---|---|---|---|
| CHENNAI | 0.60 | 0.72 | 2.26 |
| CALCUTTA | 0.63 | 0.92 | 3.42 |
| MUMBAI | 1.49 | 1.01 | -2.99 |
| DELHI | 1.28 | 1.36 | 1.32 |

(Source: LandScan 2008 and Census of India)

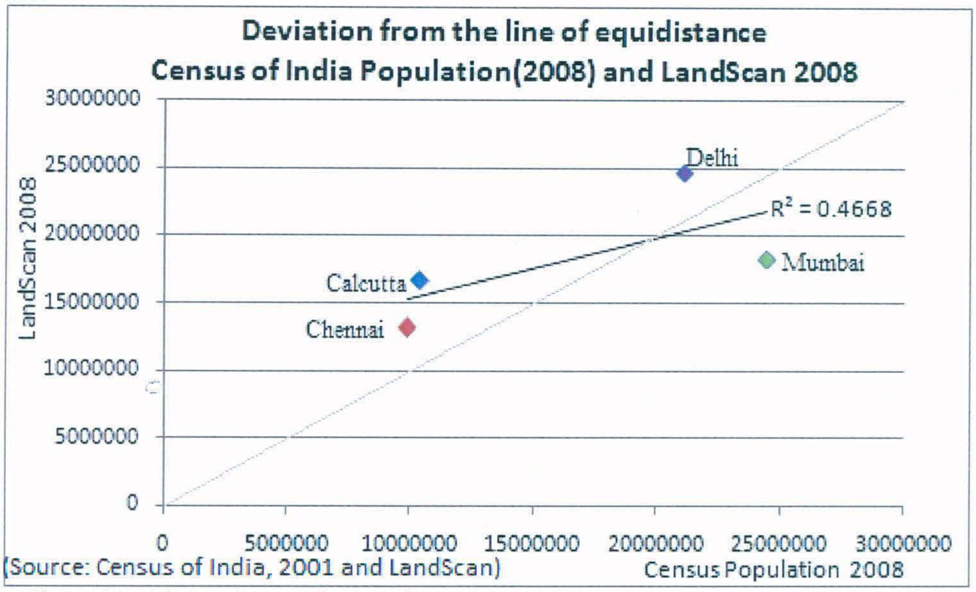


(Source: Census of India. 2001 and LandScan)

Figure No.14: Standardized difference between Census of India and LandScan population estimates in Mega Cities of India

Deviation from mean shows pattern of cities and census population behaviour towards LandScan data. Population estimates are yet to be saying that that upto a level of a large city we can use this data for estimation population at risk zoning of areas for different applications and number of other uses where as when we talk of a city wards it really far apart from reality. Though, to validate it at the mega city level showing that unlike previous works at the ward level LandScan estimates are far more larger than census population.

This proves that at the smaller level as well as we move closer to seas data distraught more. LandScan is Underestimating the population in Mumbai is show a level of 18 million which is about 24 million in 2008. Whereas LandScan population exceeds census population estimates in Delhi, Calcutta and Mumbai.



(Source: Census of India, 2001 and LandScan)

Figure No.15: Deviation of Mega Cities from the Line of Equidistance in comparison of LandScan estimates and Census Population of India

**Line of Equidistance,** if the LandScan estimates of Population are equal to the census population all the points were fallen on the gray line. But unlike this here cities are away from the line of equality. Value of $r^2$ shows that the value of o.4668 which us average deviation from line of equality. Here Delhi, Calcutta and Chennai ate above line of equality which means LandScan data is estimating population more than census of India and vice versa Mumbai showing an opposite trend where LandScan is underestimating the census population.

**Table No.6: Built-Up Structures using Satellite imageries**

| **Built-up Area ($m^2$)** | *MSS* | *ETM+* | *IRSLISS- 3/ TM* |
|---|---|---|---|
| *DELHI* | 3413107 *(1977)* | 2038235.8 (1999) | 6383404.6 *(2006)* |
| *MUMBAI* | 558327.6 *(1973)* | 665037 *(2001)* | - |
| *CALCUTTA* | 334458.56 *(1973)* | 19240798 *(2000)* | 1037723.5 *(2006)* |
| *CHENNAI* | - | 17091462 *(2001)* | 1170839.7 *(2006)* |

Land use and land cover classification statistics obtained are presented in Table MSS (1973, 1977), ETM+ (1999, 2000), TM (2006), and IRS LiSS III for years (2006). The classification scenarios for each year for built-up area of Mega cities have been explained below.There was consistent increase in the coverage of the built areas in all mega cities of India 1973 to 2000 however there was a sharp rise in 2006. The increase was as a result of rapid development in terms of urbanisation and urban expansion to meet the economic demands.

The process of urban land-cover change is most commonly described as either a change in absolute area of urban space (a measure of extent) or the pace at which nonurban land is converted to urban uses (a measure of rate). This study shows that the growth rate of Mega Cities for the 20 years time period has increased almost 3 times its area from 1990, whereas for Calcutta the size has increased twice, Delhi and Mumbai has followed the same pattern with increase of about around 300 sq. kms. There is slight increase in the patch density for Delhi and Mumbai, in case of Calcutta the trend is decreasing indicating dense urban growth, while for Calcutta the built-up area has increased greatly for the time period indicating dispersed patches of urban growth in outskirts of the city as well as in the city centres in a ring-shaped manner. While in case of Chennai city the patch density is decreased urban patches in the region. The built-up of Delhi and Mumbai stays constantly at a low level highlighting urban footprint.

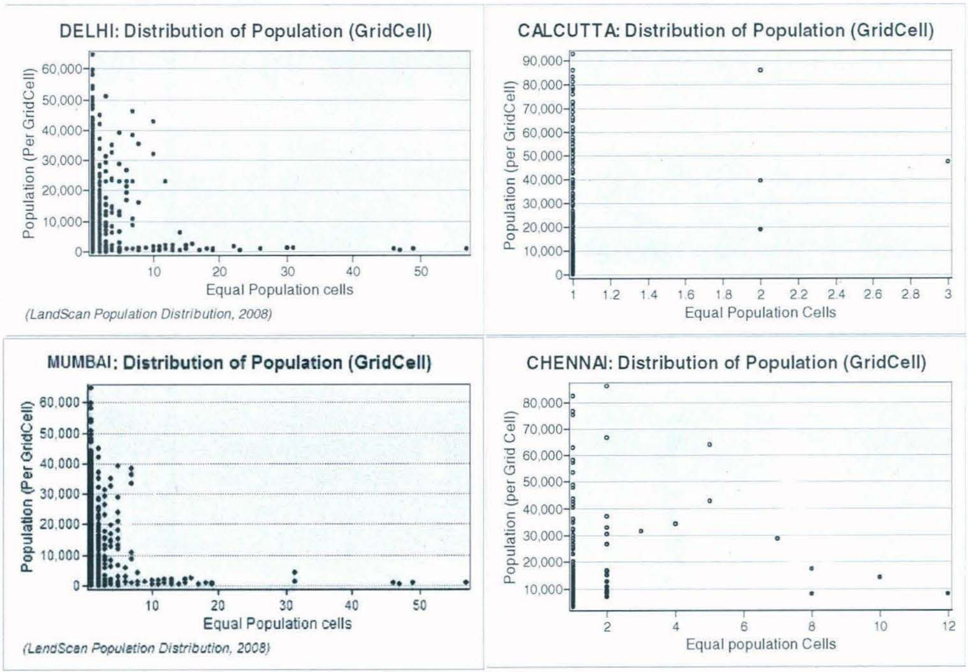
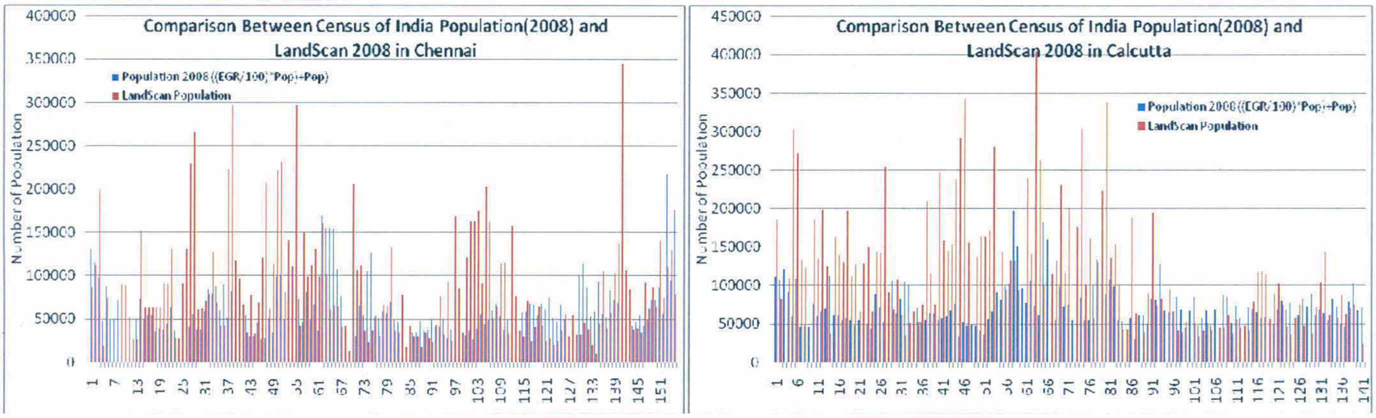


Figure No.16: Spatial population distribution per Grid cell (1x1km)

In mega cities of India Spatial distribution of population by LandScan show that Delhi and Mumbai are highly densely populated cities than that off Chennai and Calcutta. Dots in above graph show the level population living in a sq. km area (Density of population). This shows for Delhi, Mumbai, cities have not have a greatest spatial population indicating almost the urban patches are densely populated, as for Calcutta and Chennai the patches are less as well as in density of population and spatial extent.

Chennai Municipal Corporation (CMC) is the oldest municipal institution in India, Established on September 29, 1688. The corporation area has been divided into 10 zones and each zone is headed by a zonal officer. The corporation takes care of the civic functions of the Metropolis with the following authorities of the corporation to man the administrations namely: Council, Mayor, Six Standing Committees, Ward Committees and the Municipal Corporation. The city is divided into 155 administrative wards that are grouped into a city.

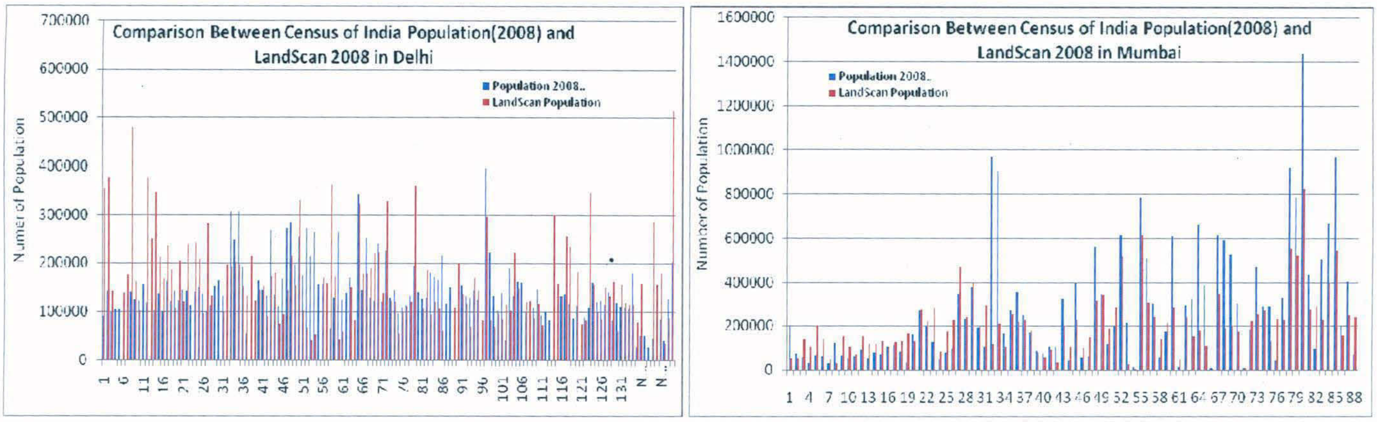


*(Source: Census of India, 2001 and LandScan)*

Figure No.17: 1) Comparison between LandScan and national Census in absolute Population in Chennai
2) Comparison between LandScan and national Census in absolute Population in Calcutta

Calcutta Municipal Corporation (KMC) governs the 10th most populated Metropolis in the world. A major amendment was introduced in the KMC Act in 1984 to remove certain procedural difficulties in the matters of assessment and valuation of land and buildings, recovery of taxes, etc. LandScan as like in all other mega city overestimating the population in each ward the main cause is the size of the wards. There are some wards which are sized smaller than pixel size of LandScan dataset. The city is divided into 141 administrative wards that are grouped into a city.

The Municipal Corporation of Delhi (MCD) is amongst the largest municipal bodies in the world providing civic services to more than an estimated population of 13.85 million people. It is next to Tokyo in terms of area and within its jurisdiction lie some of the most densely populated areas in the world. MCD came into existence in 1958 and under its jurisdiction there are 185 villages in outer Delhi as well as 153 urban villages.



*(Source: Census of India, 2001 and LandScan)*

Figure No.18: 1) Comparison between LandScan and national Census in absolute Population in Delhi
2) Comparison between LandScan and national Census in absolute Population in Mumbai

Mumbai Corporation of Greater Mumbai (MCGM) was formed in the year 1873 as Mumbai Civil Body. The MCGM is veritably the cradle of Local Self Governance in India. Through the multifarious civic and recreational services that it provides, the MCGM has always been committed to improve the quality of life. MCGM (formally Bombay Municipal Corporation) or Brihan Mumbai Municipal Corporation was established under the Bombay Municipal Corporation Act 1888. The Mayor has the functional role of sharing the corporation meetings

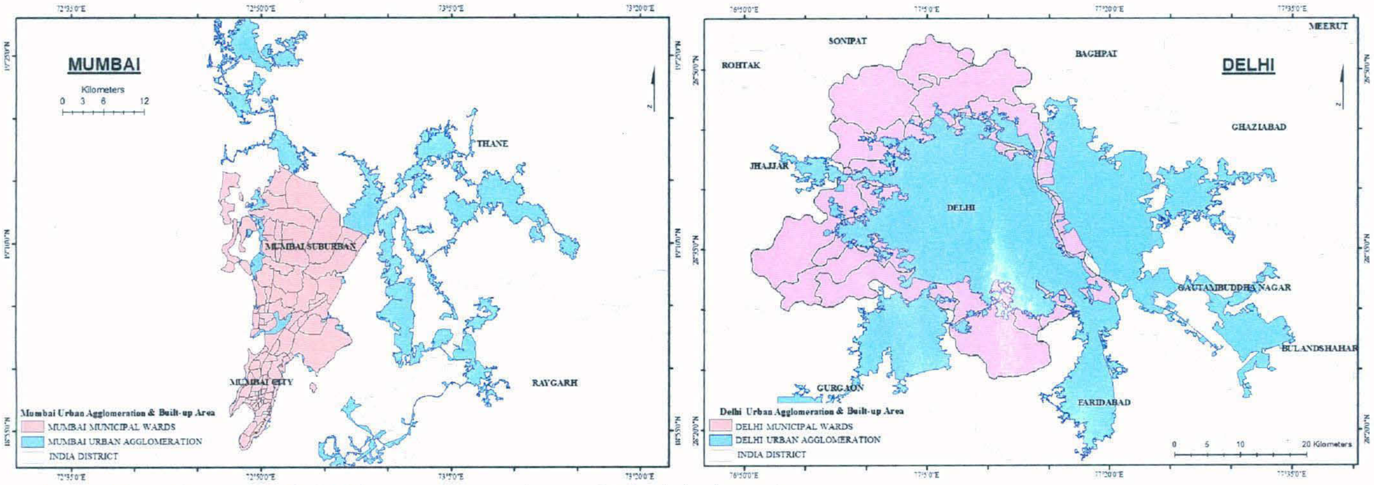


Figure No. 19: 1) Mumbai Urban agglomeration and Municipal wards
2) Delhi Urban agglomeration and Municipal wards

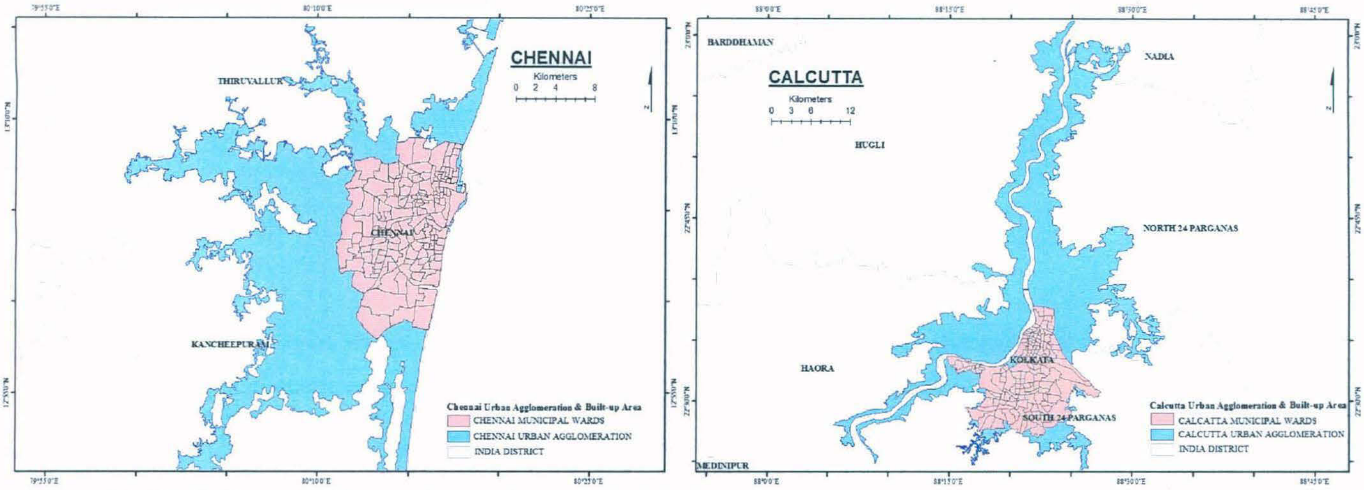


Figure No 20: 1) Chennai Urban agglomeration and Municipal wards
2) Calcutta Urban agglomeration and Municipal wards

as well as ceremonial role associated with being the first citizen. The executive power of the corporation is vested with the Municipal Commissioner and the Corporation comprises of 227 directly elected councillors representing the 24 municipal wards.

The ward generation as well as its characteristic is a function of the population. The population is often taken as a reliable surrogate for developing generation factors. The review of the available data on the demographics presents a rapid change in the growth rate in the past decades. The population trend of Delhi, Mumbai, Calcutta and Chennai over LandScan global population database presents the Population of megacities of India.

The ward-wise population for the year 2008 is presented in table no.7. The population in various wards along with the LandScan 2008 population estimates drawn on the basis of establishments is presented above.

### *Conclusion:*

The growth of cities and megacities pose a significant challenge for India and other developing nations. The economic growth and projected increases in the population will strongly influence the structure of cities as well as the settlement of urban agglomerations. The pressure of the growth of cities and urban agglomerations, tend to grow city in a haphazard way, here in Delhi, Mumbai, Calcutta and Chennai all four are showing a unique variation in pattern. Mega cities are showing spatial extent variation as well as temporal variation not only these two there are city to city differences are also there.

There is a negative percent difference in population of Mumbai which means the population estimated by LandScan is below the national population counts. Unlike other mega cities which are representing a pattern of positive difference and higher estimates. Above calculations depicts that as we move to micro levels the population estimated by LandScan moreover shows a false representation. As value of $R^2$ is .4668 for mega cities. As we already discussed in previous chapter about its pattern at state and district level and now this following pattern proves that the topography of a region effects on LandScan estimates. Sea in close proximity is also a factor which affects the error content in LandScan data.

At the ward level in mega cities LandScan fails to estimate the population further transformation are needed to estimate population at such lower level. Here we try to estimate population at ward level in Indian mega cities but it is a absolutely false attempt the data contains error ranging from -659 (ward no. 53 in Mumbai) to +86 (ward no. 47 in Chennai) in terms of percentage difference. Maximum number of ward shows a result in negative value which means the population in wards is underestimated by the LandScan. As we move to the total number of wards and there population it shows the same result as we get in at the mega city level. Mumbai is showing a negative -33.08 percent unlike Delhi (14.56), Chennai (25.01), and Calcutta (37.79).

The study has demonstrated that urbanization and its spatiotemporal form, pattern and structure can be quantified and compared across cities using spatial metrics. With the urban growth in India increasing, the need to understand the type of growth is important to plan the cities efficiently. Urban growth in India may take various spatial forms, depending upon the type of development, however, many parameters in Delhi, Mumbai, Calcutta and Chennai showed similar results. Especially Delhi and Mumbai have shown very similar growth type corresponding to the spatiotemporal urbanization and built-up density gradients. The built-up area has increased in megacities for the time period indicating dispersed areas of urban growth in outskirts of the city as well as in the city centre. Cities are undergoing changes in the urban form.

