

A geospatial study on impact of urban area expansion on the vegetation structure in East Khasi Hills District: A Case Study of Shillong, India

Kalyanjit Sarmah¹, L.K. Jha² and B.K. Tiwari³

Department of Environmental Studies, North Eastern Hill University,
Shillong-22, Meghalaya, India

ABSTRACT

Remotely sensed data is the most important data source for different environmental change study over the past 40 years. Since large collections of remote sensing imagery have been acquired in a time frame of successive years, it is now possible to study long-term spatio-temporal pattern of vegetation structure and landuse change due to the rapid expansion of urban areas. This particular study seeks an efficient and practical methodology for urban area expansion monitoring and spatio-temporal vegetation pattern analysis by integrating multitemporal remotely sensed data, in a monitoring time frame of 20 years. Human interventions in the virgin mountainous ecosystem and resultant loss of vegetation structure have become a major environmental issue in the recent past. The present study is an approach by the author to highlight the recent phase of urban development in a remote north-eastern hill station of India, an attempt to study the phase of fragmentation of vegetation structure under tremendous anthropogenic impact.

Keywords: Urbanization, Shillong, Forest cover, Vegetation, Remote sensing and GIS

Urbanization is an inevitable process globally and an important topic of major priority for the researchers, land manager, policy maker, and environmentalist all over the world (Jat et al. 2008). Urban development, particularly in developing nations, is characterized by the rapid expansion of built-up coupled with a progressive population growth which resulted in high expansion of pre-existing urban areas. There is no surprise that, cities in the developing countries are the conflict zones between economic growth, society and the environment. The cities are expanding in all directions with large-scale urban development, and it has led to considerable loss of natural vegetation such as forestland, agricultural land and wetland etc. While in the urban environment, the presence and abundance of forest land and other natural vegetation

constitute as the most vital component for the protection and sustainability of locally traditional and natural landscape, they provide a wide range of environment and social functions to cities and urban dwellers (Costanza *et al.*, 1997; Laforteza *et al.*, 2009).

Shillong, as the capital city of Meghalaya, provides a good example of the medium size city or town especially in terms of urbanization process, since city has experienced a political and socio-economic developments in last few decades. The process of urbanisation in the area started with the selection of Shillong for building a sanatorium and a cantonment by the British in 1829. In 1972, when the state of

Author for correspondence

Author's name: Mr. Kalyanjit Sarmah

Email: sarmah.kalyanjit@gmail.com

© NECEER, Imphal

Meghalaya was newly formed as a separate state, Shillong became its capital.

At the beginning of the 20th century, Shillong had a population of only 9621 persons that has swelled to 2,67,662 persons by the turn of the 21st century. This tremendous growth has been powered by waves of immigration and rising importance of Shillong as an important urban centre in the North East. As a result of the urban expansion, the natural landscape of Shillong and its surroundings has changed largely due to the conversion of area under natural vegetation to built-up area. It is believed that such kind of information can be of great value to support the development of sustainable urban policies, forest planning and management, urban forest planning and management and may form a key component of urban quality of life indicators. Therefore, the study area of Shillong that exhibits this very strong manifestation of the process of urbanisation on the landscape characteristics particularly the natural elements like forest cover is an ideal selection for the study. Remote sensing data of various spatial, radiometric, spectral and temporal resolutions have been used to characterize environmental and ecological problems associated with the urban growth. The development in remote sensing techniques has greatly enhanced our knowledge of urban ecological processes (Banister *et al.*, 1997; Longley and Mesev, 2000). In addition to remote sensing, geographical information system (GIS) and several spatial analysis techniques have also been developed for better understanding of the geographical phenomena of the urban development processes and urban ecological processes. Regional assessment and monitoring of land use and land cover change is the key to understand the dynamics that drive changes in urban growth and forest cover (Brannstrom *et al.* 2008).

The primary objective of this study is to monitor the spatio-temporal characteristics of urban expansion and to determine its consequential forest cover change in the study area from medium resolution data by the used of remote sensing and GIS. This study allowed us to characterize and determine the condition of urbanization process and its effect on forest landscape of the study area so that it may provide as basic information for urban environmental monitoring.

