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Urban Sprawl Mapping using Multi-Sensor and Multi-Temporal Satellite Remote Sensing Data & GIS

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ABSTRACT

Multi-sensor and multi-temporal satellite remote sensing data and GIS have been used usually to examine and study the patterns of urban sprawl. Bina town of Sagar district, Madhya Pradesh (India), a very fast growing town of the district Sagar was selected to perform this study and to examine its urban growth. Six multi-sensors and multi-temporal satellite data from 1972 to 2014 and population censuses from 1931 to 2011 of the study area were used in this work. The aim of this study is to produce the base map and urban sprawl maps for the studies area at varied period to recognize and evaluate the substitutable relationship of urban growth and population growth. Results indicate the places having a significant increase in impervious surface are mainly along the transport network and demonstrate connective patterns of the town. It is concluded that the remote sensing and GIS techniques supplemented with census data are very efficient and effective for studying the urban sprawl.

Keywords: Urban Sprawl, Population Growth, Remote Sensing Data and GIS

I. INTRODUCTION

This Urban sprawl is an indicator of urban form. Urban form can be defined as the spatial pattern of human activities (Anderson et al. 1996) at a certain point in time. It can be categorized into three classes: density, diversity and spatial-structure pattern. The spatial structure of a urban area, characterized as the general shape, may distinguish land use phenomena as monocentric versus polycentric forms, centralized versus decentralized patterns and relentless versus disrelentless expansion. In a broader sense, urban form may engage conceive class, such as block or location design (Cervero et al. 1997).

Urban sprawl is often defined by four land use characteristics (Ewing, 1997) i.e. low density, scattered development, commercial strip development and leap frog development. The last three indicators are spatial-structure based phenomena of sprawl, compared to density-based sprawl. Commercial strip and leapfrog developments often occur in particular parts of an urban area along the edges, such that the degree of derived sprawl of a whole urban area depends on factors like size and degree of discontinuity of the scattered growth conditions. The availability of satellite image data in different forms has ensured that many successful applications in urban sprawl study and LULC mapping have been carried out by Friedman (1980), Jackson, et al. (1980), Griffith (1981), Larry, et al. (1989), Green, et al. (1994), Steinnocher, et al, (1999), Archer (1999), Barr, et al. (1999), Bauer, et al. (1999), Stephen, et al. (2001), Herold, et al. (2003), Hasse, et al. (2003), Clifton, et al. (2008), Rahman, et al. (2011), Tamilenthi, et al. (2011), Pareta (2012[a]), Pareta, et al. (2012[b]), Abubakr, et al. (2013), etc.

Bina is a tehsil headquarter / municipal council and a very fast growing town of the district Sagar (Fig. 1). It is also a major commercial and industrial center. Previously Bina town was known as Etawa village. In 1923, a new railway junction was established near the Etawa village, so the name of Bina town derived from the Bina River flowing nearby the junction. Bina railway junction of western central railway is an important landmark in the town and is a very important junction point in the country. It is well connected by rail with all the major cities of India like Mumbai, Delhi, Kolkata, Bangalore, Sagar, Bhopal etc. The only refinery of central India, under Bharat Oman Refineries Limited (BORL) is located around the town was instated in May 2011.

The Bina and Betwa rivers flow through the area. Most of the Bina town lies on Deccan Trap and Vindhyan rock formations. The general slope of the town is towards North and North-West direction. 80% of the drainage flows towards North West direction. Winter season starts from November to the end or midst of February and summer season starts from March to the midst of June. Average minimum temperature recorded in the town is 7°C in January, whereas the average maximum temperature in May is 40.0 °C. Average rainfall is around 1235 mm annually.

