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Delineating urban, suburban and rural areas using Landsat and DMSP-OLS night-time images

Case Study of Hyderabad, India

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Abstract— **The number and size of urban settlements are increasing in all the continents of the world at a rapid pace. Urban sprawl is associated not only with changes in landcover and area, but also ecological, climate and social transformations. Mapping the growth and spread of urban areas is important. Remote sensing has long been used to map human settlements. Today the availability of a large number of satellites and sensors, determining the appropriate image to map urban area is a research area itself. This study compares two satellite images: Landsat Enhanced Thematic Mapper data and Defence Meteorological Satellite Program, Operational Linescan System image to map the urban footprint of the city of Hyderabad, India. Landsat ETM data is captured during the daytime and gives spectral reflectance values while the DMSP-OLS data captures artificial lights from human settlements at night and produces brightness information. The results show an accuracy of more than 90% in the classification and delineation of urban, suburban and rural landcover types. This study shows that in addition to spectral reflectance captured by satellites from different features on the earth surface during the daytime, differences in the degree of brightness of the lights emitted from urban areas at night is also an effective indicator in delineating landcover types.**

I. INTRODUCTION

Urbanization, commonly defined as the process of becoming urban [1], is an important process in today's world. It involves demographic, ecological, social and economic transformations of a place. Mapping the nature of these changes is important especially in rapidly growing urban areas [2]. In an increasingly urbanizing world, remote sensing is widely applied to delineate urban footprints i.e. the extent of urbanized areas on a regional scale. Urbanization is a relatively new process in India with approximately 28% of the population living in urban areas [2-4]. However, the process of urbanization is rapid in the country. The number of towns has risen from 1827 in 1901 to 5161 in 2001 [2, 3, 5].

Urban footprints are understood as the spatial extent of the man-made structures defining a city. This paper compares the capabilities of very different remotely sensed data sets – Landsat Enhanced Thematic Mapper (ETM) and Defense Meteorological Satellite Program – Operational Linescan System (DMSP-OLS). The main objectives of this paper are:

- To compare and evaluate Landsat ETM data and DMSP-OLS night time images for the classification of urban footprints.
- To assess the accuracy of urban footprints obtained from two different sources of satellite images.

II. STUDY AREA AND DATA SETS

The study concentrates on the city of Hyderabad and its surrounding areas known as Hyderabad Urban Agglomeration. Hyderabad is the capital city of the state of Andhra Pradesh in South India. It is a sprawling metropolis and a cosmopolitan city with a population of 6.12 million in 2005 and a current growth rate of 2.42 percent per year [6]. Hyderabad Urban Agglomeration (HUA) is the sixth largest in India, with a population of 5.75 million in the year 2001. The urban agglomeration radiating out of Hyderabad covers an area of 778.17 sq km and comprises of Hyderabad and twelve other surrounding municipal corporations. The Hyderabad Metropolitan Area is surrounding the Hyderabad Urban Agglomeration and covers an area of 1905 sq. km. [6]

Two satellite image datasets were acquired for 2001. The first, Landsat – 7 ETM+ has a spatial resolution in panchromatic mode of 15 m ground sampling distance. It is sufficient enough for landcover classification into urbanized and non-urbanized areas [5]. With its field of view of about 185 km, the satellite can survey large metropolitan areas. Measurement of both areal coverage and spatial distribution are needed to describe the morphology of an urban area adequately [7], both of which are met by the image obtained from the Landsat ETM sensor.

The other satellite imagery used for this study is the radiance calibrated DMSP-OLS night-time data set for 2001. This image was prepared from individual fixed gain images captured by satellites F12 and F15. However, this image was not calibrated to radiance [8, 9] and the brightness values, ranging from 0 – 653, as obtained from the image were used in the study. With a spatial resolution of 1 km the starting basis for the delineation of the urban footprint significantly differs from the Landsat imagery.

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III. METHODOLOGY

For the delineation of urban and sub urban landcover types, two different methods were followed: image classification and image thresholding. A method of image classification was applied to both the image datasets. While the Landsat image was classified into different landcover types, the DMSP-OLS image was first classified into brightness zones followed by a method of thresholding to demarcate urban, suburban and rural areas.

The classification of the Landsat data was based on an object-oriented, hierarchical approach [10]. After a multi-resolution segmentation, the classes are identified hierarchically, starting with classes of significant seperability from other land cover types and ending with those of lower seperability. Specifically, an object-oriented fuzzy-based methodology was used to combine spectral features such as the NDVI together with texture, shape and context information from the original data set (fig 1). In addition, principal component analysis was used to extract the urban footprint. The urban footprint of Hyderabad as obtained from Landsat data is shown in fig 5.

