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Research Article

Rapid Urban Expansion and Its Implications on Geomorphology: A Remote Sensing and GIS Based Study

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Topography, vegetation, climate, water table, and even the anthropogenic activities all are affected by urban growth through diverse mechanisms. The present study focuses on the implications of urban expansion on geomorphology in the historical city of Gwalior in central India. The expansion of urban area has been quantified by deriving data for four decades (1972–2013) from the Landsat images. The results show that the urban built-up area has increased by 08.48 sq. km during the first eighteen years (1972–1990) which has increased to 16.28 sq. km during the next sixteen years (1990–2006). The built-up area has gone up to 23.19 sq. km in the next seven years (2006–2013). Overall during the last 40 years the growth of the urban built-up is nearly three times of the built-up areas in 1972. The average decadal growth rate of population is 27.28 percent while that of built-up land is 36.29 percent. The construction activities have affected important geomorphic features such pediplain, buried pediplain, residual hills, and denudational hills. It was concluded that, instead of shortsighted urban development, proper measures should be taken in accordance with scientific planning for the urban expansion of the city in the future.

1. Introduction

Urbanization and urban growth has been considered as one of the essential indicators of economic growth and development of a country. Along with the increase of population, cities are growing rapidly in physical dimension in the past few decades. This process of urbanization has brought about significant changes in landscape pattern and land cover of the area concerned. At the same time it has caused various negative effects in terms of physical environment such as loss of agricultural land, surface and groundwater depletion, changes in geomorphic features, flooding, and landslides. With the increase of population day by day it has become inevitable to adopt proper urban planning to attain a sustainable environmental stability of an area. Rapid growth of urbanisation along with poor planning and unregulated industrial activities causes contamination in surface as well as groundwater [1]. In urban geomorphology man acts as physical process to change the natural terrain to cityscape. Urban geomorphology is the surface component of urban geology and forms the important subfield of environmental geology [2]. Towns and cities are mostly expanded in accordance to the relief of the terrain and the relief changes as per the planning and needs of construction [3]. The other factors that influenced the geomorphological process in the urban environment are the weathering of the building stones due to air pollution [4]. Anhert [3] was of the opinion that settlement geography is incomplete without taking into consideration the morphology and hydrology of an area.

There is a need to understand the dynamic interaction between the different aspects of urban expansion as expansion of built-up area, construction activities over natural features which cause diversion and destruction of aquifers, and the specific geomorphic features of the urban area. The streams become overloaded with sediments and thus change the courses. [5, 6]. The groundwater supply of the urbanised area also gets reduced and as a result drainage frequencies increase [7–9]. The local landforms or geomorphic features have played a very crucial role in the establishment and development of settlements in the history of civilization. A settlement to flourish has always taken advantage of local topography or relief and the hydrological conditions.