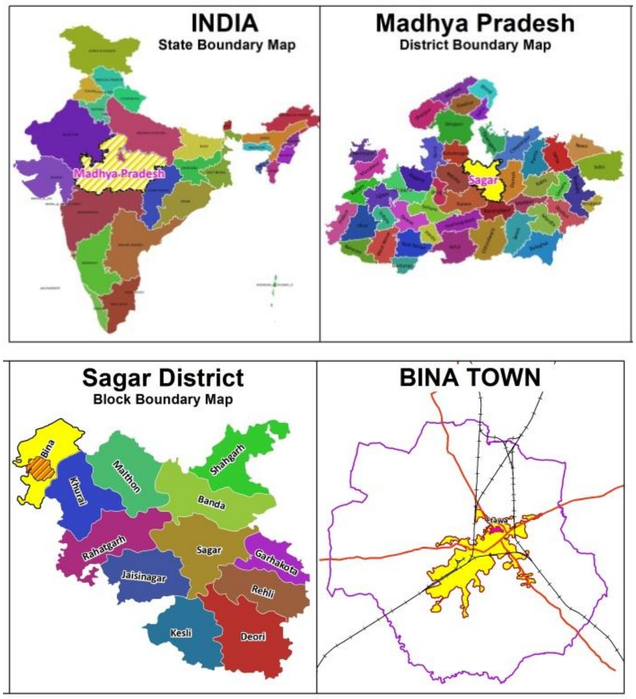

Figure 1: Location map of the study area

II. DATA USED AND SOURCES

The data collection was done from both primary and secondary data sources. The primary data collected were the Survey of India toposheets of 1:50,000 scale for the corresponding region, Landsat-1 to 7 satellite imageries for year 1972, 1981, 1990, & 2000 have been downloaded from Global Land Cover Facility (GLCF) website, Landsat-8 satellite imagery for year 2014 has been downloaded from http://earthexplorer.usgs.gov website, and IRS LISS-III for year 2010 has been downloaded from bhuvan.nrsc.gov.in website. The secondary data collected included the demographic details from the census abstracts of the study area for 1931, 1941, 1951, 1961, 1971, 1981, 1991, 2001 and 2011 from the Sagar District Census Hand Book and Directorate of Census Operations, Census of India. The current master plan map of Bina town was obtained from Town and Country Planning, Bhopal (M.P.). The details of different data layer and its sources are given in Table 1

TABLE I

DIFFERENT DATA LAYERS AND SOURCES

S. No.	Data Layer	Source	
1.	Base Map	Survey of India Topographical Map at 1:50,000 No. 54 L / 04(1985-86)	
2.	Urban Extent Mapping	Remote Sensing Data	
		Landsat-1 MSS (57 m)	01st Dec., 1972
		Landsat-3 MSS (57 m)	16thApril, 1981
		Landsat-5 TM (30 m)	05thNovember, 1990
		Landsat-7 ETM (30 m)	01st October, 2000
		IRS-P6 LISS-III (23.5 m)	23rd October, 2010
		Landsat-8 OLI (30 m)	26thSeptember, 2014
3.	Elevation Map	ASTER - DEM (30 m)	02nd December 2007
4.	Demo-graphic Data	Census of India, 1931-2011	

III. METHODOLOGY

A. Rectification Process

Satellite data acquired by different satellites are generally geometrically distorted due to the acquisition system and the drive of the platform. A geometric rectification of the satellite data is essential to match an image with other existing data. The satellite data used at this time for analysis are of different type of satellite data, sensors and spatial resolution. It is most significant that all satellite data are located with respect to a common setting of reference. In order to correct the distortion in satellite data due to sensor geometry and altitude, 13 well distributed GCP's (Ground Control Points) were selected from the Survey of India toposheets. All the images were corrected using ERDAS Imagine-2013 software. Total root mean square error (RMSE) for the rectification procedure was kept below then 1 pixel. All the satellite data were transformed to the Universal Transverse Mercator (UTM) projection on the World Geodetic Datum of 1984 (WGS-84), UTM Zone- 43. This projection system has been used for better calculation and verification of distances between utilities, area and the span length.

B. **Visual Image Interpretation**

Virtually all people live with the visual perception of their environment. The visual interpretation of satellite images is a complex process. Satellite image interpretation goes well beyond image object recognition to decipher image to understand spatial and landscape patterns. This process can be divided into 2 steps:

- The recognition of image objects such as streets, build-up, agricultural land, rivers, etc.
- A true interpretation which is fine tuned by virtue of past experience. Domain specific knowledge is critical to success in true interpretation of satellite images.