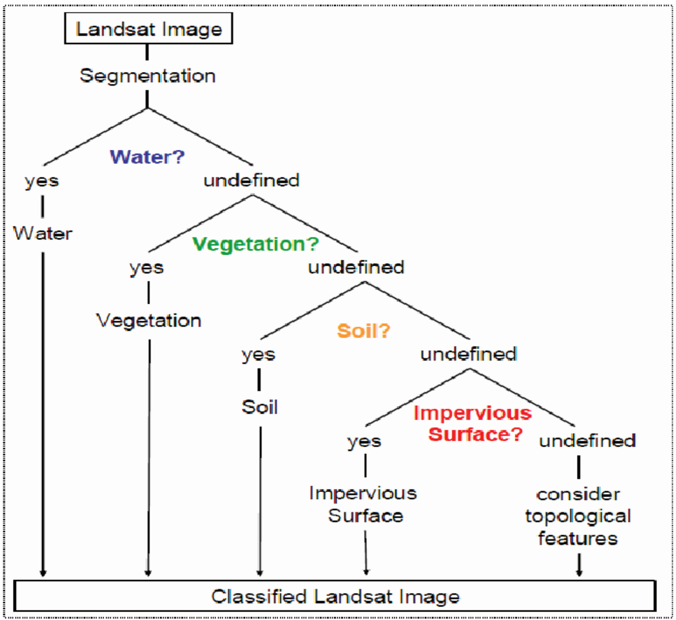

Figure 1: Hierarchical classification structure for Landsat Data

The DMSP/OLS dataset was processed in two stages:

Stage 1: Supervised classification by maximum likelihood:

The method of supervised classification by maximum likelihood is one of the most common methods of image classification. Spectral signatures were collected from a representative sample of the study area and the image was classified initially into 25 classes based on their brightness values. These classes were later merged to produce 7 classes of urban brightness. Figure 2 shows the classified DMSP-OLS image. It shows a clear zonation on the basis of brightness values.

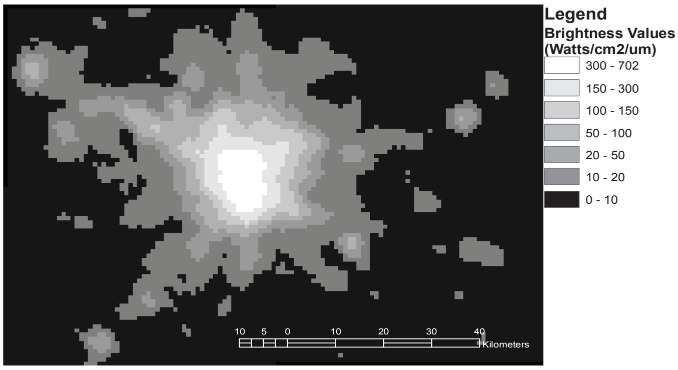

Figure 2: Classified DMSP-OLS night time image

Stage 2: Determination of threshold value:

The process of thresholding is a common method to systematically sort and categorize the lighted pixels in the DMSP-OLS dataset. It helps to denote the optimum brightness value demarcating the urban core, sub urban and rural areas. A method of thresholding was used to delineate urban areas from DMSP-OLS images by Imhoff [11], Amaral et al [12] and Roychowdhury et al [2]. Imhoff [11] proposed the thresholding method to delineate urban areas of the United States. It was found that most of the American cities can be delineated at a threshold of more than 89% of the lighted pixels. Amaral et al [10] delineated urban areas of Brazil at a threshold of 30%. Applying the method of thresholding for the state of Maharashtra in India, a threshold value of 20% was found to delineate most successfully large urban areas of the state [2].

In this study, threshold brightness ranging from 100% to 1% were calculated for the DMSP-OLS image. The perimeters of the areas enclosed by the threshold values were calculated. A threshold value of 100% gives the perimeter of the areas enclosed by all the pixels in the image. As the threshold value decreases, the bright pixels tend to separate from the relatively less bright ones (fig 6). The graphs of perimeter against threshold values are given in figure 3 and figure 4.

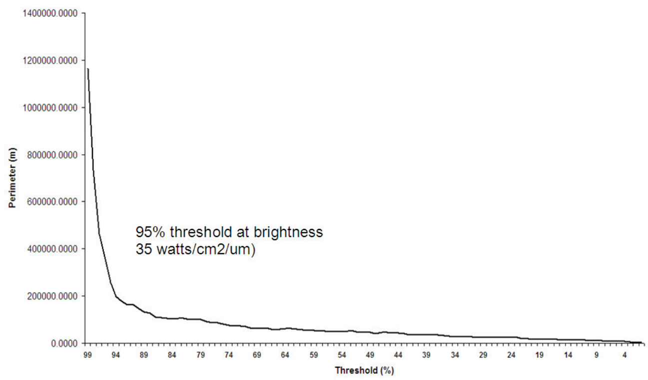

Figure 3: Perimeter of areas enclosed by 100% to 1% thresholds

Figure 3 shows the perimeter as obtained from threshold values ranging from 1% to 99%. Figure 4 gives a closer look at the change in perimeter at an interval of every 10% threshold value. Figure 3 shows a gradual transition in the perimeters of areas enclosed by the different threshold values. A break of slope can be noted at threshold of 95%. A closer look into the threshold values in fig 4 denotes another sharp breakpoint at 70%.