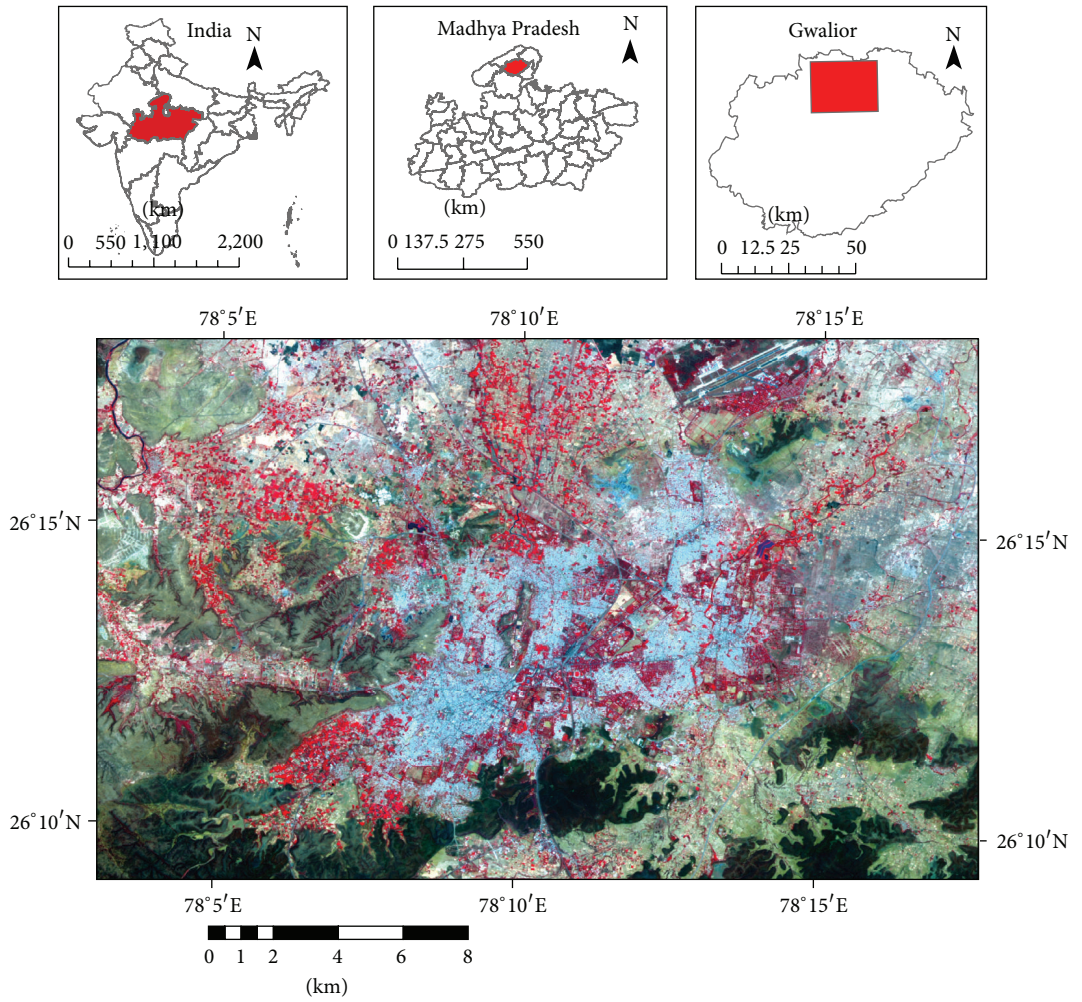

Figure 1: Location map of the area.

The expansion of a city over the years and the construction activities gradually alter the topography of the area. These changes ultimately affect the rate of geomorphic process such as weathering and erosion [4].

As a result in the long run various geoenvironmental problems mentioned above start to play their role with the increase in human activities. To address this issue multisensor satellite data products over four decades have been used to quantify the urban expansion of the historical city of Gwalior. Satellite data have been extensively used by the researchers [10–25] all over the globe to study the urban expansion and their problems due to the availability of high resolution images.

2. Study Area

Gwalior, the historical city of Madhya Pradesh, is well known for its magnificent fort and the royals of the Scindia dynasty worldwide. The region is also well remembered for its role in the 1857 revolt and also for Rani Lakshmi Bai's heroic resistance. Gwalior city was the capital city of the princely state of Gwalior until 1948 and the summer capital of Madhya Bharat State from 1948 to 1956. When Madhya Bharat became part of Madhya Pradesh, it became a separate district. Historically, in 18th A.D. hermit-saint Gwalipa cured a Chieftain Suraj Sen from a deadly disease. Suraj Sen named this city by his name as gratitude. With the different dynasties that ruled the city of Gwalior, it was renowned not only by the warrior kings but also by the famous poets, musicians, saints, and freedom fighters (http://www.Gwalior.nic.in/). After independence, the city has gained a status of a major urban centre of Gwalior Chambal division due to industrial expansion and migration of people from the surrounding areas. The Gwalior city is located in between 26°10′–26°18′N latitude and 78°6′E–78°15′E longitude with an average elevation of 212 m. Geographically it is well connected with both roads and railways. It is well connected with other parts of the state as National Highway 3 and National Highway 92 passes through it. The location map is given in Figure 1. It is the administrative headquarters of Gwalior district and Gwalior division. The Gwalior city is the largest urban and commercial centre for the surrounding districts of Morena, Bhind, Sheopur, Datia, Guna, and Shivpuri. The area of Gwalior Municipal Corporation is about 173.65 sq. km.

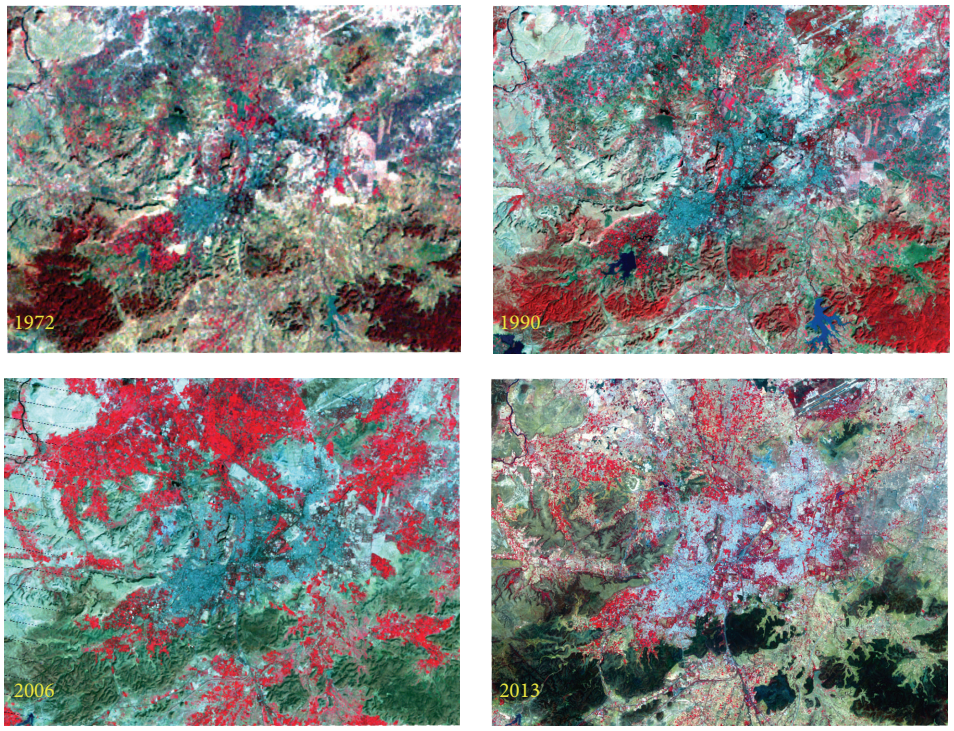

Figure 2: Different years FCC of Landsat images.