*Table No.7: Urban Agglomerations in Indian Mega Cities at Ward level*

| *Chennai Agglomeration* | | | | *Calcutta Agglomeration* | | | | *Mumbai Agglomeration* | | | | *Delhi Agglomeration* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***WARD No.*** | ***Population 2008 ((EGR/100)*Pop)+Pop)*** | ***LandScan Population*** | ***Percent Difference [(LandScan/ Census)*100]*** | ***WARD No.*** | ***Population 2008 ((EGR/100)*Pop)+Pop)*** | ***LandScan Population*** | ***Percent Difference [(LandScan/ Census)*100]*** | ***WARD No.*** | ***Population 2008 ((EGR/100)*Pop)+Pop)*** | ***LandScan Population*** | ***Percent Difference [(LandScan/ Census)*100]*** | ***WARD No.*** | ***Population 2008 ((EGR/100)*Pop)+Pop)*** | ***LandScan Population*** | ***Percent Difference [(LandScan/ Census)*100]*** |
| *1* | 131107 | 86793 | -51.06 | *1* | 111335 | 186659 | 40.35 | *1* | 200496 | 54754 | -266.18 | *1* | 91433 | 355452 | 74.28 |
| *2* | 114440 | 111698 | -2.46 | *2* | 107495 | 83011 | -29.49 | *2* | 74699 | 54188 | -37.85 | *2* | 142413 | 376239 | 62.15 |
| *3* | 97921 | 200024 | 51.05 | *3* | 121059 | 97449 | -24.23 | *3* | 55161 | 143109 | 61.46 | *3* | 98712 | 142503 | 30.73 |
| *4* | 47609 | 19688 | -141.82 | *4* | 91127 | 108189 | 15.77 | *4* | 32389 | 103381 | 68.67 | *4* | 104680 | 213108 | 50.88 |
| *5* | 87323 | 74212 | -17.67 | *5* | 59320 | 302742 | 80.41 | *5* | 67713 | 202659 | 66.59 | *5* | 104891 | 148401 | 29.32 |
| *6* | 50446 | 46950 | -7.45 | *6* | 109241 | 271629 | 59.78 | *6* | 62431 | 141345 | 55.83 | *6* | 119547 | 139512 | 14.31 |
| *7* | 49333 | 147984 | 66.66 | *7* | 45940 | 133487 | 65.58 | *7* | 30762 | 48588 | 36.69 | *7* | 203492 | 177153 | -14.87 |
| *8* | 71678 | 62763 | -14.20 | *8* | 47859 | 124069 | 61.43 | *8* | 124654 | 36279 | -243.60 | *8* | 141345 | 479204 | 70.50 |
| *9* | 43839 | 89480 | 51.01 | *9* | 46276 | 112684 | 58.93 | *9* | 69264 | 152827 | 54.68 | *9* | 124643 | 163030 | 23.55 |
| *10* | 87471 | 88207 | 0.83 | *10* | 76786 | 186557 | 58.84 | *10* | 51325 | 106245 | 51.69 | *10* | 121724 | 102917 | -18.27 |
| *11* | 63928 | 52161 | -22.56 | *11* | 59486 | 134472 | 55.76 | *11* | 65089 | 69966 | 6.97 | *11* | 158069 | 193718 | 18.40 |
| *12* | 38774 | 26717 | -45.13 | *12* | 65668 | 198824 | 66.97 | *12* | 94755 | 156776 | 39.56 | *12* | 119364 | 376955 | 68.33 |
| *13* | 48134 | 26717 | -80.16 | *13* | 70679 | 125502 | 43.68 | *13* | 53244 | 120497 | 55.81 | *13* | 107556 | 251909 | 57.30 |
| *14* | 73529 | 152827 | 51.89 | *14* | 112880 | 37428 | -201.59 | *14* | 78096 | 118554 | 34.13 | *14* | 103658 | 346787 | 70.11 |
| *15* | 49035 | 63611 | 22.91 | *15* | 60665 | 163805 | 62.97 | *15* | 71769 | 130362 | 44.95 | *15* | 137827 | 212675 | 35.19 |
| *16* | 54418 | 63611 | 14.45 | *16* | 60565 | 139630 | 56.62 | *16* | 108846 | 108404 | -0.41 | *16* | 101805 | 169885 | 40.07 |
| *17* | 54857 | 63611 | 13.76 | *17* | 54548 | 130038 | 58.05 | *17* | 114601 | 128271 | 10.66 | *17* | 163118 | 236450 | 31.01 |
| *18* | 35703 | 63611 | 43.87 | *18* | 57937 | 196253 | 70.48 | *18* | 86236 | 135886 | 36.54 | *18* | 120147 | 185909 | 35.37 |
| *19* | 39008 | 63611 | 38.68 | *19* | 55600 | 112684 | 50.66 | *19* | 38332 | 167846 | 77.16 | *19* | 142358 | 107318 | -32.65 |
| *20* | 38433 | 90328 | 57.45 | *20* | 46519 | 126640 | 63.27 | *20* | 163548 | 135933 | -20.31 | *20* | 124141 | 205831 | 39.69 |
| *21* | 44702 | 90328 | 50.51 | *21* | 55940 | 66215 | 15.52 | *21* | 270031 | 278350 | 2.99 | *21* | 143778 | 120884 | -18.94 |
| *22* | 62911 | 130403 | 51.76 | *22* | 46719 | 127967 | 63.49 | *22* | 199514 | 223026 | 10.54 | *22* | 142670 | 240018 | 40.56 |
| *23* | 37499 | 27989 | -33.98 | *23* | 49458 | 149025 | 66.81 | *23* | 125509 | 283132 | 55.67 | *23* | 112895 | 319410 | 64.66 |
| *24* | 39353 | 27989 | -40.60 | *24* | 44336 | 66215 | 33.04 | *24* | 47824 | 81627 | 41.41 | *24* | 140034 | 242861 | 42.34 |
| *25* | 40132 | 91600 | 56.19 | *25* | 88945 | 143994 | 38.23 | *25* | 77914 | 173619 | 55.12 | *25* | 150261 | 208738 | 28.01 |
| *26* | 51779 | 130403 | 60.29 | *26* | 71319 | 142012 | 49.78 | *26* | 98985 | 228901 | 56.76 | *26* | 137911 | 96755 | -42.54 |
| *27* | 40881 | 228958 | 82.14 | *27* | 52442 | 254945 | 79.43 | *27* | 349226 | 471624 | 25.95 | *27* | 101808 | 281888 | 63.88 |
| *28* | 56301 | 265656 | 78.81 | *28* | 94884 | 91719 | -3.45 | *28* | 233093 | 242020 | 3.69 | *28* | 113622 | 132107 | 13.99 |
| *29* | 38088 | 60908 | 37.47 | *29* | 106495 | 68372 | -55.76 | *29* | 379906 | 396667 | 4.23 | *29* | 152596 | 296503 | 48.53 |
| *30* | 37972 | 62180 | 38.93 | *30* | 64228 | 107194 | 40.08 | *30* | 195708 | 198237 | 1.28 | *30* | 164607 | 259981 | 36.69 |
| *31* | 58702 | 71165 | 17.51 | *31* | 82803 | 60881 | -36.01 | *31* | 103228 | 292497 | 64.71 | *31* | 131957 | 102146 | -29.18 |
| *32* | 84391 | 79196 | -6.56 | *32* | 104665 | 35093 | -198.25 | *32* | 967354 | 118662 | -715.22 | *32* | 150888 | 196811 | 23.33 |
| *33* | 78740 | 127539 | 38.26 | *33* | 100460 | 51203 | -96.20 | *33* | 903006 | 213785 | -322.39 | *33* | 307138 | 193388 | -58.82 |
| *34* | 87786 | 68581 | -28.00 | *34* | 63161 | 65766 | 3.96 | *34* | 167586 | 108836 | -53.98 | *34* | 247700 | 203747 | -21.57 |
| *35* | 59870 | 42938 | -39.43 | *35* | 71138 | 52450 | -35.63 | *35* | 273437 | 257271 | -6.28 | *35* | 307036 | 196472 | -56.27 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *36* | 90055 | 42938 | -109.73 | *36* | 51902 | 74467 | 30.30 | *36* | 358652 | 219751 | -63.21 | *36* | 193852 | 151965 | -27.56 |
| *37* | 51541 | 222322 | 76.82 | *37* | 54521 | 209497 | 73.98 | *37* | 248485 | 226744 | -9.59 | *37* | 56257 | 134719 | 58.24 |
| *38* | 81854 | 297940 | 72.53 | *38* | 63785 | 115315 | 44.69 | *38* | 171934 | 184454 | 6.79 | *38* | 263922 | 214973 | -22.77 |
| *39* | 69350 | 117363 | 40.91 | *39* | 64176 | 75797 | 15.33 | *39* | 88557 | 77944 | -13.62 | *39* | 186797 | 123820 | -50.86 |
| *40* | 95245 | 96610 | 1.41 | *40* | 55384 | 246827 | 77.56 | *40* | 73943 | 55892 | -32.30 | *40* | 164490 | 144920 | -13.50 |
| *41* | 42319 | 65838 | 35.72 | *41* | 57887 | 158607 | 63.50 | *41* | 109891 | 93288 | -17.80 | *41* | 144945 | 152208 | 4.77 |
| *42* | 54841 | 34350 | -59.65 | *42* | 59229 | 144562 | 59.03 | *42* | 110316 | 37574 | -193.60 | *42* | 133182 | 90716 | -46.81 |
| *43* | 30592 | 77367 | 60.46 | *43* | 67338 | 153360 | 56.09 | *43* | 329155 | 200116 | -64.48 | *43* | 267615 | 172604 | -55.05 |
| *44* | 30985 | 32919 | 5.87 | *44* | 76434 | 238875 | 68.00 | *44* | 44271 | 109160 | 59.44 | *44* | 135992 | 181126 | 24.92 |
| *45* | 45656 | 68700 | 33.54 | *45* | 34887 | 291109 | 88.02 | *45* | 395500 | 225651 | -75.27 | *45* | 109989 | 76707 | -43.39 |
| *46* | 27188 | 120225 | 77.39 | *46* | 52147 | 343499 | 84.82 | *46* | 56537 | 103006 | 45.11 | *46* | 168491 | 93958 | -79.33 |
| *47* | 27955 | 207834 | 86.55 | *47* | 48193 | 156065 | 69.12 | *47* | 62760 | 149650 | 58.06 | *47* | 273538 | 145553 | -87.93 |
| *48* | 51366 | 62180 | 17.39 | *48* | 49642 | 163463 | 69.63 | *48* | 559115 | 315492 | -77.22 | *48* | 286212 | 214075 | -33.70 |
| *49* | 34079 | 113266 | 69.91 | *49* | 46950 | 137716 | 65.91 | *49* | 345569 | 343621 | -0.57 | *49* | 196287 | 154755 | -26.84 |
| *50* | 98571 | 221497 | 55.50 | *50* | 41713 | 163463 | 74.48 | *50* | 119962 | 189175 | 36.59 | *50* | 255148 | 329066 | 22.46 |
| *51* | 100572 | 232181 | 56.68 | *51* | 36959 | 163463 | 77.39 | *51* | 203133 | 285269 | 28.79 | *51* | 174366 | 103976 | -67.70 |
| *52* | 48343 | 81422 | 40.63 | *52* | 56038 | 170935 | 67.22 | *52* | 614653 | 515579 | -19.22 | *52* | 273824 | 67683 | -304.57 |
| *53* | 54478 | 141375 | 61.47 | *53* | 65664 | 281269 | 76.65 | *53* | 215117 | 28342 | -659.01 | *53* | 214738 | 40004 | -436.79 |
| *54* | 81186 | 111319 | 27.07 | *54* | 91532 | 166750 | 45.11 | *54* | 17161 | 3211 | -434.46 | *54* | 265091 | 54538 | -386.07 |
| *55* | 66854 | 297795 | 77.55 | *55* | 81665 | 143846 | 43.23 | *55* | 782543 | 615662 | -27.11 | *55* | 157508 | 210356 | 25.12 |
| *56* | 73813 | 42938 | -71.91 | *56* | 98357 | 92888 | -5.89 | *56* | 509603 | 310529 | -64.11 | *56* | 156422 | 172084 | 9.10 |
| *57* | 46641 | 150917 | 69.09 | *57* | 102677 | 132352 | 22.42 | *57* | 305026 | 243777 | -25.12 | *57* | 160121 | 159709 | -0.26 |
| *58* | 81538 | 98994 | 17.63 | *58* | 196439 | 132556 | -48.19 | *58* | 56241 | 141877 | 60.36 | *58* | 64107 | 362530 | 82.32 |
| *59* | 48284 | 112353 | 57.03 | *59* | 151474 | 93126 | -62.65 | *59* | 176614 | 215679 | 18.11 | *59* | 128277 | 172697 | 25.72 |
| *60* | 66284 | 130482 | 49.20 | *60* | 96724 | 121302 | 20.26 | *60* | 610607 | 286965 | -112.78 | *60* | 265589 | 43989 | -503.76 |
| *61* | 37284 | 99233 | 62.43 | *61* | 77515 | 240001 | 67.70 | *61* | 17529 | 47837 | 63.36 | *61* | 125949 | 58335 | -115.91 |
| *62* | 168902 | 161012 | -4.90 | *62* | 105934 | 140587 | 24.65 | *62* | 293028 | 242711 | -20.73 | *62* | 138932 | 59566 | -133.24 |
| *63* | 155590 | 101503 | -53.29 | *63* | 72961 | 404195 | 81.95 | *63* | 329016 | 154895 | -112.41 | *63* | 170792 | 150938 | -13.15 |
| *64* | 154870 | 61090 | -153.51 | *64* | 61078 | 263483 | 76.82 | *64* | 661423 | 178805 | -269.91 | *64* | 314086 | 83668 | -275.40 |
| *65* | 154572 | 64985 | -137.86 | *65* | 181928 | 100873 | -80.35 | *65* | 386745 | 113759 | -239.97 | *65* | 343179 | 323624 | -6.04 |
| *66* | 107495 | 64110 | -67.67 | *66* | 159399 | 171199 | 6.89 | *66* | 9397 | 6665 | -40.99 | *66* | 144596 | 177592 | 18.58 |
| *67* | 76337 | 40952 | -86.41 | *67* | 123514 | 114980 | -7.42 | *67* | 614745 | 349323 | -75.98 | *67* | 252231 | 177915 | -41.77 |
| *68* | 78694 | 41507 | -89.59 | *68* | 54923 | 132498 | 58.55 | *68* | 589546 | 189579 | -210.98 | *68* | 129506 | 190397 | 31.98 |
| *69* | 57560 | 14153 | -306.70 | *69* | 98480 | 230341 | 57.25 | *69* | 526527 | 204644 | -157.29 | *69* | 123509 | 220819 | 44.07 |
| *70* | 58107 | 206576 | 71.87 | *70* | 72169 | 115132 | 37.32 | *70* | 304895 | 174616 | -74.61 | *70* | 241490 | 222197 | -8.68 |
| *71* | 29770 | 106866 | 72.14 | *71* | 75405 | 199428 | 62.19 | *71* | 10104 | 12042 | 16.10 | *71* | 120882 | 138275 | 12.58 |
| *72* | 65577 | 111627 | 41.25 | *72* | 55618 | 47297 | -17.59 | *72* | 188005 | 222695 | 15.58 | *72* | 225595 | 328273 | 31.28 |
| *73* | 54457 | 36862 | -47.73 | *73* | 55456 | 175559 | 68.41 | *73* | 471883 | 257039 | -83.58 | *73* | 129399 | 122495 | -5.64 |
| *74* | 105425 | 22729 | -363.84 | *74* | 84309 | 304306 | 72.29 | *74* | 288840 | 272146 | -6.13 | *74* | 145540 | 119752 | -21.53 |
| *75* | 126592 | 37313 | -239.27 | *75* | 55402 | 100673 | 44.97 | *75* | 291480 | 130331 | -123.65 | *75* | 97127 | 55262 | -75.76 |
| *76* | 52549 | 54274 | 3.18 | *76* | 55075 | 160822 | 65.75 | *76* | 45155 | 234516 | 80.75 | *76* | 108868 | 100923 | -7.87 |
| *77* | 51007 | 29738 | -71.52 | *77* | 100099 | 57736 | -73.37 | *77* | 332383 | 225964 | -47.10 | *77* | 113192 | 111809 | -1.24 |
| *78* | 58341 | 66667 | 12.49 | *78* | 133849 | 130103 | -2.88 | *78* | 919763 | 555180 | -65.67 | *78* | 131428 | 120802 | -8.80 |
| *79* | 57219 | 64563 | 11.37 | *79* | 95915 | 222800 | 56.95 | *79* | 786608 | 522802 | -50.46 | *79* | 195329 | 360058 | 45.75 |
| *80* | 69561 | 133055 | 47.72 | *80* | 87643 | 338475 | 74.11 | *80* | 1436450 | 824538 | -74.21 | *80* | 140708 | 273858 | 48.62 |

| | | | |
|---|---|---|---|
| *81* | 50123 | 36958 | -35.62 |
| *82* | 46564 | 34145 | -36.37 |
| *83* | 47675 | 77048 | 38.12 |
| *84* | 36143 | 17948 | -101.38 |
| *85* | 30424 | 42277 | 28.04 |
| *86* | 34717 | 29471 | -17.80 |
| *87* | 34345 | 29246 | -17.43 |
| *88* | 47518 | 18785 | -152.96 |
| *89* | 37154 | 33893 | -9.62 |
| *90* | 37588 | 28139 | -33.58 |
| *91* | 48963 | 22766 | -115.07 |
| *92* | 41815 | 43832 | 4.60 |
| *93* | 40722 | 76751 | 46.94 |
| *94* | 49958 | 32705 | -52.75 |
| *95* | 28135 | 93747 | 69.99 |
| *96* | 37722 | 25047 | -50.60 |
| *97* | 58053 | 168172 | 65.48 |
| *98* | 40007 | 85875 | 53.41 |
| *99* | 44936 | 34350 | -30.82 |
| *100* | 31076 | 120225 | 74.15 |
| *101* | 36818 | 162208 | 77.30 |
| *102* | 27135 | 162208 | 83.27 |
| *103* | 38819 | 174789 | 77.79 |
| *104* | 55470 | 91023 | 39.06 |
| *105* | 44229 | 202605 | 78.17 |
| *106* | 50687 | 163964 | 69.09 |
| *107* | 59538 | 51525 | -15.55 |
| *108* | 68394 | 64088 | -6.72 |
| *109* | 53237 | 114000 | 53.30 |
| *110* | 38142 | 116237 | 67.19 |
| *111* | 48917 | 32919 | -48.60 |
| *112* | 40470 | 157001 | 74.22 |
| *113* | 54257 | 76095 | 28.70 |
| *114* | 78865 | 36457 | -116.32 |
| *115* | 57748 | 30613 | -88.64 |
| *116* | 58866 | 71142 | 17.26 |
| *117* | 67599 | 24213 | -179.18 |
| *118* | 67310 | 40472 | -66.31 |
| *119* | 54146 | 64406 | 15.93 |
| *120* | 67903 | 42937 | -58.15 |
| *121* | 60821 | 25087 | -142.44 |
| *122* | 74354 | 27750 | -167.94 |
| *123* | 51000 | 20077 | -154.02 |
| *124* | 46730 | 24371 | -91.74 |
| *125* | 66461 | 35801 | -85.64 |

| | | | |
|---|---|---|---|
| *81* | 107338 | 136522 | 21.38 |
| *82* | 98455 | 153803 | 35.99 |
| *83* | 55377 | 99844 | 44.54 |
| *84* | 53149 | 43025 | -23.53 |
| *85* | 70935 | 42559 | -66.68 |
| *86* | 57119 | 188407 | 69.68 |
| *87* | 30263 | 63533 | 52.37 |
| *88* | 61439 | 115556 | 46.83 |
| *89* | 60828 | 38273 | -58.93 |
| *90* | 50298 | 90573 | 44.47 |
| *91* | 82796 | 194904 | 57.52 |
| *92* | 81577 | 73696 | -10.69 |
| *93* | 127260 | 83274 | -52.82 |
| *94* | 67163 | 136366 | 50.75 |
| *95* | 64733 | 95909 | 32.51 |
| *96* | 65845 | 65835 | -0.02 |
| *97* | 84956 | 42035 | -102.11 |
| *98* | 69307 | 38452 | -80.24 |
| *99* | 45097 | 52517 | 14.13 |
| *100* | 67379 | 61550 | -9.47 |
| *101* | 85479 | 51170 | -67.05 |
| *102* | 46894 | 33532 | -39.85 |
| *103* | 57982 | 42250 | -37.24 |
| *104* | 66911 | 51122 | -30.88 |
| *105* | 47652 | 40243 | -18.41 |
| *106* | 69275 | 56838 | -21.88 |
| *107* | 90239 | 45297 | -99.22 |
| *108* | 87078 | 44882 | -94.01 |
| *109* | 85424 | 60268 | -41.74 |
| *110* | 51707 | 37040 | -39.60 |
| *111* | 73021 | 56568 | -29.08 |
| *112* | 57912 | 45082 | -28.46 |
| *113* | 70259 | 48488 | -44.90 |
| *114* | 71356 | 41056 | -73.80 |
| *115* | 69539 | 78912 | 11.88 |
| *116* | 64671 | 118080 | 45.23 |
| *117* | 57410 | 119182 | 51.83 |
| *118* | 58877 | 114368 | 48.52 |
| *119* | 44086 | 56416 | 21.86 |
| *120* | 49742 | 88763 | 43.96 |
| *121* | 68071 | 103022 | 33.93 |
| *122* | 79398 | 75990 | -4.49 |
| *123* | 69432 | 45746 | -51.78 |
| *124* | 77895 | 36095 | -115.80 |
| *125* | 95952 | 57207 | -67.73 |

| | | | |
|---|---|---|---|
| *81* | 433710 | 274071 | -58.25 |
| *82* | 97033 | 289340 | 66.46 |
| *83* | 506477 | 227755 | -122.38 |
| *84* | 669089 | 400838 | -66.92 |
| *85* | 969736 | 546530 | -77.44 |
| *86* | 196992 | 161992 | -21.61 |
| *87* | 405673 | 251320 | -61.42 |
| *88* | 71449 | 241722 | 70.44 |

| | | | |
|---|---|---|---|
| *81* | 127045 | 107295 | -18.41 |
| *82* | 128607 | 186451 | 31.02 |
| *83* | 179178 | 94110 | -90.39 |
| *84* | 172400 | 120872 | -42.63 |
| *85* | 165621 | 106696 | -55.23 |
| *86* | 216647 | 59916 | -261.58 |
| *87* | 116281 | 265278 | 56.17 |
| *88* | 151274 | 125391 | -20.64 |
| *89* | 127361 | 108345 | -17.55 |
| *90* | 162516 | 200003 | 18.74 |
| *91* | 154666 | 137471 | -12.51 |
| *92* | 133266 | 116868 | -14.03 |
| *93* | 129326 | 69342 | -86.50 |
| *94* | 145276 | 171019 | 15.05 |
| *95* | 125716 | 143567 | 12.43 |
| *96* | 121922 | 83490 | -46.03 |
| *97* | 395340 | 297650 | -32.82 |
| *98* | 222061 | 83343 | -166.44 |
| *99* | 133413 | 69131 | -92.99 |
| *100* | 103794 | 97039 | -6.96 |
| *101* | 138438 | 84103 | -64.61 |
| *102* | 41120 | 114337 | 64.04 |
| *103* | 191451 | 103225 | -85.47 |
| *104* | 133526 | 222242 | 39.92 |
| *105* | 162149 | 149727 | -8.30 |
| *106* | 161832 | 167855 | 3.59 |
| *107* | 98113 | 119862 | 18.15 |
| *108* | 95970 | 121134 | 20.77 |
| *109* | 108341 | 87360 | -24.02 |
| *110* | 147613 | 117339 | -25.80 |
| *111* | 93739 | 71842 | -30.48 |
| *112* | 101275 | 95564 | -5.98 |
| *113* | 82633 | 157747 | 47.62 |
| *114* | 119461 | 301373 | 60.36 |
| *115* | 135222 | 158648 | 14.77 |
| *116* | 134116 | 133130 | -0.74 |
| *117* | 137552 | 255923 | 46.25 |
| *118* | 116836 | 234093 | 50.09 |
| *119* | 87459 | 144945 | 39.66 |
| *120* | 114115 | 182963 | 37.63 |
| *121* | 107976 | 75908 | -42.25 |
| *122* | 89940 | 83171 | -8.14 |
| *123* | 109065 | 346888 | 68.56 |
| *124* | 161494 | 157771 | -2.36 |
| *125* | 120609 | 98441 | -22.52 |

