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Remote Sensing Application in Monitoring Impact of Mining Activities on Urban Growth. Case of Makrana Marble Mines, India

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A B S T R A C T

The main focus of this study is to ascertain the relationship between urban and mining growth of Makrana City using remote sensing and spatial metrics. This relationship was assessed on the basis of information extracted by temporal remote sensing data from 1972-2012. To establish the relationship, the satellite data are classified into built up and mining area. Over the four decades there has been vast increase in built up of the city, by 1345 hectare, along with the significant increase of the mining area by 148 hectare during the same period. There is huge increase in consumption rate and absorption coefficient; especially high absorption coefficient found during 2003-2012 for mining and built up indicated enormous increase in growth of city. The FRAGSTATS tool is used to evaluate the urban growth with change in mining area. The results showed that built up area and mining area changed significantly over time. The analysis also exhibits a spread out pattern of built up area development with huge growth in city periphery. Most of new built areas are developed near and along the mining area. The remote sensing data integrated with spatial metric approach provides important information that can be used to understand the mining growth impact on urban development.

1. INTRODUCTION

Economic growth and urbanization are linked with each other. Economic growth often triggers the conversion of rural land into urban land [1]. Economic growth of any area depends on the availability of resources. Minerals are good resource for industrialization, playing an important role in the economy. As economy of India is mainly based on agriculture and its availability of good mineral resources enhances the growth. The more industrialization matured, the more opportunities are created for work and investment [2]. The availability of mineral resources increases the industrial activities and it attracts more people to cities as consumers or workers. Industrial development activities facilitate urban areas to grow [3].

Urbanization is the social process whereby cities grow and societies become intensely urbanized. Urbanization is significant all over the world. There are many factors that influence urbanization such as population growth, good prospects for livelihood, good availability of facilities etc. [4], [5].

Conventional surveying and mapping techniques are time consuming and costly. The information on urban sprawl is not readily available in case of most of the urban centers, especially in the developing countries. Mapping from remote sensing techniques has several advantages because it is synoptic, repetitive and multi temporal. Remote sensing technique is also cost-effective. Remote sensing technique also provides information of change in magnitude, direction and pattern in land use. It is a versatile tool for mapping and monitoring of natural features as well as manmade features. Subsequently, there is an increasing research interest towards the use of remote sensing techniques for urban studies [4], [6], [7].

Landscape is comprised of spatial patches categorized in different patch classes used for spatial metric calculation [8]. Spatial metrics provide a platform to assess change in land use patterns over time [9]. Spatial metrics analysis is significant for the quantitative characterization of spatial composition and pattern of urban growth. Remote sensing integrated with spatial metrics can provide more efficient and effective spatially reliable information of urban change [10].

The present study approaches the marble mines of Makrana city which is part of Nagaur district of Rajasthan, India. These mines have one of the world major deposits of marbles. Makrana marble is a metamorphic rock having 90 to 98 percent $CaCO_3$. Makrana has various mining ranges, popularly known as Doongri, Devi, Ulodi, Saabwali, Gulabi, etc. The Makrana marble has made a perceptible dent in marble industry because of its blockability, whiteness, high CaO (50-56%), low MgO (0.90–1.77%), as compared to other marbles [11]. Marble mining has very good prospects in Rajasthan state. Rajasthan has more than 90% of Marble deposits of India. Makrana is the third largest producer of marble. It accounts for 13% of the total marble production in the Rajasthan state. The production of Marble was of 63.420 thousand tons in 1970; it reached to 5,686 thousand tons in 2002 in Rajasthan State. In 1970, the revenue collected by marble was of 679.600 thousand rupees, which reached to 780,313 thousand rupees in 2002 in Rajasthan [12]. Mining in Makrana is significantly inducing industrialization in the city. There is a huge potential of mineral-based industries in the area. The present rate of marble production of Makrana is of 0.12 million tons per year, with annual revenue of Rs 360 million [13]. Thus, there is a vast increase in Marble Cutting and Polishing units in the area. Mining based industries are providing lots of job opportunities to local communities as well as for people who are living nearby the city.

The changes in built up area and mining area are quantified by using multi temporal remote sensing data. The main objective of this paper is to assess the changes in built up area for a period of 30 years due to increase in marble mines of Makrana city by applying remote sensing and spatial metrics.

This information is used to establish a harmonic relationship in mining development and built up growth.

