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Study of Energy Flux Model Using Geospatial Technology

DEBJIT DATTA[1], CHANDAN ROY[2] AND VENKATA RAVIBABU MANDLA[3]

[1]Energy and Environmental Engineering, VIT University, Vellore, INDIA

[2]Department of Civil Engineering, Maharishi Markandeshwar University, Mullana, Ambala, Haryana, INDIA

[3]Division of Environmental and Water Resources Engineering, VIT University, Vellore, INDIA

***Email:** ddatta240@gmail.com, chandanroy.bankura@gmail.com*

Abstract: *Surface energy estimation has a significant and key role in urban environment, climate as well as in the surroundings. This research study goal was to analyse the Landsat series data in biophysical parameters for estimating land surface temperature and heat fluxes over the year 2003 and 2016 and realizing its effect on heat disturbance over the Hyderabad region. Result shows that during the year 2003 to 2016 there is rapid increase urban area which in turn has a direct impact on the land surface temperature and heat fluxes and which leads to a significant rise of 1.40°C has been observed. Classification of the LU/LC using remote sensing data is an accurate way of monitoring the special growth and distribution of the urban area. The analysis of the Normalised Difference Vegetation Cover (NDVI) is done and the increase of 17.53% of the urban area has been observed which major land covers change. Thus from the study it is observed the energy flux in the urban area has increased from 2003 to 2016 because of lack of vegetation cover it overall energy flux value increased to 46.80W/m^2.*

Keywords: *Remote sensing, Urban built-up, Landsat, LU/LC, NDVI, Energy flux.*

1. Introduction

The increase rapid change and drastic change in the urban surrounding causes the change in the local level environmental condition, climatic condition at an alarming rate. The temperature gradient between the urban and rural region, causes changes because of deforestation, industrialization & human settlement which are the factors behind it [1].

The Land Surface Temperature (LST) is a significant parameter for improving the urban life standards and a healthier surrounding atmosphere so that proper environmental standards are achieved which is more reliable and eco-friendly. In the current scenario LST is one of the most important parameter in the calculation of the land cover and other earth surface models [2]. The heat maps requires the role of the parameter like LST, evaporation, heat fluxes and other urban features on the environment in order for the classification [3]. The heat fluxes are generally of two components that is solar input radiation and heat discharge. Through satellite data, various temporal and spatial resolutions can be studied by dealing with the parameters like NDVI, LST & Heat flux.

2. Study Area

The study was carried out over the municipal region of Hyderabad of latitude 17°22’31” N and longitude 78°28’27”E. Major parts of the city has a mountainous terrain has a total area of 650 km^2. The area of interest for the study is the municipal boundary of the Hyderabad municipal corporation covering a total area of 97.915 km^2.

3. Data

The spatial data acquired for the Hyderabad area from the United State Geographical Survey website. Spectral data has been considered and three parameters are considered:

1. NDVI.
2. LST.
3. Heat Flux.

In this current study we have taken different satellite data for the classification of NDVI for the Hyderabad region. The Normalized Difference Vegetation Index were estimated using Landsat 5, Landsat 7 and Landsat 8 satellite data over different Land use / Land Cover of the Hyderabad region.

Table 1: *Landsat satellite data details*

S.No	Satellite Data	Date of Collection
1	Landsat – 5	21/05/1990
2	Landsat– 7	17/05/2003
3	Landsat – 8	15/05/2016

3. Methodology

- First the raw data were collected from earth explorer and we overlay those data with the Hyderabad boundary layer data and we classified the image and then collected it as per the required time period. With the help of ARCGIS software we can able to do the NDVI classification by overlaying the subset image in the programme and then the classification occurred.
- Secondly the raw thermal data of the Landsat series is being taken for the selected Hyderabad study area and with the help of algorithm and mathematical equation the classification of the LST is being done with the help of same programme ARCGIS.

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- The correlation of the LU/LC with LST over the Hyderabad region were being done in order to monitor the drastic change in the Land cover and rise of the LST over the particular area for the given time frame.
- The estimation of the latent heat flux was being calculated by collecting the significant parameter like net solar radiation, surface temperature, surface emissivity and other important parameter. All are taken and with the help of algorithm and equation the analysis of the heat flux were being estimated.