Study area

The area selected for carrying out the present study is delineated by the coordinates 91° 47'40.35 E to 91° 57'51.70 E longitude and 25° 32' 54.45 N to 25° 35'37.60 N latitude. This area includes the Shillong city and its surroundings which covers a total area about 147 sq km including the Shillong basin that covers an area of 45 sq. km. The area consists of seven urban centres viz. Shillong Municipality, Shillong Cantonment, Mawlai, Nongthymmai, Pynthorukhrah, Madanrting and Nongmynsong and 32 villages as per the Master Plan of Shillong 1991-2011 recording a population of 3,31,373 persons. In determining the study area we followed the Greater Shillong Planning Area (GSPA) boundary for ; however, we limited our area of interest to a distance 8 km radius from the city centre since the area delineated by the GSPA is meant for future growth and may include large amounts of rural lands. In this study our concerned is with spatial pattern of urban built-up land, therefore, the area falling outside the 8 km buffer zone has been excluded from the present study. The physiography of the area is hilly with step escarpments having shallow or deep valley. The highest point in the area is the Shillong peak (1964 msl) which is also the highest point of the state of Meghalaya. The rainfall pattern is monsoonal covering the period from middle June to October with an average annual rainfall of 1530 mm The vegetation is dominated by *pinus kesiya* with a number of angiosperms in high or low occurrence and can be broadly be classified as: subtropical pine forest, the rolling grassland and mixed ever-green forest along with groves of bamboo with *bambus polida* and *dendrocalmus hamilton* being main the bamboo species (Singh, 1992).

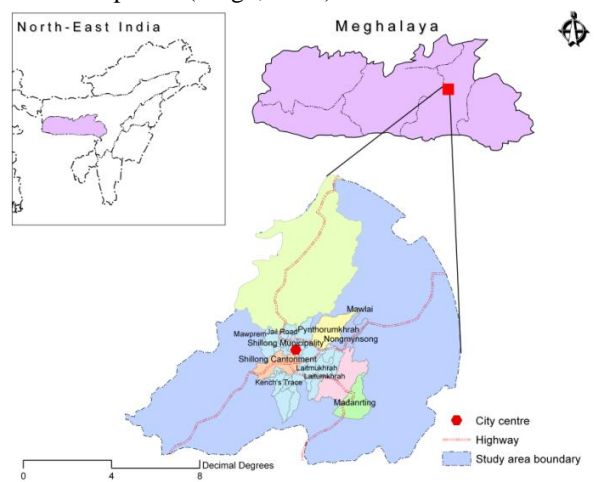


Figure 1. Study Area

Materials and methods

Image data preparation

In this study, we used two cloud-free remote sensing data of Landsat-TM (Thematic Mapper) for 1987 and IRS-P6 LISS III for 2008 having near anniversary dates which were obtained in the dry season (October to March). These images were corrected to remove atmospheric effect and then georeferenced to the local Universal Transverse Mercator (UTM) coordinate system, Datum WGS 1984, zone 46 north using a Survey of India topographic map of 1:50000 scale as a reference. The resulted root mean square (RMS) error was found to be 0.20 and 0.24 for 1987 and 2008 image respectively. Subsequently, both the images were re-sampled to 30 m pixel size for all bands using the nearest neighbour algorithm method. After geometric correction, a normalization method termed histogram matching in ERDAS Imagine 9.1 was used to compensate for the effects of differing solar illumination or vegetation growth changes evident on Images (Yang, 2010). Histogram matching is a purely statistical technique that relates the cumulative density function of one image to the density functions of another to eliminate the subjective problem and reduce the dependence on a geometrically accurate spatial match between multi-date images (Chavez and MacKinnon, 1994). Finally, by means of the GIS the study area boundaries layer was extracted from the image using the 'AOI (Area of Interest)' function in the 'Data Preparation' module of Erdas Imagine 9.1 software.

Image Analysis and Accuracy assessment

The images were analysed and classified separately using the supervised maximum likelihood classification method for the subset-image of the study area to obtain a LULC (Landuse/Landcover) map. A supervised technique involves three major steps: selection of training area, generation of the spectral signature for the training areas, and classification of the sub-scene on the basis of signature generated (Lillesands and Kiefer, 2000). The classification was based on training sample points from fieldwork and visual interpretation, and the training samples in the images were generated to represent the typical information of LULC classes. For the purpose of this study, we identified five major types of LULC classes including forest vegetation, non-forest vegetation, built-up, barren land and water bodies. The 'built-up' class includes residential area of single houses and apartment buildings, shopping centers, industrial and commercial facilities, highways and major streets.

The 'non-forest vegetation' class includes grassland, shrubs, cropland and stony/rocky land. The classification accuracy of the two classified image (1987 and 2008) was evaluated with the ground truth from the field; a number of 300 samples were selected randomly in order to perform accuracy assessment operation. The overall accuracy was calculated by using "Accuracy assessment" tool of Erdas Imagine 9.1 software.