2. STUDY AREA

Makrana is located at 27°03′N/74°43′E-27.05°N/74.72°E in the Nagaur district of Rajasthan state of India. Makrana has plenty of marble outcrops. Makrana is famous for the white marble mined from the mines around it. It has an average elevation of 408 meters (1338 feet). It is said that the Taj Mahal was built from Makrana marble.

The marble mines are located in the vicinity of the Makrana city. Thus, they are directly affecting the built environment of the city. This area has vast marble deposits which provide opportunities to lots of people to grow. This area has plenty of prospects to study the impact of mining on land use change with special attention on urban sprawl. Therefore it is an interesting location to assess the influence of mines on urban sprawl.

3. METHODS AND MATERIALS

The influence of mining on urban sprawl is assessed using Landsat satellite data of September 1972, October 1989, October 2000, February 2003 and March 2012. Reports of Census of India and Department of Mine and Geology were also used as secondary data. Landsat data were classified by using uniform method for analysis of satellite data. The data were classified into two categories i.e. built area and mining area. The change in urban area is represented by built up category of land use in this study.

Built up area is defined for settlements including residential, commercial and industrial area existing in the Makrana city. The built up area is captured for the Makrana city and surrounding of the mining area of Makrana. Built up area is captured using satellite data and Erdas software. At the beginning, all satellite data are brought on common enhancement level using enhancing tools (such as linear stretching and histogram equalization) of Erdas. Area of interest layer is prepared using AOI tool of Erdas to capture and differentiate built up area from the rest of satellite data. The supervised method is used by selecting reflectance signature for classification of built up area. Classified built up data are re-checked with satellite data to find out wrongly classified or missing pixels and these pixels were updated adequately. The same method of classification of satellite data was used for all years.

Mining area was also classified using same satellite data for same period. Satellite data enhanced using linear, data scaling, Gamma and Gaussian methods for efficient mapping of mining area. The marble deposit map from Natani (2007) is used as reference for the identification of location of mining area during classification using satellite data. Mining area is mapped by creating an area of interest around mines, then classified using supervised method. The same method is applied for the classification of mining area for all four-year data.

Consumption rate, absorption coefficient and spatial metrics are used to assess the relationship between mining and urban growth. The following equations were used to calculate the consumption rate and absorption coefficient. The formulas for the consumption rate and absorption coefficient are given below:

$$CR = A/P$$

where:

CR – consumption rate;

A – area extent of land use class;

P – population.

$$AC = A_2 - A_1 / P_2 - P_1$$

where:

AC – absorption coefficient;

A_1, A_2 – area extent early and later years;

P_1, P_2 – population figure for the early and later years.

Population data used in this research was obtained from the Census of India. This population data was not available exactly for the same year of land use map, so projected population data was used for analysis [15]. Spatial metrics using FRAGSTATS version 4.2 have provided platform for the description of spatial structure and pattern of change [14]. In this research, urban landscape heterogeneity is assessed for urban and mining area. FRAGSTATS has been used for the calculation of metrics.

The extent of subdivisions of urban and mining area is measured by using number of patch (NP) metrics. Largest patch index (LPI) at the class level quantifies the percentage of total landscape area comprised by the largest patch. As such, it is a simple measure of dominance.

The Edge Density (ED) measures the total amount of the edge of the urban patches divided by the total landscape area. ED increase with the new urban development and decrease with merging and fusing of urban patches. The edge density (ED) metrics is used to measure the total length of edges of the built up and mining area patches.

The area weighted mean patch fractal dimension (AWMPFD) is used to measure the shape complexity of urban and mining patches. Higher fractal dimension values indicate that patches are more complex and fragmented in shape. AWMPFD value ranges between 1 and 2, and as the value increases for AWMPFD, it means that built up or mining area is moving to more irregular and complex shape, whereas if a value is near to 1 then it indicates the relatively simple shape such as rectangular, circle or square.

Table 1. Spatial metrics used for the study.

