crops and plants as well as ecosystem hydrology because cardamom, coffee, tea and native forest plants are highly sensitive to precipitation changes.

1. Bruijnzeel, L. A. and Procter, J., In *Tropical Montane Cloud Forests* (eds Hamilton, L. S., Juvik, J. O. and Scatena, F. N.), Springer, New York, 1995, pp. 38–78.
2. Stadtmüller, T., In *Cloud Forests in the Humid Tropics: A Bibliographic Review*, The United Nations University, Tokyo, and Central Agronomico de Investigacion Y Ensenanza, Turrialba, Costa Rica, 1987.
3. Hamilton, L. S., Juvik, J. O. and Scatena, F. N. (eds), In *Tropical Montane Cloud Forests*, Springer, New York, 1995, pp. 1–23.
4. Doumenge, C., Gilmour, D., Perez, M. R. and Blochus, J., In *Tropical Montane Cloud Forests* (eds Hamilton, L. S., Juvik, J. O. and Scatena, F. N.), Springer, New York, 1995, pp. 24–37.
5. Meyers, N., Mittermier, R. A., Mittermier, C. G., da Fonesca, G. A. B. and Kent, J., Biodiversity hotspots for conservation priorities. *Nature*, 1992, **403**, 853–858.
6. Lawton, R. O., Nair, U. S., Pielke, R. A. and Welch, R. M., Climatic impact of tropical lowland deforestation on nearby montane cloud forest. *Science*, 2001, **294**, 584–589.
7. Markham, A., Potential impact of climate change on tropical forest ecosystems. *Clim. Change*, 1996, **39**, 141–143.
8. Hulme, M., Osborn, T. J. and Jones, T. C., Precipitation sensitivity to global warming: comparisons of observations with HadCM2 simulation. *Geophys. Res. Lett.*, 1998, **25**, 3373–3382.
9. Salinger, M. J., Climate variability and change: past, present and future – an overview. *Clim. Change*, 2005, **70**, 9–29.
10. Yue, S., Pilon, P. and Cavadias, G., Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *J. Hydrolol*., 2001, **259**, 254–271.
11. Cleveland, W. S. and Devlin, S. J., Locally weighted regression: an approach to regression analysis by local fitting. *J. Am. Stat. Assoc*., 1988, **83**, 596–610.
12. Sen, P. K., Estimate of the regression co-efficient based on Kendall's tau. *J. Am. Stat. Assoc*., 1968, **63**, 1373–1389.
13. Van der Molen, M. K., Vugts, H. F., Bruijnzeel, L. A., Scatena, F. N., Pielke Sr, R. A. and Kroon, L. J. M., Mesoscale climate change due to lowland deforestation in the Maritime tropics. In *Mountains in the Mist: Science for Conserving and Managing Tropical Montane Cloud Forest* (eds Bruijnzeel, *et al.*), University of Hawaii Press, Honolulu, USA, 2006.
14. Ray, D. K., Nair, U. S., Lawton, R. O., Welch, R. M. and Peilke Sr, R. A., Impact of land use on Costa Rican tropical montane cloud forests: Sensitivity of orographic cloud formation to deforestation in the plains. *J. Geophys. Res*., 2008, **111**, 1–16.
15. Still, G. J., Foster, P. N. and Schneider, S. H., Simulating the effects of climate change on tropical montane cloud forests. *Nature*, 1999, **398**, 608–610.

ACKNOWLEDGEMENTS. M.M. thank the National Institute of Advanced Studies, Bangalore for financial support. We thank the reviewers for their comments on the earlier version of this manuscript. We also thank the forest department, Government of Kerala for giving precipitation data of Gavi and Periyar site. We thank the staff members of Tea Estates India Limited, High wavys, Tamil Nadu for providing climate data.

Received 23 October 2008; revised accepted 9 October 2009

Satellite-based geomorphological mapping for urban planning and development – a case study for Korba city, Chhattisgarh

Arindam Guha*, K. Vinod Kumar and A. Lesslie

Geosciences Division, National Remote Sensing Centre,
Indian Space Research Organisation, Hyderabad 500 625, India

Geomorphology is an important aspect which guides immensely in urban planning. Mapping of geomorphology not only gives an idea about the variations in landscape but also indirectly facilitates in evaluating the resources of an area. Present study shows the capability of satellite data in delineating major geomorphological units in an industrial area like Korba city. It has also been observed that geomorphological maps along with other relevant terrain-related information such as lithology and geological structures can delineate few important zones; each of these zones is suitable for specific type of urban development and planning. This communication highlights how a simplistic approach like logical integration of geomorphological and geological information can provide valuable inputs for urban planning and development.