| | | | |
|---|---|---|---|
| *126* | 48881 | 55898 | 12.55 |
| *127* | 56597 | 30713 | -84.28 |
| *128* | 101555 | 54904 | -84.97 |
| *129* | 100469 | 32284 | -211.20 |
| *130* | 101130 | 32283 | -213.26 |
| *131* | 114165 | 45184 | -152.67 |
| *132* | 87069 | 37710 | -130.89 |
| *133* | 52620 | 20106 | -161.71 |
| *134* | 58500 | 9542 | -513.08 |
| *135* | 93481 | 44264 | -111.19 |
| *136* | 56038 | 105639 | 46.95 |
| *137* | 52065 | 39333 | -32.37 |
| *138* | 83473 | 57222 | -45.88 |
| *139* | 72135 | 103261 | 30.14 |
| *140* | 68685 | 137591 | 50.08 |
| *141* | 103997 | 345157 | 69.87 |
| *142* | 58241 | 106747 | 45.44 |
| *143* | 38283 | 83648 | 54.23 |
| *144* | 43157 | 37928 | -13.79 |
| *145* | 46523 | 38614 | -20.48 |
| *146* | 55098 | 33906 | -62.50 |
| *147* | 41415 | 92271 | 55.12 |
| *148* | 48752 | 62504 | 22.00 |
| *149* | 72069 | 87203 | 17.36 |
| *150* | 71973 | 64743 | -11.17 |
| *151* | 87141 | 140905 | 38.16 |
| *152* | 55772 | 74188 | 24.82 |
| *153* | 217633 | 110312 | -97.29 |
| *154* | 94548 | 129733 | 27.12 |
| *155* | 177179 | 78118 | -126.81 |
| ***Total Chennai Wards*** | ***9865791*** | ***13155656*** | ***25.01*** |

| | | | |
|---|---|---|---|
| *126* | 61857 | 75147 | 17.69 |
| *127* | 83094 | 47943 | -73.32 |
| *128* | 72373 | 76270 | 5.11 |
| *129* | 88506 | 37082 | -138.68 |
| *130* | 60485 | 70780 | 14.54 |
| *131* | 68448 | 103836 | 34.08 |
| *132* | 63799 | 143110 | 55.42 |
| *133* | 54241 | 61311 | 11.53 |
| *134* | 83328 | 8143 | -923.31 |
| *135* | 72098 | 57966 | -24.38 |
| *136* | 49537 | 86970 | 43.04 |
| *137* | 45508 | 63167 | 27.96 |
| *138* | 78869 | 70669 | -11.60 |
| *139* | 102223 | 74780 | -36.70 |
| *140* | 67313 | 53373 | -26.12 |
| *141* | 70826 | 24100 | -193.89 |
| ***Total Calcutta Wards*** | ***10386447*** | ***16695297*** | ***37.79*** |

| | | | |
|---|---|---|---|
| ***Total Mumbai Wards*** | ***24454755*** | ***18376187*** | ***-33.08*** |

| | | | |
|---|---|---|---|
| *126* | 123701 | 84983 | -45.56 |
| *127* | 115881 | 151134 | 23.33 |
| *128* | 140954 | 132354 | -6.50 |
| *129* | 82465 | 162764 | 49.33 |
| *130* | 118056 | 61268 | -92.69 |
| *131* | 112285 | 155652 | 27.86 |
| *132* | 108141 | 119108 | 9.21 |
| *133* | 107176 | 115333 | 7.07 |
| *134* | 180986 | 115706 | -56.42 |
| *NDMC 1* | 26716 | 78957 | 66.16 |
| *NDMC 2* | 50612 | 159451 | 68.26 |
| *NDMC 3* | 50699 | 197142 | 74.28 |
| *NDMC 4* | 26973 | 636594 | 95.76 |
| *NDMC 5* | 45077 | 287391 | 84.31 |
| *NDMC 6* | 36366 | 155945 | 76.68 |
| *NDMC 7* | 83874 | 180361 | 53.50 |
| *NDMC 8* | 41581 | 34518 | -20.46 |
| *NDMC 9* | 126675 | 88639 | -42.91 |
| *Cantonment* | 201847 | 516193 | 60.90 |
| ***Total Delhi Wards*** | ***21106744*** | ***24704315*** | ***14.56*** |

*Chapter No. 4*

# Estimation of population distribution, urban population density at ward level in Indian Mega Cities

## 4.1 Introduction:

The population census 2001 results show that, India's urban population officially amounted to 28.6 crore inhabitants. At this time, it was almost the equivalent of the entire population of the United States of America. Yet, as the urbanisation rate, as defined by the Census of India, remains one of the lowest in the world (27.8%), and as the natural growth rate of the country remains relatively high (+1.6% / year), it is generally agreed that India is the country which presents the highest potential of urban growth among the world economies. However, besides this official figure of rate of population change, the 'Mega Cities' having more than 5 million inhabitants surpassed in 2001. On a scientific point of view, one can put in question, not only the problem of population growth, but the representation of the phenomenon, in so far as the statistical approach of the population growth in India does not allow to take in account the dramatic increase of mega cities.

*The "megacities":*

The concept of megacities, which nourishes a significant media literature at a world scale, is not an Indian category of statistics, but an international one. Indeed, the Indian official statistics classify cities into 6 categories. The "Class I" group of cities with more than 100000 inhabitants, "Class II" towns with more than 50000 inhabitants, "Class III" more than 20000 inhabitants and so on. In the 1891 census, the "Class I" numbered 23 cities for an overall total population of about 250 million inhabitants1. In 2001, there were... 394.Indeed, like most other big countries of the World (China, USA, Brazil...), the Indian urban network is not affected by urban primacy[1].

The reason is that, during the past century, the urban system has been dominated, not by one, but by *four megacities* making up the 4 apexes of a lozenge: ***Mumbai, Delhi, Calcutta and Chennai***. In *1872, Calcutta was the first agglomeration to exceed one million* inhabitants outside industrialised countries. *Mumbai took it over in 1991*, which comes first as far as international metropolitan economic jobs are concerned. But finally, it is the agglomeration of the political capital, Delhi, which has today reached the top spot. Old capital of the Mogul

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[1] Primacy index is defined as : (population of city of rank 1) / (population of city of rank 2). According to the theories of probability (Pareto), a primacy is "abnormally" high if it is more than 2 According to Moriconi-Ebrard (1994), the average national primacy index was 5.3 at a world scale. In India the primacy index has never surpassed 1.5 since the modern population censuses exist (1867-1872)

Empire, Delhi was a modest city of 162,000 inhabitants in 1872. In 1951, the agglomeration was still twice less populated than Mumbai and three times less than Calcutta. Delhi started expanding only after the Independence and will reach almost 25 million inhabitants in 2011, compared to 22 million for Mumbai. In 2011, Chennai would be shoulder to shoulder with Bangalore and Hyderabad, with about 8 million inhabitants each.

**Table No.8: Agglomerations of more than 5 million inhabitants in the 2011 horizon**
(Population in thousands (000) of inhabitants)

| *Evolution of population since 1872* | *1872* | *1901* | *1951* | *1961* | *1971* | *1981* | *1991* | *2001* | *2011** |
|---|---|---|---|---|---|---|---|---|---|
| **Delhi** | 162 | 240 | 1537 | 2527 | 3941 | ***5783*** | ***8723*** | ***15725*** | ***24867*** |
| **Mumbai** | 652 | 813 | 2967 | 4152 | ***6592*** | ***9422*** | ***12572*** | ***16434*** | ***21780*** |
| **Calcutta** | 1093 | 1503 | 4761 | ***5903*** | ***7421*** | ***9194*** | ***10916*** | ***13206*** | ***16509*** |
| **Chennai** | 422 | 541 | 1416 | 1729 | 3170 | 4290 | ***5361*** | ***6560*** | ***8276*** |
| *Bengaluru* | 143 | 162 | 786 | 1207 | 1664 | 2922 | 4087 | ***5701*** | ***7891*** |
| *Hyderabad* | 368 | 449 | 1130 | 1251 | 1815 | 2562 | 4280 | ***5742*** | ***7746*** |
| *Ahmadabad* | 120 | 186 | 877 | 1206 | 1752 | 2558 | 3298 | 4525 | ***6196*** |
| *Pune* | 132 | 164 | 600 | 738 | 1135 | 1686 | 2485 | 3761 | ***5461*** |

(Source: Provisional Population Totals, Census of India- 2001)

These figures contradict the UN's projection that Mumbai, with an expected population of 26 million in 2015, would become the world's second largest agglomeration. The slightly higher growth rate of Delhi's population is not only responsible for these results, but the official statistical definition given by the Census of India, which minimize the real population of Delhi agglomeration

Over the last 50 years, the world has faced dramatic growth of its urban population. The number of so-called mega cities increased in the period from 1975 until today from 4 to 22, mostly in less developed regions.[2] Especially Indian mega cities are among the most dynamic regions on the planet. During the last 50 years the population of India (today 1.2 billion) has grown two and a half times, but the urban population has grown nearly five times. The number of Indian mega cities will

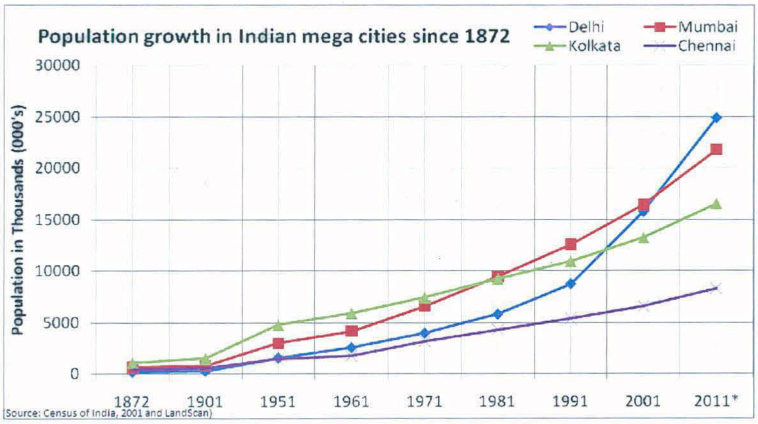

Figure No.21: Temporal agglomeration growth in Mega cities of India

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[2] Münchner Rück (2005): Megastädte – Megarisiken. Trends und Herausforderungen für Versicherung und RisikomanageRisikomanagement. www.munichre.com/publications/302-04270_de.pdf

double from the current three (Mumbai, Delhi and Calcutta) to six by the year 2021 (new additions will be Bangalore, Chennai and Hyderabad), when India will have the largest concentration of mega cities in the world.[3]

Intra-city migration from smaller to bigger cities is continuing along with the migration from rural to urban areas besides an enormous natural population pressure. This explosive urbanization resulting in unplanned and uncontrolled growth of large cities has had dramatic negative effects on urban dweller and their environment. Cities are facing serious shortage of power, water, sewerage, developed land, housing, transportation, and communication mixed with dramatic pollution, poor public health or educational standards, unemployment and poverty. Thus, understanding and monitoring past and current urbanization processes is the basis for future predictions and preparedness, and thus for sustainable urban planning. This study focuses on the spatiotemporal urban growth of the current Indian mega cities, Mumbai, Delhi, Chennai and Calcutta, assumingly the urban agglomerations at the furthest urban development stage as basis to analyse trends to be due in incipient mega cities in India.

For many decades, in some cases centuries, cities have been spreading (Anas et al., 1998). Research in the description, mapping, characterization, measuring, understanding and explanation of form, morphology, and evolution of urban environments has a long tradition in geographic research and planning. The classic theories of urban morphology define urban pattern as concentric rings with different land use types (Burges, 1925), as sectors, where the transportation network modifies the form of the concentric zone pattern (Hoyt, 1939), and the multiple nuclei theory having a patchy urban form with multiple centers of specialized land use (Harris and Ullman, 1945).

**Table No.9: Built-up area estimation using Satellite images for Indian Mega cities**

| **Built-up Area ($m^2$)** | *MSS* | *ETM+* | *IRSLISS- 3/ TM* |
|---|---|---|---|
| *DELHI* | 3413107 (*1977*) | 2038235.8 (1999) | 6383404.6 (*2006*) |
| *MUMBAI* | 558327.6 (*1973*) | 665037 (*2001*) | - |
| *CALCUTTA* | 334458.56 (*1973*) | 19240798 (*2000*) | 1037723.5 (*2006*) |
| *CHENNAI* | - | 17091462 (*2001*) | 1170839.7 (*2006*) |

Land use and land cover classification statistics obtained are presented in Table MSS (1973, 1977), ETM+ (1999, 2000), TM (2006), and IRS LISS III for years (2006). The classification scenarios for each year for built-up area of Mega cities have been explained below there was

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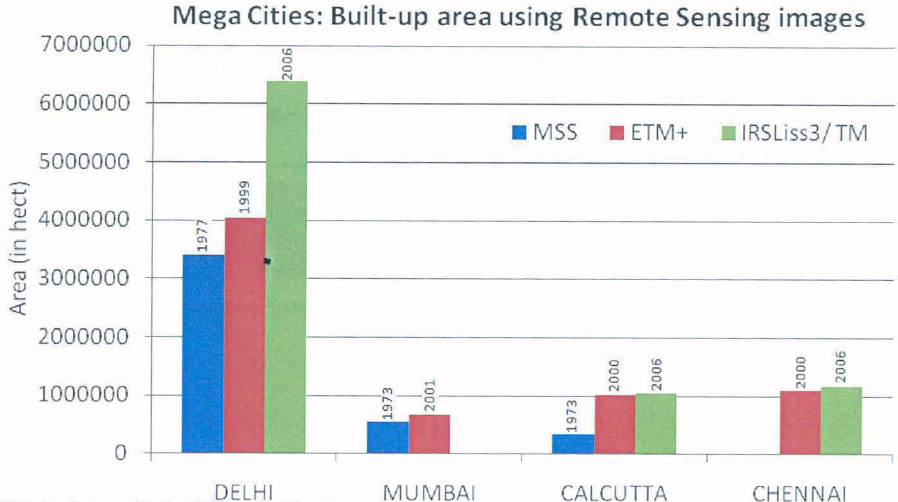
[3] Allen P.M., and Sanglier, M. (1979): A dynamic model of urban growth: II. Journal Social Biol. Struct. 2: 269-278.

consistent increase in the coverage of the built areas in all mega cities of India 1973 to 2000 however there was a sharp rise in 2006. The increase was as a result of rapid development in terms of urbanisation and urban expansion to meet the economic demands.



(Source: Census of India, 2001 and LandScan)

Figure No.21: Built-up area estimation and comparison using Satellite images for Indian Mega cities

Based on the figure we can easily attempt to say that these mega cities are growth engines of the country. Delhi is the largest Urban Agglomeration of India in terms of Built-up area it consists the largest 6383.40 km$^2$ area which four times larger that Calcutta and Chennai and Mumbai is a compact city which consists a greater amount of population in which is almost equal to Delhi, where in terms of Built-up area it is 8 times smaller than it. Although Delhi is the largest spatial extent still its spatial growth is largest.

## 4.2 Mega Cities and LandScan:

The mega cities of India, Mumbai, Delhi, Chennai and Calcutta or we can say four pillars of Indian economy. These four mega cities situated very strategically at the four ideal location over Indian sub continent. In demographic terms as we attempt to match LandScan population with the census population these mega cities. This attempt show that population estimate by LandScan population database is more or less equal to census but when we look into it a pattern emerged and shows that ***LandScan population database underestimates the heavily dense population area*** and the population density increases the ***error*** *(underestimation) increases.*

*Table No.10 Percentage difference and comparison between Census population and LandScan estimated population in Indian Mega cities*

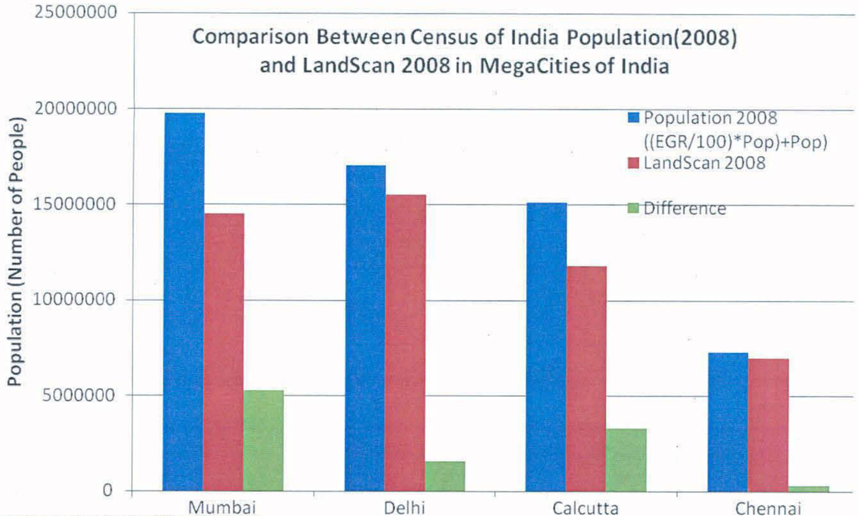
| Mega Cities of India | Population 1991 | Population 2001 | Average Annual Exponential growth (1991-2001) (1/10) | Average Decadal Exponential growth (1991-2001) (10/10) | Exponential growth (1991-2001) for 8 Years (8/10) | Population 2008 ((EGR/100)*Pop)+Pop) | LandScan 2008 | Difference | Difference (in Percent) |
|---|---|---|---|---|---|---|---|---|---|
| ***Mumbai*** | 12596000 | 16368000 | 2.62 | 26.19 | 20.96 | ***19798064*** | ***14531128*** | **5266936** | **26.603** |
| ***Delhi*** | 8419000 | 12791000 | 4.18 | 41.83 | 33.46 | ***17070876*** | ***15519328*** | **1551548** | **9.089** |
| ***Calcutta*** | 11022000 | 13217000 | 1.82 | 18.16 | 14.53 | ***15137278*** | ***11826387*** | **3310891** | **21.872** |
| ***Chennai*** | 5422000 | 6425000 | 1.70 | 16.97 | 13.58 | ***7297422*** | ***6998775*** | **298647** | **4.092** |

(Sources: provisional Population Totals, Census of India- 2011)

The four current mega cities in India, Mumbai , Delhi, Chennai and Calcutta, who are spatially distributed on the large subcontinent. Mumbai is located at the west coast on seven now-merged islands in the state Maharshtra. Delhi, located in northern India on the flood plains of river Yamuna, has the status as the National Capital Territory. Cennai is located in southern India on the eastern coast of India of the state Tamil Nadu, Calcutta, the capital of the Indian state West Bengal, is located in eastern India in the Ganghes Delta in a flat surrounding at the Hooghly River.

Referring to the Census of India 2001, in the year 2001 approximately 16.4 million people were living in Mumbai, 15.7 million people were living in Delhi and 13.2 million people were living in Calcutta 6.5 million people were living in India's fourth mega city Chennai. The dramatic pace of urbanization shows Mumbai (3.1%) and Delhi (4.1%) among the highest population growth rates of mega cities worldwide, while in contrast Calcutta's pace slows down to 1.7% . Figure shows the dramatic population development of Mumbai, Delhi and Calcutta since 1970 and a prognosis until 2015. The mega cities more or less quadrupled their population, and are expected to grow even faster intensifying the urban crisis of the largest Indian urban agglomerations.

The figure "Growth of Urban Agglomerations" shows population growth in selected cities. Delhi, Mumbai, Chennai and Calcutta are typical of large cities in more developed countries that arose in the Census Population and LandScan 2008, reached their current size, and has since experienced almost equal Population data structure. City Chennai due to it location and less historic advantage as compare to other cities of India here population accuracy is very high.



Source: Census of India, 2001 and LandScan)

Figure No.22: Evaluation of LandScan and national Census in absolute Population in Indian Mega cities

Delhi's urban area does not officially include parts of the built-up areas that have spread outside the administrative boundaries of Delhi Union Territory (in black colour). However, the true agglomeration (in blue colour) includes in a single continuous built-up area several towns and villages located in the states of Uttar Pradesh and Haryana, like Faridabad u.a. (1.1 million inhabitants in 2001).

Whereas Calcutta spreads moreover along with the river in the state West Bengal in the districts Haora and Hugli in the west and North and South 24 Parganas. Most of it is in East direction more precisely towards northeast because in there are long Marshy tracts in south-eastern region.

Unlike Delhi and Calcutta urban area in Mumbai and Chennai does not able to spread in all direction because of orographic barriers and on the rest sides it does not include parts of the built-up areas that have spread outside the administrative boundaries (in black colour). However, the true agglomeration (in blue colour) includes in a single continuous built-up area several towns and villages located in the states of Maharashtra (Thane and Raygarh) and Tamil Nadu (Thiruvallur and Kancheepuram), like Faridabad u.a. Although there are orographic barriers still the cities are yet to be grown and Mumbai which basically situated on the islands swells less horizontally and vertical expansion takes into account. Whereas Chennai an identical port city has own space to spread horizontally therefore it takes into place over the above mentioned districts of Tamil Nadu.

Many of the important and most significant changes around the world are associated with urbanization. Incidentally, more than half of the population (3.3 billion people) resides in the urban areas and by 2030 more than 70% of the population will be concentrated in the urban areas. As of now, 19 mega cities and 22 cities exist, holding more than 10 million and 5–10 million population respectively. Apart from this, 370 cities with 1–5 million people, and 433 cities with 0.5–1 million people are growing at a high rate. The current rate of urbanization (0.8%) will grow in a rapid and unbalanced pace (1.6%), most dominantly in the developing countries. Asia being one of the most populous realms is expected to have more than 54% of the world's urban population by 2050. This will result in political and economic transformations, including migration of communities and urbanization[4].