3. Materials and Methods

Since the study is based on the geospatial technology, Landsat satellite data for four different years, namely, 1972, 1990, 2006, and 2013, have been used. The logic behind selecting such years is the availability of error-free data for the study region. As mentioned earlier the time span of the study has been about four decades; hence, the data products used comprised different sensors and different Landsat series. The sensors are Multispectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM^+), and Operational Land Imager (OLI) of Landsat 1, Landsat 5, Landsat 7, and Landsat 8, respectively. The details of the digital satellite data used along with the sensor and path/row of the satellites have been given in Table 1. MSS has 04 bands, TM has 07 bands, ETM^+ has 07 bands, and OLI -TIRS has 11 bands. Out of all the bands data available three bands (Infrared, Red, and Blue) were selected for each data to make the respective False Colour Composite of the study area. Hence bands 432 for MSS and TM, bands 543 for ETM^+ and bands 654 for OLI were selected to make the FCC for the years 1972, 1990, 2006, and 2013, respectively (Figure 2). Apart from the satellite data other data used were the Topographic Sheet of the area and different census data. Use of GIS in any urban planning and development work has become one of the key components today. It can be used as database and also as tool box. In the present study GIS has been used not only for the creation of spatial database but also for creation of shape file. The GIS tool box allowed us to perform the spatial analysis, geoprocessing, and overlay of the maps. GIS has also been used in the present study as the storage for the land use maps and geomorphologic maps along with their attribute data. Apart from the onscreen digitization the mapping provided the most powerful visualisation in ARC GIS.

Table 1: Satellite data products used.

Sl Number	Satellite	Sensor	Path	Row	Year	Date
1	Landsat 1	MSS	156	42	1972	01-12-1972
2	Landsat 5	TM	145	42	1990	15-11-1990
3	Landsat 7	ETM^+	145	42	2006	19-01-2006
4	Landsat 8	OLI	145	42	2013	06-05-2013

Initially the digital satellite data products were downloaded from the website (http://earthexplorer.usgs.gov/) for the years mentioned above and were layer stacked in Erdas Imagine to get the desired FCC of the image. An area was selected for the present study and the same has been subsetted accordingly from the whole image. On the basis of the tone, texture, and particularly pattern, the urban areas of Gwalior for 2013 was first digitized by onscreen digitization method using ARC GIS software. Similarly for the other years the Gwalior urban areas were digitised and the shape files were created, respectively, with two classes as built-up and non-built-up areas. The respective areas covering the shape files were calculated and the growth of urban areas was correlated with the population census data of Gwalior agglomeration. The population data for different census years (1971, 1981, 1991, 2001, and 2011) have been used (Table 2) and interpolated for the years 1972, 1991, 2006, and 2013, respectively, and the growth rates were calculated and used for correlation with

Table 2: Population of Gwalior urban agglomeration and its growth rate.

Census years	Population	Population growth rate in percent
1971	406140	
1981	555862	36.86
1991	717780	29.13
2001	865548	20.59
2011	1053505	21.72

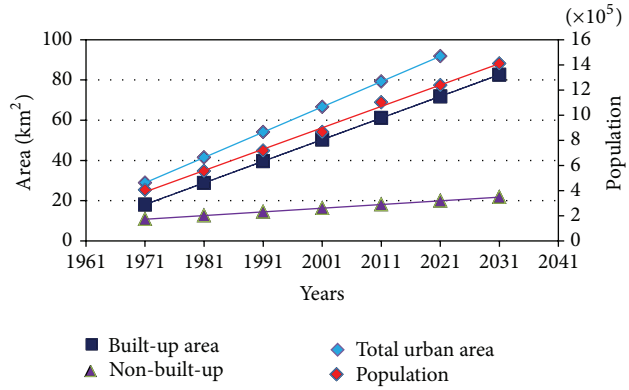

Figure 3: Decadal growth of population and their expansion in Gwalior urban area.

that of urban expansion areas showing built-up and non-built-up lands. In order to have a picture of decadal growth of population and their expansion similarly the calculated areas for urbanisation at different years were extrapolated and were correlated. An attempt has also been made to project these data for 2021 and 2031.

In order to bring out the implications on geomorphology, the geomorphic units that exist during 1972 were digitised and calculated for the area covering the urbanisation of 2013. The geomorphic units affected due to the expansion of urbanisation over the years during 1972–2013 were calculated and demarcated from this initial geomorphologic map. Ground truth check has been conducted in the selected areas with GPS and the results were correlated.

4. Results and Discussion

The present Gwalior city has three main urban clusters, namely, Gwalior, Lashkar, and Morar. The eastern base of the Gwalior Fort is the area of old city Gwalior whereas Lashkar forms the southeast and west part of the city. The word Lashkar has been derived from the Persian word meaning army or camp which forms the capital of Scindia dynasty of Gwalior State. Morar on the other hand is mainly the cantonment area that lies in the east side of the city. All the three trinodal urban clusters have witnessed an expansion of population as well as that in built-up land in the last few decades. City Centre at the central area of the city forms the major residential-cum-commercial area which has emerged in the last few decades. A Magnet City has been planned in the western part of the city along the bypass of Tighra Road. Climatically the city experiences very hot summer and very cold winter during the summer and winter seasons, respectively. The average annual rainfall of the area is around 762 mm.