Recognition and interpretation may not just follow each other but rather enhance each other in a repetitive manner (Albertz, 2007). In order to successfully recognize and interpret satellite images an understanding of key visual element is paramount. Theses visual elements are tone, shape, size, pattern, texture, shadow, and association. Tone refers to the relative brightness or color of objects in an image. Variations in tone allow the elements of shape, texture, and pattern of objects to be distinguished.

Using visual interpretation approach build-up classes were identified and digitized. Further, the water features, built-up and non-urban classes were extracted from the image and attributed (Fig. 3). Lastly, the urban extent mapping for year 1972, 1981, 1990, 2000, 2010 and 2014 have been done through the visual interpretation of satellite imageries using ESRI ArcGIS-10.2.2 software. The base map (Fig. 4) and elevation map of the study area has been also prepared by using satellite imagery, SoI toposheets, and ASTER (DEM) data.

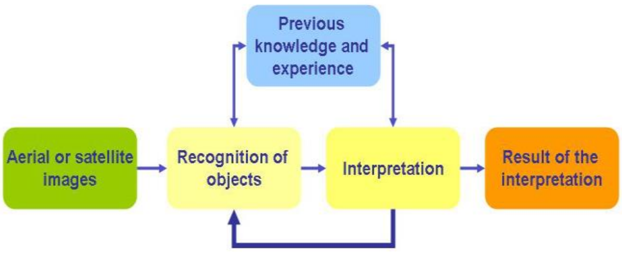

Figure 2: Visual image interpretation process, Source - Albertz 2007 with modifications

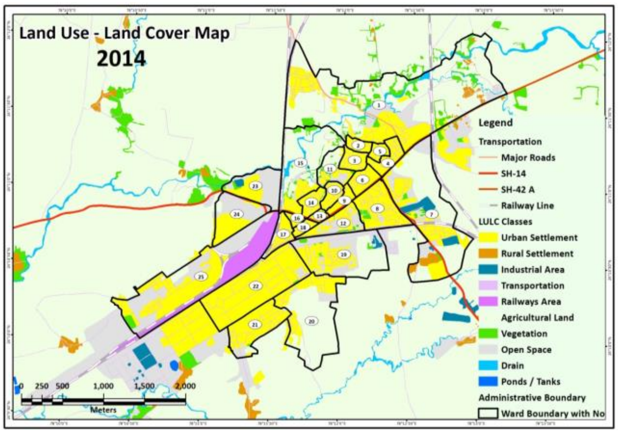

Figure 3: Land use and land cover map of Bina town - 2014

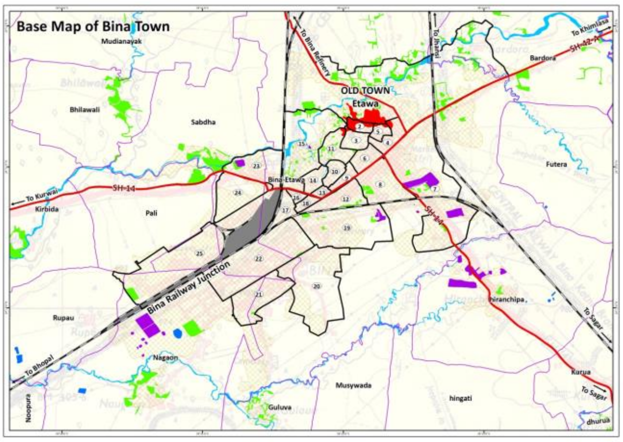

Figure 4: Base map of Bina town

IV. INDIAN MACRO PLANNING PROCESSES

In the field of town panning, India has characteristically moved along with or ahead of contemporary planning practices. From prehistoric Mohenjo Daro to the imperial town of New Delhi to Corbusier's Chandigarh, India has been a pioneer in town planning (Shrey, Kandoi, & Srivastava, 1981).

Visionary planning concepts proposed to ameliorate the 'problems of the town' by producing constellations of new, self-contained, secondary & tertiary based towns built in open country side, far from the commotion and high land values. It was based on such ideologies that a town like Chandigarh was formed; replacing the entire existing town with a town of high rise towers and parks (Hall 1988). Hence, amidst all the contradictions and innovations, the town was 'taking-off'.