Keywords: Geomorphology, land use, lithology, urban planning.

GEOMORPHOLOGY is the scientific study of landscapes and the processes that shape them[1]. The science of geomorphology has two major goals; one is to organize and systematize the description of landscapes by intellectually acceptable schemes of classification and the other is to recognize in landscapes, the evidences for changes in the processes that are shaping and have shaped them[1]. Landforms or geomorphological units are usually clearly displayed to the field observer or on remote sensing imagery. Geomorphological studies therefore can provide a basis for regional classification of terrain. Moreover, other environmental variables of interest are often controlled by geomorphological units. Therefore, geomorphology has a unique role in management and planning for urban area development. Techniques of geomorphological mapping is a fundamental tool for resource appraisal not only because they provide an effective and relatively cost effective means of generating valuable environmental data, but also because it can be adapted to surveys at different scales of enquiry. The resulting maps can be used as a basis for other environmental surveys for specific problem such as surface hazards, etc. Secondly, geomorphological studies dealing with the identification, monitoring and analysis of contemporary geomorphological processes may

*For correspondence. (e-mail: arindam_iit@rediffmail.com)

contribute substantially to the day-to-day management of urban areas, and to address problems arising from confliction between natural environment and urban development. Geomorphological studies carried out for urban development are used chiefly to help in identifying the locations of resources or the range of locations suitable for particular activities, to assist the selection of suitable locations for particular activities within the range of possibilities, and to analyse conditions within selected locations in the hope that the use of resources will be more efficient and the avoidance of environmental hazards will be more effective. Geomorphological studies carried out during and after urban development are often used to minimize environmental impact and to provide a local temporal and spatial database that facilitates the prediction of future changes and their continuous modifications[2]. In the present study, geomorphological studies are carried out in conjunction with other geological informations for urban planning and development. The study area considered for geomorphological mapping occupies approximately 400 sq. km covering the entire stretch of Korba city. Korba city sprawled in a very wide area, includes large coal-mines and many thermal power houses with an aluminum heavy industry. The main source of water in the area is Hasdeo River. Korba is a revenue district headquarter. It has one of the richest municipal corporations in the Chhattisgarh state. Moreover, per capita income in this town is highest in the state. The study area (Figure 1) is well connected by road and rail with Bilaspur and also connected to state capital Raipur by road and rail. It is approximately 200 km north-east to Raipur.

The study area is occupied by rocks of different age from Archaean to Permian. Broadly, Korba city area is

Figure 1. Location of the study area.

comprised of two major geological units. One is Archaean Granite Gneiss and other is Gondwana Supergroup rocks. Archaean Granite Gneiss is exposed at the northern and north-western part of the study area. Gneiss is massive in nature and made up of plagioclase feldspar, biotite, quartz, etc. Gondwana Supergroup of rocks overlies the Archaean Gneiss, shaly sandstone of Talchir Formation of Gondwana Supergroup overlies the gneiss and it is in turn overlain by sandstone of Barakar Formation. At north-eastern part, sandstone of Barakar Formation is overlain by ferruginous sandstone of Kamthi Formation. Rocks of Gondwana Supergroup are dipping towards south. Several intrabasinal faults are present within the Gondwana Supergroup. These faults have been formed in the period from Talchir sedimentation to close of Gondwana sedimentation[3].

Generalized stratigraphy[3] of the study area is given in Table 1. Mapping of geomorphological units are carried out to identify the potentiality of geomorphic classes for urban development. Relationship among geological structure, lithology and landscapes contributes significant inputs for urban planning and management. Presence of anthropogenic landforms like ash ponds and open-cast pits in the study area revealed how anthropogenic processes or activities have played a significant role in modifying the natural landscape pattern of the terrain and brings out the relation of these anthropogenic landscapes with other terrain elements such as lithology, geological structures and other geomorphological elements. A large portion of the study area is occupied by pediplain with isolated occurrences of pediment in the western and north-western part of the area. A linear ridge is present at the north-western flank of the study area. Flood plains are present specially along the active channel area of Hasdeo River and also along few higher order drainages. Pediplain is well dissected near the active flood plain area whereas the dissection is less as we move away from the river channel. Lower order drainages (both perennial and non-perennial) have dissected pediplain near the river system. The average altitude of the area is around 900–925 m and the regional gradient is 1 : 10,000.