5. Urban Sprawl Expansion

The result brought out a significant urban expansion of the city for the period 1972–2013 (Table 3). The total urban areas during 1972 were 34.11 sq. km out of which the share of the built-up areas was 23.84 sq. km and the rest, 10.27 sq. km, was marked as non-built-up area. The total urban area including the non-built-up land in 2013 data shows about 89.16 sq. km out of which the built-up land is 71.82 sq. km. Hence the built-up land has expanded more than threefold during the last 40 years, with an average expansion of 1.12 sq. km per year. Both built-up land and total urban area show a positive trend over time. However, the non-built-up land within the urban areas is under stress due to population pressure and the associated demand for urban expansion. As mentioned in the methodology section, to have a comparative understanding of growth of urban area and population growth, the decadal expansion of urban areas as well as the population has been calculated and projected for the years 2021 and 2031, respectively (Table 4 and Figure 3). The respective growth rates have also been obtained. The result shows that, by the end of 2021 and 2031, the population of Gwalior city will be 1.20 and 1.36 million, respectively, whereas that of built-up land will be expanded up to 71.84 and 82.58 sq. km during that period. Similarly the total urban area will be 91.08 and 104.4 sq. km out of which the non-built-up lands will be 19.94 sq. km and 21.77 sq. km during 2021 and 2031, respectively. But if we observe the result Table 3 where we can see the built-up land in 2013 is already 71.82 sq. km. hence to predict built-up land in 2021 as 71.84 seems to be not realistic as extrapolation has been done on the basis of all of the 40 years. The boom in built-up land has occurred in 2006–2013 in which it has expanded from 48.63 sq. km to 71.82 whereas during 1990–2006 the expansion was from 32.35 sq. km to 48.63 sq. km (Table 3 and Figure 4). That means where in 16 years the expansion was 16.28 sq. km in the next seven years the expansion increased to 23.19 sq. km. While there was a growth rate of 50.32 percent in built-up land in 16 years a growth rate of 47.70 has been achieved in the next seven years only. The noticeable thing is that there is a fall in the growth rate of population during this period (Table 3). It is again another clear cut indication of the increase in the rate of urbanisation in spite of the falling population growth rate. By considering the growth from 2006 the predicted built-up land during 2021 and 2031 will be 98.33 sq. km and 103.47 sq. km, respectively. As it is mentioned it is unrealistic to predict the expansion of urbanisation by extrapolating the whole period of forty years; the average decadal growth rates were calculated only up to 2011. The average decadal growth rate of population is 27.28 percent while that of built-up land is 36.29 percent which is more than the population growth rate. The urbanization area of respective years overlain with the respective satellite images

Table 3: Population and expansion of Gwalior urban area.

Year	Population	Built-up area in sq. km	Non-built-up area in sq. km	Total urban area in sq. km	Growth rate in percent			
					Population	Built-up area	Non-built-up area	Total urban area
1972	414928	23.84	10.27	34.11	—	—	—	—
1990	703723	32.35	15.38	47.73	69.60	35.71	49.76	39.93
2006	960429	48.63	18.02	66.65	36.48	50.32	17.17	39.64
2013	1072739	71.82	17.34	89.16	11.69	47.70	−3.77	33.77

Table 4: Decadal growth of population and their expansion in Gwalior urban area.

		In sq. km	In sq. km	In sq. km	Population	Built-up area	Non-built-up area	Total urban area
1971	406140	18.1	10.83	28.9	—	—	—	—
1981	555862	28.84	12.66	41.5	36.86	59.39	16.82	43.45
1991	717780	39.59	14.48	54.1	29.13	37.26	14.4	30.29
2001	865548	50.34	16.3	66.6	20.59	27.15	12.58	23.25
2011	1053505	61.09	18.12	79.2	21.72	21.35	11.18	18.86
2021	1201092	71.84	19.94	91.8	14.01	17.59	10.05	15.87
2031	1361533	82.58	21.77	104.4	13.38	14.96	9.14	13.7
Average decadal growth rate up to 2011					**27.28**	**36.29**	**13.74**	**28.96**

