Mapping of Impervious Surface using Spectral Angle Mapper (SAM) and NDVI Techniques, Case Study: Bhopal City

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Abstract
Impervious surface is essential to plot urban area development and the distribution of impervious surfaces can be used as a tool in environmental applications. Multispectral remote sensing based mapping has shown great potential in detailing land uses. Eastern area of Bhopal city has been analyzed of land use/land cover and it is derived from the results that some parts of land which has potentiality for agriculture has been gradually converted to urban plots leading to reduction of land for growing crops whereas some other areas, which tend to be impervious are left bare and it is a crucial fact that no agriculture is possible in such surfaces. Hence proper analysis regarding the surface area has to be done before executing development strategies. This paper emphasises on the parts of land in the concerned area, that can be utilized for urban development. For comparison, four types of Endmember fractions (i.e. soil, vegetation, water and imperviousness) were used in this study. Selection of Endmember fraction was done by MNF, NDWI and NDVI. Spectral Angle Mapper (SAM), a classification technique, was used to map impervious surface using land sat data of the proposed area of study. SAM classification resulted in classifying the study area into 5 landclass types with total imperviousness cover of about 27% of the area studied.

Keywords: Endmember Fraction, Impervious Surfaces, NDVI, MNF, Supervised Classification

1 Introduction
The infrastructure development policies set forth as a part of structural economic reformations established by the Government of India in the beginning of nineties has been a vital rationale behind the industrial and infrastructure development in the country. Inevitably, the area having apparently good economic growth and service affordability has grabbed massive investments for industries from all over India, even has attracted global investments. This buildout has led to ample employment opportunities, greater incomes and has upraised quality of life of the settlements and thereby refined the overall stratum of the less developed states like Madhya Pradesh. Such hasty rate of industrial growth is much likely to happen in the area around existing urban centers taking existing environmental regulations into consideration. Thus, the fertile soil resources in the outskirts of such urban area, which were once expended for agricultural purposes, have suffered anthropogenic destruction over the past decades. This urban sprawl or the radial expansion of city to its rural area has destabilized the agrarian economy and forest based resources available in that region. This perpetual agricultural landuse transformation due to growing settlement and transport facilities is observed worldwide and is now a menace of concern in most developed and also developing countries.

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Corollaries of the urban sprawl includes numerous negative impacts such as loss of essential soil functions, increased storm water runoff and soil erosion, alteration of physical and chemical properties of surface water bodies, increased heating of land exposed to solar radiation, warming up of boundary layer of atmosphere, decreased rate of percolation of water into the ground due to greater cover of impervious surfaces and affects the overall well-being of the ecosystem. Impervious surfaces associated with such adverse impacts, can be defined as any surface which does not allow infiltration of water through it and are basically associated with infrastructural elements such as building and industrial rooftops, streets, highways, parking lots and sidewalks etc. Thus the imperviousness, is an indicator of urban environmental quality, has now become crucial benchmark in urban planning and in assessing the sustainability of land use.

Conventional methods of data collection and data survey and mapping or by statistics are tedious, rough, time consuming, and lacks updation of results. Remote sensing techniques employs the science behind the sensors of the satellites to acquire a precise map of imperviousness in an area, facilitated by its speedy, flexible, cost effective, accurate procedures for the analysis of impervious surfaces. Remote sensing makes use of high or medium resolution satellite images for the characterization. Multiple remote sensing procedures have been handled so far for accurate detailing of impervious surfaces in accordance to the requirement and the nature of the area handled. Numerous ranges of satellite data are available for serving these purposes and Landsat data is one among those that provides a means to quantify and map the imperviousness over a large geographical area with good accuracy in time.

2. Study Area

The study area covers outskirts of Bhopal Municipal Corporation, the second largest populated city and the capital of Madhya Pradesh state, and also covers Mandideep and Bhojpur villages of Raisen district of Madhya Pradesh. Geographical location of the study area lies between 23°11’12.65"N 77°28’17”E, 23°3’3.33"N77°38’19.29”E is upper left and right coordinate and 23°3’7.76"N77°28’8.55”E, 23°3’0.06”N77°38’16.46”E Bottom left and right coordinate. Figure 1 a and b represents political map of MP and satellite image form google earth in which red outline rectangle shows study area of this research, respectively. Geographically, the study area is situated in Malwa plateau formed by the Deccan trap rocks and Betwa River flows over this area.