Change detection Analysis

In performing LULC change during the periods of 1987 and 2008, the post-classification comparison change detection algorithm was adopted. This method has been widely used quantitative change detection in the field of remote sensing (Wang, 2003). In the post-classification technique, two images from different dates are independently classified, and accurate classification was imperative to insure precise change detection result. Using matrix analysis imbedded in *Erdas Imagine 9.1* software, the LULC transition among different land use classes was obtained on a pixel by pixel basis. A change matrix was produced with a quantitative areal data of the overall LULC changes as well as gains and losses in each category between 1987 and 2008 were then compiled. The cross tabulation analysis on a pixel by pixel basis facilitated the determination of the quantity of conversions from a particular LULC class to other LULC categories and their corresponding area over the period that took place.

Urban Expansion and Forest cover Change Detection Analysis

The urban built-up expansion map was prepared by overlaying the extracted built-up pixels from the 1987 and 2008 classified LULC map. In order to analyze the urban expansion and its spatio-temporal pattern, firstly we divided the entire study area of Shillong city and its surroundings covering 147 sq km into four Zones (e.g. Zone-A, Zone-B, Zone-C and Zone-D the four sectors or directions north-west, north-east, south-east and south-west of the study area respectively) taking Central Business District (CBD) of Shillong city as the centre point. Further, taking the CBD as a centre; 9 concentric buffer ring of 1km unit from the CBD and 4 buffer ring with a spatial unit of 500m from road was produced separately. On this basis, we obtained the number of built-up and forest cover change area in each different spatial unit. The density change was calculated by dividing the number of pixel change (increase/decrease) by total number of pixel of the

target area or buffer zone (Wang, 2001). The resulted values of density were used to characterize the quantity and spatial distribution of urban and forest, as well as to construct a distance decay function by using GIS buffer spatial analysis tool of Arc GIS 9.3 software. These technique are effective for characterizing the quantity and spatial distribution of various types of LULC in terms of distance and orientation with respect to a pre-determine urban centre (Xu *et al.*, 2007), and one of the most important aspect of using density decay analysis of is because this technique provide a useful indices of measuring the urban development (Torrents and Alberti, 2000). In addition to the above approach, it was found that entropy approach integrated with remote sensing and GIS technique can provide information on urban forms and its periodic changes of urban development in terms of spatial phenomena and is being used extensively in many urban studies (Yeh and Lin 2001; Li and Yeh, 2004; Lata *et al.*, 2001; Sudhira *et al.*, 2004; Jat *et al.*, 2010). Therefore, we further evaluate the pattern of urban expansion process by adopting the entropy approach for the whole study area as well as for the four sections (i.e. Zones).

Shannon’s entropy (H_n) can be used to measure the degree of spatial concentration or dispersion of a random geographical variable (X_i), i.e. built-up (Theil 1967, Thomas 1981). It is calculated by

$$H_n = - \sum_i^n P_i \log \frac{1}{P_i} \tag{1}$$

where, P_i is the probability of occurrence of a phenomenon (variable) occurring in the in the i^{th} zone or spatial unit

$$P_i = \frac{x_i}{\sum_i^n x_i}$$

where, x_i is the observed value in the i^{th} zone, and n is the total number of zones. The value of entropy ranges from zero to $\log(n)$. If the distribution is maximally concentrated in one zone, the lowest value, zero, will be obtained. Conversely, an evenly dispersed distribution among the zones will give a maximum value of $\log(n)$. Relative entropy can be used to scale the entropy value into a value that ranges from 0 to 1. Relative entropy H_n is given by (Thomas, 1981) as

$$H_n = \frac{\sum_i^n P_i \log(1/p_i)}{\log(n)} \tag{2}$$

Because entropy can be used to measure the distribution of a geographical phenomenon, the measurement of the difference of entropy between time (t+1) and (t) can be used to indicate the magnitude of change of urban sprawl i.e. (Thomas, 1981)

$$\Delta E = E(t+1) - E(t) \tag{3}$$

The change in entropy can be used to identify whether the urban development or expansion is towards a more dispersed (sprawl) or compact pattern.

Results and discussion

The accuracy assessment of the LULC maps based on maximum likelihood algorithm in 1987 and 2008 was done using the error matrix. The overall classification accuracy of the 1987 and 2008 LULC map were 82.61 % and 86.43 % respectively with a kappa statistics of 0.8905 and 0.8317. Either as a producer or user accuracy of these LULC maps, the obtained accuracies are considered satisfactory, especially for forest cover and built-up lands. The cross tabulation analysis of LULC conversion matrix between (1987-2008), indicates a significant land conversion between the forest area and other LULC category. The result indicates that the conversion of forest to non-forest vegetation and built-up were very extensive.