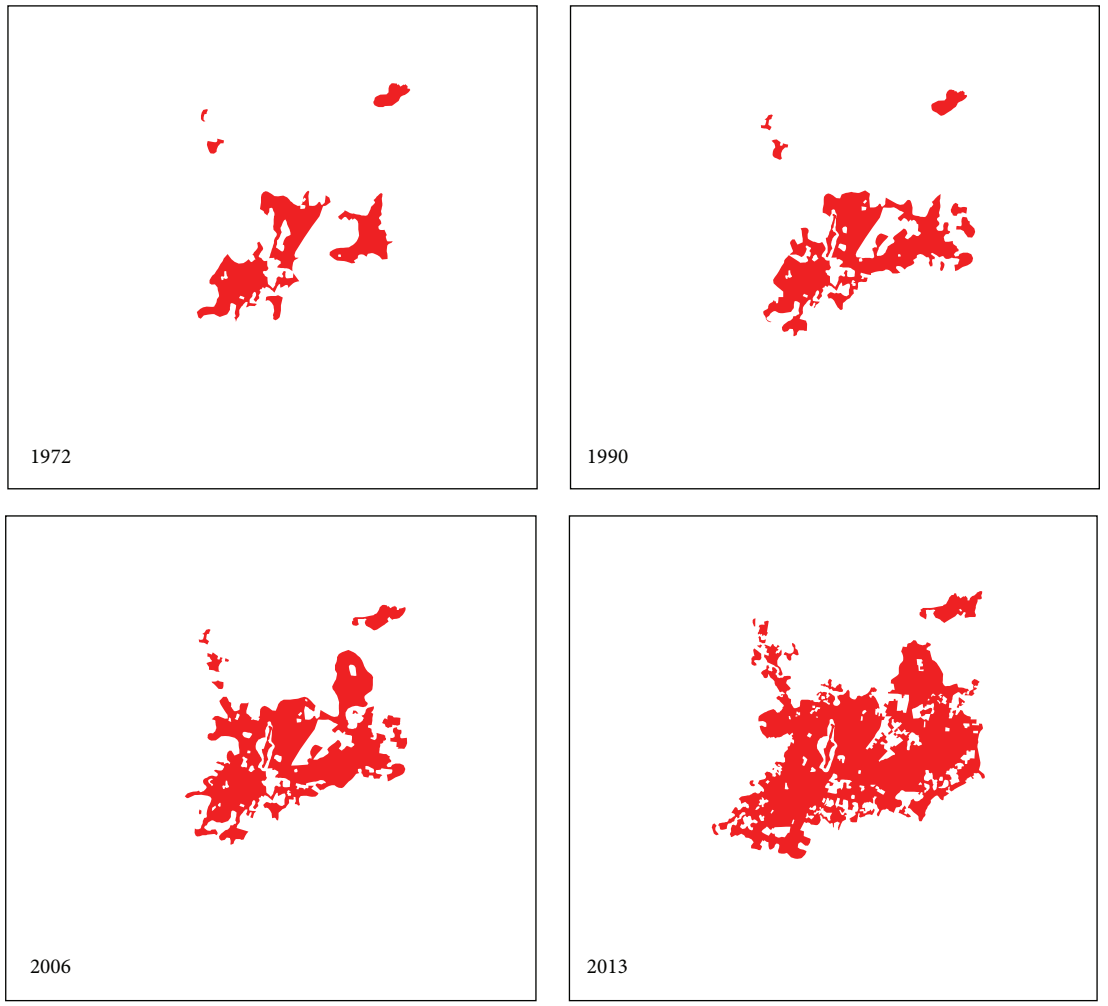

Figure 4: Urban expansions over the years.

Table 5: Geomorphic units affected due to urbanization during 1972–2013.

Geomorphic units	Plains area in sq. km			Hills area in sq. km			Total area in sq. km
Years from–to	Buried pediplain	Pediplain	Total plains	Denudational hill	Residual hill	Total hills	
1972–1990	15.67	0.01	15.68	1.26	0.00	1.26	**16.94**
1990–2006	15.99	0.48	16.47	0.79	1.18	1.97	**18.44**
2006–2013	18.12	0.01	18.13	3.59	1.25	4.84	**22.97**
1972–2013	49.78	0.50	50.28	5.64	2.43	8.07	**58.35**

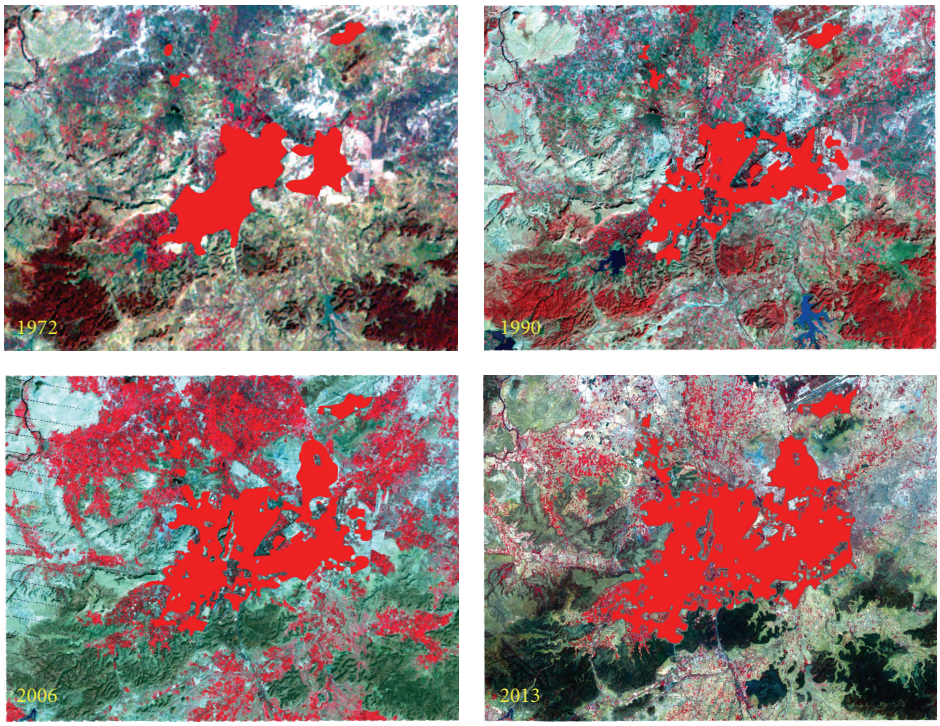

Figure 5: Urbanized map overlaid on satellite image of different years.

has been shown in Figure 5 and the urban sprawl map in Figure 6.

6. Implications on Geomorphology

The major geomorphic units that fall in the urban expansion area of today's scenario, that is, 2013, are mainly buried pediplain, pediplain, residual hill, and denudational hill (Figure 7). The geomorphic units that are affected by the urban sprawl over the years 1972, 1990, 2006, and 2013 have been given in Table 5. The urban expansion and its effect on geomorphic units (Table 5 and Figure 8) show that a total of 58.35 sq. km has been affected since 1972 out of which the plains (buried pediplain and pediplains) account for 50.28 sq. km and that of hills 8.07 sq. km. The result implies that since it is easier, cost effective, and natural trend to make buildings in plains than on the hills, initially the nearby plain areas surrounding the urban fringe of 1972 have been gradually converted to the built-up land. With increasing pressure in the recent period, conversion of hills to built-up land is in progress. The geomorphic units affected by only built-up area have also been calculated (Table 6 and Figure 9). From the table it is clear that a total of 38.99 sq. km geomorphic area has been converted to built-up land, out of which 33.18 sq. km is for the plains and the rest, 5.62 sq. km, is for the hills. The hills are converted to built-up land mostly after 2006. Initially residual hills are converted and gradually the denudational hills are affected. With increasing demand for urban space and nonavailability of plain areas, most of the denudational hills are going to be affected in future.