3.1 Estimation of NDVI

The raw satellite data were collected from different data sources and used to extract the Hyderabad city area from the subset of the obtained Landsat imageries. The band wavelengths falling in the SWIR and NIR region for different satellite imaginaries where found out.

The calculation of Normalised Difference Vegetation Cover (NDVI) was carried out and derived image were checked with the classification image and Goggle earth to determine the accuracy of the urban cover as per Zha *et.al* (2003) [4] given below:

$$NDVI = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

3.2 Estimation of LST

Conversion of the TOA values to TOA Brightness Temperature in Kelvin is given by:

$$T = \frac{\mathrm{k}_2}{\ln\left(\frac{k_1}{k_\lambda}\right) + 1}$$

Where,
T = TOA brightness temperature
k_1 = Band specific thermal conversion constant
k_2 = Band specific thermal conversion constant.
k_λ = TOA spectral radiance
Convert Kelvin to Degree Celsius,
T (in℃) = T (in K) – 273

3.3 Estimation of heat flux

The effective satellite temperature of the atmosphere is under an assumption of unit emissivity and using pre-launch calibration constants [5]. The digital number (DN) of thermal infrared band is converted in to spectral radiance (L_λ) using the calibration constants and surface emissivity. The Surface temperature is estimated as:

$$T = \frac{\mathrm{k}_2}{\ln\left(\varepsilon\frac{k_1}{L_\lambda}\right) + 1}$$

Where,
K_1 = 607.76 mWcm^{-2} sr^{-1} μm^{-1},
K_2 = 1260.56 K
L_λ = radiance
ε = emissivity
Heat balanced equation is described as:

$$R_n + A = LE + G + H$$

Where,
R_n = net radiation
A = total anthropogenic heat discharge
LE = latent heat flux.
G = ground heat flux
H = sensible heat flux

The net radiation R_n can also be expressed as an electromagnetic balance of all incoming and outgoing fluxes reaching and leaving a flat horizontal and homogenous surface as:

$$R_n = (1 - \alpha) \times R_s + E_a Rl - \varepsilon\sigma T_s^4$$

Where,
α = surface albedo
R_s = short wave incoming solar radiation (0.3 – 3 μm)
E_a = atmospheric emissivity
Rl = incoming long wave radiation (3 – 100 μm)
ε = emissivity
σ = Stefan Boltzmann constant
T_s = surface temperature.

Short wave Incoming radiation can be evaluated by remote sensor as:

$$R_s = G_{SC} \times \cos\theta \times dr \times \tau_{SW}$$

Where,
G_{SC} = solar constant (1367 W/m^2)
cosθ = sun elevation angle
τ_{SW} = transmittance
dr is inverse square relative earth sun distance which is calculated as:

$$dr = 1 + 0.033\cos(Doy\frac{2\pi}{365})$$

Where, Doy is the Julian day.

Transmittance is derived using: $\tau_{SW} = 0.75 + 2 \times 10^{-5} \times z$

Where, z is the elevation.

Atmospheric emissivity (E_a) is the efficiency with which the atmosphere emits as compared to black body. It is estimated based on the empirical equation Brutsaert (1982) [6],

$$E_a = 1.24\left(\frac{ea}{T_a}\right)$$

Where, ea = Vapour pressure of air
T_a = ambient air temperature.

The vapour pressure of air is estimated as:

$$ea = Ps \times \frac{RH}{100}$$

Where, RH = Relative Humidity
Ps = saturated vapour pressure

$$Ps = 1013.25 \times \exp\,(13.3185t - 1.9760t^2 - 0.6445t^3 - 0.1299t^4)$$

Where,

$$t = 1 - \frac{373.15}{T_s}$$

Ground heat Flux (G) is the amount of heat transmitted per unit area per unit time,

$$G = (0.1 - 0.042h) \times R_n$$

Where,
h = reference height
R_n = net solar radiation.

Sensible heat flux mathematical formulation is based on heat & mass transfer and momentum theory between the surface and the near surface environment which is expressed as:

$$H = \rho C_p \frac{(T_s - T_a)}{r_a}$$

Where,
ρ = air density
C_p = specific heat
Ts = surface temperature
Ta = ambient air temperature
r_a = aerodynamic resistance.