IRS P6 LISS-IV data of January 2008 is used as study area. LISS-IV data is acquired with three channels in spectral domain of green (0.52–0.59 μm), red (0.62–0.69 μm) and NIR (0.77–086 μm). Data has good (7 bit) radiometric resolution. Geomorphological map of the area is prepared from FCC (Figure 2) of LISS-IV image. Landforms are better studied from satellite data for its synoptic coverage[4] of LISS-IV data. Some digital image processing techniques such as contrast stretching and scaling of histogram of each band of LISS-IV data have been proved useful in enhancing the depiction of each geomorphological unit. Contrast stretching of FCC images is aimed to expand the narrow range of brightness values typically present in an input image over wider range of grey level[5]. Enhanced FCC image is used for

Table 1. Generalized stratigraphy of the study area

Age	Major rock unit	Formation	Rock type
Archaean	Granite gneiss	Unclassified	Biotite rich granite gneiss
Unconformity			
Upper carboniferous	Gondwana supergroup	Kamthi	Ferruginous sandstone
Permian		Barakar	Sandstone
		Talchir	Shaly sandstone and shale

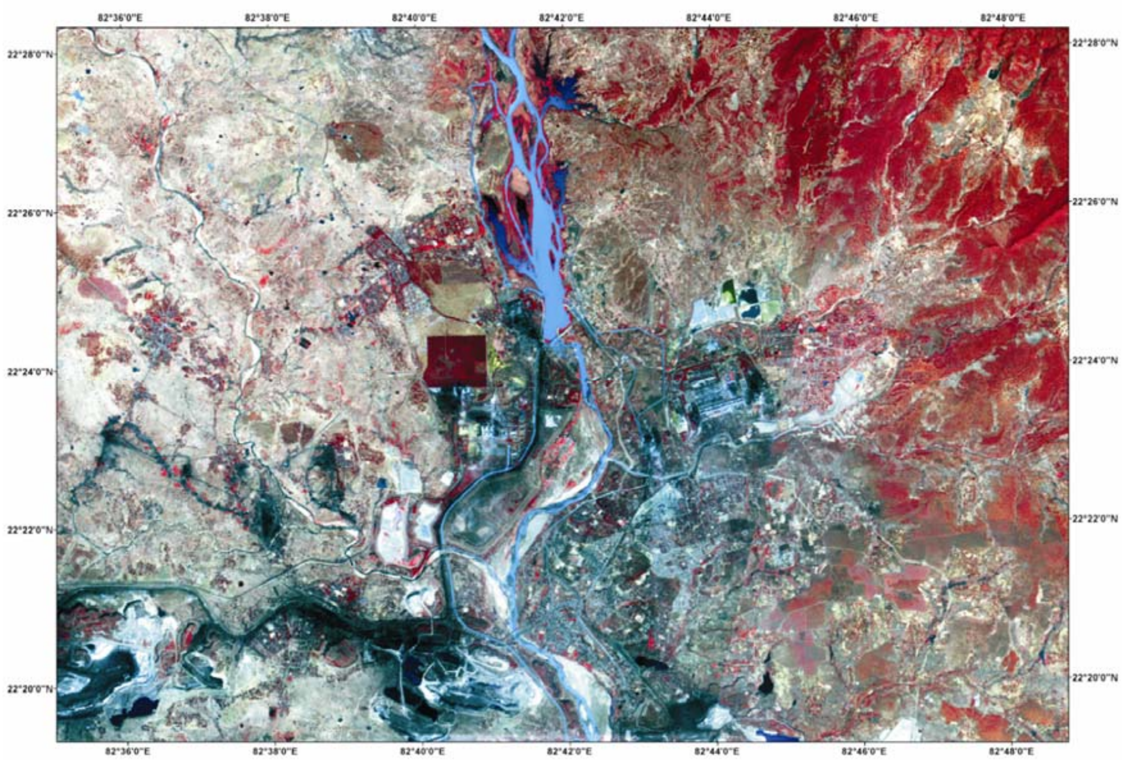

Figure 2. IRS P6 LISS-IV image of Korba.

