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Assessment of land surface temperature and heat fluxes over Delhi using remote sensing data

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ABSTRACT

Surface energy processes has an essential role in urban weather, climate and hydrosphere cycles, as well in urban heat redistribution. The research was undertaken to analyze the potential of Landsat and MODIS data in retrieving biophysical parameters in estimating land surface temperature & heat fluxes diurnally in summer and winter seasons of years 2000 and 2010 and understanding its effect on anthropogenic heat disturbance over Delhi and surrounding region. Results show that during years 2000–2010, settlement and industrial area increased from 5.66 to 11.74% and 4.92 to 11.87% respectively which in turn has direct effect on land surface temperature (LST) and heat fluxes including anthropogenic heat flux. Based on the energy balance model for land surface, a method to estimate the increase in anthropogenic heat flux (H_{as}) has been proposed. The settlement and industrial areas has higher amounts of energy consumed and has high values of H_{as} in all seasons. The comparison of satellite derived LST with that of field measured values show that Landsat estimated values are in close agreement within error of ±2 °C than MODIS with an error of ±3 °C. It was observed that, during 2000 and 2010, the average change in surface temperature using Landsat over settlement & industrial areas of both seasons is 1.4 °C & for MODIS data is 3.7 °C. The seasonal average change in anthropogenic heat flux (H_{as}) estimated using Landsat & MODIS is up by around 38 W/m^2 and 62 W/m^2 respectively while higher change is observed over settlement and concrete structures. The study reveals that the dynamic range of H_{as} values has increased in the 10 year period due to the strong anthropogenic influence over the area. The study showed that anthropogenic heat flux is an indicator of the strength of urban heat island effect, and can be used to quantify the magnitude of the urban heat island effect.

1. Introduction

The fast expansion of urban area results in change of local atmosphere and surface temperature compared to the surrounding rural area. The temperature gradient represents human-urban and rural contrast, which is due to deforestation and the replacement of the land surface by non-evaporating and nonporous materials such as asphalt and concrete. This results in reduced evapotranspiration and more rapid runoff of rain water (Carlson, 1986). The thermal behavior and characteristics of urban surface is an important data for urban planners and architects for improving city site quality making more eco-friendly. Land surface temperature (LST) and emissivity are important parameters in energy budget estimation, land cover assessment and other earth surface characteristic related studies (Srivastava et al. 2010; Chang et al. 2010). Study of the heat island requires understanding the role of land surface parameter, evapotranspiration, surface heat fluxes and the overall influence of urban features on thermal environment (Dousset and Gourmelon 2003; Boegh and Soegaard, 2004). Remote sensing can provide information on parameters such as surface albedo, vegetation index, surface emissivity and surface temperature that are inputs for estimating surface heat fluxes which are otherwise difficult in obtaining the spatial and temporal information from traditional ground based *in situ* measurements. The urban heat-island effect occurs as a result of increased sensible heat flux from the land surface to the atmosphere near cities. Sensible heat flux consists of two components, heat radiation due to solar input and heat due to anthropogenic discharge. The latter may be enhanced by changes in the usage of artificial land surface (Soushi and Yasushi, 2005). The present work follows a new method to separate the anthropogenically discharged heat and natural heat radiation from the sensible heat flux based on a heat-balance model using satellite remote

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sensing and ground meteorological data. Anthropogenic heat discharge in all the seasons in the area is found to be around 94 W/m^2 on an average, namely more than 18% of natural sensible heat flux. The objective of the study was to analyze the potential of Landsat and MODIS data in estimating surface emissivity and LST. The surface heat fluxes (including natural & anthropogenic) were quantitatively estimated over various LU/LC features using Landsat and MODIS data. Spatial and seasonal variation of heat fluxes were evaluated and compared for summer and winter seasons of year 2000 and 2010 and its effect on anthropogenic heat distribution over Delhi and surrounding areas. Net radiation was estimated from albedo, surface emissivity, surface and atmospheric temperature and solar radiation. Sensible and latent heat fluxes were estimated via the bulk resistance approach using surface and atmospheric temperature, wind speed and relative humidity.

2. Study area

The study was carried out over Delhi and surrounding areas situated between latitude 28°14′57″ N to 28°52′18″ N and longitude between 77°35′34″ E to 76°57′38″ E and altitude lies between 213 and 305 m covering an area of 5160.00 km^2. Delhi climatic type is a monsoon-influenced humid subtropical (Köppen climate classification Cwa). One of the most characteristic features of Delhi climate is extreme low and high temperature ranging to as high as 47 °C during summer while reaching as low as −0.6 °C during winter (Source IMD). January being the coldest, May/June the hottest and mean annual total rainfall is around 70 cm. Physically Delhi can be divided into three segments: the Yamuna flood plain, the ridge and the plain. The Yamuna flood plain is somewhere low-lying and sandy. The ridge constitutes the most dominating physiographic features of this territory. It originates from the Aravali hills of Rajasthan and enter Delhi from the south, extends in north-eastern direction and the rest of Delhi is categorized as a plain. Yamuna is the main river that passes through Delhi. Apart from the flood channels of Yamuna there are 3 canals, i.e. portion of Agra Canal, Hindu Canal and western Yamuna canal. The vegetation in the ridge (forest) is predominately of thorny scrub type, which is usually found in arid and semi-arid zone. Ridge Forest of Delhi falls in the category of 'Tropical thorn forest' as per the forest type classification of Champion and Seth (1968), and more especially as 'semi-arid open scrub' and among trees that are dominant is Acacias.