Class	land use/land cover		land use/land	
	covers in 1987	Change (ha)	Change (%)	Change (%) in 2008(ha)
Forest cover	8527.69	6258.87	-2268	- 15
Non-forest vegetation	2300.14	2654.78	353.84	2.40
Urban built-up	1107.44	2329.92	1222.48	8.30
Barren Land	2780.24	3472.02	691.78	4.69
Water bodies	5.922	5.76	5.76	- 0.0011

Table.1. Showing the Land use/Landcover Change dynamics of the study area

The overall changes in the LULC of study area during 1987-2008 (Table 1), shows among the LULC classes the majority on the land categories is increasing except for the forest and water bodies. The forest area is higher among the change. On the other hand, the urban area has increase considerably with and increase area of 1222.48 ha of built-up land.

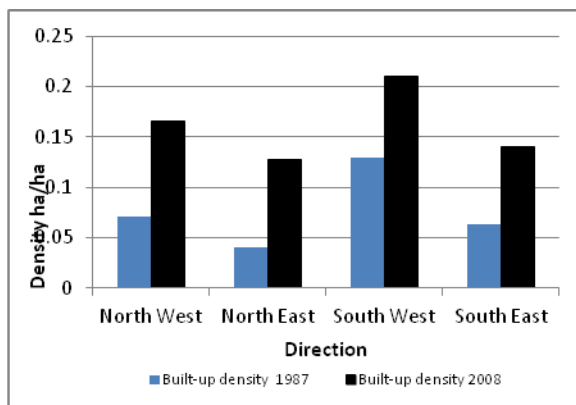


Figure 2. Comparison of urban built-up density in different Zone of the study area between 1987 – 2008.

The considerably increased in the built up with a change percentage of 8.3%, can partly be explained as a result of the population explosion especially after the Shillong became the capital of Meghalaya state in 1972. The population of Shillong was recorded with a decadal growth from 63.9% during 1970s and 175.6% during the 1980s (Ryngnga, 2003), this growth lead to the influx of population from outside plus local increase of population after Shillong became the main centre of administrative, cultural and commercial as well as due to its convenient transport system and beautiful surrounding. Shillong was becoming a perfect residential area for Meghalaya.

Urban expansion detection and analysis

The focus of this study is to monitor the spatial-temporal pattern of urban expansion and its consequential effect on forest vegetation. Therefore, at the first instance an effort was made to evaluate the spatial characteristics and pattern of the urban expansion in the Shillong city during 1987 and 2008. It is accepted that the urban development is affected by some primary location factors, i.e., the distance to urban centers and roads (Jha *et al.* 2008). We analyzed the pattern of urban built-up expansion during 1987-2008 with respect to urban centre and distance from the road in the study area. We calculated the density of changes in built-up in buffers by flowing the methods discussed earlier.

For the study period of 1987-2008, four buffer zones were constructed at a distance of 500 m each with respect to the highway. In this way we have tried to examine the urban expansion process in reference to proximity to the highway (figure, 3). A correlation of -0.88 (for a significance on 0.05) was found, thus, it shows that the relationship of urban expansion is indirectly related to the distance away from the road. An enquiry of the density change distribution curve reveals that the majority of urban expansion (70%) occurred between 0 to 1000 meter and out of this 45 % occurred between the distances of 0 - 500 metre. This is due to the factors of road density and geographical setting i.e. highly undulating topography.