Few decades back Gwalior city was situated in between the Vindhyan Hills in the west and Bijawar Hills in the South East and plains of the North East. Some of the prominent residual hills were known as Gupteshwar Hill, Fort Hill, Hanuman Hill, Amkoh Hill, and Satnarayan Hill. Hanuman Hill and GudiGuda Hill provided aesthetic as well as scenic beauty of the city. All these residual hills were affected by the urban expansion during the period under consideration.

The urban areas which expanded over the years and even crossed the GMD boundary are along the NH-3 towards Shivpuri and also towards Morena. The expansion crossed the GMD boundary mostly after 1990. The notable areas

Table 6: Geomorphic units affected due to built-up land during 1972–2013.

Geomorphic units	Plains area in sq. km			Hills Area in sq. km			Total area in sq. km
Years from–to	Buried pediplain	Pediplain	Total plains	Denudational hill	Residual hill	Total hills	
1972–1990	9.13	0	9.13	1.05	0	1.05	**10.18**
1990–2006	12.08	0.19	12.27	0.43	1.08	1.51	**13.78**
2006–2013	11.97	0	11.97	2.22	0.84	3.06	**15.03**
1972–2013	33.18	0.19	33.37	3.7	1.92	5.62	**38.99**

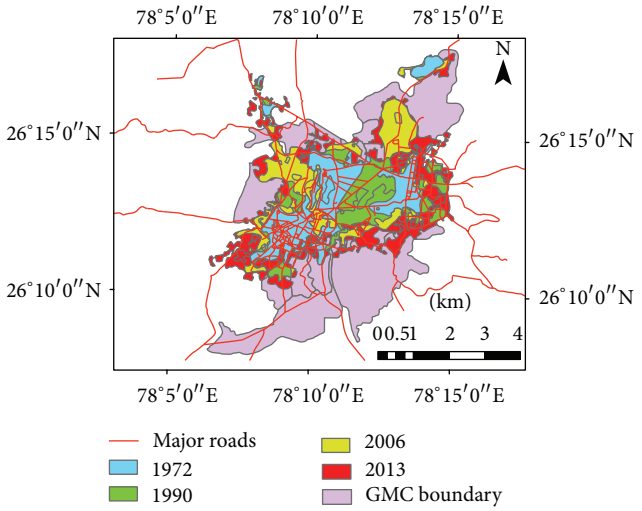

Figure 6: Urban sprawl map of Gwalior city.

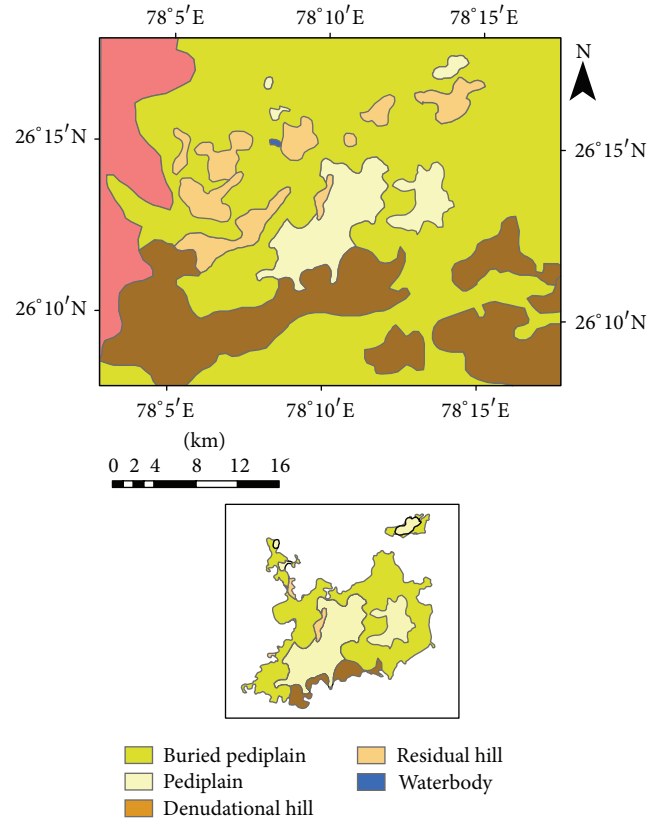

Figure 7: Geomorphological map of the area and the affected geomorphic units as per 2013 scenario.

of the extension in 2006 are the Gupteshwar and Sikander Kampu area which ultimately expanded up to Girwali in 2013. Geomorphologically the affected residual hill is Gupteshwar. Similarly on the NH-3 towards Morena the expansion covered about 4 km from the GMC boundary at Motijheel area. Presently the expansion has reached up to Padampur and adjoining areas crossing the GMC boundary towards the northwest part and towards west it is Mohanpur and adjoining areas. The most affected denudational hills are towards the south. Due to the shifting of the New High Court, Gwalior experienced massive construction of multistoried buildings towards the south. The hillocks (above 220 m MSL) which were visible during the 90s were demolished as a result of urban expansion. Presently the urban expansion towards the south has almost reached up to the boundary of the reserve forest along the Jhansi Road towards Sithauli affecting the denudational Odhapur Hill.