In India, urbanization has witnessed an unprecedented rate of growth over the last four decades. During the last 50 years, the population of India (today 1.2 billion) has grown more than double and the urban population nearly five times. Around 400 million people (28%) live in the cities, in sharp contrast to 60 million people (~15%) in 1947. It is estimated that 140 million people will move to the cities by 2020, and another 700 million by 2050. The number of Indian mega cities will increase from the current four (Mumbai, Delhi Chennai and Calcutta) to six (including Bangalore and Hyderabad) by 2011, when India will have the largest concentration of mega cities in the world. The number of cities is expected to be 68 by 2021, which will result in urban housing shortage of about 30 million units. Such interactions will create a coupling impact between the global environmental changes and the local environment of urban areas[5].

Monitoring, measurement and assessment of this urban growth is essential for city-planners, economists, environmentalists, ecologists, resource managers and the government at large. Such information will enhance the ongoing initiatives to use spatial data for local planning and better governance. Multi-temporal remote sensing is one of the important data gathering tools for analysing land-use and land-cover changes. The potential use of ***LandScan2008*** data in population studies, inventories of human settlements and energy consumption patterns has been noted since the early. The potential use of this in mapping the population and urban areas, socio-economic parameters and greenhouse gas emissions, urban heat island and energy consumption has also been documented.

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[4] United Nations, World Urbanization Prospects: The 2005 Revision, United Nations Publications, New York, 2005.

[5] Liu, J. G., and Mason, P. J., (2009), Essential Image Processing and GIS for Remote Sensing (1st Edition.), p. 443, Wiley-Blackwell.

In this study we used LandScan2008 data set over the Indian region, to detect urban footprints and their pattern, with a special emphasis on four mega cities of India (currently ranging from 8 to 20 million inhabitants). Development of a country is best represented in the spatial increase in towns and cities (urban sprawl or agglomeration), as they provide living for people of all groups and are the centres of attraction. Spatial analysis on enhancement in the night-time lights is a potential indicator of urban sprawl. The study attempts to characterize the spatial pattern of the cities to detect similarities and differences in spatial growth in the large Indian urban agglomerations.

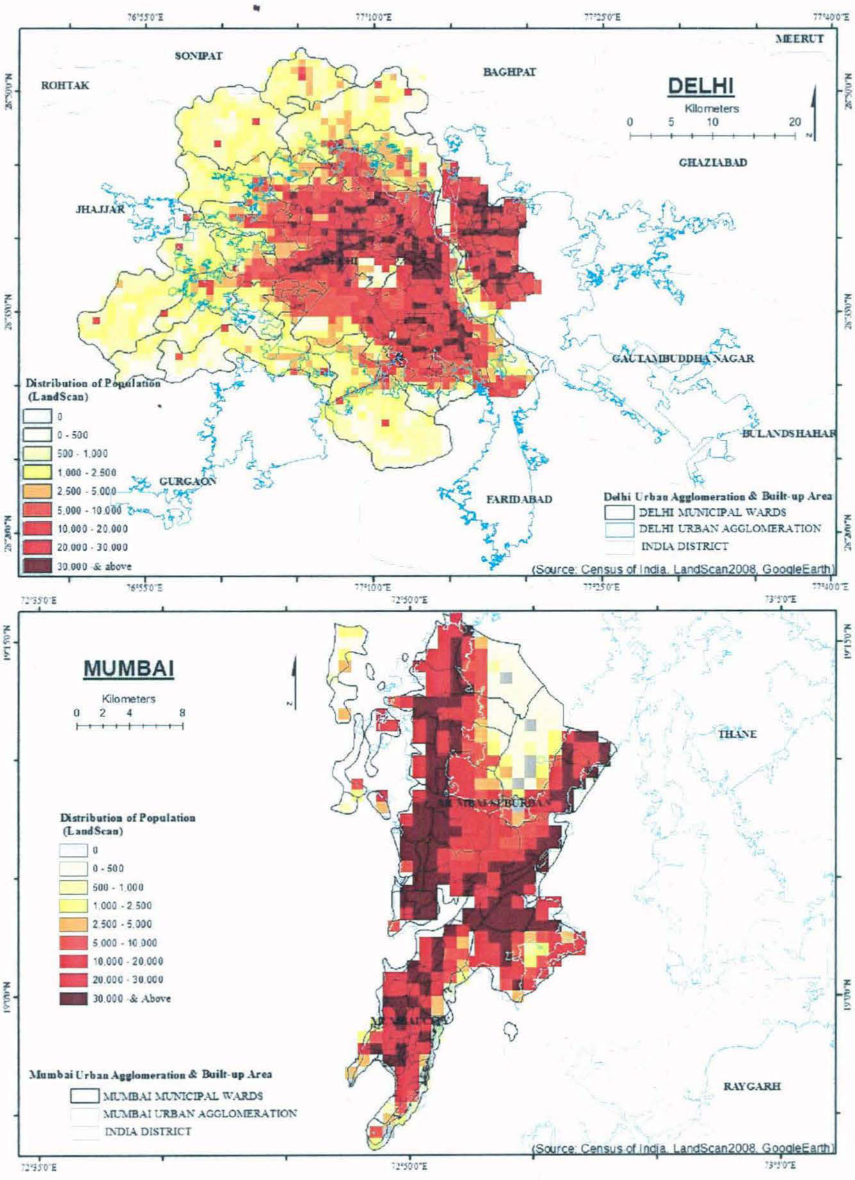

Figure No.23:

1) Evaluation of Delhi urban agglomeration and LandScan population estimates
2) Evaluation of Mumbai urban agglomeration and LandScan population estimates

Maps show mega cities of India with their built-up boundaries and location of population grid cells with their population in cities. It also shows the population change over the space. The mega cities in India are Mumbai, Delhi Chennai, and Calcutta, of which Delhi (4.1%) and Mumbai (3.1%) have the highest population growth rate of all mega cities in the world. These cities along with other developing cities are flooded with immigrant populations from different parts of the country every year, resulting in rapid urban agglomeration high concentration of population near CBD (Central Business District).

The mega cities, like Delhi, Calcutta, Chennai, and Mumbai clearly stand out from the other urban agglomerations in India. With 15.7, 13.2, 6.5 and 16.4 million inhabitants respectively, in 2001 and high average annual population growth rates of 3.1%, 4.1% and 2.0% respectively, between 1975 and 2000[6], the mega cities represent a unique cluster of urban agglomeration. Mumbai is expected to have population of more than 20 million, Calcutta and Delhi will have more than 16 million whereas Chennai expected to have population more than 8 million by 2011.These cities show a unique pattern of high built-up density at the core with decrease towards the buffer. Calcutta and Mumbai showed an elongated and disaggregated growth unlike Delhi and Chennai which had grown radially over the periods. In the recent past, Calcutta and Mumbai have also shown radial growth as a result of amalgamation of developed urban centres in the peripheries. The degree and extent of darkness in color indicated that population concentration is higher in these pixel and reduce its value as we go out from the city, Delhi is growing rapidly as in recent past it is showing an exponential growth pattern in last two decades population of Delhi is increased from 6 to 18 million and now it ranks first in terms of population, whereas Mumbai, Chennai and Calcutta are showing stagnant growth.

Maps represent Population distribution among the mega cities of India, as well as the build-up area (Blue color boundary), which spreads outside the administrative boundaries (Black color) of city. The true city region is extended within the administrative boundaries it is the High, Medium and Low class residences which are acquiring the space in the outskirts. About 2-3 km area from centre of city area is pile up with the huge population about an average of

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[6] United Nations, World Urbanization Prospects: The 2005 Revision, United Nations Publications, New York, 2005

40000 persons per sq. km. After that as we move outward it reduces rapidly upto few kms and then with slow pace.

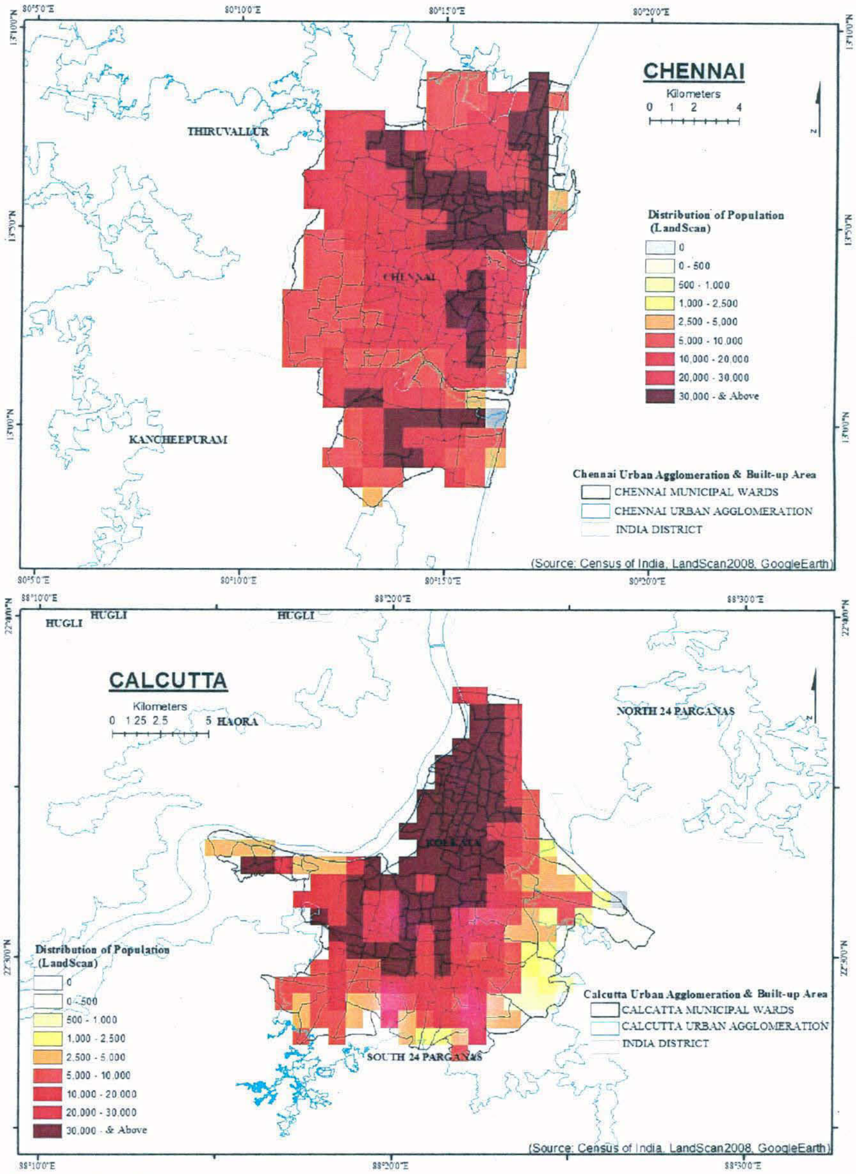


Figure No.24:

1) Evaluation of Chennai urban agglomeration and LandScan population estimates
2) Evaluation of Calcutta urban agglomeration and LandScan population estimates

Cities are showing a common pattern that all of them are situated around water bodies for both the purpose of their livelihood as well as commerce. All four cities are showing that the highest concentration of population in around their water resource areas and show decline in population density as we move outward. Mumbai is the city which is showing vertical expansion more than the horizontal, whereas there is an opposite trend in Delhi, Calcutta and Chennai. In Indian cities Delhi and Mumbai are the only cities which are specialised in high rise buildings. In this vertically expanding space population density is very high. For these kinds of cities this type of land-use pattern is ideal.

Due to different urban orographic conditions in combination with socio-economic and political impacts Indian mega cities do not converge toward a standard form. The spatiotemporal patterns of current Indian mega cities growth are reflected in decreasing redensification processes and a saturation effect for built-up densities around 80 % in the centres. It becomes apparent that the decreasing built-up density gradient from centre to urban fringes comes along with increasing urbanization rates or relocation of urbanization to satellite cities. Independent from the cities footprint, explosive urban growth increases the spatial complexity.

Urban growth in India may take various spatial forms, however, many parameters in Mumbai, Delhi, Chennai and Calcutta showed similar results. Especially Mumbai and Calcutta emerged as a very similar growth type, with similar areal growth, corresponding in the spatiotemporal urbanization and built-up density gradients, identical spatial complexity as well as the ratio of the urban core to dispersed patches. Both cities only differ in the patch density, showing highly dispersed growth in Calcutta compared to Mumbai. Delhi differs through an enormous areal growth, a coalesced urban centre, with laminar growth resulting in a dominant urban core. Still, built-up density gradients and urbanization gradients correspond to Mumbai and Calcutta, as well as the increasing complexity.

### 4.3 Change detection using remote sensing data:

A land cover classification extracting the classes' built-up areas, bare soil, vegetation, and water was performed separately on all images. The main goal is to identify the ***urban built-up areas*** to measure the changes of the urban extension over the time interval. For that purpose the classification methodology is based on an object-oriented hierarchical approach. The object oriented methodology was used to combine spectral features with shape, neighbourhood and texture features.

This study encompasses the quantitative analysis of land and land cover change in The National Capital Territory of Delhi, using remote sensing technologies. Landsat MSS satellite images for year 1977 and Landsat ETM+ for years 2000 have been utilised to quantify the changes from 1977 to 2006. The satellite images have been pre-processed using calibration techniques and by performing geometric and atmospheric corrections. Supervised

Classification methodology has been employed using Maximum Likelihood technique to categorise the images into four classes, namely: Built Structures, Vegetation, Water bodies and Barren Land to analyse land use and land cover change. It was observed that as a result of rapid urbanisation, the built-structures augmented from 25.67% in 1989 to 27.14% in 2000 and drastically to 42.55% in 2006. Due to seasonal variations, the vegetation cover and water bodies exhibited seasonal variations; the barren land has depicted a decline from 1989 to 2000 and 2000 to 2006.

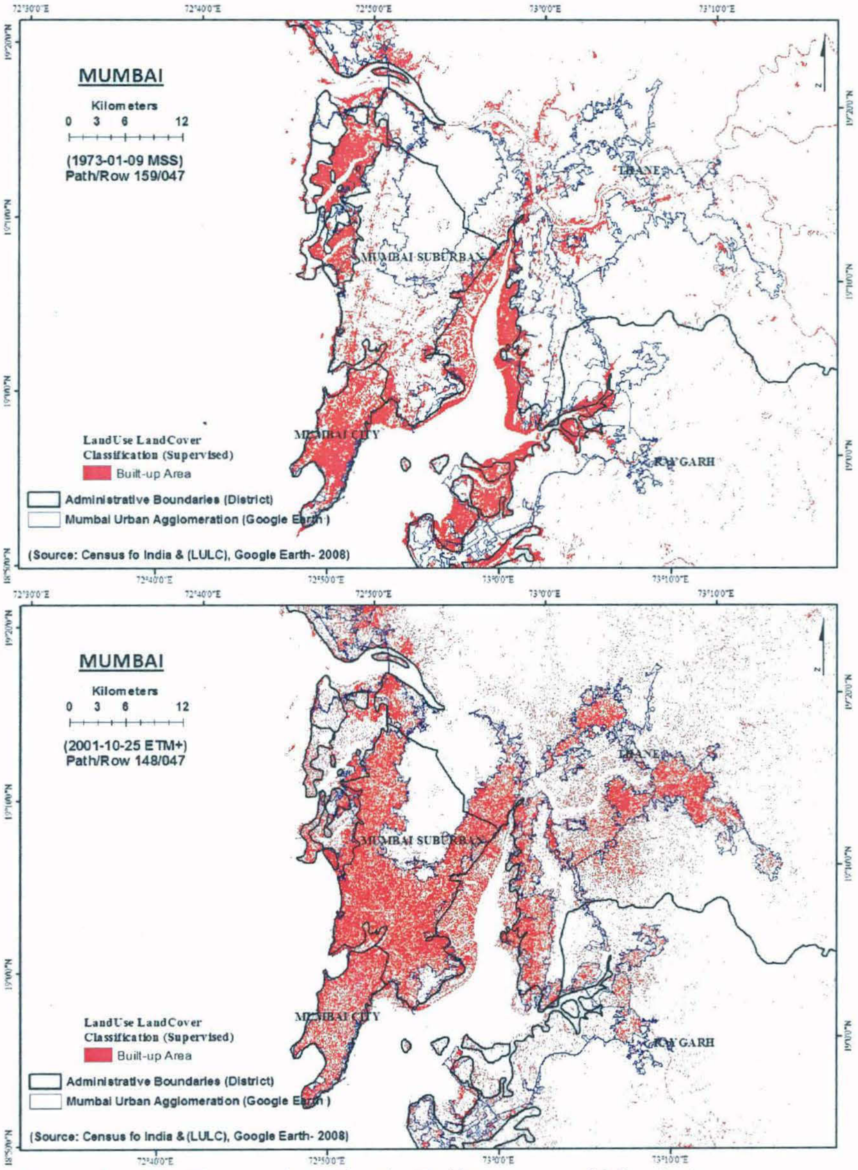


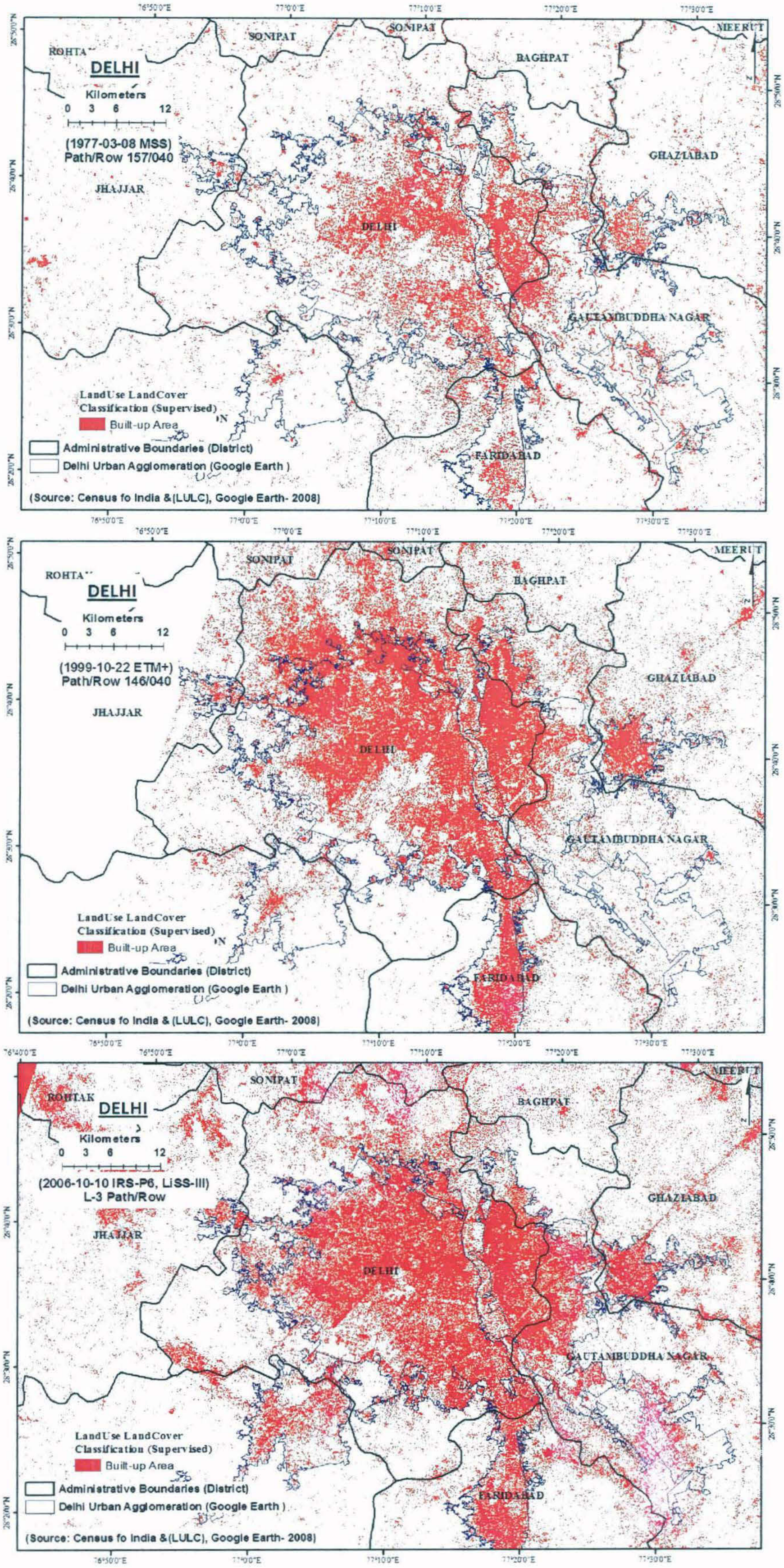
Figure No.25: Change detection in Built-up area of Mumbai

1) Mumbai MSS (1973)
2) Mumbai ETM+ (2001)

The Change Detection statistics obtained in Tables show evidence that urban development is expanding as Built Structures is having a consistent gain in (1989-2000) and (2000-2006) therefore there is a positive change for the Built Structures. Vegetation and Water bodies are showing gain and loss as a result of seasonal variations and therefore depicting a positive change in (1989-2000) and negative change in (2000-2006) statistics. The Barren Land is showing a negative change for both comparisons, which could be explained as its loss as a result of urban expansion and development. Accuracy assessment of the land use and land cover classification results obtained by computing "Confusion Matrix" in Envi 4.5 software for classification showed an overall accuracy of 80.08% for 1989, 82.54% for 2000 and 82.61% for 2006. The Kappa Coefficients for 1989, 2000 and 2006 are 0.86, 0.88 and 0.84 respectively.

Satellite Remote Sensing has proved to be a vital tool for continuous observation and quantification of environmental phenomena across varied spatial and temporal scales which are otherwise not possible to attempt through conventional mapping techniques. The multi-temporal Landsat TM and ETM+ data have provided useful analysis for the land use and land cover change in Delhi from 1973 to 2006 for a span of 33 years. It was observed that as a result of rapid urbanisation, the built-structures augmented from 1973 to 2000 and drastically to in 2006. Supervised classification technique of the images has been successful to study the change detection of land use and land cover in the region, this method provides a suitable technique to identify development of urban zones which lead to transformation in the land use and land cover configuration that consequently impacts the landscape environment. Thus, the changes quantified using remote sensing technologies provide observations which may show critical adverse and undesirable environmental impacts, hence requiring crucial sustainable land management policies and practices to avoid the endangering of the environment and sustainable development.