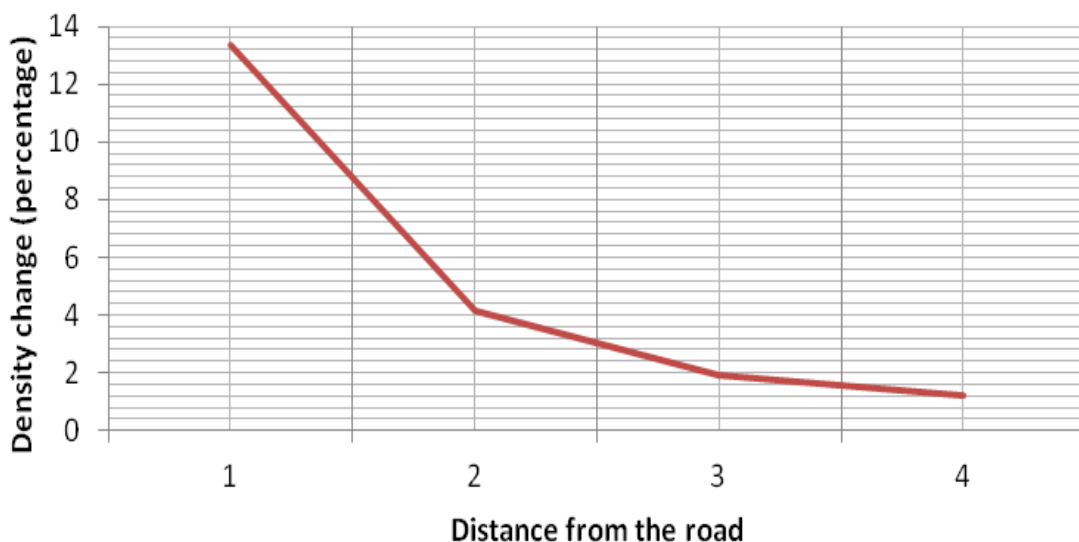


Figure 3. Area of urban built-up expansion from the highway

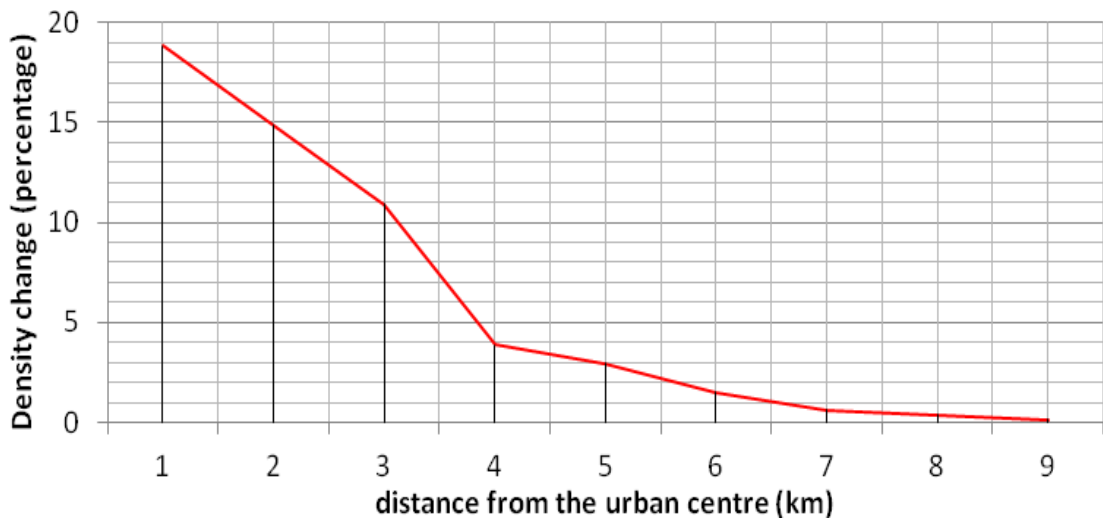


Figure 4. Area of urban built-up expansion as a function of the distance from the urban centre.

Near the urban core the road density is very high and provides a scope for the process of urban expansion. Therefore, in the urban core expansion is observed up to a distance of 0 to 2 km due to mesh of high density of road networks comprising of city roads and highways. However, as one moves away from the urban core the road density decreases and urban expansions can take place only in a linear fashion. This is further constrained due to the terrain complexity which does not favour lateral expansion. The expansion is thus restricted to a distance of only 0 to 500 m. On the 9 km buffer zone, the built-up density and the distance from the city centre was plotted. The analysis of the built-up density decay curve demonstrates that the built-up density decreases as one moves away from the city centre (Figure 4), with a correlation of -0.91 (for a significant level of 0.05). It is clear that, there is a strong relationship between urban expansion and distance from the city centre (i.e. geometry of the main urban core). If one examines the curve, the built-up expansion declines in a linear fashion up to the distance of 3 km from the CBD; the decline became abrupt for the next 1 km (i.e. 3 to 4 km) and continues to drop gradually as one moves further away. The abrupt decline is due to the dynamics of urban expansion in this zone which expansion is characterized by low density concentration of urban built-up.

This buffer area is characterised by a high road network density and is also not very far from the urban core. Thus, settlements in this zone can escape

the congestion of the urban centre but can avail the amenities available in the core as they are not very far and well connected. The urban core thus acts as a push factor and drives the expansion outwards to this buffer area. Hence, this buffer area shows the highest density change. Another factor attributed for this high density change is the conversion of hitherto lands that did not fall under built-up but have become during 1987-2008. Also, the pre-existing areas under built-up experienced intensification of the process of built-up i.e. fill up of the gaps between the pockets of settlements (i.e. the sparse settlement). This buffer area being located around the main urban core, the good road networks and the proximity to urban centre provides a push factor to expand at near distances. This buffer area has recorded an addition of 40.68 percent increase in built-up density during 1987-2008.