This region has humid subtropical climate and has deep medium black soil. Average temperature during summer is 40°C and during winter around 16°C. The annual average precipitation is 1146 mm. Being 20 kms far from Bhopal, this area is well connected to it though roadways because of the tourist attraction spot, the Bhojpur temple of historic importance in the Bhojpur village and also due to the industries developed around Mandideep area. The defined region posses a diversity of land cover classes including urban, suburban, agricultural land, rocky or hilly terrain etc.

3. Data Acquisition

Landsat 8 data was the primary source for this IS mapping. Landsat 8 imaging satellite has two sensor namely Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). OLI collects information from 9 spectral
visible/IR bands out of which 7 are consistent with Thematic Mapper and Enhanced Thematic Mapper plus. Two new spectral bands, a deep blue coastal/aerosol band and a shortwave-infrared cirrus band, to measure water quality and improve detection of high, thin clouds also included under OLI. TIRS collects information from 10-11 bands that are Thermal infrared. Acquired geotiff data was of 10 Jun 2014 under clean weather conditions. All further data processing and analysis was performed using ENvironment for Visualizing Images (ENVI 5.0) software.

4. Methodology

4.1 Flow Chart of Processing

4.2 Remote Sensing Data Pre-processing

Remote sensing raw data was obtained from USGS earth explorer website. There are two type of calibration usually apply on raw data namely geometric and radiometric. Since the data acquired for this study was a geotiff data, geometric calibration of data becomes unnecessary.

4.2.1 Radiometric Calibration

For conversion from irradiance to reflectance on the Landsat data the following formula is used:

\[ \lambda^* = M_p Q_{\text{band}} + A_p \]  

Where, \( \lambda^* \) represents planetary reflectance, without correction solar angle, \( M_p \) stands for band-specific multiplicative rescaling factor from the metadata, \( A_p \) is band-specific additive rescaling factor got from the metadata, and \( Q_{\text{band}} \) is the Quantized and calibrated standard product pixel values (DN).

Reflectance with a correction for the sun angle is then calculated by:

\[ \lambda = \lambda^*/\sin(\alpha) \quad \text{or} \quad \cos(\beta) \]  

Where, \( \lambda \) is the reflectance, \( \alpha \) is the local sun elevation angle and \( \beta \) represents local solar zenith angle and it equals to 90- \( \alpha \).

4.3 Endmember Fraction

4.3.1 Endmember Selection

The pure spectral signature of a feature is called an endmember. Selection of endmember fractions is quite difficult, and number of endmember required depends upon the landcover pattern of the area. In the aspect of extraction of urban impervious surface, there are mainly five types of extraction methods namely man computer interactive interpretation, regression analysis, regression tree analysis, artificial neural network and pixel unmixing analysis. This study employed the use of man computer interactive interpretation technique for the end member extraction purpose.

4.3.2 NDVI and NDWI

Selection of vegetation and water landcover was done at ease using Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) image respectively. NDVI measurement is to help for selection of vegetation endmember abundance. It is most suitable indicator of environment and vegetation abundance. NDWI measurement aids in selection of water endmember abundance. NDVI, NDWI are calculated by formula which is given below. NDVI is derived from ratio between difference and addition of Band 4 (Infrared) and Band 2 (Green) and NDWI from Band 4 (Infrared) and Band 2 (Blue band) of OLI sensor.

\[ NDWI = \frac{(B4-B2)}{(B4+B2)} \]  

\[ NDVI = \frac{(B4-B3)}{(B4+B3)} \]
4.4 MNF Transformation

MNF transformation reduces noise and dimension of image. Minimum Noise Fraction (MNF) transforms is essentially two cascaded Principal Components Analysis (PCA) transformations. With the increase of MNF transformation band component, number noise associated with the band increases along with the reduction in information contained in the band. Thus, MNF reduces the image dimension by enabling the selection of components with high information only. Here, MNF is calculated up to three band components and scatter plots between band 1 versus band 2 and band 2 versus band 3 are drawn and the MNF component values have been inverted for display purpose.