Constant succession and invasion along with commercialization is giving rise degeneration and regeneration of the morphological and functional urban spaces. Community design movements, coupled with vision of infinite mobility through advances in transportation technology, above all private automobiles, and ingenious economic policies continue to direct the course for cities to transition, metamorphosing into 'cities of tomorrow'.

India's urban transition is an agent for social transformation and economic mobility. This process will redefine India's stature as a less-resource intensive development that enables small urban centres to become catalysts for rural employment and contributors of economic growth (IUC and IIHS 2011). This transition not only encompasses the spatial configurations of Indian cities but also the dramatic economic dynamism.

Generation of multiple nuclei, creation of new sub-urban peripheries, compaction and vertical growth, mass transport systems, shifting spatial distribution of economic activity as well as infrastructure, emphasis on lowering footprints and environmental impacts as well as expansion of the secondary and tertiary sector, dominating industrial base followed by diminishing weight of primary sector, large scale investments, are all indicators of the trajectory of a town in transition.

However, as is prevalent in most of the cities having historical legacies, like India, much of this transition is taking place at the cost of the local cultural landscape, wherein all that is traditional and old is being replaced by modern stereotype urban landscape. Ideally, this transformation should not entail total renewal or reconstruction of the existing urban fabric, rather revive and reuse of the indigenous traditions and principles to evolve a planning practice that is close to its roots. Patrick Geddes had advocated the idea of involving historical traditions, and rediscovery of past traditions of town planning.

This phenomenon of transformation is not only evident in the large metropolises but has also percolated to small town in India. Bina, a small town and tehsil headquarter with a population of 50,000 people in Sagar district of Madhya Pradesh, is witnessing such remarkable transition from being a 'gated royal enclave' to a major commercial and agriculture base in the vicinity.

V. RESULTS AND DISCUSSION

A. **Population Growth**

Demographic factors play vital role in urban sprawl study and urban extent mapping in the study area. This change is a combination of several demographic, institutional and technological factors. The role of human element in environmental is more significant in those countries where national economy largely implies environmental / agricultural change. Moreover, the farmer himself is a prime mover in the process of an overall only depends on agricultural development (Singh, et al. 1984). The key indicators for understanding response toward adoption of agricultural / environmental innovation are population size, spatial distribution of population and growth dynamics (Ram Chandran, 1992, Misra and Sharma, 1982).

The growth of population in any region, whether it is positive or negative, generally reflects human response to his environment suitability and possibilities (Pandey, et al. 2 010). The growth of population exerts considerable influence on agricultural processes. Growing population needs more food and essentials of life. A number of studies show that population growth compels agricultural communities to change their methods and land uses (Clark, 1967). In region where most of the working population derives livelihood from agriculture, such relationships are more clearly visible. People have limited purchasing power and therefore, they have to depend to a great extent, on local food supply which affects the fundamental changes in resources technology.

The population of Bina town for past 8 decades (from 1931 to 2011) is shown in Table 2. As per Census 2011 Bina town has a population of 64,529 of which 33,577 are males while 30,952 are females. Population growth rate was calculated by three different methods i.e. arithmetic increase method, geometric increase method, and incremental increase method. It was observed that estimated population is maximum using geometric growth method. Considering the high urbanization growth of Indian cities, population calculated by geometric increase method was considered for projecting the population. Decadal population growth rate (1931-2011) of 28.33% has been obtained using this method. It is estimated that population of Bina town will be approx. 82,810 and 106,270 in year 2021 and 2031 respectively.