Metrics	Description/ Calculation Scheme	Units
NP—Number of Patch	NP equals the number of built up and mining patches in the landscape.	None
LPI—Largest Patch Index	LPI equals the area (m^2) of the largest patch of the corresponding patch type divided by total landscape area (m^2), multiplied by 100 (to convert into percentage)	Percent
AWMPFD—Area Weighted Mean Patch Fractal Dimension	Area weighted mean value of the fractal dimension values of all urban patches, the fractal dimension of a patch equals two times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2); the perimeter is adjusted to correct for the raster bias in perimeter.	None
ED—Edge Density	ED equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert into hectares).	Meters/ Hectare

4. RESULTS AND DISCUSSION

The significant increase in built up and marble mining area has clearly been seen in the last 40 years. The temporal satellite data represents the degree of increase in mining as well as in built up. The built up area of Makrana city was concentrated only in the city peripheral in 1972, but gradually increased on the periphery. The built up patches near the mining site have gradually increased from 1972 to 2012. Figure 1 shows the built up area and mining area of Makrana city for the years of 1972, 1989, 2000, 2003 and 2012. By analyzing these figures it can be concluded that there is considerable increase in built up and mining area during this period. Built up area away from city in 1972 is enormously increased in the year 2012. As shown in table 2, the built up area increased by 109.57 hectare during 1972-1989, by 103.15 hectare during 1989-2000, by 126.79 hectare during 2000-2003 and by 1005.78 hectare increased during the period from 2003 to 2012.

The built up area increased by 1345.31 ha during 40 years from 1972-2012. Mining area has changed by 25.0173 ha during 1972-1989, by 58.8069 ha during 1989-2000, by 65.1078 ha during 2000-2003 and by 217.86 ha during 2003-2012. The total change in mining area during 1972-2012 is of 366.79 hectare. Thus, the annual increase in mining area is of 9.17 ha from 1972 to 2012.

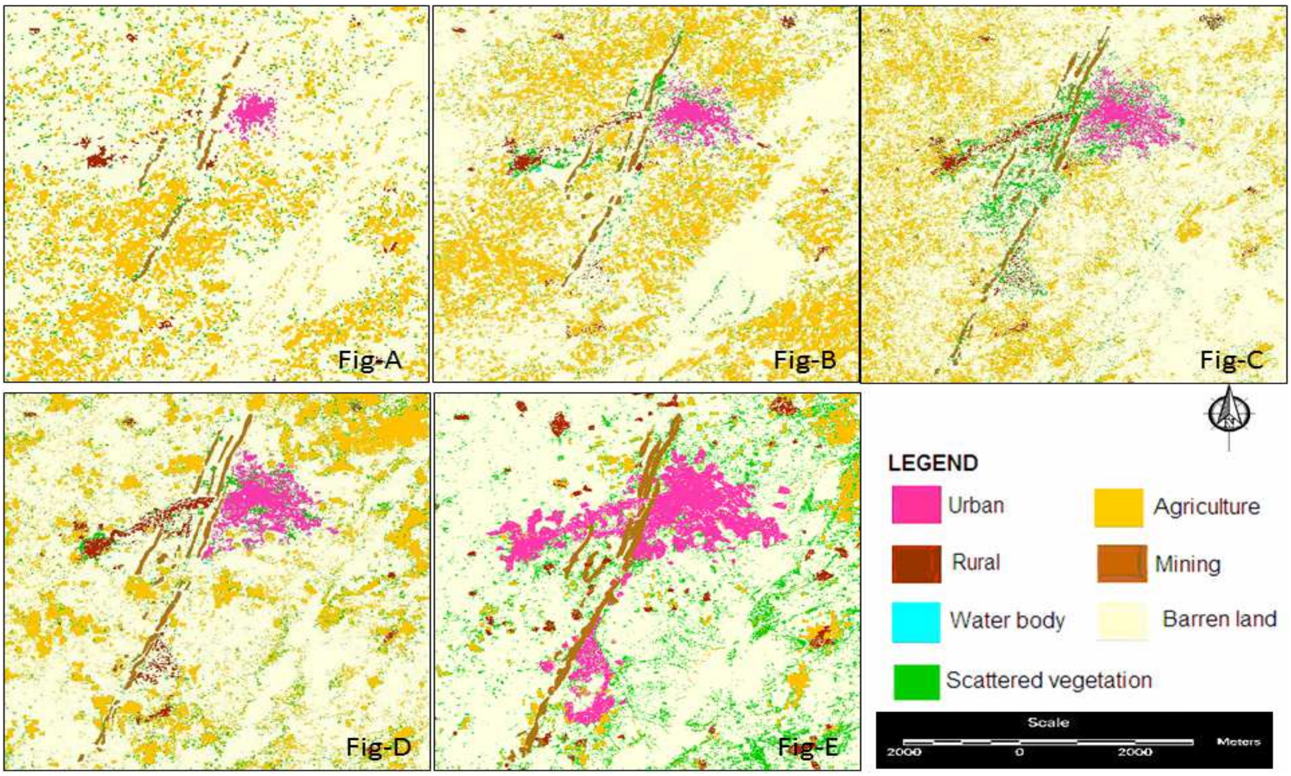

Fig. 1. Built up and Mining Map of 1972 (Fig-A), 1989 (Fig-B), 2000 (Fig-C), 2003 (Fig-D) and 2012 (Fig-E).