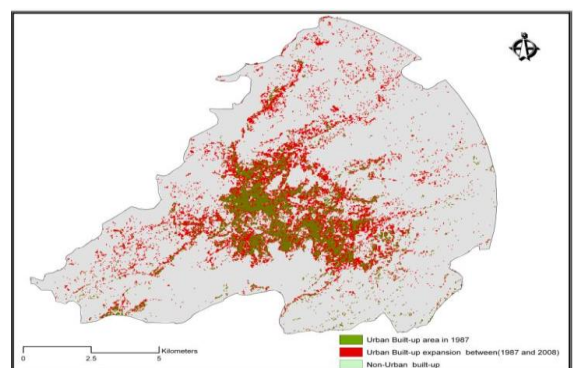


Figure 5. Urban expansion of the study area during 1987-2008 from remotely sensed data.

Figure 5 shows the overlay of the map of 1987-2008 urban built-up expansion of the study area. The map helps us to decipher the degree of urban expansion that has occurred in the entire study region. It is clear that the expansion was comparatively higher outward and spreading away out ward from the urban core in a linear order. The expansion is especially in and around the core and spreads out ward in a linear pattern. Zone wise changes in the built-up expansion are recorded, and the North east and south east direction (Figure 2) was recorded to be highest. This depicts that the spread pattern is more towards this direction. Measurement of Shannon's entropy Shannon entropy is an effective tool for monitoring spatial urban growth (Kumar et al, 2005). The entropy was calculated for the 2007 and 2008 of the study area overall and for each sector zone. This approach will help in determining the sprawl pattern as a whole and to determine direction of the sprawl. Shannon's entropy for the year 1987 and 2008 were found to be 0.65 and 0.75 with log value of 0.95 which indicate relatively high occurrence of dispersion in both the period. The high value of entropy during 1987 may imply that the urban development during 1987 was extensive sprawl and a large area of land was beginning to become more urbanized due to the creation of new towns in the area. However, during 1987-2008 the rate of sprawl is increasing. As a general the entire study area the urban expansion exhibits a leap-frog pattern (i.e. sprawl is located everywhere), however, three distinct urban expansions pattern can be identified in the study area (Figure 5). The first type which is characterise by compact or high density built-up area and second type with a relatively low density that occurred around the buffer zone of the first urban core. Finally, the third one which is found along the highway with linear spread. The first type forms the main city centre and its extended parts which expanded in a circular geometry which comprising (Shillong municipal, Shillong cantonment, and near township) and the second type which occur extended along the highway or main road (e.g. Mawlai area in Zone 2). This may be due to the flux of urban population nearby the urban core to escape from the dense urban population. Further evaluation of the entropy change in each for each sector zone, indicates that the sprawls is more towards the north-east and south-west direction (Table 2). However, majority of the low density urban expansion was observed in south-west direction.

Relationship between urban expansion and forest cover change

The forest cover has experienced dramatic changes in almost every part of the entire study area, (Figure 5). It can be seen that small and large patches of forest are distributed in the entire study region. During 1987 and 2008, a total net loss of 2265 ha forest area is recorded in study area which accounts for 15% percent of the total forest cover in 1987.

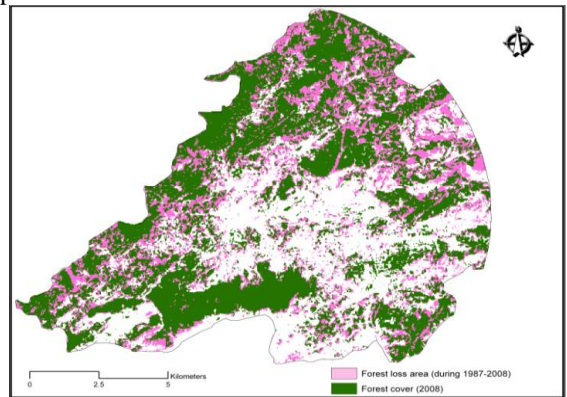


Figure 5. Forest cover change in the study area during 1987-2008 from the remotely sensed data.