TABLE II

POPULATION AND POPULATION GROWTH OF BINA TOWN FROM 1931 TO 2011

S. No.	Year	Population*	Population Growth (No.)	Decadal Growth (%)
1.	1931	10,849		
2.	1941	8,979	(-) 1,870	(-) 17.24%
3.	1951	12,720	3,741	41.66%
4.	1961	24,476	11,756	92.42%
5.	1971	33,476	9,000	36.77%
6.	1981	33,886	0410	01.22%
7.	1991	41,621	7,735	22.83%
8.	2001	51,181	9,560	22.97%
9.	2011	64,529	13,348	26.08%
				28.33%#
10.	2021	82,810ϕ	18,281	28.33%
11.	2031	106,270ϕ	23,460	28.33%

Source: Census of India, M.P. Sagar District Census Hand Book 1931-1981, and Census of India, 1991, 2001 & 2011

Note:
* *Population as per Census of India*
\# *Average Decadal Population Growth Rate from 1931 to 2011*
ϕ *Estimated Population using Geometric Growth Method*

Above figure shows the population growth per year. From the above data we can conclude that population of the town increased at greater rate (more than 25%) in 1951, 1961, 1971 and 2011, while in 1941, the population has decreased (-) 17.24%.

B. **Distribution of Population**

The population distribution means the spatial arrangement of people in a region which is, mainly based on the aggregate of investigations about the people within small real units of a region population distribution is a dynamic process which is ever changing and its cause and effect very in a spatial-temporal frame (Clerk, 1973). The spatial distribution of population in the Bina town is shown in Table 3. Ward-wise population data for year 2011 has been used to show the spatial distribution of population and density in Bina town (Fig. 5). It is notice that the ward no. 08 has a highest population, while ward no. 18 has a lowest population. Ward no. 05, 09, 13 & 16 have a highest population density (more than 500 person per hectare), while ward no. 01, 07, 20 & 25 have lowest population density (less than 25 person per hectare).

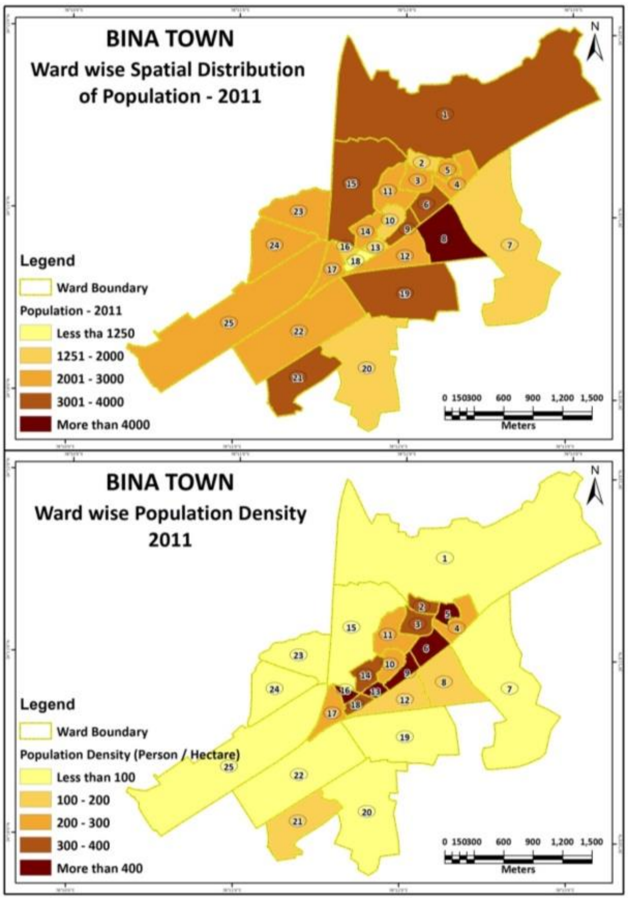

Figure 5: Ward wise spatial distribution of population and density - 2011

The overall population distribution in the Bina town is closely related to the physical and socio-cultural factors. Population distribution is a dynamic process which manifests the varying natures of mains adjustment with physical resources. Population density has been in encountered under various typology previews to reveal different aspect of population distribution.