Table 3 shows the consumption rate and absorption coefficient of built up and mining areas. After analyzing data in table 3 we note that there is a continuous increase in land consumption rate of built up area of 0.00578, 0.00408, 0.00442, 0.00568 and 0.1253 corresponding to the years 1972, 1989, 2000, 2003 and 2012 and land consumption rate for mining area is of 0.00587, 0.00270, 0.00280, 0.00342, and 0.00426 for the same years. The land absorption coefficient for built up is of 0.00300 during 1972-1989, 0.00548 during 1989-2000, 0.00787 in 2000-2003, 0.02898 during 2003-2012 and 0.01419 during 1972-2012. For mining land absorption coefficient in 1972-1989 was 0.00068, in 1989-2000 was 0.00312, in 2000-03 was 0.00404, in 2003-2012 was 0.00627 and in 1972-2012 was 0.00386. The land absorption coefficient values, higher during 2003-2012 for built up and mining as compared to previous period, indicate that the enormous increase in built up and mining area and huge growth as compared to the past implies that it will increase in future, as well. The consumption rate of mining is assessed with production of marble with available data of production and revenue of marble mining. The marble production from Makrana mines was of 466.66 thousand tons in 1997-98; revenue for this period was 101688.57 thousand rupees, whereas in 1998-1999 the production increased to 486.01 thousand tons and revenue increased by 107817.45 thousand rupees for this fiscal year. In 1999-2000 production reached to 581.62 thousand tons and the revenue collected for this was of 131744.23 thousand rupees. During 2000-2002, the production of marble was of 773.37 thousand tons and revenue from this production for this period was 190786.52 thousand rupees [16].

Table 2. Change, trend in urban and mining.

Category	1972-1989		1989-2000		2000-2003		2003-2012		1972-2012	
	Built up	Mining	Built up	Mining	Built up	Mining	Built up	Mining	Built up	Mining
Area change (ha)	109.57	25.01	103.15	58.80	126.79	65.10	1005.78	217.86	1345.31	366.79
% Change	0.57	0.13	0.54	0.31	0.66	0.34	5.3	1.15	7.08	1.93
Annual change	6.44	1.47	9.37	5.35	42.26	21.71	111.75	24.21	33.63	9.17

Table 3. Land consumption rate and land absorption coefficient of urban and mining.

Consumption rate			Absorption Coefficient		
Year	Built up	Mining	Year	Built up	Mining
1972	0.00578	0.00587	1972-1989	0.00300	0.00068
1989	0.00408	0.00270	1989-2000	0.00548	0.00312
2000	0.00442	0.00280	2000-2003	0.00787	0.00404
2003	0.00568	0.00342	2003-2012	0.02898	0.00627
2012	0.01253	0.00426	1972-2012	0.01419	0.00386

4.1. Spatial metrics based analysis

Landscape metrics have been calculated for different land use classes to ascertain change in their spatial structure, complexity, size and shape using FRAGSTATS 4.2 [14]. The results of spatial metrics have been displayed in Figure 2. In this analysis urban, rural and mining classes are used to understand the spatial relationship between built up and mining development. Also, urban and rural classes have been combined as built up in this research. Figure 2 has all four spatial metrics – number of patch (NP), landscape patch index (LPI), edge density (ED) and area weighted mean patch fractal dimension (AWMPFD) – analyzed in this study.

NP is a landscape metric that indicates the level of fragmentation of built up and mining area. Figure 2a illustrates that the city is becoming clumped patch at the center, while the outskirts are relatively fragmented, and the same trend can be seen in case of mining. This indicates that built up and mining area classes patches are increasing during the study period. Both classes are showing the same type of trend in increase of patches such as patches are increased from 1972 to 2000 and then decreased from 2000-2012 for both classes. The decrease in number of patches in 2012 indicated that built up and mining area became more compact. Built up class is following the mining trend as new patches are increasing along and near the mining excavation in study area.