Geomorphologically the fluvial aspects within the Gwalior urban area are as follows. There have been two streams Swarnarekha and Morar Rivers which flow south to north through the western and eastern part of the city, respectively. Swarnarekha River originates from 3.5 km up stream of Barai village and forms tributary of Sankh River. The Morar River on the other hand originates at a distance of about 15 km upstream of Ramaua Dam in Gwalior district and flows through the eastern part of the city. Out of the two rivers the Swarnarekha River has been channelized in 2001 (Figure 10). The Morar River receives the rain water from the catchment area through various nallas. Siltation throughout its course within the city is visible due to the disposal of the solid waste materials which obstructs the carrying capacity of the sediments. Water logging problems have also been seen in the low lying areas (Figure 11). Even in the channelized Swarnarekha River there has been less infiltration of the rain water and consequently water logging problems and choked drainages and overflowing of the sewers are visible. Both rivers get the natural rain water as well as the domestic waste following through the natural slope and the sewer lines from the respective catchment areas. The worst problem arises from the colonies and urban areas that have been expanded outside the catchment areas where there was no suitable draining system. In these areas the rain water as well as the domestic water due to the lack of proper drainage management could not flow the natural slopes and hence the water logging problem arises.

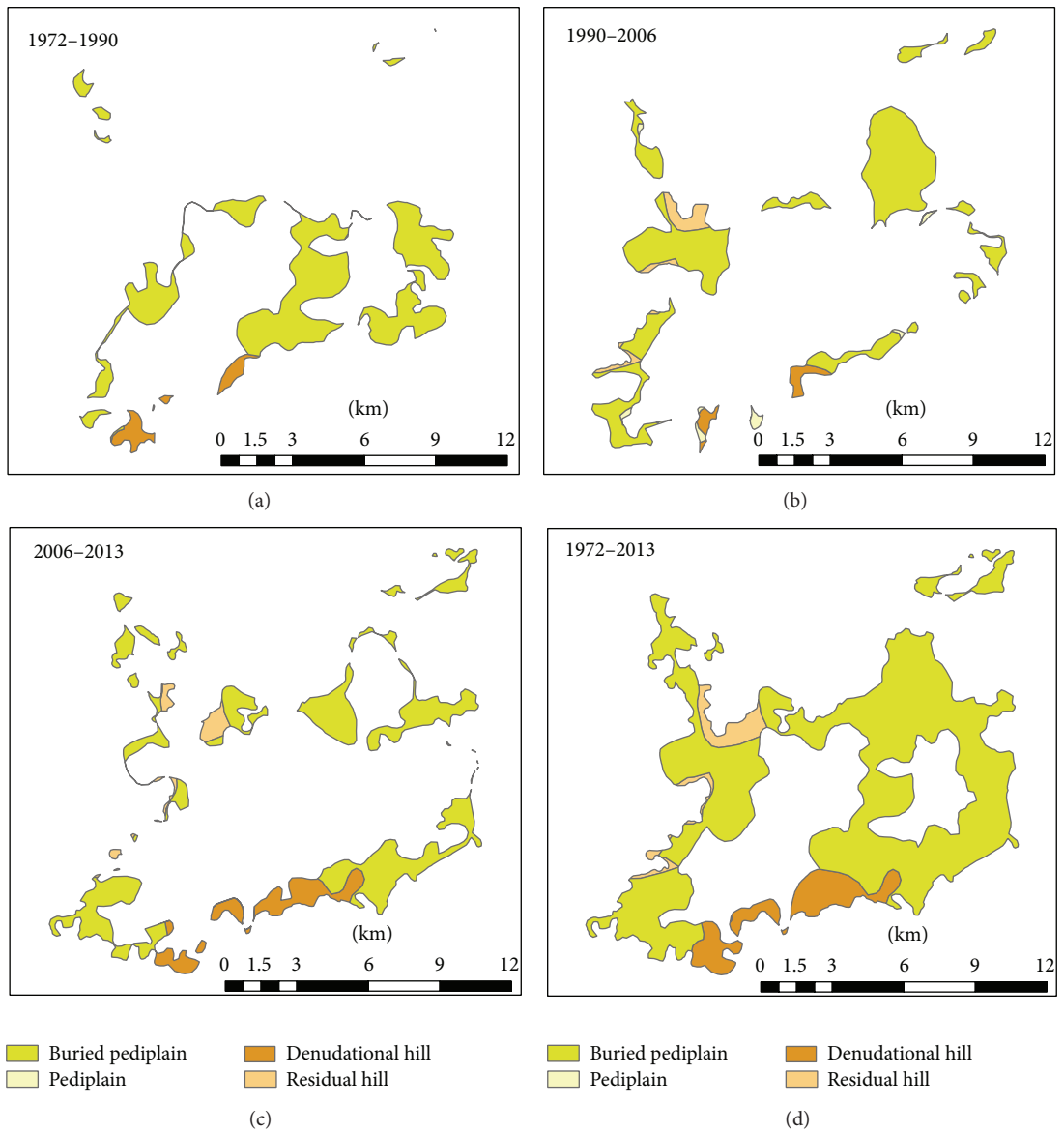

Figure 8: Urban expansion on geomorphic features (a) during 1972–1990, (b) during 1990–2006, (c) during 2006–2013, and (d) during 1972–2013.