By analyzing the scatter plots obtained, “Mixing triangle” was developed for each plot. The three land cover types dominating in the area are represented in the scatter plots (Figure 3). From the scatter plots it is observed that the soil land cover is not dominating to vertex of mixing triangle and it is identified to be in middle of mixing triangle.

Remaining Regions of Interest (ROI) selection was accomplished through visualization of MNF transform components. If ROI has two or more pixels then mean spectra is calculated and it is considered as reference spectra of land cover. Spectral signature of each endmember with statistics parameters is shown below Figures 4b, 5a, 5b, 6a, 6b. Figure 4a exhibits the ROIs represented using different colours viz., soil as maroon covering 103 pixels, rock in red with 275 pixels, urban in yellow with 176 pixels, water in blue with 74 pixels and vegetation in green with 215 pixels.

4.5 SAM Classification

Spectral Angle Mapper classification is final step of this research work. It is a supervised classification method which determines the degree of similarity between two spectra by treating the spectra as vectors in a space with dimensionality equal to the number of bands. Spectral Angle Mapper (SAM) is a physically-based spectral classification that calculates the spectral angle between the spectrum of image pixel and the sample reference spectrum which is the purest spectrum and takes the angle as the pixel value of output image. Mean spectra is taken as reference spectra for

![Figure 3. Scatter plots of the MNF bands with indicated feature spaces for specific land cover.](image)

![Figure 4. (a) Study area with regions of interest. (b) Plot of vegetation spectra with statistics value.](image)
SAM classification. Threshold angle suitable of the image under analysis is found by various trials by altering the angle until suitable SAM classified image is got.

5. Analysis of Results

SAM classification diversified the study area into five land cover types comprising soil, rock, urban, vegetation and water which is represented in seine, red, yellow, green and blue color respectively and unclassified region is shown in black color in classified image Figure 7a. As per definition of IS, both rock and the urban classes, as water does not percolate through their surface is classified here as Impervious Surface and could be clearly identified and distinguished by means of SAM technique as shown in Figure 7b.

Figure 5.  (a) Plot of urban spectra along with statistics value. (b) Plot of rock spectra along with statistics value.

Figure 6.  (a) Plot of water spectra along with statistics value. (b) Plot of soil spectra along with statistics value.

Figure 7.  (a) SAM classified image of the study area. (b) Impervious surface map of the study area.
The extent of each landcover type in the area under study was quantified repetitively, by varying the spectral angle and the result obtained as given in the Table 1. From the table it can be observed that the most suitable spectral angle for this study was 0.40 radians. As a whole, impervious surface (rocks and urban area) covers about 27% of the study area. Since the image used for study was of June month, no much percentage of vegetation (8.632%) is observed and hence, soil covers maximum area (63.324%) of the location of the study.

### 6. Conclusion

This paper mainly focused on applying SAM transformation technique for identifying and mapping the imperviousness in the Eastern area of Bhopal city. From the results arrived at the end of this study, it can be identified that the study has greater cover of soil (63.324%) relative to impervious area (27%) and is also concluded that SAM, utilizing the accuracy of spectral signatures generated from MNF, NDVI and NDWI techniques, is one of the efficient, ease and effective way of mapping IS. The nature of urban sprawl can be studied from the IS map and this data can be utilized for a synergic urban development planning in near future. From the results obtained, it is suggested that in the upcoming infrastructure planning, maximum utilization of the imperviousarea should be done instead of utilization of agrarian land, so that the area available for percolation of water and for cultivation is conserved for a sustainable ecological, environmental and human balance.

### 7. Acknowledgement

The authors would like to thank United States Geological Survey (USGS) Earth Explorer, for providing the required Landsat dataset for this study.

### 8. References

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