Increase in the LPI values implies increased built up and mining patches during the study period, especially in the E and W direction along the mining. Higher values at the center indicate the aggregation at the center and on the verge of forming a single urban patch, whereas largest patches were found in E direction (2003). LPI is having continuous increase from 1972 to 2012 for both classes (Figure 2c). This increase indicated considerable growth in built up and mining area during this period. The LPI has increased by 639% from 1972 to 2012 for built up class, while LPI increased by 366% from 1972 to 2012 for the mining area. Built up areas have highest LPI increase from 2003 to 2012, mining area also having the maximum LPI increase during 2003-2012. This LPI indicates the increase in patch size of built up as well as of mining.

ED always increases with a greater number of patches within a reference area and decreases with merging and fusing of patches. ED is increasing for built up and mining area during 1972-2012. Built up and mining area classes indicated that there is enormous increase in fragmentation and development of built up and mining areas during 1972-2012 (Figure 2d). Mining area increased during 1972-2012, which indicates a new mining area development. ED maximum increase during 2003-2012 for built up and mining area indicates huge increase in new developments.

Fractal property of patch has been measured area weighted mean patch fractal dimension (AWMPFD) to find out shape complexity and this also improves the measure of class patch fragmentation. If the value is greater than 1 indicates the increase in shape complexity and near to 2 then shape is more complex. AWMPFD was increasing for built up and mining area from 1972 to 2012.

However, AWMPFD exhibits more or less no major changes but shape remains complex during the study period. This implies that an increase in NP, LPI and ED, in this context, does not affect the shape complexity as new built up and mining area is taking place in and around Makrana city.

Built up area and mining patch values increased from 1972 to 2000 and then decreased from 2000 to 2003 for both classes, which indicates that developed area of both classes are moving towards compact patches. In 1972, both built up area and mining area were small, which is confirmed by small LPI and NP values, whereas high LPI values in 2012 implies that built up area and mining area converted into large areas. By 1989, NP values increased enormously especially for built up area and also increased for mining area with an increase in AWMPFD value, which indicates that built up and mining area started to spread outward. The high value of LPI in 2012 correlated with a decrease in the NP and a slight increase in AWMPFD for built area indicate that the built up area has become more homogeneous. Mining area has also the same trend in 2012, which implies close correlation of built up and mining growth. The 2003 and 2012 maps show that built up area expansion occurred in linear pattern west and south of the city. This west and south linear expansion of built up along the mining area, indicated an increase in development of urbanized patches at some distance from core built. This increase in built up is confirmed by increase in ED value. The high value of ED and AWMPFD in 2012 reflected that increase in size and the fragmentation of built up area and same trend is revealed by mining area in 2012.