Such areas have been witnessed mostly in the southern and northern parts of the city. Similarly the urban areas outside the GMC boundary have also been suffering from the lack of sewer and proper drainage system. To sum up, the major implications of urbanisation for geomorphology of the study area include drastic altercations and even destruction of important geomorphological features such as buried pediplains and denudational hills and major changes in the fluvial and drainage systems of the region.

7. Conclusion

This study attempts to explore the implications of urban expansion on the geomorphological features of Gwalior city. Rapid urbanisation has led to significant changes and destruction of important geomorphological features of Gwalior city, which has been captured in the study through Remote Sensing and GIS techniques. The results show that the geomorphic features which are likely to be affected in future are the residual hills and the denudational hills apart from the plain areas due to the urban expansion. The natural drainage network of the city also gets affected by the urban expansion and the drainage is likely to be modified in future. The waste water disposal system will affect the water quality in the city unless proper precautionary measures are taken. A first hand database created for this study can provide critical inputs in understanding the urban dynamics of the city. Urban planners and authorities in the future may take into account the environmental problems that may arise by unscientifically demolishing the natural topographic features

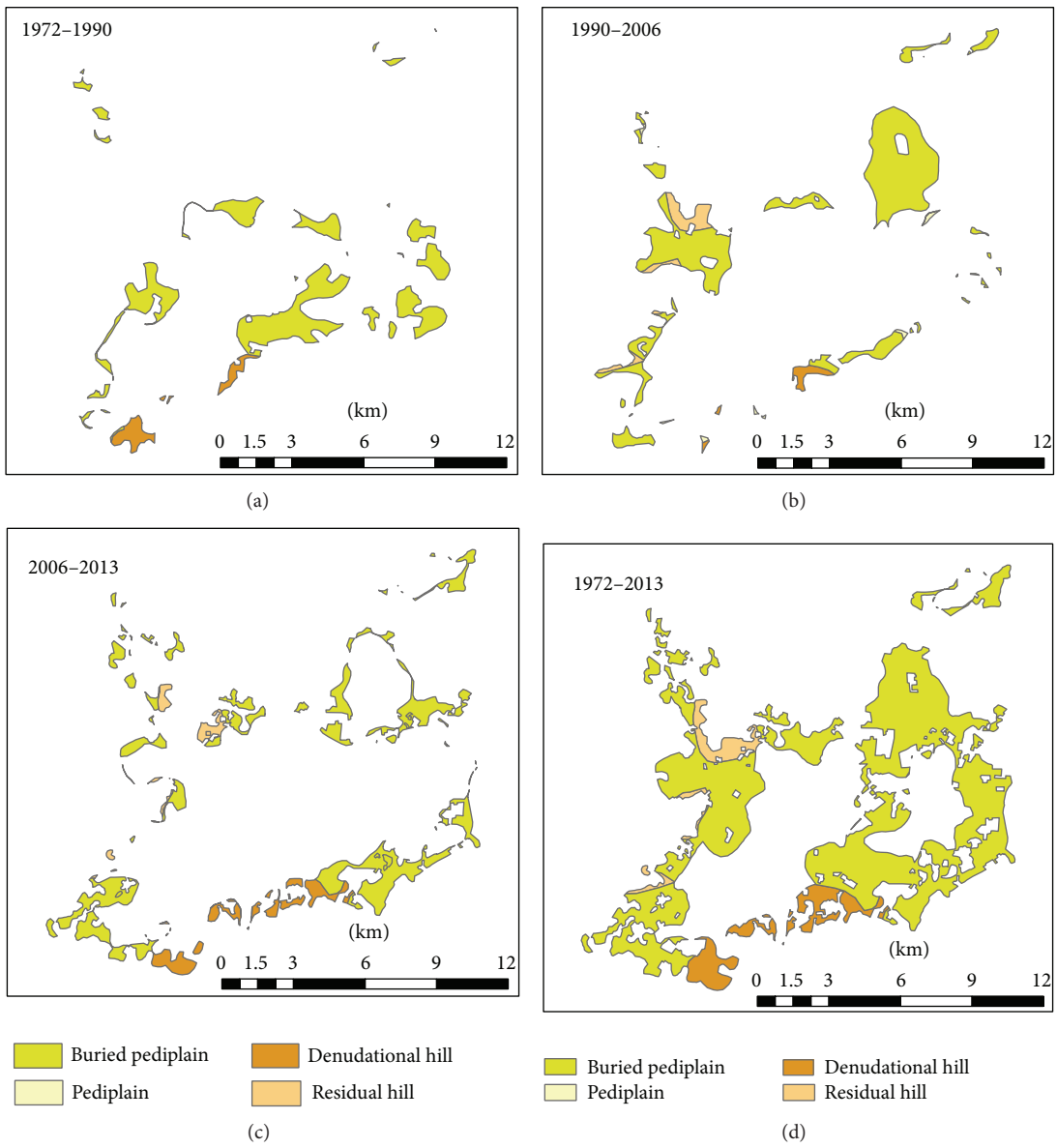

Figure 9: Expansion of built-up land geomorphic units (a) during 1972–1990, (b) during 1990–2006, (c) during 2006–2013, and (d) during 1972–2013.

Figure 10: Channelisation of Swarnarekha River.

Figure 11: Water logging and siltation in Morar River.

and landforms for the expansion of built-up land. Hence, taking into account the microgeomorphological features of the city and its surrounding areas, proper measures should be implemented for the improvement of future scenario.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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