The latent heat is estimated as,

$$LE = \rho C_p \frac{(e_s - e_a)}{\gamma(r_a + r_s)}$$

Where,
e_s = saturation vapour pressure (hPa) at the surface temperature
r_s = stomatal resistance (s/m) which depends on vegetation, meteorological and atmospheric conditions.

4. Result and Discussion

4.1 LU/LC through Satellite Data

The classification was measured and analysed using satellite data for the year 1989, 2003 & 2016. Table 2 shows the proper classification of the LU/LC in terms of area and percentage. Figure 1, figure 2 and Figure 3 shows the NDVI classification of the Hyderabad region for the year of 1990, 2003 and 2016 respectively.

Table 2: *Estimation of LU/LC through NDVI*

Year		Water Bodies	Vegetation	Barren Land	Urban Area
1990	km^2	193.48	255.81	1297.00	158.79
	%	10.69	13.43	68.10	8.39
2003	km^2	94.72	158.6	1271.38	312.71
	%	5.93	7.73	69.71	15.87
2016	km^2	51.45	345.6	1017.31	526.23
	%	2.89	19.21	50.62	33.40

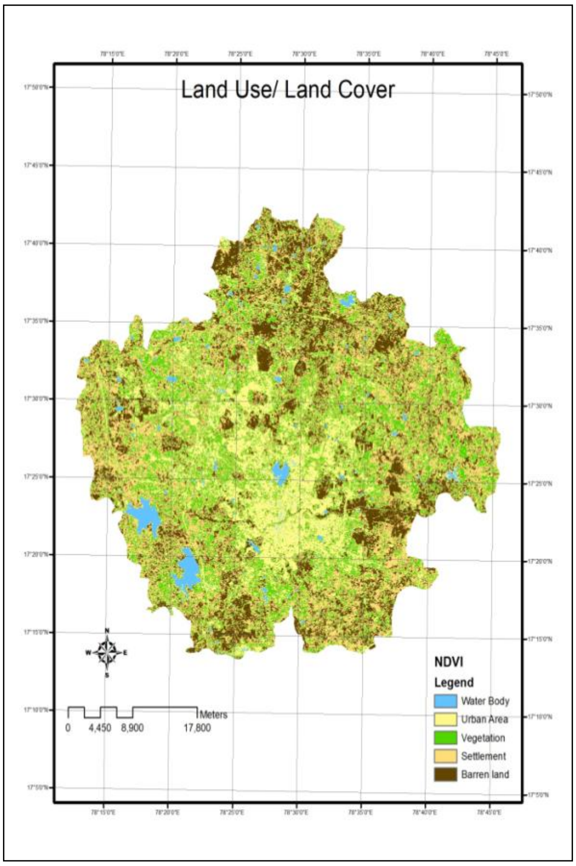

Figure 1: *NDVI Classification of the Hyderabad Region for the year of 1990*

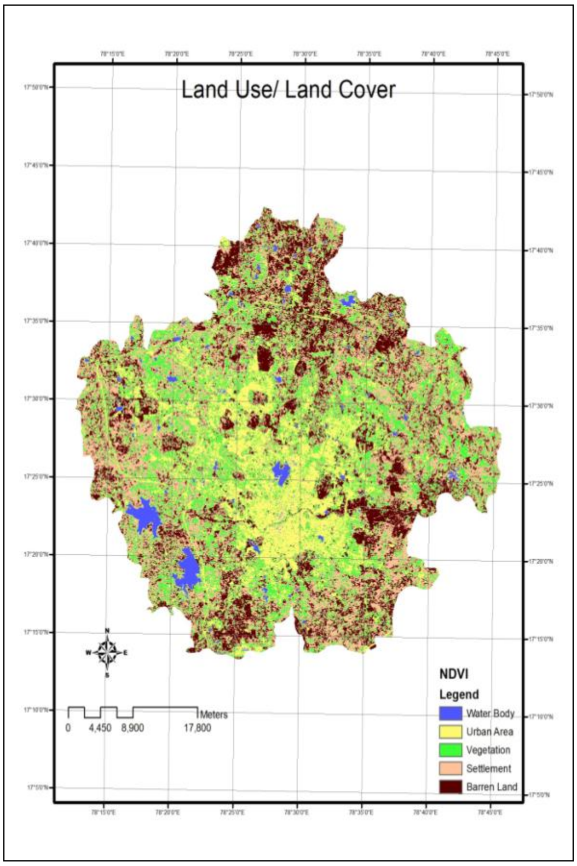

***Figure 2:** NDVI Classification of the Hyderabad Region for the year of 2003*

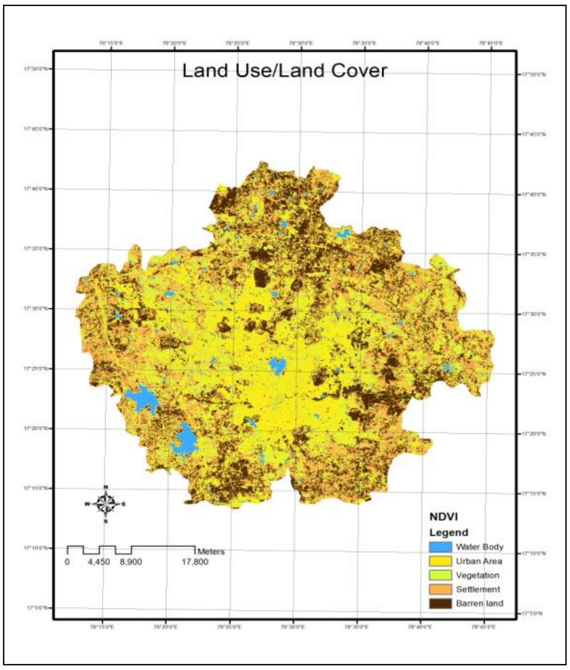

***Figure 3:** NDVI Classification of the Hyderabad Region for the year of 2016*

From the above classification of the NDVI clearly states that in this research study we have taken the satellite data from 1989 to 2016 year a time span of 27 years:

- In the Figure 1 NDVI Classification of the Hyderabad Region for the year of 1990 to Figure 3 NDVI Classification of the same region for the year of 2016 come up with surprising results.
- The urban area has been increased drastically as we can see from the above classification, it clearly showing the outcomes have severely affected the climatic and environmental condition in an around the Hyderabad region.
- The analysis of the NDVI is done the basis of Land use and Land cover. As per the result were being observed the urban area had increased from 2003 to 2016 at 17.53%.
- The rapid increase in the urbanization along with industrialization has clearly played the major role in the change of the LU/LC of the particular region and it already showing its effect in climatic, environmental aspect.

4.2 Analysis of LST using Landsat series data

The Land Surface Temperature for the year 2003 & 2016 are being observed over the urban area and a correlation were being developed between the LST and LU/LC. From the Table 3 it clearly shows the LST analysis for the selected time period and its increasing value of the LST for the different classification of Land Cover. Figure 4 and Figure 5 shows the NDVI classification of the Hyderabad region for the year of 2003 and 2016 respectively.