70%, 95% and 97% thresholds were calculated and the areas enclosed by these values were overlaid on the classified DMSP-OLS image (fig 6).

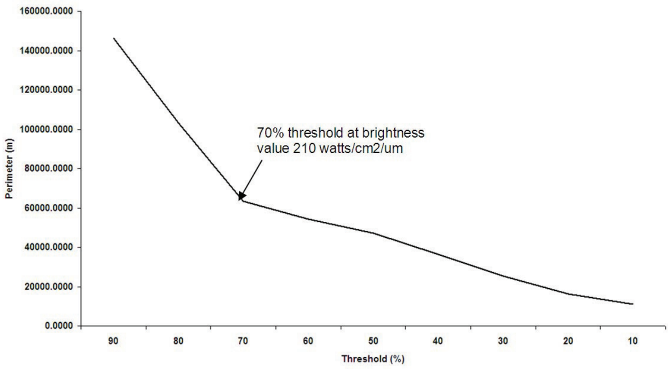

Figure 4: Perimeter of areas enclosed within selected threshold values (10% interval)

IV. Results and Validation

The classification result from the Landsat ETM imagery displays a complex urban footprint of a coalescent urban core and a complex, sprawling suburban to splinter development in rural areas. The capabilities of the comparatively high geometric resolution of Landsat data results in an urban footprint revealing small and large open spaces within the urban core.

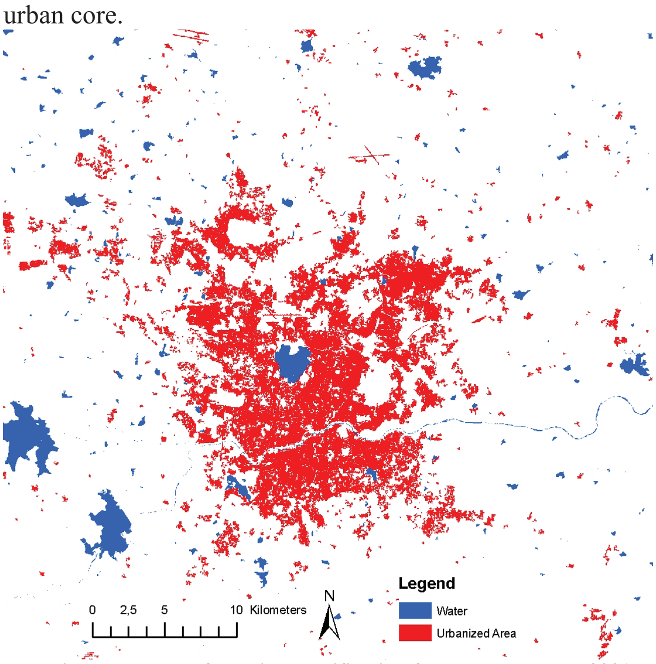

Figure 5: Urban footprint classification from Landsat data 2001

From the classified DMSP-OLS image and the threshold values (fig 6), it was found that at 70 % threshold (denoted by the red polygon in fig 6), the urban and the suburban areas are clearly distinguished. This threshold encloses areas with brightness values of more than 200 watts/cm^2/um and covers an area of approximately 179 square Kilometres. At 95% threshold the inner suburbs are separated from the outer suburbs. The area within the 95% threshold (blue polygon in fig 6) is approximately 813 square Kilometres. This coincides with the Hyderabad Urban Agglomeration. The rural areas are differentiated from the urban areas at a threshold of 97% (the orange polygon in fig 6). The area included within this threshold forms the Hyderabad Metropolitan Area and extends for approximately 1260 square Kilometres.

The validation of the result was carried out in two stages. Firstly, the classified Landsat data was compared to the unclassified Landsat imagery. Due to the absence of any other source of field or ground truth data the unclassified Landsat imagery was used as the reference image and classification results of 250 randomly distributed pixels were visually compared. This accuracy assessment indicated 91.2% accuracy over the two landcover classes (water and urbanized area).

The second step of validation was to compare the classified urban footprint from Landsat imagery with the classified urban footprint from the DMSP-OLS image (fig 6). 250 randomly distributed pixels were chosen from the classified DMSP-OLS image. The classified Landsat data was used as the reference image and the accuracy of classification was tested. Pixels lying within the 70% threshold and overlaying the urban class in the classified Landsat image were compared to those reported as urban in the DMSP-OLS classification. The overall classification accuracy was 93% in this case.

