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Land surface emissivity retrieval based on moisture index from LANDSAT TM satellite data over heterogeneous surfaces of Delhi city

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ABSTRACT

Emissivity and surface temperature enables better understanding of the overall urban land use/land cover classes and in turn helps in understanding the energy budget issues. In the present study it has been demonstrated that the notion of the assumed spectral emissivity (i.e. 1) induces errors in modeling the surface energy budget and urban climatology (micro-climate), especially over heterogeneous surface areas (urban) where emissivity is far smaller than unity.

An attempt has been made to derive emissivity by using normalized difference moisture index (NDMI). The emissivity per pixel has been retrieved directly from satellite data and has been estimated as narrow band emissivity at the satellite sensor channel in order to have least error in the surface temperature estimation. The estimated emissivity values over few land use/land cover (LULC) classes of LANDSAT TM have been compared with the literature values and field measurement emissivity data using infrared thermometer.

A strong correlation is observed between surface temperatures with NDMI over different LULC classes. A regression relation between these parameters has been estimated (Pearson's correlation of 0.938), indicating that surface temperatures can be predicted if NDMI values are known. The error in field data (in situ) and satellite derived surface temperature is within the range of 2–3 °C. The correlation coefficient between the satellite derived and field observed surface temperature is very high ≈0.942 (significant at p value = 0.01). The results suggest that the methodology is feasible to estimate NDMI, surface emissivity and surface temperature with reasonable accuracy over heterogeneous urban areas.

1. Introduction

Accurate surface emissivity is desired in land surface models for better simulations of surface energy budgets from which surface temperature in the model is calculated (Jin et al., 1997). Emissivity (ε) is defined as the "emitting ability" of a natural material, compared to that of an ideal blackbody at the same temperature. The emissivity of natural land surface is determined by soil structure, soil composition, organic matter, moisture content, and vegetation-cover characteristics (Van de Griend and Owe, 1993). The value of emissivity always lies between 0 and 1 (Jin and Liang, 2006).

The knowledge of surface emissivity is important for estimating the land surface temperature. It can reduce the error on estimating the surface temperature from thermal satellite data. Current emissivity databases consists MODIS, ASTER and Landsat products. Several researchers have estimated LST using LANDSAT (Barsi et al., 2003; Sobrino et al., 2004; Xian and Crane, 2006), ASTER (Gillespie et al., 1998; Jimenez-Munoz et al., 2006) and MODIS data (Sobrino et al., 2003).

The emissivity parameter needs to be retrieved directly from satellite data to take into account, the changes of emissivity due to humidity, vegetation growth and others temporal parameters.

Voogt and Oke (2003) provided an overview of techniques for thermal remote sensing over urban climates. Several researchers have used classification over urban areas to analyze the urban surface temperature and its effect (Qin et al., 2001; Sobrino et al., 2004, 2012; Xian and Crane, 2006; Chen et al., 2006; Hartz et al., 2006; Yuan and Bauer, 2007; Myint et al., 2011). However, only a few works have properly addressed the problem of surface emissivity retrieval over urban heterogeneous surfaces. Pu et al. (2006) used a constant value of emissivity for all materials, although the authors stated that it is not wise decision to use the same value of emissivity (ε) for all types of surfaces i.e. emissivity = 1. On the contrary,

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Peng et al. (2008) and Xu et al. (2008) retrieved spectral emissivity (ε) over urban areas in a pixel-by-pixel basis.

Many studies have been carried out in order to retrieve land surface emissivity, such as temperature-independent spectral indices (TISI) methods (Zhu, 2006; Li and Becker, 1993; Becker and Li, 1995). This kind of algorithm combines middle wave infrared data (MWIR: 3.4–5.2 μm) with thermal infrared data (TIR: 8–14 μm) to estimate emissivity. Gillespie et al. (1998) developed this method for ASTER data and estimated emissivity with high accuracy. But the accuracy of this algorithm depends on some assumptions and ties to atmospheric correction. NDVI methods proposed by Caselles and Sobrino (1989) and developed by Van de Griend and Owe (1993) supplied a technique to calculate emissivity, and its successful performance in natural surface. But this method assumes the land surface is mainly made up of two types i.e. vegetations and soil, which is not in agreement with land surface. Jimenez-Munoz et al. (2006) used NDVI based emissivity method to obtain surface emissivities over agricultural areas from ASTER data, and found that band 13 gave most accurate emissivity measurement. Wan and Dozier (1996) utilized classification-based emissivity method and applied results to split window method, which performed satisfactorily and the accuracy of land surface temperature was ±1 K. Snyder et al. (1998) also used this method to retrieve global emissivity without considering the complicated urban surface (heterogeneous).

Urban surface is more complex phenomena and spectral heterogeneity is notable due to the spatial resolution, especially for thermal image. So the occurrence of mixed pixel is common and therefore effective emissivity should be looked into more cautiously.