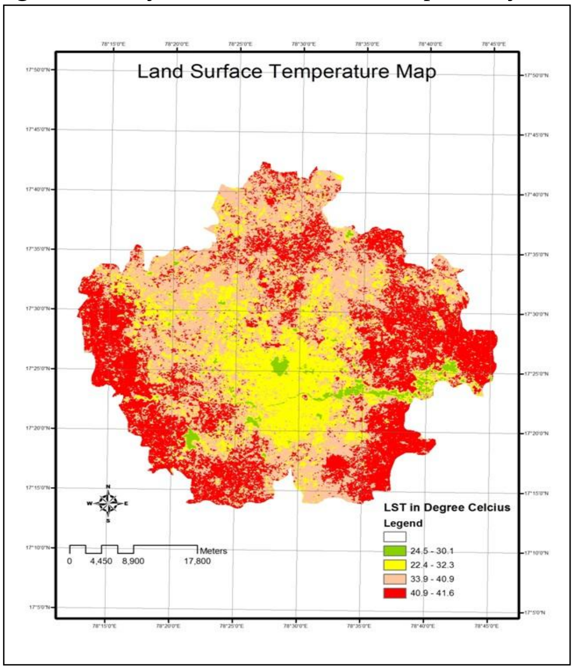

***Figure 4:** LST Classification of the Hyderabad Region for the year of 2003*

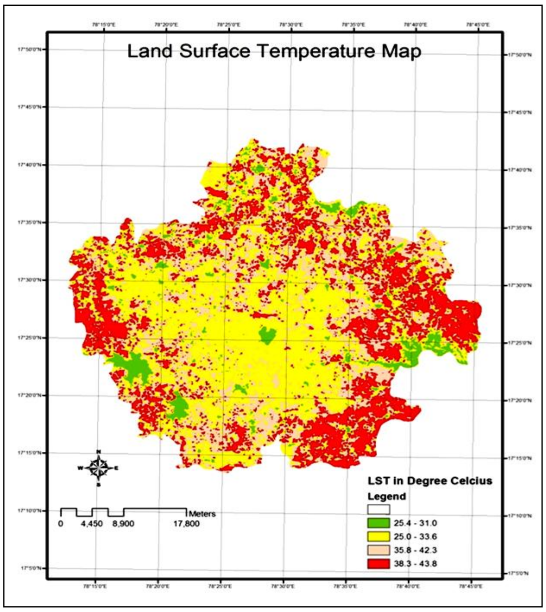

***Figure 5:** LST Classification of the Hyderabad Region for the year of 2016*

***Table 3:** LST analysis using Landsat series data*

Year	Land Use/Land Cover	Temperature Range (°C)
2003	Water Body	24.5 – 30.1
	Vegetation	22.4 – 32.3
	Urban Area	33.3 – 40.9
	Barren Land	40.9 – 41.6
2016	Water Body	25.4 – 31.0
	Vegetation	25.0 – 33.6

	Urban Area	35.8 – 42.3
	Barren Land	38.3 – 43.8

In today modern world when we consider global climatic condition and environmental issues LST is one of the important factors that are taken into consideration.

- A correlation is made between LST and LU/LC over the selected region of our study in order to accurately measure the LST in the various classification of the land cover for the particular summer season and to the particular time period.
- The analysis of the Land Surface Temperature is estimated as it is one of the important parameter to derive the energy flux. As per the study is concerned the vegetation decreased and it is one of the reason for the increase in the LST for the urban area from 2003 to 2016, it increase to 1.40°C.
- Thus from the year 2003 to 2016 particularly in the urban dominated area the LST has increased to 1.40°C in just 13 years, the factor responsible are all manmade as from the earlier NDVI Classification it already been showed how the urban settlement is increasing rapidly as the time frame. Population, Industrialization, increase in the consumption of the vehicles result in emission of more harmful greenhouse gases. The combinations of all these factors are collectively responsible behind the increase in the LST.

4.3 Analysis of Heat Flux using Landsat series data

The heat flux were being estimated, a correlation were being done between LU/LC and heat flux. This study shows the Heat flux estimation of the year 2003 & 2016 for the Hyderabad region as shown in Table 4. Figure 6 and Figure 7 shows the heat flux classification of the Hyderabad region for the year 2003 and 2016 respectively.

Table 4: *Heat flux analysis using Landsat series data*

Year	Land Use/Land Cover	Heat Flux Range (W/m^2)
2003	Water Body	3.4 – 12.5
	Vegetation	41.5 – 45.4
	Urban Area	45.4 – 79.1
	Barren Land	79.1 – 89.6
2016	Water Body	-5.2 – 4.5
	Vegetation	30.5 – 54.0
	Urban Area	55.0 – 125.9
	Barren Land	97.8 – 114.8

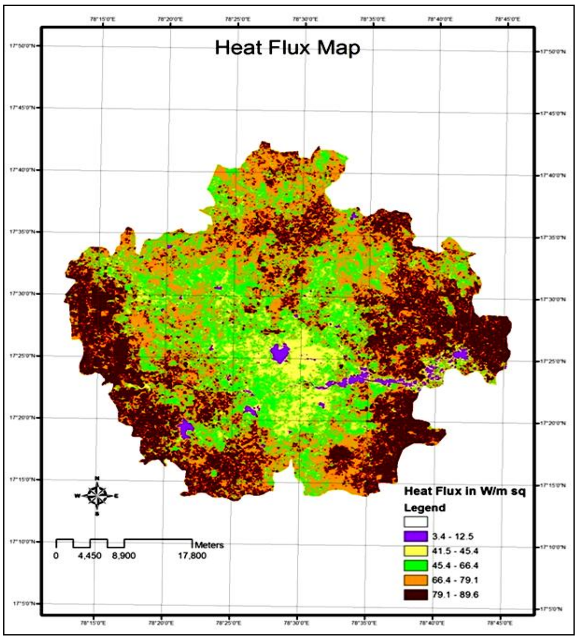

Figure 6: *Heat Flux Classification of the Hyderabad Region for the year of 2003*