The city was inhabited from 1200 BC lived In the city on the Yamuna River in the 1980s, around five million people In 2000, the population of Delhi as compared to the 1980s, has doubled to around ten million now 2006, the population of the city at around 11.5 million In the metropolitan region of Delhi, however, more than 18 million people.



(Source: Census fo India &(LULC), Google Earth- 2008)

Figure No.26: Change detection in Built-up area of Delhi

1) Delhi MSS (1977)
2) Delhi ETM+ (2001)
3) Delhi IRS P6 LISS-3 (2006)

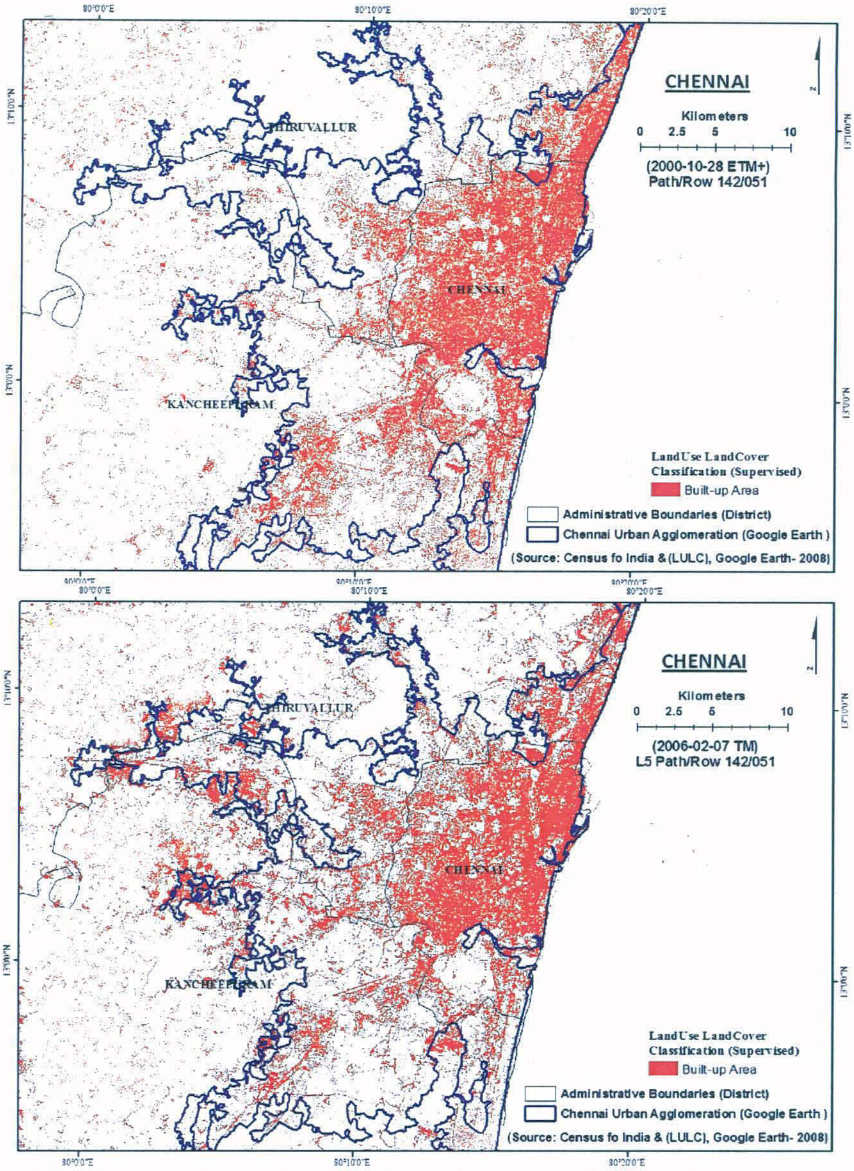


Figure No.27: Change detection in Built-up area of Chennai

1) Chennai ETM+ (2000)
2) Chennai TM (2006)

Due to a large amount of mixed spectral information in such a coarse ground resolution the accuracy is limited. But for the requirement of mapping the city footprint, its spatial dimension and the spatial developments over the years, the Landsat images provide enough information for an assessment of urban change.[7] Post classification comparison was found to be the most accurate procedure and presented the advantage of indicating the nature of the changes. A comparative analysis of land cover classifications for the available times performed independently was therefore implemented to monitor and analyse the land cover

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[7] Mas, J.-F. (1999): Monitoring land-cover changes: a comparison of change detection techniques. International Journal of Remote Sensing, vol. 20, No. 1, pp. 139-152.

changes in the metropolitan areas of Mumbai, Delhi, Chennai and Calcutta. Pixel wise change detection was implemented checking the land cover classes individually of the available years. Figure shows the result of the change detection for all four Indian mega cities, displaying the urban footprints and their spatiotemporal evolution since the 1970s.[8]

Delhi has witnessed a recent spurt in urbanization. The depletion in the forest and natural vegetation cover has reduced water availability in the river Yamuna. The present study quantifies these changes. Satellite data from Landsat MSS, ETM+ and Indian Remote Sensing Satellite (IRS-p6) from 1987 to 1992 have been combined with rainfall data and ground truth to assess both the spatial and the temporal degradation in the region. The total Delhi area has been subdivided into four equal regions and each of these have been analyzed separately. Further, the Delhi city region has been subdivided and analyzed for quantifying the spatial changes. A rainfall ratio has been introduced to account for normalising the rainfall occurring in each year. This ratio has been used to estimate the vegetation cover and

the water availability in the river under the same normal rainfall conditions in each of the years under consideration. Results indicate that the forest cover is constantly declining with the most severe depletion occurring in northeast Delhi. However, due to increase in rains over the past few years, the forest and the vegetation covers in 1992 have increased in some parts of south Delhi.

The result of the change detection shows three very different urban footprints of the Indian mega cities. While the urban footprint of Mumbai and Chennai is determined by the coastal and hilly orographic, the urban footprints of Delhi and Calcutta are not subject to orographic restrictions.

The peninsula of Mumbai forces the urbanized areas on available land, with an axial growth in the outskirts caused by transportation networks and hilly barriers. The polycentric structure and development of satellite cities in the 1970s steadily increased due to land shortage in the urban centre and dramatic population pressure. The result is a complex urban footprint, spatially polycentric with axial growth lines, a large urban core and a dispersed urban-rural fringe. The urban footprint of Delhi, only slightly influenced by orography, results in a

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[8] Taubenböck, H., Pengler, I., Schwaiger, B., Cypra, S., Hiete, M., Roth, A (2007): A multi-scale urban analysis of the Hyderabad Metropolitan area using remote sensing and GIS. In: Urban Remote Sensing Joint Event, Paris, France. p.6.

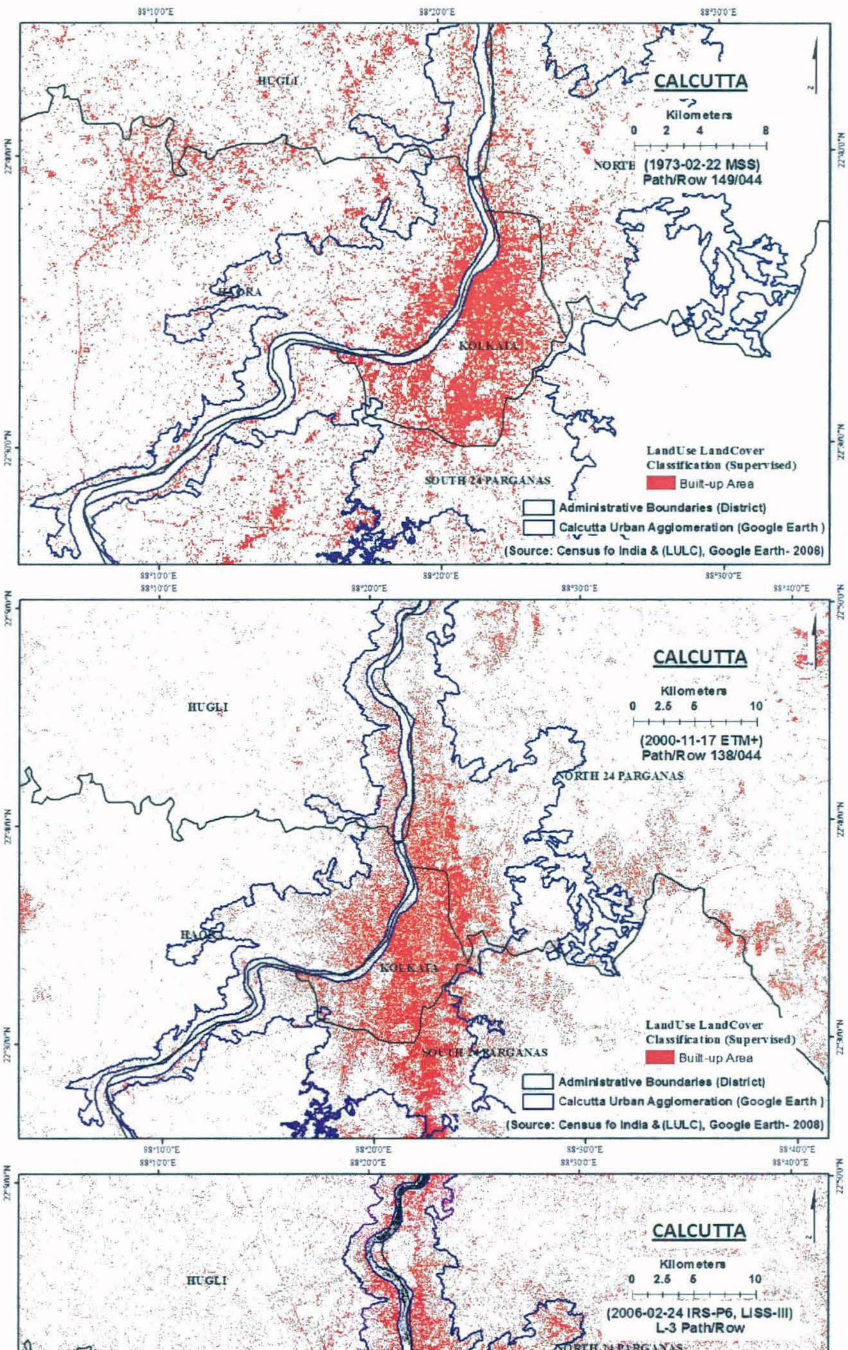

*Figure No.28: Change detection in Built-up area of Calcutta*

1) *Calcutta MSS (1973)*
2) *Calcutta ETM+ (2000)*
3) *Calcutta IRS P6 LISS3 (2006)*

classic concentric urban ring-shaped growth with axial growth sectors caused by transportation networks. The polycentric structure of the 1970's shows coalescence between the satellite cities and the urban core today. Growth is predominantly laminar and clustered, with dispersion solely in the peripheral catchment area of Delhi. Calcutta shows an oval urban footprint along the Hooghly River not influenced by orographic barriers. The monocentric spatial structure shows oval-shaped and laminar growth with little dispersion.

## 4.4 Conclusion:

Satellite Remote Sensing has proved to be vital information for continuous observation and quantification of environmental phenomena across varied spatial and temporal scales which are otherwise not possible to attempt through conventional mapping techniques. The multitemporal Landsat MSS, TM, ETM+ and IRS LISS -3data have provided useful analysis for the land use and land cover change in Mega Cities from 1971 to 2006 for a span of 17 years. It was observed that as a result of rapid urbanisation, the built-structures augmented from 25.67% in 1989 to 27.14% in 2000 and drastically to 42.55% in 2006. Supervised classification technique of the images has been successful to study the change detection of land use and land cover in the region, this method provides a suitable technique to identify development of urban zones which lead to transformation in the land use and land cover configuration that consequently impacts the landscape environment. Continuous spread in built up is observed by using Remote Sensing datasets of various years and thus it evident that urban agglomeration is not restricted with administrative limits.

India Megacities are master in terms of variation not only in demographic terms also in spatial agglomeration growth. In terms of area Delhi is the largest city followed by Mumbai Calcutta and Chennai. LandScan pixel sizes represent it clearly. Urban extent and variability in terms of density and population is quite evident in Delhi, where inner part of city represents a percentage difference of 9 percent but cities like Mumbai and Calcutta reflects topographic effect, which is quite clear from LandScan datasets.

Mapping and monitoring of these changes is scale-dependent. But such monitoring datasets at the national level are important to provide a level of stratification of the area for detailed analysis of urban footprints and identification of linkage with other ancillary and legacy datasets. Megacities are places where many factors converge to create fertile grounds for risk emergence.

*Chapter No - 5*

# NATURAL HAZARD RISK MANAGEMENT:

## Floods and Coastal /Sea Level Change in India

### 5.1 Introduction:

The Natural Hazards are "those elements of the physical environment, harmful to man and caused by forces extraneous to him"[1]. More specifically, in this document, the term "natural hazard" refers to all atmospheric, hydrologic, geologic (especially seismic and volcanic), and wildfire phenomena that, because of their location, severity, and frequency, have the potential to affect humans, their structures, or their activities adversely. The qualifier "natural" eliminates such exclusively manmade phenomena as war, pollution, and chemical contamination. Hazards to human beings not necessarily related to the physical environment, such as infectious disease, are also excluded from consideration here. Figure 1-1 presents a simplified list of natural hazards, and the boxes on the following pages briefly summarize the nature of geologic hazards, flooding, tsunamis, hurricanes, and hazards in arid and semi-arid areas.

"Natural," a natural hazard has an element of human association. A physical event, such as a Flooding, that does not affect human beings is a natural phenomenon but not a natural hazard. A natural phenomenon that occurs in a populated area is a hazardous event. A hazardous event that causes unacceptably large numbers of fatalities and vast property damage is a natural disaster. In areas where there are no human interests, natural phenomena do not constitute hazards nor do they result in disasters. This definition is thus at probability with the perception of natural hazards as unavoidable disorder causes by the unrestrained forces of nature. It shifts the burden of cause from purely natural processes to the concurrent presence of human activities and natural events[2].

Although humans can do little or nothing to change the incidence or intensity of most natural phenomena, they have an important role to play in ensuring that natural events are not converted into disasters by their own actions. It is important to understand that human intervention can increase the frequency and severity of natural hazards. For example, when the toe of a landslide is removed to make room for a settlement, the earth can move again and bury the settlement. Human intervention may also cause natural hazards where none existed before. Volcanoes erupt periodically, but it is not until the rich soils formed on their eject are

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[1] Burton, I., Kates, R.W., and White, G.F. The Environment as Hazard (New York: Oxford University Press, 1978).

[2] Hays, W.W. (ed.) Facing Geologic and Hydrologic Hazards. Earth-Science Considerations, Professional Paper 1240-B (Reston, Virginia: U.S. Geological Survey, 1981).

occupied by farms and human settlements that they are considered hazardous. Finally, human intervention reduces the mitigating effect of natural ecosystems. Destruction of coral reefs, which removes the shore's first line of defence against ocean currents and storm surges, is a clear example of an intervention that diminishes the ability of an ecosystem to protect itself. An extreme case of destructive human intervention into an ecosystem is desertification, which, by its very definition, is a human-induced "natural" hazard.

The planning process in development areas does not usually include measures to reduce hazards, and as a consequence, natural disasters cause needless human suffering and economic losses. From the early stages, planners should assess natural hazards as they prepare investment projects and should promote ways of avoiding or mitigating damage caused by floods, earthquakes, volcanic eruptions, and other natural catastrophic events. Adequate planning can minimize damage from these events. It is hoped that familiarizing planners with an approach for incorporating natural hazard management into development planning can improve the planning process in Latin America and the Caribbean and thereby reduce the impact of natural hazards.

### 5.2 Floods in India:

Flooding is the only major natural hazard in India that occurs with an unfailing regularity. Some of the most unusual and unprecedented floods have been recorded on different rivers of the subcontinent in the most recent decades[3]. The 1986 flood on the Godavari River, with a peak discharge of about 99,300 $m^3/s$ (Indian Academy of Sciences Earth and Planetary Science,2001), is the largest flood on record in the entire Indian subcontinent till date. The recent literature on monsoon floods is dominated by firstly on the spatiotemporal aspects of floods, secondly research focused on the impact of monsoon floods on the fluvial systems and finally remote sensing and GIS-based research that has gained considerable momentum in the last few years. A few studies on the flood processes and the impact of climate change have also been undertaken.

Two types of flooding can be distinguished: first, land-borne floods, or river flooding, caused by excessive run-off brought on by heavy rains, and Secondly, sea-borne floods, or coastal flooding, caused by storm surges, often exacerbated by storm run-off from the upper

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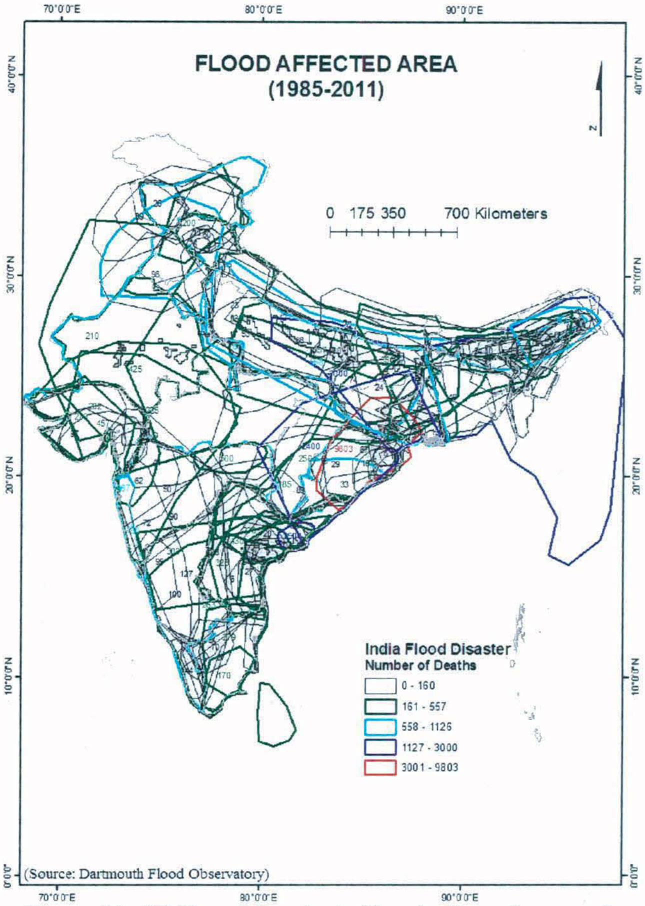
[3] Kale, V.S., (2003), The spatio-temporal aspects of monsoon floods in India: Implications for flood hazard management, *in* Gupta, H. K., ed., Disaster Management: Universities Press, Hyderabad, p. 22-47.

watershed. Tsunamis are a special type of sea-borne flood. Both the floods are important from the point of view of our study. Land borne or river borne flood to study the impact of flooding in inner parts of country and its effect on large cities and Sea borne floods fulfils our next desire of change in sea level and coastal dynamics in India. Based on the given map we can conclude that the eastern region of India experiences saviour flooding. Almost every type of flood occurs in this region. Orissa, Chhattisgarh, West Bengal is the most flood prone region followed by North-eastern states and Bihar, Jharkhand Region.

### 5.2.1 River flooding

Land-borne floods occur when the capacity of stream channels to conduct wafer is exceeded and water overflows banks. Floods are natural phenomena, and may be expected to occur at irregular intervals on all stream and rivers. Settlement of floodplain areas is a major cause of flood damage.

River floods are triggered by heavy rainfall or snow melt in upstream areas, or tidal influence from the downstream. Ground conditions such as soil, vegetation cover, and land use have a direct bearing on the amount of runoff generated. River floods occur when the river run-off volume exceeds local flow capacities. The river levels rise slowly and the period of rise and fall is particularly long, lasting a few weeks or even months, particularly in areas with flat slopes and deltaic areas. Failure or bad operation of drainage or flood control works upstream can also sometimes lead to riverine flooding.



(Source: Dartmouth Flood Observatory)

Figure No.29:No. of Deaths in Flood affected areas of India (1985-2011)

Urban areas situated on the low-lying areas in the middle or lower reaches of rivers are particularly exposed to extensive riverine floods. In most major river basins, flood plains are subjected to annual flooding. Often, urban growth expands over some of the floodplains, reducing the area into which floods can naturally overflow. Where parts of the city are below flood level and are protected by artificial levees, there is risk that they may be breached and cause devastating urban flooding.

When towns and cities get flooded by major rivers overtopping their banks flood protection has to be seen in the context of the entire river basin, which may fall in more than one administrative jurisdiction. Where a river basin lies within a single nation state, integrated river basin management principles should be applied by an agency cutting across ministries concerned with both rural and urban interests to ensure that activities in upstream areas do not worsen the flood situation for towns and cities downstream. For large, international rivers, river basin commissions are required to manage the water resources and floods in the entire basin for the benefit of all communities in the different nations sharing the basin.[4]

### 5.2.2 Coastal flooding

Storm surges are an abnormal rise in sea water level associated with cyclone and other storms at sea. Surges result from strong on-shore winds and/or intense low pressure cells and ocean storms. Water level is controlled by wind, atmospheric pressure, existing astronomical tide, waves and swell, local coastal topography and bathymetry, and the storm's proximity to the coast. Most often, destruction by storm surge is attributable to: Wave impact and the physical shock on objects associated with the passing of the wave front. Hydrostatic/dynamic forces and the effects of water lifting and carrying objects. The most significant damage often results from the direct Impact of waves on fixed structures. Indirect impacts include flooding and undermining of major infrastructure such as highways and railroads. Hooding of deltas and other low-lying coastal areas is exacerbated by the influence of tidal action, storm waves, and frequent channel shifts.