To investigate the relationship between the spatial characteristics of forest cover change and urban expansion process we adopted the GIS buffer analysis technique which was discussed above. On that basis, we analyse the distance decay function of forest density decrease with relation to distance to city centre and highway. During the study period of 1987-2008, on the four buffer zones with a space of 500 meter, the forest cover decline was plotted against distance to road. The forest decline was found to take place in a liner pattern with 0.99 (for a significance value of 0.05) was obtained. However, ANOVA testing revealed that the found out relationship cannot be stated with a high degree of confidence (F value of 0.17). Therefore we cannot consider road as the major factor influencing forest cover decline. Other factors such as agricultural cultivation and geo-environmental factors might be playing an important role in the decline of forest cover. The change in forest density decrease in the nine buffer zones (1 km apart) was further plotted against proximity to the city centre (CBD). It was found that the increase density values of forest cover loss increases when one approaches to the city centre. The statistical correlation found a correlation coefficient of 0.77 for a significant level of 0.50.

Table 2. Showing the zone wise entropy and log value of the study area

Zones	Entropy (Hn)		Log (n)	
	1987	2007	1987	2007
Zone 1	0.580283362	0.653977371	0.602059991	0.84509804
Zone 2	0.894585218	0.754786174	0.954242509	0.954242509
Zone 3	0.703630375	0.76014986	0.903089987	0.954242509
Zone 4	0.51783094	0.709672286	0.84509804	0.903089987

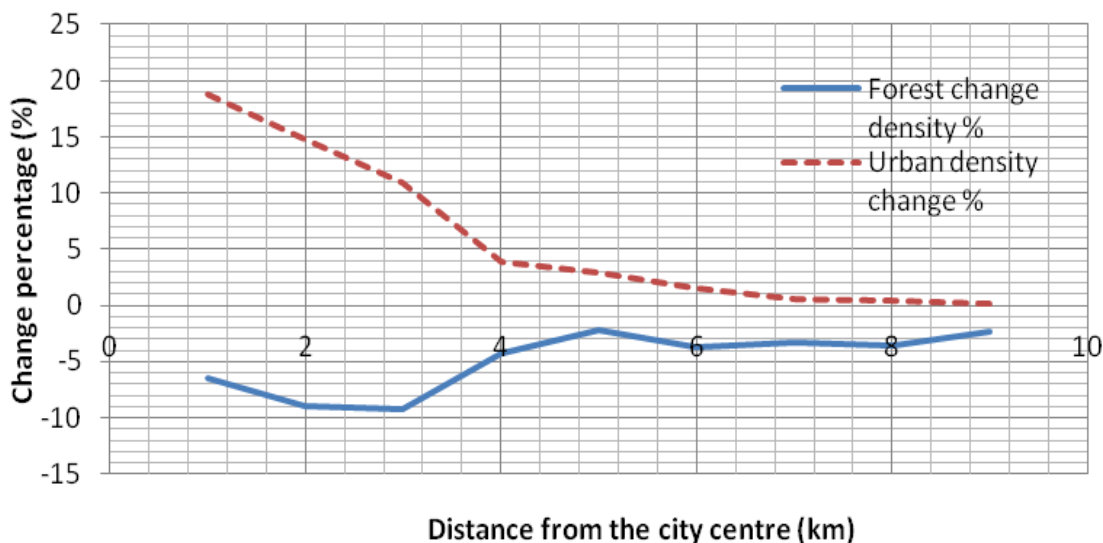


Figure 6. Relationship between increased built-up density and forest cover decline density.

The forest cover decline curve showed a sharp decline up to a distance of 0-5 km (percentage forest change density change as shown in Figure 6). However, after a distance from 5-6 km buffer zone it shows a steady decline in forest cover density change in an irregular pattern. We further examine the relationship between the forest cover decline and urban expansion by plotting the values on the graph above (figure 6) and calculating the correlation between the decreasing forest areas with the increased built-up area. A correlation coefficient of -0.87 was found at the significance level of 0.05; this confirmed that the forest cover decrease in the study area is highly affected by the urban built-up expansion and there is the possibility of further forest cover decline as the built up area would increase in the future. Figure 6, shows the relationship between forest decline density and the urban expansion density. The curve exhibits an irregular pattern for the first 0 - 5 km and henceforth both the curves moves almost parallel to each other. This means that as one moves farther there is a decrease in the urban density and an improvement in the forest cover. The highest decline in forest area is observed at the distance between 1 to 3 km buffer zone. This is the zone that experiences the highest urban expansion in

the study area. This is because the region is located where the urban expansion intensity is highest in the entire study area. A forest density decrease of 30% and 35% was observed in the 1st and 3rd km buffer zones.