3. Data and material

The seasonal & diurnal heat fluxes were estimated using Landsat TM-5 and MODIS datasets over different Land use (LU)/Land Cover (LC) of Delhi area over 10 year of time period. Landsat TM-5 data is used for preparation of land use/land cover maps and estimation of surface temperature and heat fluxes.

All the satellite images were geometrically rectified and atmospheric FLAASH correction was applied in all datasets of Landsat and MODIS (Table 1). The land use/land cover classifications were performed using Landsat image of February 2000 and 2010 datasets. Eventually, the land surface was classified into eight types of land cover classes: agriculture, settlement, water body, Open scrub, Open space with grass, Forest, Bare soil and Industries. The datasets were used to retrieve biophysical parameters like NDVI, albedo and surface emissivity to estimate surface temperature, net radiation and sensible heat flux.

Table 1
The following datasets were used to compute seasonal and temporal LST and heat fluxes.

Dataset used	Summer		Winter	
	Year (2000)	Year (2010)	Year (2000)	Year (2010)
Landsat TM-5	May 9	May 5	February 3	February 14
MODIS level 1B data	May 10	May 22	February 28	February 26

4. Methodology

Heat fluxes was estimation over various land use/land cover on several days of winter (February) and summer (May) seasons of year 2000 and 2011. After applying the geometric correction, the subset images of radiance were created both for visible and near infrared bands of Landsat TM-5 and MODIS datasets. For effective estimation of temperature, the surface emissivity values are to be derived at pixel level (Kant and Badarinath, 2002). It is found that the emissivity over vegetation in 8–14 μm region remains more or less uniform (Nichol, 1995). The proportion of vegetation cover in conjunction with NDVI was taken to estimate pixel emissivity (Grind and Owe, 1993).

$$\varepsilon = a + b^{*}\ln(\mathrm{NDVI}) \tag{1}$$

where $a = 1.0094$ and $b = 0.047$ where, $\mathrm{NDVI} = \rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}} / (\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}})$ ρ = Reflectance

Landsat-TM band 6 imagery was converted from spectral radiance (as described above) to a more physically useful variable (NASA, 2004). This is the effective at-satellite temperatures of the viewed Earth-atmosphere system under an assumption of unity emissivity and using pre-launch calibration constants (Mansor and Cracknell, 1994). The digital number (DN) of thermal infrared band is converted in to spectral radiance (L_λ) using the calibration constants and incorporation of surface emissivity estimates the surface temperature as,

$$T = \frac{K_2}{\ln\left(\frac{\epsilon K_1}{L_\lambda}\right) + 1} \tag{2}$$

where $K_1 = 607.76$ mWcm^{-2} sr^{-1} μm^{-1}, $K_2 = 1260.56$ K, L_λ = radiance, ε = emissivity

The split window used for MODIS was developed by Wan and Dozier (1996), and is defined as.

$$\begin{aligned} T_s &= c + \left(A_1 + A_2\frac{1-\epsilon}{\epsilon} + A_3\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_{31}-T_{32}}{2} \\ &\quad + \left(B_1 + B_2\frac{1-\epsilon}{\epsilon} + B_3\frac{\Delta\epsilon}{\epsilon^2}\right)\frac{T_{31}-T_{32}}{2} \end{aligned} \tag{3}$$

$$\varepsilon = (\varepsilon_{31} + \varepsilon_{32})/2$$

$$\Delta\varepsilon = \varepsilon_{31} - \varepsilon_{32}$$

The narrow band emissivities can be obtained from the broad band values using the relation (Rubio et al., 1997),

$$\varepsilon_i = A\,\varepsilon_{8-14} + B \tag{4}$$

i = 31, 32 band, A & B are coefficients (Rubio et al. 1997) where T_{31} and T_{32} are the brightness temperatures measured for MODIS bands 31 and 32, respectively; ε_{31} & ε_{32} are MODIS band 31 and 32 surface emissivity; and $A1$, $A2$, $A3$, $B1$, $B2$, $B3$ and C are regression coefficients. These coefficients are available during algorithm execution via a look up table (LUT) based on the results of radiative transfer simulation under a large range of surface & atmospheric conditions are derived using linear regression.