High tides and storm surges caused by tropical depressions and cyclones can cause coastal floods in urban areas located at estuaries, tidal flats and low-lying land near the sea in general. Coastline configurations, offshore water depth and estuary shape can influence the intensity of coastal floods. Moreover, high tides may impede the discharge of rivers and drainage systems, leading to local or riverine floods. Tidal effects in the estuarine reaches can keep the river levels high for long periods of time and sustain flooding. Thus the cities

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[4] Nageswara Rao, G., 2001, Occurrence of heavy rainfall around the confluence line in monsoon disturbances and its importance in causing floods: Proceedings of Indian Academy of Sciences Earth and Planetary Science, v. 110, p. 87-94.

located in estuarine reaches have to bear the combined impacts of riverine as well as coastal floods due to storm surges and tidal effects. Coastal areas are exposed to sea erosion, which is particularly likely with the increase in the sea roughness due to climate change. Tsunamis, mainly triggered by powerful offshore earthquakes, can also cause coastal floods though infrequently.

Local drainage capacity is primarily made up of a local storm water drainage system composed of storm drainpipes, curb inlets, manholes, minor channels, roadside ditches and culverts. This system is intended to convey storm flows efficiently to the community's primary drainage system, such as the main river channel or the nearest large body of water.

### 5.2.3 Spatio-Temporal Distribution of Flood in India:

Floods will continue to havoc disaster in India unless ecological measures to manage them are not taken up on a long-term basis. Every year, from the month of June to September, India receives 75 per cent of the total annual rainfall. Hence it is not unusual to see floods causes' trouble in many parts of the country. Millions of hectares of area get affected by it. India remains perpetually vulnerable to floods as every year, 5 to 6 tropical cyclones occur in the Bay of Bengal and other natural disasters like landslides and earthquake also occour on a regular basis. Every year, millions of people get displaced from their homes and huge damage is caused to crops and other assets. Despite National Flood Control Programme being launched in India in 1954, India has still not managed to evolve a decent flood management system.

Several traditional measures to control floods have been tried so far like building embankments to control the flow of river and constructing reservoirs to ensure release of water at a controlled rate. However experience has shown that these structural measures to control floods are negated by large scale deforestation that has taken place over the years in several parts of the country. Advancement in construction technology has also has had a negative impact on flood control as large scale construction activities have started to take place on the flood plains. Economic factors become more important and those who support the construction activity on the flood plain turn a blind eye to the disastrous impact it can have on the environment.

It has also been argued by some environmentalists that in order to control floods, the level of water in the reservoir of the dam should be kept at minimum level. However in order to generate hydro-electricity and bring more agricultural area under irrigation, the level of the water in the reservoir is kept high which leads to flooding in the upstream areas. Thus the measure that is often touted as a solution to the flood woes itself becomes a cause of it[5]. Hence it is high time for the government to look for ecological measures that can help in the management of floods on a durable, long-term basis. Afforestation of the flood plains must be encouraged as trees not only absorb rainfall water but also obstruct its flow to the rivers. Construction activities on the flood plains should be stopped altogether.

***Temporal Distribution of Flood in India:*** Heavy rain, Tropical cyclone, Monsoonal rain, Torrential Rain, Extra-tropical cyclone, Dam/Levy, break or release during high flood period in the country regular annual features. Over bank flood due to breaches in the embankment render the fertile cultivable land unsuitable for crop production due to deposition of coarse sand on the surface to a variable depth.

***Table No.11: Flood Damages in India 1985-2011***

| *Year* | *Area (Flood affected)* | *Deaths* | *Displacement* | *Main Cause* |
|---|---|---|---|---|
| *1985* | 508429.08 | 1041 | 347000 | 1,2 |
| *1986* | 846039.05 | 457 | 6740000 | 1,3 |
| *1988* | 2027755.64 | 2120 | 3820000 | 1,3 |
| *1989* | 1223004.98 | 818 | 32000 | 1,3 |
| *1990* | 2090376.25 | 1014 | 539517 | 1,2,3,4 |
| *1991* | 2182229.52 | 824 | 3243000 | 1,2,3 |
| *1992* | 1895359.31 | 409 | 30000 | 1,2,3 |
| *1994* | 2761523.39 | 1066 | 819000 | 1,2,3 |
| *1995* | 123053.83 | 57 | 1003200 | 1,2,3 |
| *1996* | 499878.76 | 2982 | 7240000 | 1,2,3 |
| *1997* | 1480001.46 | 808 | 150000 | 2,3 |
| *1998* | 413679.15 | 1368 | 145000 | 1,5,6 |
| *1999* | 360905.87 | 9848 | 10000000 | 2,4 |
| *2003* | 169112.09 | 77 | 3014000 | 3 |
| *2004* | 1971716.98 | 3465 | 40201000 | 1,3 |
| *2005* | 2542256.61 | 1872 | 8148857 | 1,3 |
| *2006* | 3326334.84 | 1360 | 3087200 | 1,3 |
| *2007* | 2583028.52 | 1876 | 15195000 | 1,3 |
| *2008* | 1537342.64 | 3903 | 1305000 | 1,3,6 |
| *2009* | 712752.23 | 387 | 1840000 | 1,3,4,6 |
| *2010* | 749202.27 | 534 | 723980 | 1,3,4 |
| *2011(June*)* | 62047.17 | 9 | 500 | 3,4 |

*(Main Cause: Heavy rain=1, Tropical cyclone=2, Monsoonal rain=3, Torrential Rain=4, Extra-tropical cyclone=5, Dam/Levy, break or release=6*

*(Source: (Compile):Dartmouth Flood Observatory, www.dartmouth.edu/~floods ©2008 Dartmouth Flood Observatory)*

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[5] Government of India Ministry of Home Affairs; (2004); DISASTER MANAGEMENT IN INDIA; National Disaster Management Division/MHA/GOI/28/06/2004

Floods have been a regular feature during the period 1985 to 2011. Although all data are not available for the period, the following data that could be collected during the study period helps us appreciate the intensity of the damages caused by floods during these 25 years. Also when look on the main cause of flood annually earlier the main cause behind floods are Heavy rain, Tropical cyclone, Monsoonal rain up till 2004 after that causes for floods replaced by Torrential Rain, Dam/Levy, break or release.

Over the years 1985-1995, the loss of lives and displacement of people on an average was less than 4000 and 50 lakh per annum respectively which is very less as compare to coming years. The year 1995, 2003 was relatively flood free.

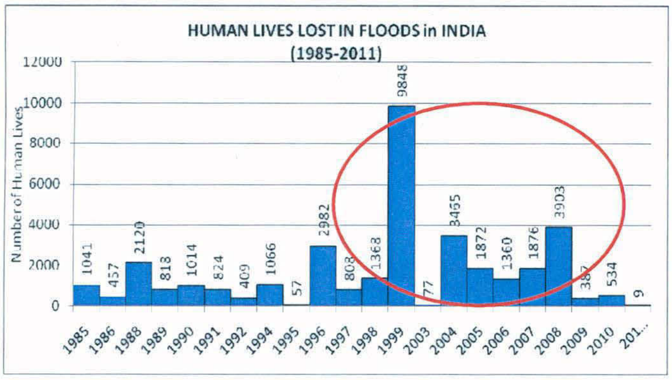

Figure No.30: Number of Deaths due to flood (1985-2011)

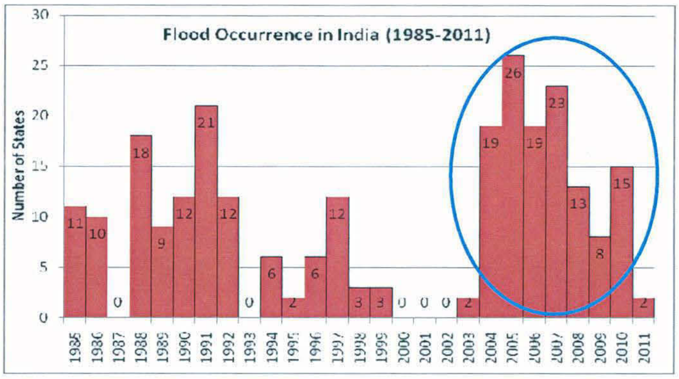

Figure No.31: State-wise flood occurrence in India (1985-2011)

During 1996-2008, it was as high of the total flood damages. Devastating floods occurred during 1999, 2004 & 2008. During 2004-2008, five successive waves of flood occurred. Analysis of data on the extent of area affected by flood further reveals (1985-2011) the severity of flood after the 1996.

In India, flood diversion areas are rural areas that are deliberately flooded in emergencies in order to protect cities. Earlier numbers of these types of regions are less as compare to now a day's situation. Flood affected states in the country is increasing rapidly where there were only 2-10 flood affected states in 1985-2000. Showing a totally different situation number of flood affected states reaches a level of 26 out of 35 states and range of there occurrence reaches upto 13 -26 which is very high. The number of deaths and displacement due to flood also supports the statement. Unlike all the situation of area under flood shows a totally different scenario where as the loss of Lives, displacement shows an increasing trend. Area under flood remains constant. Therefore which show that the flood area is not expanding we are acquiring the river space and then affect us adversely.

*Frequency distribution of Flood Occurrence in INDIA (1985 - 2011)*

| State / Year | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Flood Occurrence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Jammu & Kashmir* | 1 | | | 1 | | 1 | | | | | | | 1 | | | | | | | | | 1 | 1 | | | 1 | | **7** |
| *Himachal Pradesh* | 1 | | | 1 | | 1 | 1 | | | 1 | | | 1 | | | | | | | | 1 | | 1 | | | 1 | | **9** |
| *Punjab* | 1 | | | 1 | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | | | 1 | | **7** |
| *Chandigarh* | 1 | | | 1 | | | | | | | | | | | | | | | | 1 | 1 | | 1 | | | 1 | | **6** |
| *Uttarakhand* | | | | | | 1 | 1 | | | | | | | | | | | | | | 1 | 1 | | | | 1 | | **5** |
| *Haryana* | | | | 1 | | | 1 | | | | | | | | | | | | | 1 | 1 | | 1 | | | 1 | | **6** |
| *Delhi* | | | | 1 | | | 1 | | | | | | | | | | | | | | 1 | | 1 | | | 1 | | **5** |
| *Rajasthan* | | | | 1 | | 1 | 1 | | | | | | | | | | | | | 1 | | 1 | 1 | | | 1 | | **7** |
| *Uttar Pradesh* | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | | 1 | | | | | | | | | | 1 | 1 | 1 | 1 | | 1 | 1 | | **14** |
| *Bihar* | 1 | 1 | | 1 | | 1 | 1 | | | | | 1 | 1 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | **14** |
| *Sikkim* | | | | | | | | | | | | | | | | | | | | | 1 | | | 1 | | | | **2** |
| *Arunachal Pradesh* | | | | | | | | | | | | 1 | | | | | | | | 1 | 1 | | | 1 | | | | **4** |
| *Nagaland* | | | | | | | | | | | | | | | | | | | | 1 | 1 | | | 1 | | | | **3** |
| *Manipur* | | | | | 1 | | | | | | | | | | | | | | | 1 | 1 | | 1 | | | | | **4** |
| *Mizoram* | | | | | 1 | | | | | | 1 | | | | | | | | | 1 | | | | | | | | **3** |
| *Tripura* | | 1 | | | | | 1 | | | | | | | | | | | | | 1 | 1 | 1 | | 1 | | | | **6** |
| *Meghalaya* | | 1 | | 1 | | 1 | | | | | | | | | | | | | | 1 | 1 | 1 | | 1 | | | | **7** |
| *Assam* | | | | 1 | 1 | 1 | 1 | 1 | | | 1 | 1 | 1 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | **15** |
| *West Bengal* | | 1 | | 1 | | 1 | 1 | | | | | 1 | 1 | | 1 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | **13** |
| *Jharkhand* | | 1 | | 1 | | | 1 | | | | | 1 | 1 | | 1 | | | | | 1 | 1 | 1 | 1 | 1 | | 1 | | **12** |
| *Orissa* | 1 | 1 | | 1 | 1 | | 1 | 1 | | 1 | | | | | 1 | | | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | **15** |
| *Chhatisgarh* | | 1 | | 1 | | | 1 | 1 | | | | | | | | | | | | | 1 | 1 | 1 | 1 | | | 1 | **9** |
| *Madhya Pradesh* | | 1 | | | | | 1 | 1 | | | | | | | | | | | | | 1 | 1 | 1 | | | | | **6** |
| *Gujarat* | | | | 1 | | 1 | 1 | 1 | | | | | 1 | 1 | | | | | 1 | 1 | 1 | 1 | 1 | | | | | **11** |
| *Maharashtra* | 1 | | | 1 | 1 | | 1 | 1 | | 1 | | | 1 | 1 | | | | | | 1 | 1 | 1 | 1 | | | | | **12** |
| *Andhra Pradesh* | | 1 | | 1 | 1 | 1 | 1 | 1 | | 1 | | 1 | 1 | 1 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | **16** |
| *Karnataka* | 1 | | | | 1 | | 1 | 1 | | | | | 1 | | | | | | | | 1 | | 1 | | 1 | | | **8** |
| *Goa* | 1 | | | | | | 1 | 1 | | | | | | | | | | | | | 1 | 1 | 1 | | 1 | | | **7** |
| *Kerala* | 1 | | | | 1 | | 1 | 1 | | | | | 1 | | | | | | | 1 | | 1 | 1 | | | | 1 | **9** |
| *Tamil Nadu* | | | | | | 1 | 1 | 1 | | 1 | | | 1 | | | | | | | | 1 | | 1 | 1 | 1 | 1 | | **10** |
| **Total** | **11** | **10** | **0** | **18** | **9** | **12** | **21** | **12** | **0** | **6** | **2** | **6** | **12** | **3** | **3** | **0** | **0** | **0** | **2** | **19** | **26** | **19** | **23** | **13** | **8** | **15** | **2** | **252** |

(Source: (Compile):Dartmouth Flood Observatory, www.dartmouth.edu/~floods ©2008 Dartmouth Flood Observatory)

***Spatial Distribution of Flood in India:*** When we talk of flood in India too has been suffering heavily due to flood. Though, Government of India (GOI) has been spending large amount of money on flood control, its main focus is on irrigation. GOI has launched 'National Flood Control Programme' in 1954 and set up the "Rashtriya Barh Ayog" (RBA), "National Flood Commission", in 1976 to evolve a coordinated, integrated and scientific approach to the flood control problems in the country and to draw out a national plan fixing priorities for implementation in the future. The RBA in its report in 1980 identified flood prone districts in India including Surat in the state of Gujarat. It is interesting to note that some of the districts of Gujarat are also drought prone covered under Drought Prone Area Program. Despite these efforts, India is still repeatedly witnessing massive flood such as one seen in Surat in 2006.[6]

***Table No.13: Flood Affected Area & Annual Flood Damages in India(1953-2004)***

| *Item* | *Unit* | *Average Annual Flood Damage During* |
|---|---|---:|
| Area Affected | Million Hectare | 7.63 |
| Population Affected | Million | 32.92 |
| Human Lives Lost | Nos. | 1590 |
| Cattle Lost | Nos. | 94485 |
| Cropped Area Affected | Million Hectare | 3.56 |
| Value of Damage to Crops | ` Crores | 705.87 |
| Houses Damaged | Million | 1.23 |
| Value of Damage to Houses | ` Crores | 269.7 |
| Value of Damage to Public Utilities | `Crores | 806.78 |
| Value of total Damage to Houses, Crops and Public Utilities | ` Crores | 1805.18 |

*Source: Central Water Commission*

Flood is a perpetual natural hazard in the flood plains of monsoon Asia, where over 80% of annual precipitation is received in the four wet months from June to September. The problem of river flooding is of great concern in the India. One of the most devastating of its kind was experienced in September –October 2000. When look on the main cause of flood annually earlier the main cause behind floods are Heavy rain, Tropical cyclone, Monsoonal rain up till 2004 after that causes for floods replaced by Torrential Rain, Dam/Levy, break or release. Further as we spatial trend distribution of flood in India show, in last 25 years each every state of country experienced flood. Flood occurrence in India at the state level divide country into zones:

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[6] Sanyal, J. and Lu, X. X., 2003, Application of GIS in flood hazard mapping: A case study of Gangetic West Bengal, India: GIS Development, International Journal of Remote Sensing, v. 26, p. 4445 – 4454.

*Zone 1*- Very High Flood Occurrence (15 & Above flood years): Andhra Pradesh, Orissa, and Assam; *Zone 2*- High Flood Occurrence (10-15 flood years): Bihar, Uttar Pradesh, West Bengal, Jharkhand, Maharashtra, Gujarat, and Tamil Nadu; *Zone 3*- Medium Flood Occurrence (5-10 flood years): Chhattisgarh, Kerala, Himachal Pradesh, Karnataka, goa, Meghalaya, Rajasthan, Punjab, Jammu & Kashmir, Haryana, Tripura and Madhya Pradesh; *Zone 4*- Low Flood Occurrence (1-5 flood years): Delhi, Chandigarh, Arunachal Pradesh, Manipur, Mizoram, Nagaland, and Sikkim.

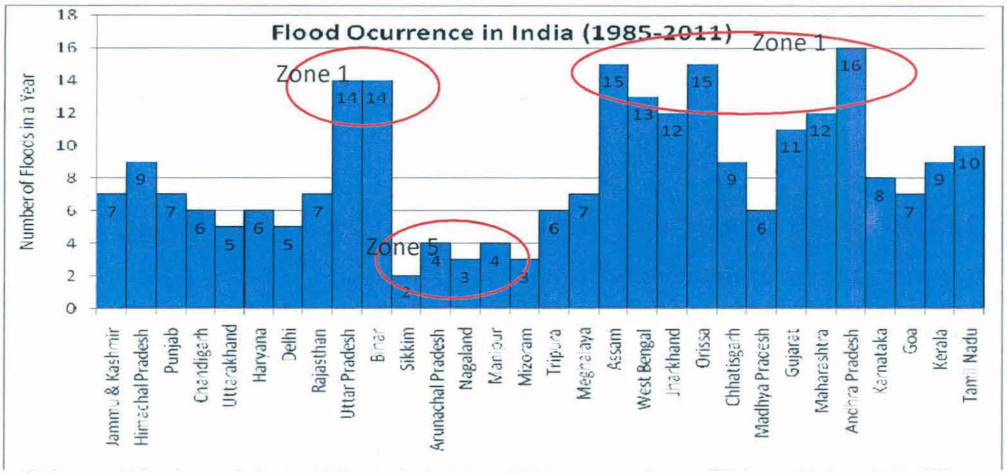

Figure No.32: Number of Flood incident in a state in last 25 years (1985-2011)

Andhra Pradesh, Orissa, Bihar, Uttar Pradesh, these four states are fall in zone 1 which is experiencing very high flood activity these states are showing a common link they are situated on the eastern region of India where there is NW Monsoon winds are very strong as well as tropical cyclones are also a common phenomenon in this region. Assam is a state which also falls in zone 1 but the conditions are very different here flood is the function of Monsoonal Winds as well as Topography, High altitude and large river.

Unlike zone 1 there is a totally different situation in Arunachal Pradesh, Manipur, Mizoram, Nagaland, and Sikkim, these states falls under zone 4 not because they are dry because, here in these states relief is very high and undulated therefore water is unable to accumulate.

## 5.2.4 Measures to mitigate flood hazards:

Floods are a consequence of natural hydro-meteorological phenomenon, combined with their interaction with the catchment characteristics. Through interventions in changing the characteristics of the catchment the run-off processes can be altered, thereby making it possible to reduce the magnitude of the flood hazard thus generated.

Urban drainage systems, made up of channels, culverts, sewers etc., are meant to prevent local floods by conveying storm water away from vulnerable sites. Mostly this is done with the aim of draining storm water as fast as possible out of town. This practice may be benign in coastal cities or in agglomerations with no exposed living spaces downstream, but if cities or urban districts upstream of other riverside settlements drain storm water too quickly, this may cause urban floods downstream. Thus the sustainable urban drainage systems aim for adequate, but not too excessive, drainage in order to mitigate local floods, without creating new hazards downstream.

With reference to riverine floods in cities the respective upstream conditions have to be taken into account which requires considering urban floods not as isolated phenomena but as closely interlinked with overall basin characteristics. If upstream discharge is to be reduced, upstream land use issues have to be addressed. Most basically, there are four major strategies of land-use planning by which upstream surface runoff can be reduced: Limit surface sealing, Preserve forest cover, Preserve wetlands, and Promote affirmative agricultural practices.

Risks due to urban coastal floods cannot be reduced by mitigating the flood hazards due to storm surges or tsunami as they are purely generated by natural processes. They have to be essentially dealt with by managing the exposure.

### 5.2.5 Remote Sensing and GIS in Flood Management:

The flood plains, being very fertile, can be used for economic activities like agriculture. Those living in flood plains for these activities should have an efficient early warning mechanism that ensures their evacuation before the calamity strikes. With the advancement in space technology that India has achieved, remote-sensing should be effectively used for prediction of rainfall and floods. It is only with these comprehensive and holistic measures that an efficient management of floods can be ensured in India with least damage to life and property.

Flood Risk Management has emerged in recent years as one of the most significant engineering and societal challenges in the worldwide. Flood hazard seems to be increasing as climate change takes effect. In fact, of all natural risks, floods pose the most widely distributed natural risk to life today. Risk management is a fundamental activity geared to the evaluation of schemes for reducing but not necessarily eliminating the overall risk, as in many cases risk cannot be entirely eliminated. 'Water problem'; is also a 'people problem'.

Flood Risk Management therefore requires a holistic approach, addressing the scientific and engineering issues of rainfall, runoff, rivers and flood inundation as well as the human and socio-economic issues of planning, development and management.

There are Three components determine flood risk i.e. flood hazard, vulnerability and exposure. However, flood risk has been defined in several ways in the natural hazard literature; however one of them is the following definitions framework:[7]

- Hazard: the threatening natural event including its probability of occurrence
- Exposure: the values/humans that are present at the location involved
- Vulnerability: the lack (or loose) of resistance to damaging/destructive forces

Flood risk can be mathematically calculated as the product of hazard, exposure and vulnerability. By following this approach a large GIS database can be designed and developed in order to spatially represent the three components of risk.[8]Mapping defines the area at risk and should be the basis for all flood damage reduction programmes and subsequent actions. The maps often have a legal connotation in terms of zoning and other structural and non-structural measures undertaken, so they need to be accurate and credible. One of the key outputs of the flood risk management plans will be flood risk maps at river basin level. The purpose of a flood risk map is to increase public awareness of the areas at risk of flooding, provide information of areas at risk by defining flood risk zones to give input to spatial planning and support the processes of prioritizing, justifying and targeting investments in order to manage and reduce the risk to people, property and the environment.