interpretation of geomorphic units and the boundaries are delineated with onscreen digitization process to prepare the geomorphological map (Figure 3) of the area. Geomorphological map is finalized after validating interpreted geomorphological units in the field. Reference geological map (1 : 250,000) published by Geological Survey of India (GSI) is taken as reference to identify lithology and geological structures. At first, reference geological map is georeferenced with IRS P6 LISS-IV image. Then, a preliminary vector map on lithology and geological structures is prepared from reference GSI map. After this, these maps are updated with the help of satellite data. Terrain elements such as drainage density, soil pattern and image elements such as tone, texture, etc. have been proved useful in updating the available geological information. Based on these inputs from satellite data, few additional lineaments are also mapped from satellite data and boundaries of lithounits are also updated. Finally, fieldwork is carried out to validate this map with reference to ground truth and updation is made in terms of modifying the boundaries between two lithounits in few places. Finally, an updated geological map (Figure 4) is prepared after incorporating all such changes.

Geomorphological map prepared from satellite data is combined with lithological map using Boolean operator to delineate different zones; characteristics of potential resource availability, environmental degradation, land use, etc. In the present case, geomorphological and lithological maps are overlaid using the Boolean operation with logical operator ‘OR’. This has identified areas with ‘unique’ character in the urban zone map. Geological structure map is not incorporated in logical integration to create the urban zone map as line informations cannot be integrated with polygon informations. But this information is taken into consideration to understand the variation caused by geological structures in influencing the potentiality of each zone for urban planning.

There are few natural geomorphological units present within the area. These are pediplain, pediment, linear ridge and flood plain. Pediplain is an extensive, multiconcave,

