Characterizing the Physical Environment of Kolkata by Spectral Unmixing of Landsat TM

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Abstract

Mega-cities worldwide and particularly in developing countries of Asia are experiencing urbanization induced land use land cover change (LULCC) at unprecedented rate. Ensuring future environmental sustainability in these dynamic areas require environmentally informed planning and decision making. A first step in this regard is to accurately characterize the physical environment of mega urban centers and their immediate surroundings. In this study urban land-cover is modeled as a combination of three primary components—vegetation, impervious surface, and soil (V-I-S)—in addition to water. Focusing on the metropole area of Kolkata and its adjacent city of Howrah in eastern India, this study tested the suitability of Multiple Endmember Spectral Mixture Analysis (MESMA) for estimating the sub-pixel abundance of the V-I-S components using a Landsat TM imagery of 2010. Endmembers are selected based on established purity measures followed by MESMA using varying complexity. Mapping accuracy is estimated empirically by overlaying results on Google Earth.

Introduction & Objectives

At medium spatial resolution of a multispectral imagery such as Landsat, reflectance of a pixel in urban area often represents mixture of V-I-S components. Pixel based approach (hard classifiers) that assume a pixel to be entirely composed on single components are thus limited in accuracy and fail to characterize sub-pixel properties. Linear Spectral Mixture Analysis (LSMA) overcomes these limitations and provides sub-pixel abundance estimates by modeling a pixel reflectance as linear combination of endmember (pure) spectra. In urban areas, variability in the reflectance of endmember causes low accuracy in fractional estimates, if produced using single endmembers. Multiple Endmember Spectral Mixture Analysis (MESMA) addresses this issue by allowing to vary both type and number of endmembers on a per pixel basis. The objective of this study is to test the suitability of MESMA for characterizing the complex urban environment in and around the city of Kolkata and Howrah.

Study Area

Kolkata (formerly Calcutta) is the capital of the Indian state of West Bengal. It is the main business, commercial and financial hub of eastern India and the northeastern states. The city is more than 300 years old and it served as the capital of India during the British governance until 1911. Much of the city was originally a vast wetland, reclaimed over the decades to accommodate the city’s burgeoning population. Howrah is the second largest and an industrial city of West Bengal. The twin cities of Kolkata and Howrah has urbanized and expanded vary rapidly, especially after the independence (1947). Except, Salt Lake neighborhood of Kolkata, the whole region has never undergone any full-fledged urban planned design policies and it shows intense urbanization in the old core city areas and vast sprawling along the city fringes and suburbs. This study covers an area of about 3536 sq. km. Approximately 15 million people resides just in the city of Kolkata and the density of population in this region is about 900+ persons sq. km. This city has extremely heterogeneous land use pattern with high intensity urban development which makes extraction of land use information from a medium resolution imagery challenging.

Methods

To address the issue of spatial and spectral variability in reflectance this study applied MESMA:

- Endmembers are selected using purity measures: Pixel Purity Index (PPI), Average Endmember RMSE, Minimum Average Spectral Angle (MASA) and Count based Endmember selection (CoB)
- Models of three different levels of complexity (2, 3 and 4 endmembers) are tested for each pixel where shade is present. To address these challenges and compare the multi-temporal Landsat TM imagery of the study area to capture the historical urban growth. Addressing the issue of transferability of endmembers especially in spatially heterogeneous and temporally dynamic urban landscape is a challenge. We anticipate to address this issue in future research both shallow and deep water areas needs to be included explicitly as endmembers.
- Besides visual comparison, future plan includes quantitative accuracy assessment by correlating fractional estimates of randomly selected Landsat TM pixels with results of object based image analysis (OBIA) of high resolution SPOT imagery.
- Future research also includes application of MESMA on radiometrically normalised multi-temporal Landsat TM imagery of the study area to capture the historical urban growth.

Results

Fractional Maps

Fractional cover outputs of MESMA are shown below for the study area (Figures 4). Bright areas represent higher fractions, dark areas lower fractions, and black pixels indicate the absence of the material or masked water bodies.

Discussion and Conclusions

Several potentially significant findings emerge from this preliminary analysis:
- More than 60 % of the study area was modeled using 4 endmembers, highlighting the sub-pixel heterogeneity. This is due to highly heterogeneous land use patterns, building materials and high intensity development that require relatively more complex models.
- Even though 13 endmembers for built up areas are used, in some predominantly built up areas MESMA failed to produce fractions within acceptable RMSE (i.e. within 2.5% of reflectance). This can be attributed to difference in used construction materials resulting in high intra class spectral variability.
- A visual accuracy analysis of the fractional cover maps is conducted by overlaying them on temporally coincident high spatial resolution imagery in Google Earth. Initial comparison shows good agreement, thus establishing the suitability of MESMA for accurately modeling spatially heterogeneous and spectrally variable reflectance in urban areas.
- Although water bodies are masked before MESMA analysis, some areas with water may have been excluded and vice versa contributing error in the final output. To address this issue in future research both shallow and deep water areas needs to be included explicitly as endmembers.

Selected References