TABLE III

WARD WISE SPATIAL DISTRIBUTION OF POPULATION AND DENSITY

S.No.	Ward No.	Ward Name	Population 2011 (Census of India)	Population Density (Person / Hectare)
1	01	Pratap Ward	3,514	17.65
2	02	Madia Ward	1,488	335.90
3	03	Khiria Ward	2,557	345.10
4	04	Kannoongo Ward	2,330	240.84
5	05	Katra Ward	2,392	584.07
6	06	Jawahar Ward	3,727	437.42
7	07	Chandrashekhar Azad Ward	1,860	20.32
8	08	Veer Sabarkar Ward	4,850	195.80
9	09	Achwal Ward	3,399	650.02
10	10	Pathak Ward	1,548	248.17
11	11	Manorma Ward	2,711	212.68
12	12	Shastri Ward	2,900	179.46
13	13	Bilgainya Ward	1,557	571.89
14	14	Subhash Ward	2,853	384.33
15	15	Shivaji Ward	3,769	74.88
16	16	Maszid Ward	1,887	771.16
17	17	Ram Ward	2,277	250.45
18	18	Shiv Ward	1,203	349.66
19	19	Gandhi Ward	3,211	61.66
20	20	Rajiv Ward	1,425	23.47
21	21	Bheem Ward	3,144	117.09
22	22	Ganesh Ward	2,967	48.15
23	23	Indira Gandhi Ward	2,291	99.06
24	24	Nanak Ward	2,345	94.55
25	25	Bhagwat Singh Ward	2,325	23.72
		Total	64,529	253.50*

** Average population density*

C. **Urban Expansion**

The urban periphery area is frequently described by a conflict between contending needs for area from many types of improvement. To keep away from disarray and to ensure the nature of the earth, dynamic, since quite a while ago settled and publicly recognized planning is essential to: develop the infrastructure; avoid urban coalescence; safe agricultural activity; and give recreational access. Good planning and sufficient organization are vital however these are just conceivable if they are based on consistent, precise and up-to-date data. Generally, in Bina (Madhya Pradesh) India, there have not been the accessible assets to map, plan, and screen improvements in a satisfactory and convenient style. These days, owing to the accessibility of distinctive satellite information and auxiliary data, GIS can be created and urbanization and urban expansions / monitoring / developments / changes can be observed substantially all the more successfully.

The shape of the Bina town is based on the railway line which has situated in surrounding the town. Multi-temporal remotely sensed data (Landsat - 1, 3, 5, 7, 8, and IRS LISS-III data) were used for this urban extent mapping, which is provided a visual and historical perspective of the urban expansion experienced in Bina town between 1972 and 2014. We adopted a simple method of vectorization directly on the images of different dates to find ‘where’ the urban had extended. ArcGIS-10.2.2 software was used to assemble and integrate the data in order to create the spatio-temporal urban map for the Bina Town (Fig. 6).

It is evident from the interpretation and integration of multi-temporal and multi-resolution aerospace data and other maps that Bina town has experienced a significant urban growth in the period of 1972 to 2014. The change detection shows that the urban area of Bina town was respectively 333.72 Ha in 1972, 353.14 Ha in 1981, 371.90 Ha in 1990, 389.85 Ha in 2000, 423.60 Ha in 2010, and 437.94 Ha in 2014 (Table 4). This town had extended by 104.22 Ha in the period 1972-2014 at a growth rate of 02.48 Ha/year. An urban expansion trend of Bina town is shown in Fig. 7.

TABLE IV

URBAN EXPANSION CORRESPONDING TO THE POPULATION GROWTH IN BINA TOWN

Year	Population	Population Growth	Area (in Hectare)					
	(No.)	(No.)	Urban	Rural	Total	Change in Urban	Change in Rural	Total Change
1931	10,849							
1941	8,979	(-) 1,870						
1951	12,720	3,741						
1961	24,476	11,756						
1971-72	33,476	9,000	291.56	42.15	333.72			
1981	33,886	410	308.96	44.18	353.14	17.39	2.02	19.42
1990-91	41,621	7,735	325.47	46.42	371.9	16.51	2.24	18.75
2000-01	51,181	9,560	337.59	52.26	389.85	12.12	5.83	17.95
2010-11	64,529	13,348	367.03	56.57	423.6	29.43	4.31	33.75
2014	-	5,486*	376.55	61.38	437.94	9.52	4.81	14.33

** Population growth (No.) through the yearly average estimation*

The urban expansion and LULC change in the Bina town has been and still is, fast and almost uncontrolled. The increase population and rapid urbanization causes great change in the town and the problem of the expansion in town, from Etawa village (old town) to Bina town nearby the railway junction is complex by the fact that, it must take place within the built-up area which is not possible.