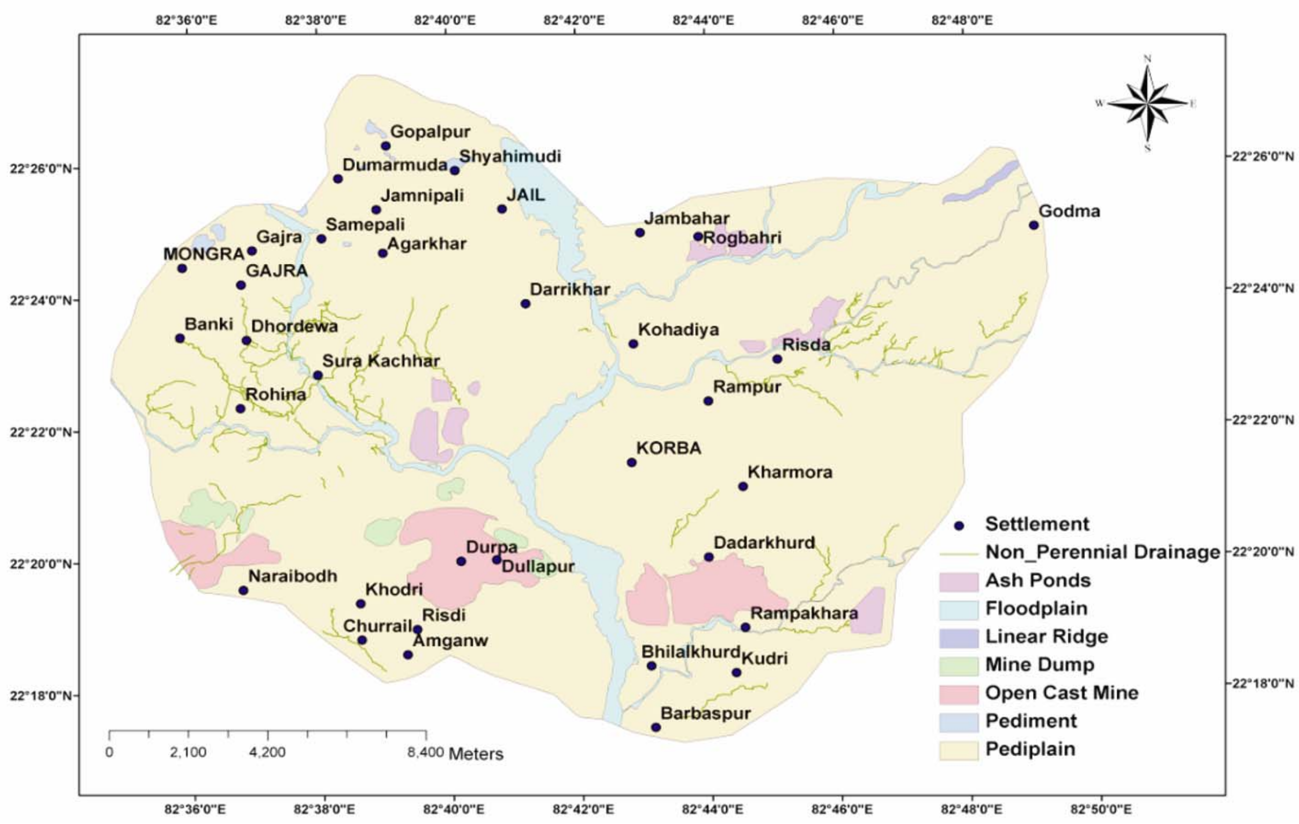

Figure 3. Geomorphological map prepared by interpreting satellite data with field validation.

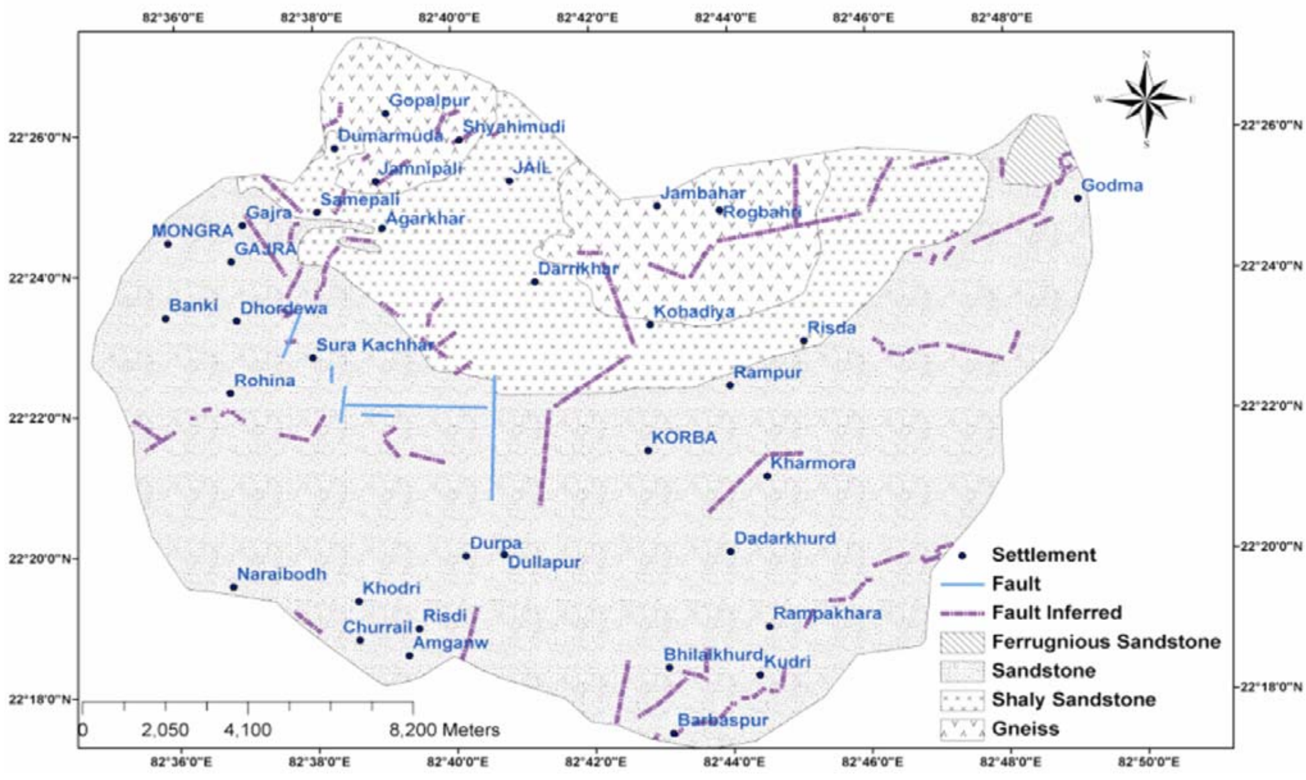

Figure 4. Satellite-based updated geological map of the study area. Source: Reference geological map from Geological Quadrangle Map, GSI, 1979.