However as we move further away i.e. a distance of 4 to 9 km there is a gradual decline in urban expansion and low interference in the forest cover resulting in a much better forest cover as compared to the zones lying closer to the urban core. In the absence of high impact of urban expansion some other bio-physical factors are responsible for the slow decline in forest cover or the presence of protected areas (for e.g. Raid Laban Reserved Forest in the southern part). Even though the forest decline is low in the latter zones i.e. 4 to 9 km, the absolute area affected in them is large. In contrast to it the intensity of density change is highest in the zones near the urban core but the area affected is less. This is because the areas near the core are characterised by high urbanisation and the area under forest is already less. Hence, even though the intensity is highest the area involved is low.

Thus, even though the relationship between decline in forest cover and urban expansion was found to be

significant there are hidden intricacies like the relationship between intensity and change in absolute area that are not straightforward. Hence, intensive studies especially regarding the relationship between the different elements need to be taken up in future.

Conclusion

The study attempted to understand the spatial and temporal pattern of urban expansion and its consequential effect on forest cover in Shillong city and its environ between 1987 and 2008. The urban expansion of Shillong city and relationship with the surrounding forest landscape changes in the last 21 years has been investigated using remote sensing data. The results of this study indicates that there have been significant changes in the urban built-up expansion and this has led to a modification of natural landscape, particularly with evidence of extensive degradation in forest land of the study area.

Analysis of the built-up expansion reveals that the city of Shillong has extended its urban expansion in every direction albeit at differing intensities. The urban centre and road network played an important role in the process of this expansion. The direction of the road also determined the direction, intensity and pattern of the urban expansion. Most of the expansion pattern is characterised by the intensification of the process in the pre-existing urban areas by filling the gaps between the pockets/patches of settlements.

The result of the urban-forest relationship analysis clearly reflects that the urban built-up expanded mostly at the expense of the forest and other non-forest vegetation cover area. This rise in the urban expansion has come at the cost of declining forest cover especially close to the urban core. However, there is no obvious relationship found between the road network and decline in forest cover because of the low road density as we move away from the city core. The urban expansion process in the region is inevitable, however with proper management and planning it can be directed in a desirable and sustainable way, by protecting natural vegetation and ecological area. It is suggested that top priority should be given to the issues of declining natural vegetation and ecological while planning. The urban development plan ignoring these issues will jeopardize the conservation of natural resources and future sustainability of the urban environment.

The use of integrated approach by combining remote sensing, GIS and geo-statistical technique helped in

identifying the urban expansion process and its consequential impact on spatial characteristics of forest cover land. However, to construct a strong empirical explanation on the phenomenon of forest cover decline by limiting to a single aspect like urbanization processes only may not be sufficient, especially in a region like Shillong where geo-environmental factors like topography may also prove to play a very important role in determining the vegetation cover. Therefore, in future studies, it is necessary to explore and incorporate the other fundamental factors like socio-economic and biophysical etc. to study the urban environment in order to provide an improved explanation for the forest landscape change phenomena in the area.

References

- Banister, D., Watson, S. and Wood, C. (1997). Sustainable cities: transport, energy and urban form. *Environment and Planning B*, 24, 125-143.
- Howarth, P. J. (1986). Landsat digital enhancements for change detection in urban environment. *Remote Sensing of Environment*, 13, 149-460.
- Jat, M. K., Garg, P. K. and Khare, D. (2008). Modelling of urban growth using spatial analysis techniques: a case study of Ajmer city (India). *International Journal of Remote Sensing*, 29: 2, 543-567, doi: /10.1080 /01431160701280983.
- Kumar, M., Mukherjee, N., Sharma, G. P., and Raghubanshi, A. S. (2010). Land use pattern and urbanization in the holy city of Varanasi, India: a scenario. *Environment Monitoring and Assessment*, 167:417-422.
- Longley, P. A., and Meisev, V. (2000). On the measurement and generalization of urban form, *Environment and Planning A*, 32, 473-448.
- Ryngnga, P. K. Ryngnga (2003). Expansion of Shillong urban agglomeration-A note, *Hill Geographer*, 13 (1&2):51-56.
- Singh, G. (1992). Urban growth and Changing Land use pattern in Shillong, unpublished M.Phil thesis, School of Human and Environmental Sciences, North Eastern Hill University.
- Stow, D. A., Chen, D. M. (2002). Sensitivity of multitemporal NOAA AVHRR data of an urbanizing region to land-use/land-cover changes and misregistration, *Remote Sensing and Environment*, 80, 297-307.
- Weng, Q. (2001). A remote sensing-GIS evaluation of urban expansion and its impact on surface temperature in the Zhujang Delta, China, *International Journal of Remote Sensing*, 22(10):1999-2014.
- Weng, Q. (2001). Spatial Analysis of urban growth impact on vegetative Greenness with Landsat TM Data, *Geocarto international*, 16(4):17-25.