More than half of the total population of Bina live along the transportation line i.e. railway line and major roads. The areas between three railway lines close to old Etawa town have contained the most raised centralization of Bina town settlements. Most of the core functions of the town are also located here. The area has been quickly, and continuously, changing since 1923 when a new railway junction was established near the Etawa village. There are both old and new settlements, residential expanses are contrasted with occupational, and there have been unembellished losses of greenspace in the urban areas. Housing covers the private, community, and co-operative sectors and includes all social levels. The variety of kind and style of housing is moderate, and can be characterized by structure typology and historic expansion: slums, separate and semi- separate houses; terrace-houses, and apartment blocks, all of which can be observed at different locations in the area.

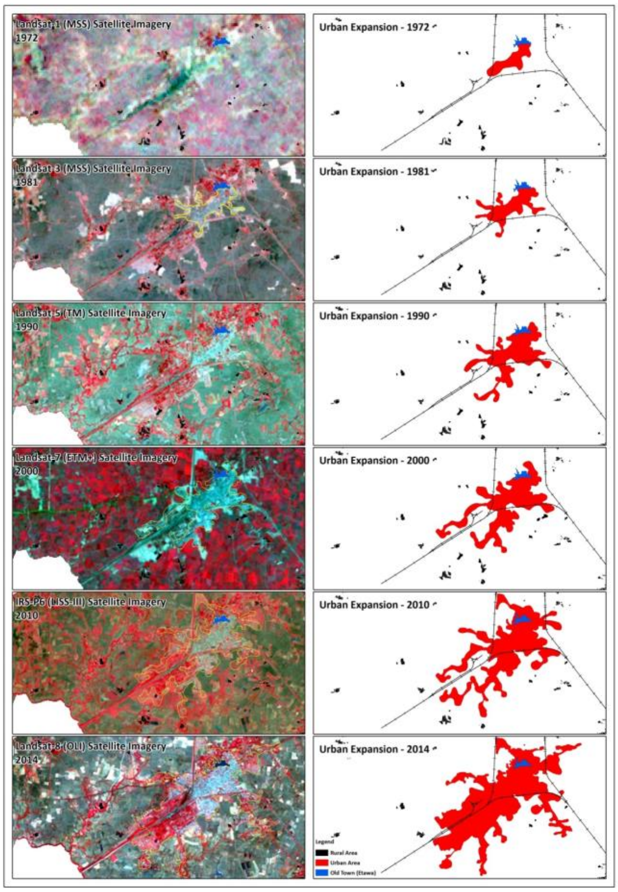

Figure 6: Spatio-temporal urban map of Bina town

Thus the pressures of the continuous growing town center gradually change the surrounding environment and neighborhoods. Sprawl generally refers to some type of development with impacts such as loss of agricultural land, open space, and ecologically sensitive habitats. In simpler words, as population increases in an area or a town expands to accommodate the growth; this expansion is considered as sprawl. Usually sprawls take place on the urban fringe, at the edge of an urban area or along the railway as well as major roads.

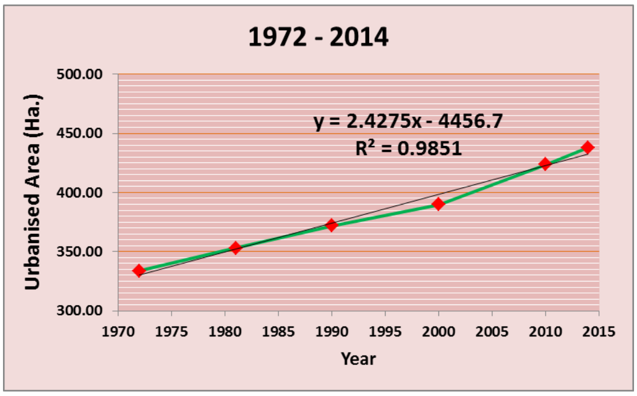

Figure 7: Urban expansion trend of Bina town- past, present, and future

D. Accuracy Assessment

Classification without a proper objectively done accuracy assessment is not complete (Lillesand, 2000). Accuracy of LULC classification for year 2014 was performed using random sample of size 103. Lagging the base information it was not possible to estimate the accuracy of LULC map of year 1972, 1981, 1990, 2000, 2010.