Figure 5. Ash ponds in gneiss.

Figure 6. Pediment surface developed over gneiss.

thinly alluviate rock cut erosion surface and it generally represents the end result (the 'peneplain') of the mature stage of erosion of near horizontal bedded (5–10 degree dip towards south) sandstone and shaly sandstone. Pediplain is wide and in places modified by anthropogenic landforms like mine dumps, open-cast pits and ash ponds (Figure 5). Ash ponds are man made depressions used for storing ash and slug of thermal power plants present in this area. Pediment is a broad, flat or gently sloping, rock floored erosion surface where thickness of soil cover is less or soil cover is absent and the area is occupied by moderately weathered rock surface. Pediment is formed in isolated fashion and generally formed over gneiss and occasionally over sandstone (Figure 6). Flood plain is formed by sand or silt transported and deposited by a major river and its tributaries and it is restricted by the active portion of the river channel. Linear ridges are formed by younger sandstone of the Gondwana Supergroup. Ferruginous sandstone of Kamthi Formation is compact and mechanically more competent than the Barkar sandstone and therefore appears as prominent ridges. Gneisses occur at the northern and north-western portion of the area. Gneiss is a more chemically and mechanically competent rock and forms good pediment surface or moderately weathered pediplain. Based on integration of geomorphological information and geological information in GIS platform using Boolean logical operator, seven distinct zones are delineated (Figure 7). Each zone is characterized by specific environmental degradation, resource availability, land cover pattern which helps in evaluating the requirements for urban development and planning for each unit. Geological structure map has added more variation within these zones and therefore put more challenges in planning. The zones thus demarcated by logical combination of geomorphology and geological informations are discussed here. Table 2 summarizes the different zones and their potentiality for urban development.

Zone I represents ash ponds which occur within sandstone and shaly sandstone. This zone requires strict environmental monitoring as ash ponds developed over these rock units may create problems in groundwater resources. Toxic elements/slag elements from ash ponds may disperse to groundwater system of porous and permeable rocks like sandstone. Moreover, if geological structures are present close to ash ponds or underneath the ponds then this may play as conduits for dispersion of toxic element to groundwater system. Presence of perennial and non-perennial drainages near this zone pose more challenges for planners. For this purpose, methods need to be developed to stop surface dispersion of ash material through surface drainages.

Zone II represents mining activity which is represented by anthropogenic landforms resulting from mining. This zone also requires environmental monitoring and several measures can be taken up like forestation over dump, partial filling up of the abandoned open-cast pits, etc. to maintain environmental balance and preserving the original pattern of natural landscape.

Zone III includes pediment and pediplain surfaces developed over gneisses. This zone may not be suitable for dense urbanization as less weathered gneiss rarely stores groundwater. This zone can be used for agriculture if adequate arrangements can be made by pitting the surface into a pond to store water. Lineaments developed over this zone, however would enhance recharge of groundwater and along these lineaments, human habitats can grow. As the gneissic basement is compact, mechanically and chemically competent, this zone is suited for developing heavy industries. It is also suited for ash pond.

Zone IV represents pediments developed over sandstone and shaly sandstone. This zone can be used for transplantation, etc. which in turn will add humus to the zone. It would also increase the thickness of the soil profile so that in future it can be used for agriculture.

Zone V represents a natural ridge developed by competent ferruginous sandstone. This zone is not suitable for any kind of urban development but if developed