### 5.2.6 Floods in Bihar:

Indian floods were a series of floods in various states of India during the monsoon season. The 2008 floods mostly affected the western regions of Maharashtra state and Andhra Pradesh as well as northern Bihar. In India, the monsoon season generally lasts from June to September. According to Ministry of Home Affairs (India)'s disaster management unit, countrywide death toll from floods in various state was 2,404 between June to September The

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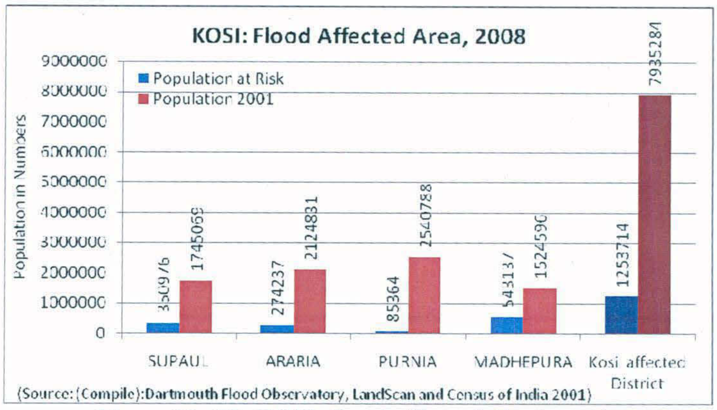
[7] Cenderelli, D.A. and Wohl, E.E., 2003, Flow hydraulics and geomorphic effects of glacial-lake outburst floods in the Mount Everest region, Nepal: Earth Surface Processes and Landforms, v. 28, p. 385-407.

[8] Prasad, A.K., Vinay Kumar, K., Singh, S. and Singh, R.P., 2006. Potentiality of multi-sensor satellite data in mapping flood hazard: Photonirvachak, v. 34, p. 219-231.

2008 Bihar flood was one of the most disastrous floods in the history of Bihar, an impoverished and densely populated state in India. A *breach* in the *Kosi embankment* near the Indo-Nepal border (at Kusha in Nepal) occurred on 18 August 2008. The river changed course and inundated areas which hadn't experienced floods in many decades. The flood affected over 2.3 million people in the northern part of Bihar.



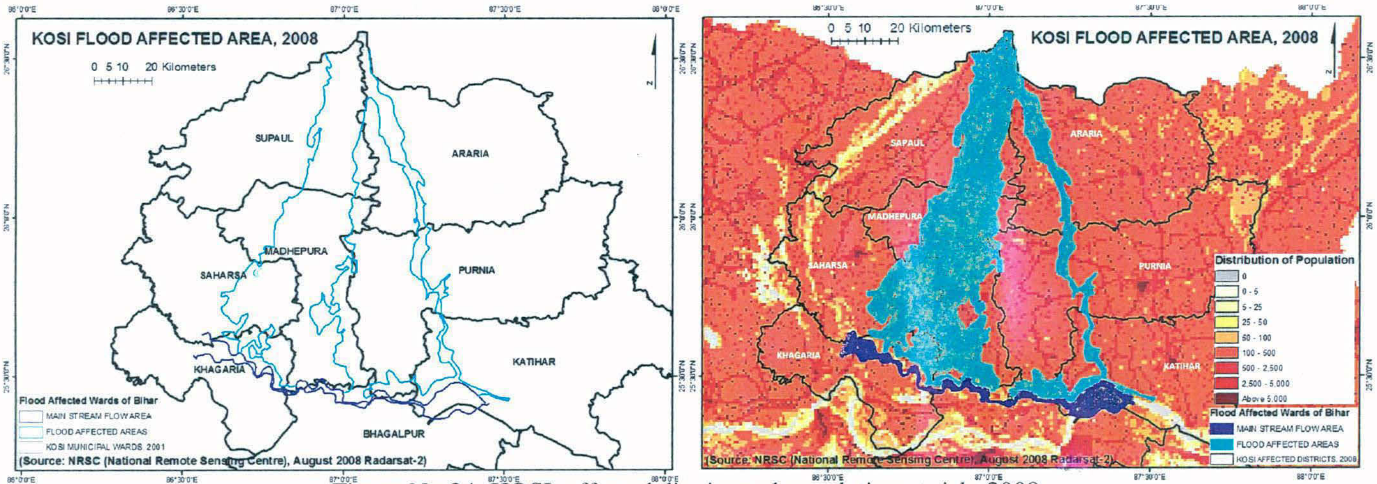
(Source: (Compile):Dartmouth Flood Observatory, LandScan and Census of India 2001)

Figure No.33: KOSI, flood affected district and estimation of population at risk

Flooding occurred throughout the Kosi River valley in northern Bihar, in the districts of Supaul, Araria, Purunia, and Madhepura,. The southeast Tarai ecoregion of Nepal was also affected. The flood killed 250 people and forced nearly 1253714 people from their homes in Bihar. More than 300,000 houses were destroyed and at least 340,000 hectares (840,000 acres) of crops were damaged. Villagers in Bihar ate raw rice and flour mixed with polluted water. Hunger and disease were widespread. The Supaul district was the worst-hit; surging waters swamped 1,000 square kilometres (247,000 acres) of farmlands, destroying crops.

***Table No.14: Population at Risk : Kosi Flood 2008***

| ***District*** | ***Population at Risk*** | ***Population 2001*** | ***Percentage Share of District*** |
|---|---|---|---|
| SUPAUL | 350976 | 1745069 | 20.11 |
| ARARIA | 274237 | 2124831 | 12.91 |
| PURNIA | 85364 | 25,40,788 | 3.36 |
| MADHEPURA | 543137 | 15,24,596 | 35.62 |
| ***Kosi affected District*** | ***1253714*** | ***7935284*** | 15.80 |



(Source: NRSC (National Remote Sensing Centre), August 2008 Radarsat-2)

(Source: NRSC (National Remote Sensing Centre), August 2008 Radarsat-2)

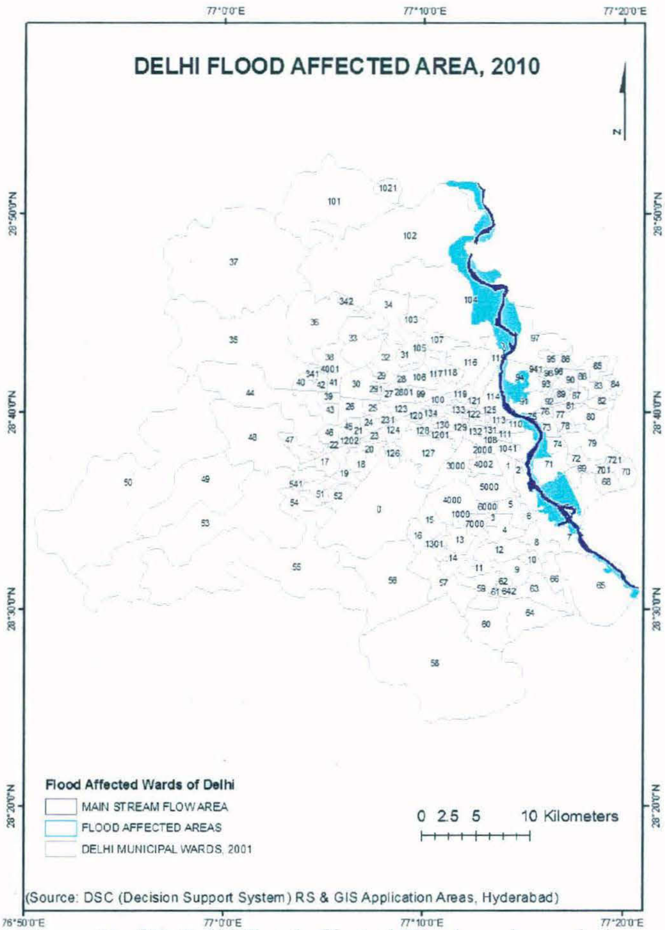
Figure No.34: KOSI, affected district and population at risk, 2008

Population Risk Assessment using LandScan 2008 data shows that the affected population due to flood breach in the Kosi embankment near the Indo-Nepal border is about ***1433901*** *(Using LandScan 2008)* in 5 districts of north Bihar Supaul, Madhepura, Araria, Khegaria are four most affected districts including more than 50 percent of district area as well as population. Overall, more than 1.4 million people in 13 districts of Bihar are flood affected. More than 225,000 houses have been destroyed.[9] Therefore based on these we can easily estimate and relocate the population at risk as well as we can predict the estimation ho affect population and area. Sorrow of Bihar 'Kosi river' every years this region experience flood still in 2008 it is because of sudden breach a large number of persons got affected. Flood affected four districts in which 1253714 numbers of people get affected which is 15.80 percent of the population living in these four districts.

### 5.2.7 Floods in Delhi, 2010:

Population at Risk due to Flood in Delhi shows that at the application point of view, When the Flood occurs in river surrounding region is increased by several meter the affected the population in Delhi was 173424 out of total population 1490056 which is 11.64 percent of total population living in Flood Plain area of Yamuna/ Delhi. Regional Variation is also there in the Population at risk due to sea level rise.

Ward no. 71 was the most affected state because of its low plains of Yamuna. It is the 48.46 percent of population of ward 71 living these areas will displace with the rise in water of River. Ward no, 75, 94, 102 and 104 were the most affected



(Source: DSC (Decision Support System) RS & GIS Application Areas, Hyderabad)

Figure No.35: Delhi flood affected Wards and population at risk, 2010

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[9] Indian Meteorological Department (IMD), UNICEF- "SITUATION REPORT BIHAR FLOODS 2008 OVERALL SITUATION FLOOD FORECAST"

states after Ward 71 with the population affected of 22.21, 15.90, 14.50 and 13.26 respectively. Ward no. 115 and 65 is the least affected of flood in the year 2010 with only 0.12 and 0.98 percent of their population. Ward no. 74, 2 , 91 and 7 were other affected wards with change in water level with a small amount of population share 9.09, 6.76, 6.73 and 5.60 respectively.

*Table No.15: Population at Risk : Delhi Flood 2010*

| *Delhi Ward No.* | *Population at Risk* | *Population 2001* | *Percentage Share of Wards* |
|---|---|---|---|
| 2 | 9629 | 142413 | 6.76 |
| 7 | 11404 | 203492 | 5.60 |
| 65 | 1682 | 170792 | 0.98 |
| 71 | 58577 | 120882 | 48.46 |
| 74 | 13225 | 145540 | 9.09 |
| 75 | 21570 | 97127 | 22.21 |
| 91 | 10403 | 154666 | 6.73 |
| 94 | 23102 | 145276 | 15.90 |
| 102 | 5964 | 41120 | 14.50 |
| 104 | 17704 | 133526 | 13.26 |
| 115 | 164 | 135222 | 0.12 |
| *Delhi* | ***173424*** | ***1490056*** | ***11.64*** |

### 5.3 Sea Level Change in India:

Due to global warming many subsystems of the global water cycle are likely to intensify, resulting in many regions in an increase of flood magnitude as well as flood frequency. Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. Heavy thunderstorm drains appear to have increased in frequency. Urban areas may help to increase thunderstorm activity because their built-up surfaces attain higher temperatures than surrounding areas and create a local air circulation that produces an 'urban heat island'. Dust particles caught up in that circulation act as nuclei on which moisture in clouds condenses, forming rain droplets that eventually may develop into the large rain drops of a major thunderstorm.

The purpose of coastal regulations in India is to preserve the coastal environment by regulating the use of land near the Indian coastline. Developmental activities along the Indian coast are governed by the provisions of the Coastal Regulation Zone (CRZ) Notification 1991, under the Environment Protection Act 1986. This notification provides guidelines for protection and use of the land within 500 meters of the coast and 100 meters along the tidal influenced water bodies. The notification classifies India's coastal stretch into CRZ-I (ecologically sensitive areas), CRZ-II (built up municipal areas), CRZ-III (rural areas) and

CRZ –IV (the islands of Lakshadweep and Andaman & Nicobar); and has been amended 19 times.

The Ministry of Environment and Forests (MoEF) now proposes to replace the existing notification with a Coastal Management Zone (CMZ) Notification based on the recommendations of the Swaminathan Committee Report. Concerns have, however, been raised about this move on account of its impact on: coastal communities and ecosystems, conservation and sustainable development.

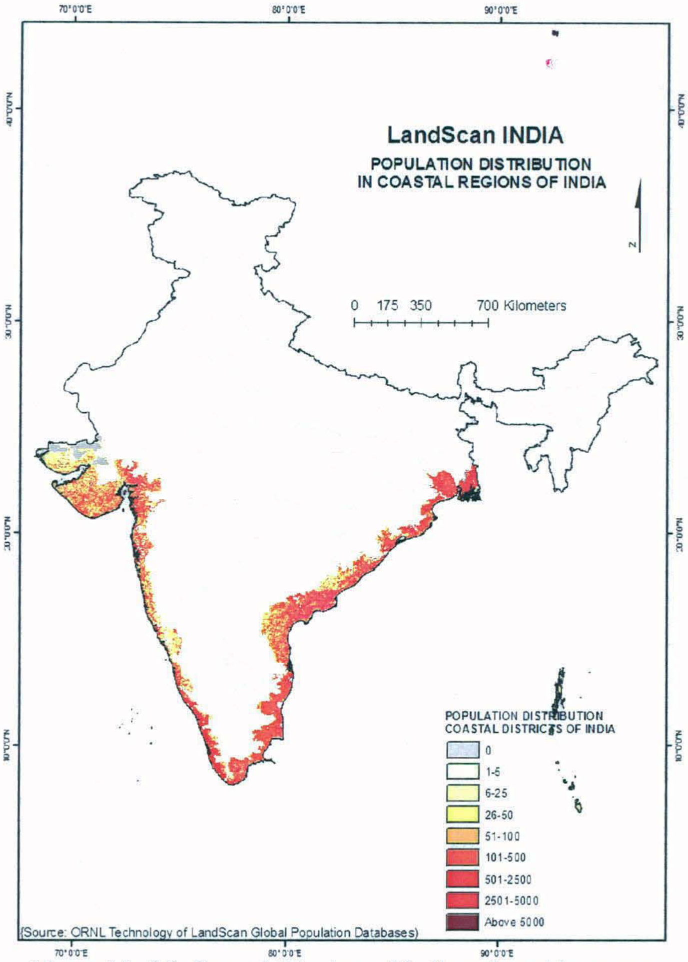

Figure No.36: Coastal Districts of India vulnerable to sea level rise

Coastal plains are a geologic feature found around the world and on both the eastern and western coasts of India. Coastal plains are characterized by an area of flat low lying land that is situated adjacent to a water body often a sea or ocean. It is also of note that coastal plains are separated from the interior of the larger land mass by other unique features. Coastal plains have limited vegetation; however grasses and trees are not uncommon. The coastal plains of

India are relatively expansive regions which contribute significantly to the geography of the region.

*Eastern Coastal Plains:* The eastern coastal plains are located on a wide stretch of land between the Eastern Ghats of India and the Bay of Bengal. This stretch of land stretches to 120 km in width at parts. The eastern coastal plains extend from Tamil Nadu in the south to West Bengal in the north. The eastern coastal plains have rivers draining into them and river deltas also occupy the valleys. The region of the eastern coastal plains is an expansive area and is divided into six regions. The six regions of the eastern coastal plains of India are the Mahanadi Delta, the Southern Andhra Pradesh Plain, the Krishna Godavari deltas, the Kanyakumari Coast, the Coromandel and the Sandy Coastal regions.

The eastern coastal plains are characterized by a temperature that exceeds 30 degrees Celsius and also experiences high levels of humidity. The rainfall of the region is also abundant in the region with rainfall amounts in excess of 1000mm annually with the amount usually approaching 3000mm. It is also of note that this region of the eastern coastal plains is subject to both northeast and southwest monsoon rains when these storms are in season.

*Western Coastal Plains:* The western coastal plain of India in contrast to the eastern coastal plain is located on a narrow strip of land. The western coastal plains are located in the west of India between the Western Ghats and the Arabian Sea. They extend from Gujarat in the north down 50 km to the south in Kerala and are characterized by numerous backwaters and rivers that flow into the region. These rivers that flow into the region lead to the forming of estuaries that are found in the western coastal plains of India. The storm activity here is considerably less than on the eastern coastal plains. The maximum storm activity on the western coastal plains occurs in the month of March. The western coastal plains are smaller than their eastern counterpart and the region is divided into three parts. The western coastal plains are divided into the regions of Konkan, Kanara, and the Malabar Coast.

### 5.3.1 Spatio-Temporal distribution of Sea level Change:

It is projected that global warming will cause sea levels to rise by as much as 5 mm per year over the next 100 years. Rising sea levels threaten entire nations on low-lying islands in the Pacific and Indian Oceans.[10]

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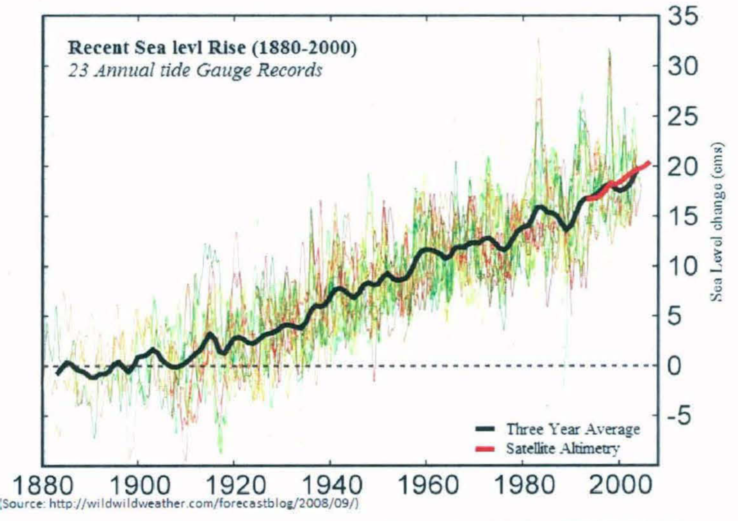
[10] WWF: http://wwf.panda.org/about_our_earth/aboutcc/problems/rising_temperatures/sea_levels/

Most of the world's coastal cities were established during the last few millennia, a period when global sea level has been near constant. Since the mid-19th century, sea level has been rising, likely primarily as a result of human-induced climate change. During the 20th century, sea level rose about 15-20 centimeters (roughly 1.5 to 2.0 mm/year), with the rate at the end of the century greater than over the early part of the century[11]. Satellite measurements taken over the past decade, however, indicate that the rate of increase has jumped to about 3.1 mm/year, which is significantly higher than the average rate for the 20th century[12]. Projections suggest that the rate of sea level rise is likely to increase during the 21st century, although there is considerable controversy about the likely size of the increase. As explained in the next section, this controversy arises mainly due to uncertainties about the contributions to expect from the three main processes responsible for sea level rise: thermal expansion, the melting of glaciers and ice caps, and the loss of ice from the Greenland and West Antarctic ice sheets.

***Causes of sea level rise:*** Before describing the major factors contributing to climate change, it should be understood that the melting back of sea ice (e.g., in the Arctic and the floating ice shelves) will not directly contribute to sea level rise because this ice is already floating on the ocean (and so already displacing its mass of water). However, the melting back of this ice can



(Source: http://wildwildweather.com/forecastblog/2008/09/)

Figure No.37: Recent change in sea level rise (1880-2000)

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[11] Bruce C. Douglas: (1997); Global Sea Rise: A Redetermination; Volume 18, Numbers 2-3, 279-292, DOI: 10.1023/A:1006544227856

[12] Richard A. Kerr(2006); A Worrying Trend of Less Ice, Higher Seas; Vol. 311 no. 5768 pp. 1698-1701 DOI: 10.1126/science.311.5768.1698

lead to indirect contributions on sea level. For example, the melting back of sea ice leads to a reduction in albedo (surface reflectivity) and allows for greater absorption of solar radiation. More solar radiation being absorbed will accelerate warming, thus increasing the melting back of snow and ice on land. In addition, ongoing breakup of the floating ice shelves will allow a faster flow of ice on land into the oceans, thereby providing an additional contribution to sea level rise.

There are three major processes by which human-induced climate change directly affects sea level. First, like air and other fluids, water expands as its temperature increases (i.e., its density goes down as temperature rises). As climate change increases ocean temperatures, initially at the surface and over centuries at depth, the water will expand, contributing to sea level rise due to thermal expansion. Thermal expansion is likely to have contributed to about 2.5 cm of sea level rise during the second half of the 20th century, with the rate of rise due to this term having increased to about 3 times this rate during the early 21st century[13]. Because this contribution to sea level rise depends mainly on the temperature of the ocean, projecting the increase in ocean temperatures provides an estimate of future growth. Over the 21st century, the IPCC's Fourth Assessment projected that thermal expansion will lead to sea level rise of about 17-28 cm (plus or minus about 50%). That this estimate is less than would occur from a linear extrapolation of the rate during the first decade of the 21st century when all model projections indicate ongoing ocean warming has led to concerns that the IPCC estimate may be too low.

A second, and less certain, contributor to sea level rise is the melting of glaciers and ice caps. IPCC's Fourth Assessment estimated that, during the second half of the 20th century, melting of mountain glaciers and ice caps led to about a 2.5 cm rise in sea level. This is a higher amount than was caused by the loss of ice from the Greenland and Antarctic ice sheets, which added about 1 cm to the sea level. For the 21st century, IPCC's Fourth Assessment projected that melting of glaciers and ice caps will contribute roughly 10-12 cm to sea level rise, with an uncertainty of roughly a third. This would represent a melting of roughly a quarter of the total amount of ice tied up in mountain glaciers and small ice caps.

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[13] Church, J. A., Gregory, J. M., Huybrechts, Kuhn, M., Lambeck, K., Nhuan, M. T., Qin, D. and Woodworth, P. L., Changes in sea level. In Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, ambridge, UK, 2001, pp. 639–693.

The third process that can cause sea level to rise is the loss of ice mass from Greenland and Antarctica. Were all the ice on Greenland to melt, a process that would likely take many centuries to millennia, sea level would go up by roughly 7 meters[14]. The West Antarctic ice sheet holds about 5 m of sea level equivalent and is particularly vulnerable as much of it is grounded below sea level; the East Antarctic ice sheet, which is less vulnerable, holds about 55 m of sea level equivalent. The models used to estimate potential changes in ice mass are, so far, only capable of estimating the changes in mass due to surface processes leading to evaporation/sublimation and snowfall and conversion to ice. In summarizing the results of model simulations for the 21st century, IPCC reported that the central estimates projected that Greenland would induce about a 2 cm rise in sea level whereas Antarctica would, because of increased snow accumulation, induce about a 2 cm fall in sea level. That there are likely to be problems with these estimates, however, has become clear with recent satellite observations, which indicate that both Greenland and Antarctica are currently losing ice mass, and we are only in the first decade of a century that is projected to become much warmer over its course.