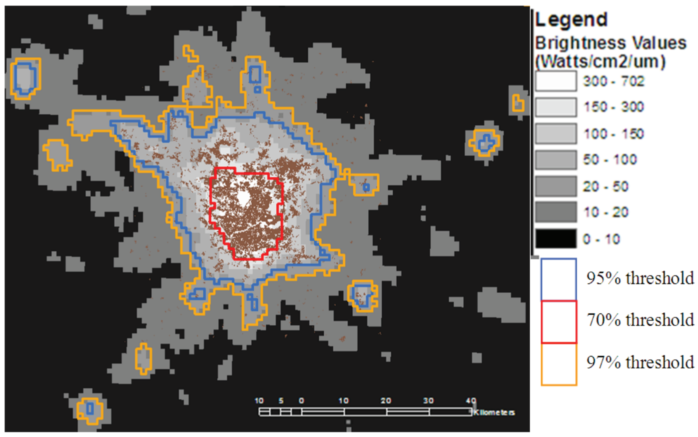

Figure 6: Urban areas obtained from Landsat images (brown polygon) enclosed within 95%, 97% and 70% threshold values. The urban area as obtained from Landsat data also coincides with the bright zones in the classified DMSP-OLS data.

V. Discussion and Conclusion

In general it can be concluded that the basic spatial character of the classified urban footprints from both data sets – Landsat data and DMSP-OLS night-time imagery – correspond to each other. Of course, the coarse geometric resolution of DMSP OLS does not allow detection of small-scale open spaces or local characteristics as Landsat does, but the general delineation of the urban footprint shows high accuracies. Thus, it depends on the question to be answered what kind thematic or geometric detail is needed.

The method of thresholding proves suitable in the context of India. However the level of threshold varies from region to region. For example, in this study it was found that the urban core and the sub urban regions were separated at a threshold of 70%. However for the cities of Mumbai, Pune, Nagpur and Nashik in the state of Maharashtra [2] a threshold of 20% differentiated the urban and sub urban areas. The difference in the threshold levels can be explained by variations in levels of urbanization of the cities. In the study by Roychowdhury et al [2] it was found that for Mumbai, there were three distinct threshold breakpoints at 20%, 50% and 70% of radiance values. For the cities of Pune [2], two thresholds were noted at 20% and 50% of radiance values while for Nagpur there was only one threshold at 50%. When ranked on the basis of their total population, Mumbai is the largest followed by Pune and Nagpur respectively. This shows that the sizes of urban areas and their level of urbanization determine the amount of radiance and brightness recorded by the DMSP-OLS sensor, which in turn determined the optimum threshold value.

The areas enclosed within the threshold brightness values in the city of Hyderabad were compared with the published areas of Hyderabad city, Hyderabad Urban Agglomeration and Hyderabad Metropolitan Area (table 1) as recorded in the Indian census and the Greater Hyderabad Municipal Corporation (GHMC). The DMSP-OLS derived urban footprint was most accurate in delineating the Hyderabad Urban Agglomeration (threshold 95%) with an error of 4.5%. The city of Hyderabad (threshold 70%) was delineated with an error of 17.5% while the Hyderabad Metropolitan Area (threshold 97%) was 33% larger in DMSP-OLS than was reported by the Greater Hyderabad Municipal Corporation [6]. These errors in areas may be attributed to scaling issues. The ground sampling distance of the DMSP-OLS dataset is approximately 1 square Kilometre, coarse enough to produce uncertainties in the landcover. In addition to this, the classification was based solely on brightness values obtained from the image which can vary over a region for a number of reasons such as blooming effects for larger urban areas.

Table 1: Difference in the areas (Km^2) predicted from DMSP-OLS data and published census/GHMC datasets

Regions	Census/GHMC Area (Square Kilometre)	DMSP-OLS Area (Square Kilometre)	% difference (net)
Hyderabad city	217	179	17.5
Hyderabad Urban Agglomeration	778	813	4.5
Hyderabad Metropolitan Area	1905	1260	33

The brighter areas in the classified DMSP-OLS data coincided with the urban area as obtained from Landsat data (fig 6). The brightest part of the classified DMSP-OLS image is enclosed within 70% threshold value while comparatively less bright areas are within 95% and 97% threshold polygons.

This study successfully shows that DMSP-OLS night-time images can be used to delineate urban, sub urban and rural landcover types. In the absence of published landcover maps for India, this is a useful method to define urban area boundaries. With an overall classification accuracy of 93% and an error of only 4.5% in defining Hyderabad Urban Agglomeration, it can be conclusively said that along with Landsat data DMSP-OLS radiance calibrated dataset is a useful data set to delineate urban, suburban and rural areas at regional scale.

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