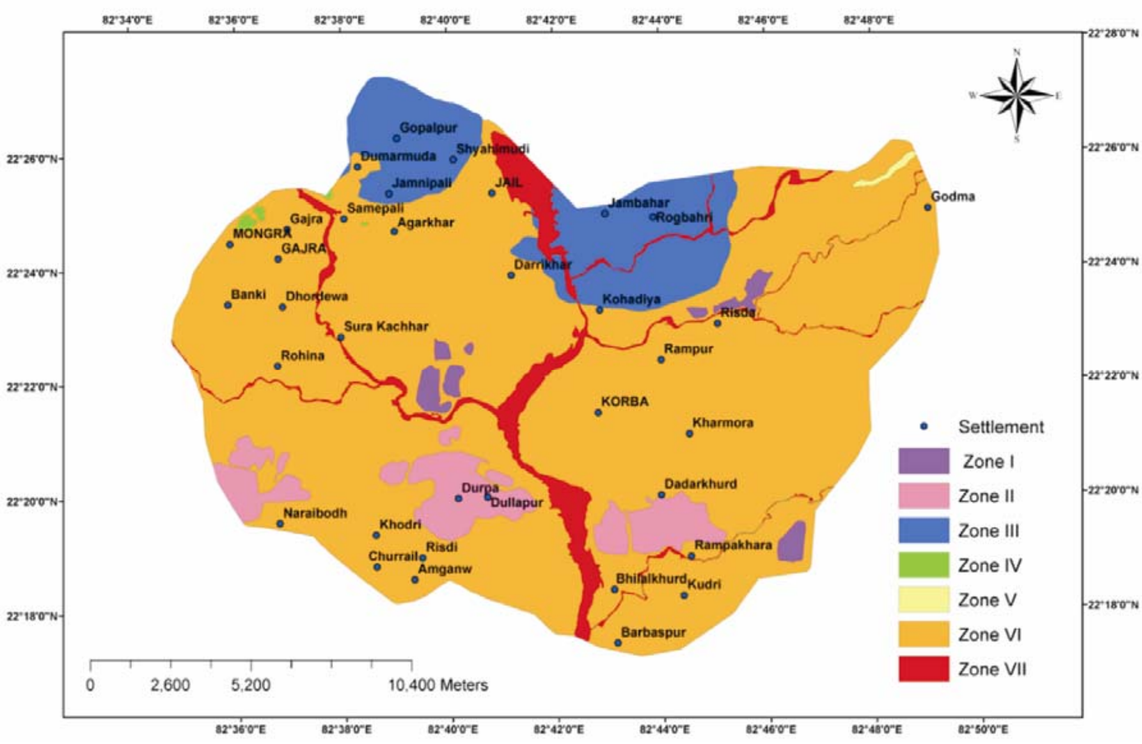

Figure 7. Urban zone map prepared by logical integration of geological and geomorphological information.

Table 2. Brief descriptions of urban zone

Urban class/zone	Description	Scope for environmental degradation	Potentiality for urban development
Zone I	Area influenced by ash pond	High	Poor
Zone II	Area influenced by open cast mining activity	High	Poor
Zone III	Pediment and Pediplain developed over gneisses	Low	Moderate
Zone IV	Pediment developed over sandstone	Low	Moderate to good
Zone V	Linear ridge developed over ferruginous sandstone	Low	Moderate
Zone VI	Pediplain developed over sandstone	Moderate	Very good
Zone VII	Floodplain area	Low	Good

properly may be used for amusement park, natural park, etc.

Zone VI is most pervasive zone in the area. This includes pediplain surfaces developed over sandstone, shaly sandstone and ferruginous sandstone. This zone is most suitable for agriculture as it occupies almost horizontal planar area with good soil cover, surface and groundwater storage. As good aquifers develop in this zone; this area is most suitable for urbanization. In fact main urbanization has already been taken place within this zone. However, extensive and unplanned urbanization may also cause environmental degradation in the area.

Zone VII represents flood plain area over sandstone, shaly sandstone, gneiss, etc. Flood plains are suitable for cultivation even in dry season.

This study demonstrates the importance of geological and geomorphological criteria to delineate several distinct zones. These zones are of different potentials for urban development and therefore different urban planning methods need to be adopted for each zone.

1. Bloom, A. L., *Geomorphology – A Systematic Analysis of Late Cenozoic Landforms*, Pearson Education, 2003, 4th edn, pp. 1–3.
2. Gupta, A. and Ahmed, R., *Geomorphology*, 1999, **31**, 131–149.
3. Vaidyanadhan, R. and Ramakrishnan, M., *Geology of India*, Geological Society of India, 2008, vol. 2, pp. 617–630.
4. Gupta, R. P., *Remote Sensing Geology*, Springer-Verlag, 2003, 2nd edn, pp. 431–435.
5. Lillesand, T. M. and Kieffer, R. W., *Remote Sensing and Image Interpretation*, 1999, 4th edn, pp. 420–496.

ACKNOWLEDGEMENTS. We are grateful to Director, NRSC, ISRO for his support and encouragement during the course of work. We thank Dr P. S. Roy, Deputy Director, RS&GISAA for his support and overall guidance.

Received 21 August 2008; revised accepted 13 October 2009