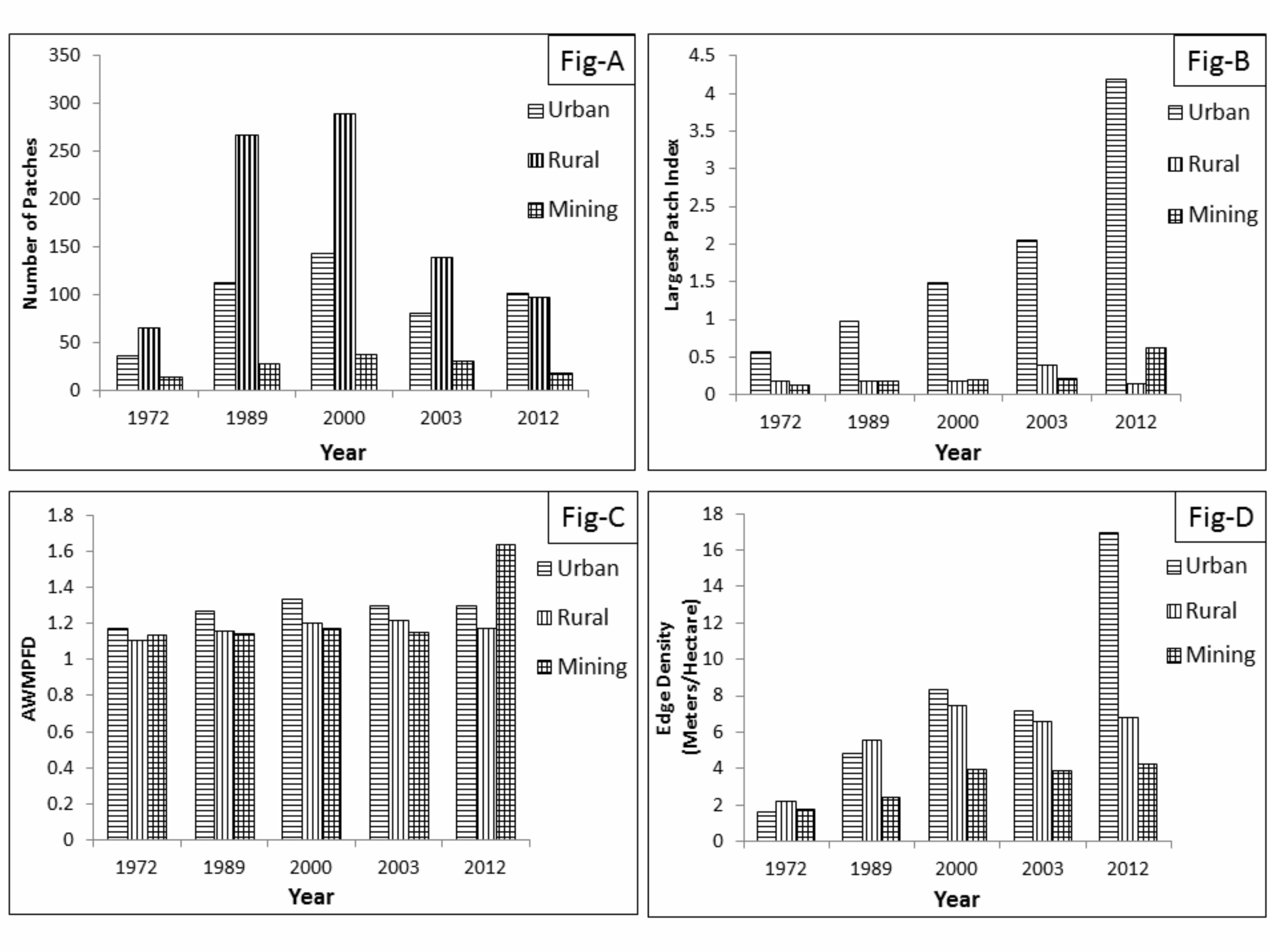

Fig. 2. Spatial metric change analysis for built up and mining area using FRAGSTATS *(refer to Table 2 for parameter descriptions).*

5. CONCLUSION

The remote sensing satellite data provide useful information about the trend of urbanization as well as for mining in this study area. Remote sensing technique integrated with spatial metric provided an approach to demonstrate the dynamic phenomena like built up and mining.

The results of spatial metric of built up and mining area have shown similarities in change of parameters indicating that built up area and mining development have some similar growth trend. Figure 2 clearly showed this trend. The built up growth along mining area indicated that this growth has had certain impact on mining development. This built up development is also verified by the increase in values of ED and AWMPFD from 1972 to 2012. The rapid increase in built up contributed to the high increase in NP and the same trend is reflected in mining growth.

These spatial data have been analyzed for defining the relationship between urbanization and mining. There is considerable increase of 306.71 thousand tons in production of marble during 1997-2002 with the annual increase of 61.34 thousand tons from 1997-2002, whereas revenue from 1997-2002 increased by 89,097.95 thousand rupees with an annual increase of 17,819.59 thousand rupees. If we compare the production of marble during 1997-2000 increased by 114.96 thousand tons and in 2000-02 it increased by 191.75 thousand tons in only 2 years. The revenue was increased by 30,055.6 thousand rupees during 1997-2000 whereas in 2000-2002 it increased by 59,042.29 thousand rupees.

In 2000-2003 the absorption coefficient for urban was the highest in comparison with the absorption coefficient of other periods. Makrana marble mines in that area is one of the best resources for the people as it is providing resources for living in that area with the increase in population and urbanization.

These rich deposits in the vicinity of the city are providing jobs for more than 100 thousand people out of which 60 thousands are deployed directly in mining. Indirect employment in mining includes transporters, mechanics/workshop owner, masons, artisans etc. This will provide more opportunity to grow the population in Rajasthan.

This relationship between built up and mining plays an important role for the local development authorities and municipality. Also this relationship can be used to predict and quantify urban growth; this can be used for optimal planning of the land and natural resources. In the absence of planning policies it can cause degradation of land, therefore, it is important to implement policies for planning the built up area as well as techniques for management of the mining for better use of land for longer span of time.

Remote sensing technology is indispensable for dealing with dynamic phenomena of land use. Without remote sensing data, one may not be able to monitor and estimate the built up and mining growth effectively, for the elapsed time period especially in developing countries.

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