Emissivity has strong seasonality and land use/land cover dependence. Specifically, emissivity depends on surface-cover type, soil moisture content, soil organic content, vegetation density. For example, broadband emissivity is usually around 0.96–0.98 for densely vegetated areas, but it can be lower than 0.90 for bare soils (Jin and Liang, 2006). With the above background this work aims to estimate the emissivity of urban surface (heterogeneous) targets from biophysical parameters, such as the NDMI which gives an indication of the wetness of the land surface and to estimate the surface temperature and its relationship with different LULC classes. The relationship between derived surface temperature and NDMI has also been analyzed.

2. Study area

The capital city of India, New Delhi is geographically situated between 28°23′17″–28°53′00″ North and longitude 76°50′24″–77°20′37″ East. It lies at an altitude between 213 and 305 m and covers an area of 1483 km^2. It is situated on the bank of river Yamuna. The climate of Delhi is influenced by its remote inland position and prevalence of air of continental character, which is characterized by extreme summer heat in June (48 °C), alternating with severe winter cold December (3 °C). The climate is of semi-arid nature due to marked diurnal differences in temperature, high saturation deficit and low/moderate annual average rainfall (60 mm). The urban population of Delhi increased at 2.09% annual growth rate during 2001–2011. The latter is influenced by the gradual shifting of the rural area and its merger with urban and peri-urban areas. As per census 2001, NCT Delhi has a population of 16.65 million and 20.09% decennial population growth has been observed during 2001–2011. With the continuation of the current population growth trend, the total population of National Capital Territory (NCT) Delhi (16.75 million in the year 2011) would be 22.5 million in 2021. The selected study area contains almost all sort of representation of typical urban land features, including vegetation, water bodies, builtup, bare soil, etc.

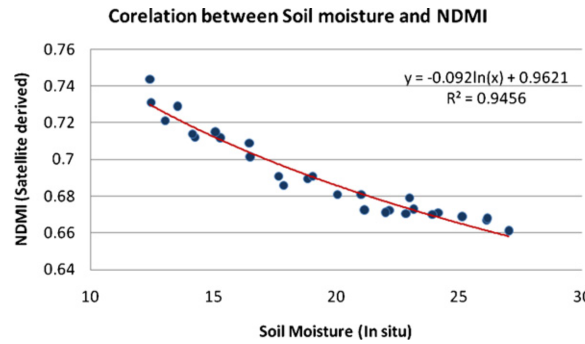

Fig. 1. Logarithmic regression coefficient between soil moisture (in situ) with NDMI.

3. Methodology

3.1. Image pre-processing

Satellite datasets of LANDSAT TM over Delhi area of October 25, 2009 of path/row 146/40 has been used for estimation of NDMI, emissivity and surface temperature. DN values were converted to at-sensor radiance, using Eq. (1.1) for LANDSAT TM which is expressed in $Wm^{-2}\,sr^{-1}\,\mu m^{-1}$.

$$L_\lambda = \text{gain} \times \text{DN} + \text{bias} = \left(\frac{L_{\max} - L_{\min}}{255}\right) \times \text{DN} + \text{bias} \tag{1.1}$$

The maximum radiance depends on the spectral band and gain setting. The gain setting value is mentioned in LANDSAT TM handbook. LANDSAT TM level-1G was geometrically corrected before further processing. For standardization, GCPs, toposheets and LANDSAT TM data were compared to each other and was noticed that geometric accuracy was low. Hence there was a need to further rectify the datasets. The image was geometrically rectified to a common Universal Transverse Mercator (UTM) WGS84 coordinate system and were resampled to its spatial resolution using the nearest-neighborhood algorithm. The RMSE between the two images was less that 0.325 pixel which is acceptable (Jensen, 2007).

3.2. The normalized difference moisture index (NDMI)

The NDMI is the normalization of the bands moisture difference response, between near infrared (NIR) band 4 and SWIR band 5 (Eq. (1.2)). Hunt and Rock (1989) found that ratio TM 5/4 band was linearly correlated to relative water content of leaf. The NDMI was derived using following relation:

$$\frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}} \tag{1.2}$$

Fiorella and Rippley (1993) reported that TM 4/5 is highly correlated to wetness ($R^2 = 0.97$) and have higher correlation than the Tasseled Cap Index. Hardinsky et al. (1983) reported that the NDMI was highly correlated with canopy water content.

A field survey was carried out for collection of soil moisture data in and around the study area. Around 28 sample sites were surveyed, soil samples were also collected, covering all the major land use/land cover classes. A standard protocol was adopted for determination of soil moisture, using soil moisture meter in the laboratory. Thereafter a relationship between soil moisture and NDMI was drawn (Fig. 1). Fig. 1 shows a strong negative relationship between these two variables and the value of logarithmic regression (R^2) is 0.9456.