The sample was established inside the boundary of study area. The LULC of these sites was estimated with a sample footprint of 3m by 3m. Based on the reference and map LULC classes a confusion matrix was created (Table 5). User accuracies for various lands cover classes ranged from 83% to 100% while producer accuracy ranged between 67% to 100%. In both cases the built-up cover classes have accuracies better than 96%. The total accuracy of the LULC map was estimated to be 95%.

E. Modern Day Bina Town

Previously Bina town was known as Etawa village. In 1923, a new railway junction was established near the Etawa village (old town) then the town has developed between the Etawa and new Bina junction and other part of the town has developed along the state highway. The roads inside the old town are extremely narrow which makes movement of heavy vehicles difficult. Moreover, owing to having old habitats, widening of roads is not possible. SH-14 (from Sagar to Kurwai), SH-42A

(Bina to Khimlasa) and Bina Refinery Road play important role in the development of the town as all the major facilities, services, government offices, institutions are developing along these roads. The residential areas of the town are developing around these roads while the agricultural areas along the state highways are feeling the pressures of development. At present, the shape of the town is "Connective Patterns". The dynamic growth map of Bina town is shown in Fig. 8.

TABLE V

CONFUSION METRICS FOR ACCURACY ASSESSMENT OF LULC CLASSIFICATION OF YEAR 2014

Land Use / Land Cover Classes	Rural Settlement	Urban Settlement	Industrial Area	Agricultural Crop Land	Agricultural Fallow Land	Open Land	Forest	Rocky / Barren Land	River	Tanks / Reservoir	Number of Sample	User Accuracy
Rural Settlement	17	1									18	94.44
Urban Settlement		26	1								27	96.30
Industrial Area			8								8	100.00
Agricultural Crop Land				17	1						18	94.44
Agricultural Fallow Land					13	1					14	92.86
Open Land						5					5	100.00
Forest							5	1			6	83.33
Rocky / Barren Land								2			2	100.00
River									2		2	100.00
Tanks / Reservoir										3	3	100.00
Number of Sample	17	27	9	17	14	6	5	3	2	3	**103**	96.14
Producer Accuracy	100.00	96.30	88.89	100.00	92.86	83.33	100.00	66.67	100.00	100.00	92.80	
											Total Accuracy =	**94.47**

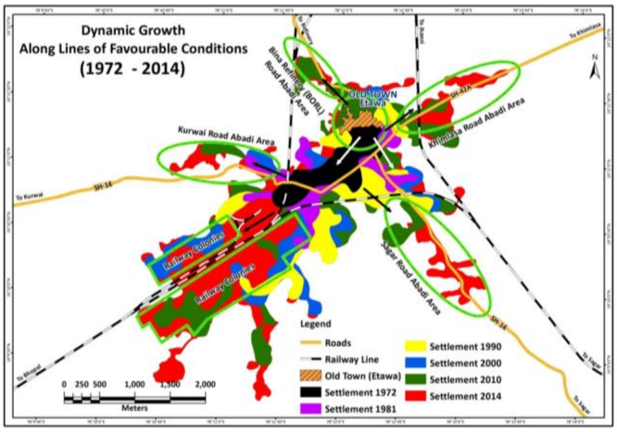

Figure 8: Dynamic growth map of Bina town (1972 - 2014)

VI. CONCLUSION

Our research shows the dynamics of change in the urban area in Bina town of Madhya Pradesh. Historical overviews of urban development provide insights into future development and expansion trends. The maps and database can contribute to the research and technology base needed to understand the dynamics of urban phenomena.

The study of Indian cities in transition with example of Bina town successfully demonstrated the utility of integrating multi-temporal satellite imagery with GIS database to dynamically urban land characteristics. A new urban planning, considering the factors such as lines of favourable condition and urbanisable area choice, is recommended to improve the present situation and control the future expansion of the town.

VII. ACKNOWLEDGMENT

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