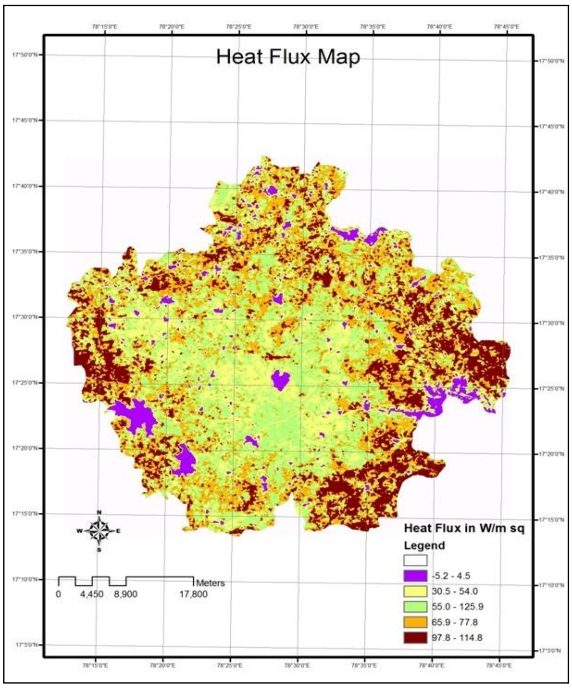

Figure 7: *Heat Flux Classification of the Hyderabad Region for the year of 2016*

The derived LST and heat fluxes provide urban environment which is useful for developing as well as planning an eco-friendly urban environment.

- Classification of the LST which can be clearly stated from the above figure 4 and figure 5. Heat flux Classification of the Hyderabad Region for the year of 2003 and Heat flux Classification of the Hyderabad Region for the year of 2016 is shown in figure 6 and figure 7.
- Lack of vegetation cover in cities, increase in human population growth, drastic need for energy

consumption, increase in the urban settlement causing the rise in the LST and heat fluxes.

- Estimation of the energy flux and to study the energy flux model. Thus from the study it is observed the energy flux in the urban area has increased from 2003 to 2016 because of lack of vegetation cover it overall energy flux value increased to 46.80W/m^{2}.
- Thus maintaining urban forest cover gives a solution to tackle these problems effectively in maintaining urban heat. Government along with planners should give much focus and concentration in developing green campaigns.

5. Conclusions

High surface temperature is caused mainly due to lowering of vegetation and change in LU/LC cover because of deforestation, increase in the urban settlement, industrialisation and other factors responsible to it. Development is necessary the modern world but not at the cost of environment, sustainable development, developing eco-friendly model, monitoring the local and the global climatic condition are needed. In the mean while in last 26 years from 1990-2016 urban area reduces from 8.39% to 33.40% and water bodies reduces to 10.69 % to 2.89%.

The estimation of the heat flux is important in order to develop an energy efficient model in different cities. Countries across the globe are putting many efforts to monitor their regional climatic and surrounding area aspect through the help of remote sensing, monitor and taking preventive measure to all the factors that are responsible for the change in the LU/LC, LST & heat flux.

In today's modern smart cities, main goal is to conserve the resources, utilise the resources to its optimal benefits and conserving them for the future generation in order to maintain balance. In this current global scenario the rise in the surface temperature has become one of the significant challenges in today's life.

Thus providing solution to these this problem can be traced and located. Government should implement Green building technology for sustainable planning, construction, design of building in order reduce the negative impact on the environment. Study help to monitor the LST and accurate measurement of the energy flux so that precaution and measures can be taken in order to reduce the impacts that had already given to the climate and the surrounding environment.

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