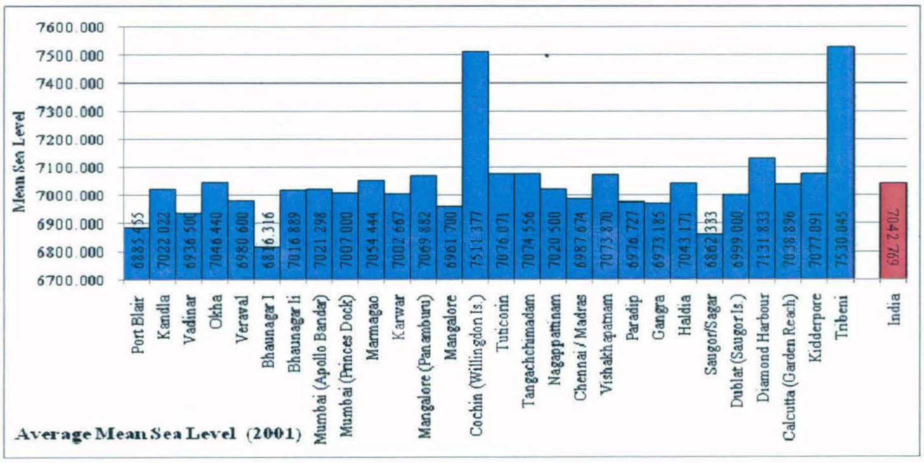

Figure No.38: Mean Sea level in selected stations of India

Mean sea level is rising along the Indian coast. Among these states, the estimates for coastal states Maharashtra, Kerala, and Orissa showed a sea level rise of 0.78, 1.14 and 0.75 mm/year respectively, whereas the estimate for Tamil Nadu showed a decrease in sea level (– 0.65 mm/year). The present estimates do not significantly differ from those in the earlier study, except for Tamil Nadu.[15]

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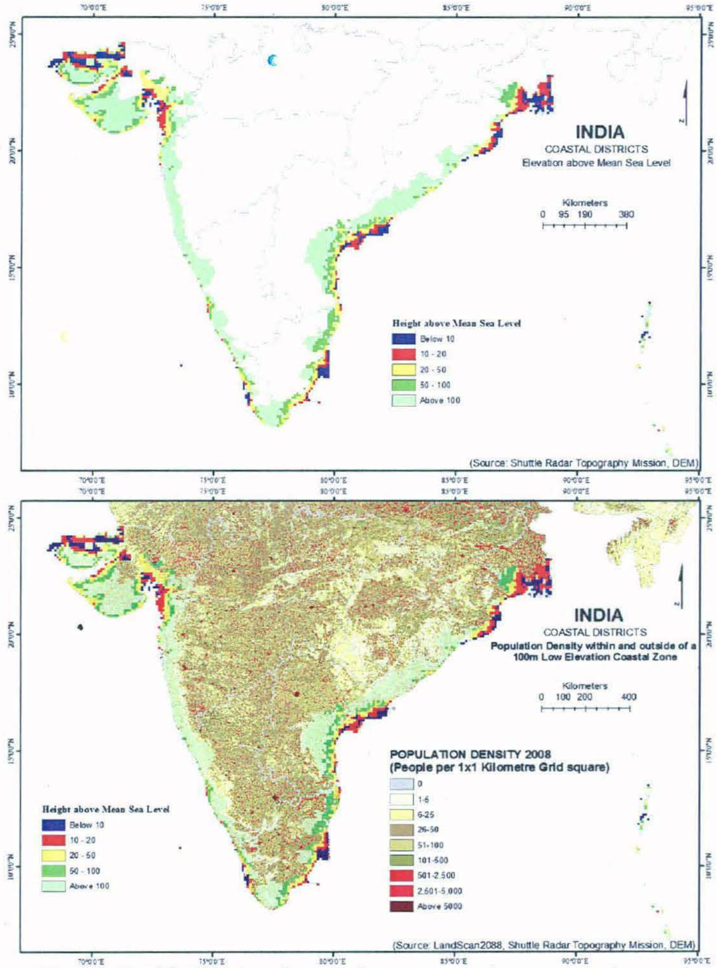
[14] Anonymous, Extreme sea level variability along the coast of India. Joint Indo-UK programme on impacts of climate change in India. National Institute of Oceanography, Technical Report NIO/TR- 6/2004, 2004.

[15] Emery, K. O. and Aubrey, D. G., Tide gauges of India. *J. Coast.Res.*, 1989, **5(3)**, 489–501.

Global warming is making sea level rise. Sea level, however, will not rise appreciably overnight, not in months, not even in years. The rise will assume dangerous proportions only over a substantial length of time, perhaps over decades. The statement is not considered to make you complacent, but you need not panic either. The sensationalist movies and documentaries that you have been watching show the sea invading deep into eastern India, inundating the capital of West Bengal Kolkata.



(Source: Shuttle Radar Topography Mission, DEM)

(Source: LandScan2088, Shuttle Radar Topography Mission, DEM)

Figure No.39: Regional variations population at risk due to change in sea level upto 100 mts

Sea-level rise increases the risk of coastal floods, particularly in case of storm surges. Many million more people are projected to be flooded every year due to sea-level rise by 2080s. Those densely populated low-lying areas where adaptive capacity is relatively low are especially at risk. Climate change also works in an indirect way to aggravate urban flooding.

These data are available with the Permanent Service for Mean Sea Level (PSMSL)[16]. Mean sea level changes obtained by an analysis of trends could be either caused by global warming or due to vertical movements of the land, where the instrument is located. In order to get the net sea level rise at a place, rates of vertical land movements need to be included. In general based on above graph we can conclude that on an average Mean sea level is equal for every station where as when we look at it more concisely Cochin and Tribeni station show unexpectedly high levels.

Mapping variations in regional sea level changes of different parts of the Indian Ocean could help developing countries better adapt to the effects of climate change. Conversely, Zanzibar could experience falls, whilst the Seychelles and the east coasts of Kenya and Tanzania may see little or no rise. The Maldives may only experience substantial sea-rises during the winter monsoon[17].

Observations from the Indian Oceans cover a relatively short period, so any changes seen may be a result of decadal variability. Mapping variations in sea level changes of different parts of the India based on map show that if sea level rises a large and important coastal part of India will submerged into the sea. As we know that a large proportion of population of India is living in coastal area which will have to move out. Also we large cities like Mumbai, Calcutta, Chennai, and many more relatively small towns, which are not only cities they are growth poles of India and base of Indian economy. Map represents the pattern of slow upto 100 meters which show the regions which disturb with the change in sea level. Here we have classified the slop into five categories. Dark blue color in the map depicts First class, 0 to 10 meter height from sea level. Which is the most prone to change in sea level, slight change in sea level will affect this region followed by the Red color which ranges upto 20 meters and Yellow, Green and White color falls under classes upto 50, 100 and above 100 respectively.

### 5.3.2 Vulnerability of Indian Coastal Region to damage from Sea Level Rise:

One indicator of vulnerability of a coastal region to inundation is the topographic slop. One can get feel from variation in topographic slop by examining the 100 m contour (along with

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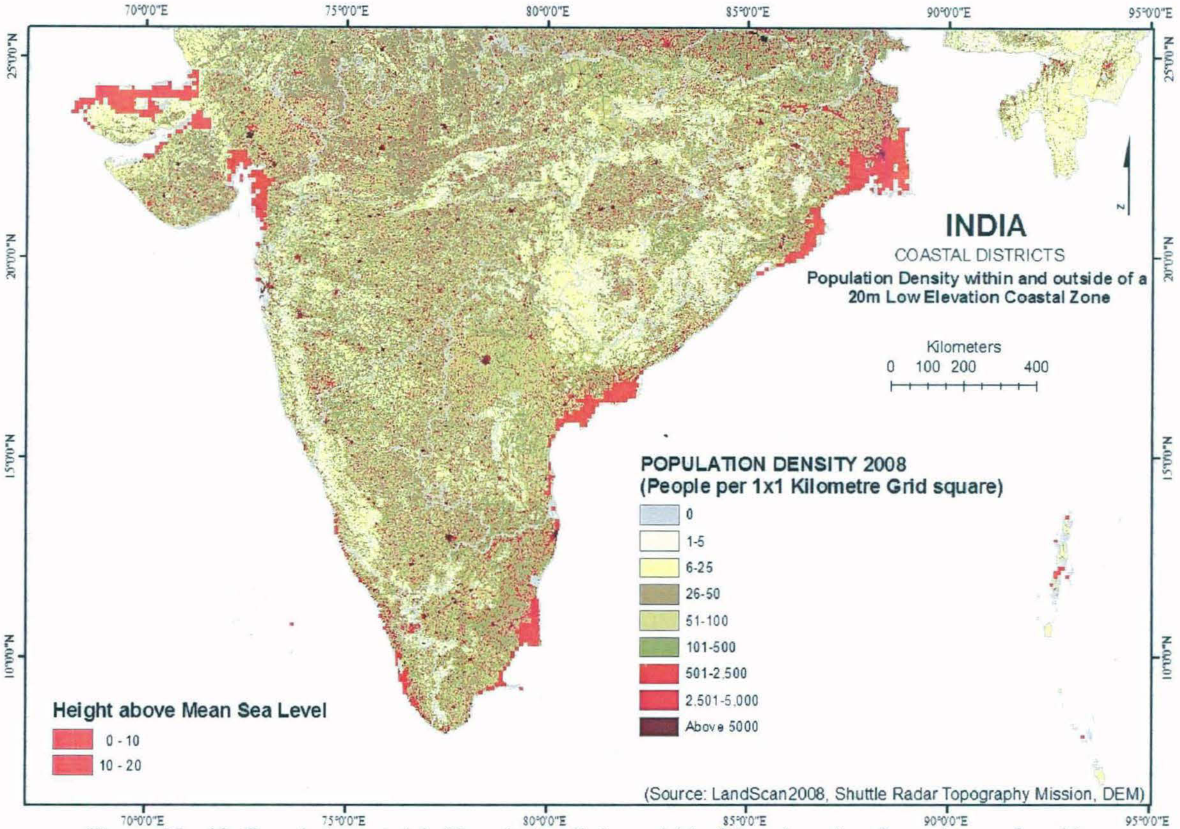
[16] Permanent Service for Mean Sea Level Joseph Proudman Building 6 Brownlow Street Liverpool L3 5DA, UK psmsl@pol.ac.uk: and www.psmsl.org

[17] The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report.

10m, 20m and 50 meter contour). The slop is generally greatest in central western coast. The east coast slopes are usually smaller than those on the west coast.

The sea level rise that we are concerned with will be of a few meters. We should then be examining the coastal slops using maps which resolves the topography every one meter or so. While there are obviously many challenges to projecting future sea level rise, even a seemingly small increase in sea level can have a dramatic impact on many coastal environments. A large proportion of population live in coastal areas that are less than 10 meters above sea level, and a large number of cities that have populations over five million are located in these at-risk areas. With sea level projected to rise at an accelerated rate for at least several centuries, very large numbers of people in vulnerable locations are going to be forced to relocate. If relocation is delayed or populations do not evacuate during times when the areas are inundated by storm surges, very large numbers of environmental refugees are likely to result.



(Source: LandScan2008, Shuttle Radar Topography Mission, DEM)

Figure No.40: Population at risk (Population living within 20m elevation from the sea level.)

According to the IPCC, even the best-case scenarios indicate that a rising sea level would have a wide range of impacts on coastal environments and infrastructure. Effects are likely to include coastal erosion, wetland and coastal plain flooding, salinization of aquifers and soils,

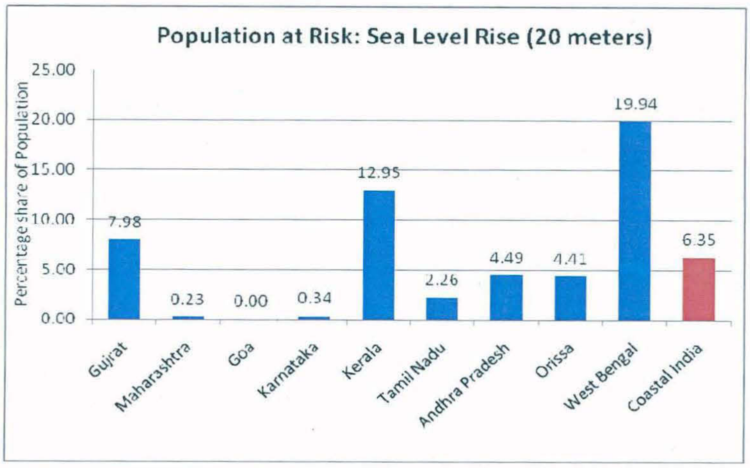


Figure No.41: Percentage population share of state living below 20m elevation from MSL in India

and a loss of habitats for fish, birds, and other wildlife and plants[18]. The Environmental Protection Agency estimates that 26,000 square kilometers of land would be lost should sea level rise by 0.66 meters, while the IPCC notes that as much as 33% of coastal land and wetland habitats are likely to be lost in the next hundred years if the level of the ocean continues to rise at its present rate. Even more land would be lost if the increase is significantly greater, and this is quite possible. As a result, very large numbers of wetland and swamp species are likely at serious risk.

Population at Risk due to Sea Level Rise shows that at the application point of view, as if the sea level around Indian coastal region is increased by 20 meter the affects the population will be 30982340 out of total population 488032285 which is 6.35 percent of total population living in coastal region of India. Regional Variation is also there in the Population at risk due to sea level rise.

***Table No.16: Population at Risk : Sea level Rise upto 20 meters***

| *Sea level Rise (20 meters)* | *Population at Risk* | *State Population* | *Percentage Share of State* |
|---|---:|---:|---:|
| Gujarat | 4037192 | 50596992 | 7.98 |
| Maharashtra | 227199 | 96752247 | 0.23 |
| Goa | 0 | 1343998 | 0.00 |
| Karnataka | 177827 | 52733958 | 0.34 |
| Kerala | 4124243 | 31838619 | 12.95 |
| Tamil Nadu | 1403867 | 62110839 | 2.26 |
| Andhra Pradesh | 3400794 | 75727541 | 4.49 |
| Orissa | 1617383 | 36706920 | 4.41 |
| West Bengal | 15993835 | 80221171 | 19.94 |
| **Coastal India** | **30982340** | **488032285** | **6.35** |

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[18] IPCC, 2007: Climate Change 2007: Impacts, Adaptation, and Vulnerability . Contribution of Working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, Martin L., Canziani, Osvaldo F., Palutikof, Jean P., van der Linden, Paul J., and Hanson, Clair E. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, 1000 pp.

West Bengal is the most affected state due to sea level rise because of its low delta plains of Hooghly. It is the 19.94 percent of population of west Bengal living these areas will displace with the rise in sea level by 20 meters. Kerala and Gujarat are the most affected states after West Bengal with the population affected of 12.95 and 7.98 respectively. Goa, Maharashtra and Karnataka are the least affected states with change in sea level with a smallest amount of population share 0.00, 0.23, 0.34 respectively.

### 5.4 Conclusion:

Losses due to natural and man-made disasters will continue to increase because of our continuing population growth and the increase of the concentration of growth in risk prone areas such as coastal regions, flood plains.

On an average more than 1000 people died every year due to floods in India. As in 2008 Kosi flood hit four districts of Bihar about 1.2 million people got affected (15.80 %) in four districts. In 2010 Delhi, along Yamuna river floodplain about 11 municipal wards were affected. From Landscan datasets it was estimated to about 0.17 million people, out of about 1.5 million people in these wards. Thus, LandScan estimates are useful enough to locate and estimate the persons under risk of flood as well as in change in sea level.

Sea level rise is a great threat to the *30.9 million people of India*, who are projected to be environmental refugees if the sea level rises to the level of 20m above of now. Out of nine coastal states there are five most risk prone, thus about 6 percent population might be affected with this change. It is threatening to the basic human right of large number of population. We can easily estimate the population at risk with the LandScan data.

*Chapter No. 6*

# Conclusion and Bibliography

**Observations:**

Detailed and contemporary spatial population data are valuable for assessing the risks and burden of hazards, for planning humanitarian assistance, resource allocation, or public health strategies. The construction of a detailed population database for India has been attempted here using LandScan and Census data. Population estimates are yet to be saying that that upto a level of a large city we can use this data for estimation population at risk zoning of areas for different applications and number of other uses where as when we talk of a city wards it really far apart from reality. Though, to validate it at the mega city level showing that unlike previous works at the ward level LandScan estimates are larger than census population.

LandScan represents Mumbai population around 18 million where as census enumerated it to around 24 million where as LandScan estimated population for Chennai Delhi and Calcutta is on higher side. This might be because of sea land boundary problem in Mumbai. The main problem with the statistics available concerns the reliability of the population figures used. If the city population figures are not very accurate, the calculation of urban and rural proportions is seems to be incorrect.

From this dissertation we can conclude that to macro levels the population estimated by LandScan is moreover represents a pattern of stability. As value of $R^2$ is .998 for states but when we look into the districts the error increased and $R^2$ drop down to .664 and it further increase at ward level in mega cities value of $R^2$ reaches .4668. Based on the finding and study in this dissertation we can say that topography of region effected the LandScan population estimates and its pattern at state and district level.

Population totals per State (district level for Costal districts of India) were compared to the census projected population estimates for the year 2008. The two population datasets were adjusted to 2008 for this calculation. The LandScan dataset was near perfect here, as the population data were matched (approximately) to Census population estimates in the modelling procedure. However, the aim is to observe how far away the LandScan datasets is from these contemporary estimates. $R^2$ (0.999) value was extracted and differences in population estimates per state/district were mapped.

The population estimated by LandScan is far below or on high side for selected mega cities population count, for Mumbai, it is (33.08 %) below, where as far Delhi, Channa, Calcutta it is 14.25, 25.01 and 37.79 respectively on higher side. As we already discussed in previous chapters about its pattern at state and district level and now this following pattern proves that the topography of a region effects on LandScan estimates. Sea in close proximity is also a factor which affects the error content in LandScan data.

At ward level population estimates are also less comparable, since there was no consistency observed in estimated population. For wards it ranges from say maximum of -659 (ward no. 53 in Mumbai) to +86 (ward no. 47 in Chennai). Maximum number of wards show a negative trend in value, which means that estimated population is under estimated. But in case of Delhi flood during September 2010, the affected population estimated are quite comparable at ward level.

The study has demonstrated that urbanization and its spatiotemporal form, pattern and structure can be quantified and compared across cities using spatial metrics. The urban growth in India increasing, need to understand the type of growth is important to plan the cities efficiently. Urban growth in India may take various spatial forms, depending upon the type of development, however, many parameters in Delhi, Mumbai, Calcutta and Chennai showed similar results. Especially Delhi and Mumbai have shown very similar growth type corresponding to the spatiotemporal urbanization and built-up density gradients. The built-up area has increased in megacities for the time period indicating dispersed areas of urban growth in the outskirts of the city as well as in the city centre. Cities are undergoing changes in the urban form as well.

Remote Sensing has proved to be vital information for continuous observation and quantification of environmental phenomena across varied spatial and temporal scales which are otherwise not possible to attempt through conventional mapping techniques. The multitemporal Landsat MSS, TM, ETM+ and IRS LISS -3data have provided useful analysis for the land use and land cover change in Mega Cities from 1971 to 2006 for a span of 17 years. It was observed that as a result of rapid urbanisation, the built-structures augmented from 25.67% in 1989 to 27.14% in 2000 and drastically to 42.55% in 2006. Supervised classification technique of the images has been successful to study the change detection of land use and land cover in the region, this method provides a suitable technique to identify development of urban zones which lead to transformation in the land use and land cover configuration that consequently impacts the landscape environment. Continuous spread in built up is observed by using Remote Sensing datasets of various years and thus it evident that urban agglomeration is not restricted with administrative limits.

LandScan estimates for population at Risk for Kosi flood of 2008 in four districts of Bihar, namely Araria, Puruliya, Madhepura and Sapaul is about1.2 million people (15.81 %) for Delhi flood of September 2010, the estimated affected population is about 0.17 million, which are quite close to Census derived figure. Thus, LandScan estimates are useful enough to locate and estimate the persons under risk of flood as well as in change in sea level.

It is estimated that the Sea level rise is a great threat to the *30.9 million people of India*, who are projected to be environmental refugees if the sea level rises to the level of 20m above of now. Out of nine coastal states there are five most risk prone there 6 percent population affects with this change.

**Conclusion:**

Hazards are considered a serious and regular threat to lives and property in India. This is where the Population risk assessment based on the government underestimated. Here based on above studied it has been attempt to assess the demographic effects of Sea level change and flood risk over India, which were considered the key hazards leading to population at risk impacts. Sea level change was considered to be more localized and not further considered. Flood risk exhibited the biggest effect and is thus considered of major importance. The analysis shows that the Population and risks posed by natural disasters are large for India, and there is a clear case for specifically considering these impacts in Population and risks planning. Particular flood risk, for which an event of the size of the 2004 event may mean losses exceeding 15 crore, can lead to large Population and risks impacts.

As key applications, the flood modelling may inform the mainstreaming of disaster risk into is discussed in more detail in chapter *five*. As well, and more specifically, another application is contingency liability planning for public and private sector agents in disaster exposed and vulnerable countries involving setting aside reserves or seeking risk financing mechanisms. As another application, such modelling may inform relief and reconstruction efforts post event. The analysis demonstrates that disasters like Sea level change and floods may ripple through community and indirectly affect sectors that were not hit directly by the disaster event.

The Gridded Population of the World is a useful dataset in conjunction with the National Census projections as it shows a future scenario of the spatial distribution of populations. As already stated outright, this method has limitations for short-run forecasting. Future investments should include further data development such that more rigorous estimates of future population, along with estimates of associated uncertainty, can be made at a sub national level. When shown with urban area extents for 2008, it is possible to see how the urban areas might grow over the next decade both in spatial extent and in population density compared to the year 2008. It clearly represent as much more densely populated than surrounding rural areas. Further improvements in resolution to the underlying population and boundary data will make it possible to gain greater insight in the expected future population of urban areas, and current and future peri-urban areas. Overall, we conclude that in the face of massive disaster risk, the government position should be one of risk abhor and risks should be explicitly accounted for before actual events materialize.

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