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Thermal Mapping Using Remote Sensing and GIS Techniques

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Abstract: *In the study mapping of Land surface temperature (LST) has been carried out using LANDSAT-8 data and ArcGIS techniques. LST have wide application viz; evapotranspiration, global climate change, hydrological cycle, vegetation monitoring, urban climate, land use/land cover mapping and environmental studies. An attempt has been made using LANDSAT-8 TIRS B10 (Thermal Band) to derive LST of different land cover surfaces of the study area. Various mathematical algorithms developed were used in processing of LANDSAT-8 data in ArcGIS software for deriving the LST from it. LANDSAT-8 satellite imagery Band 10 data, during 23 Jan. 2016, 08 Feb.2016, 11March 2016 and 12 April 2016 were processed for thermal analysis. LST maps have been prepared from it showing the spatial and temporal distribution of land surface temperature in the watershed. Furthermore, land use/land cover mapping (LU/LC) was carried using bands 2, 3, 4, 5 & 6 of the LANDSAT 8 data. LU/LC mapping done by supervised classification using the maximum likelihood classification algorithm of ArcGIS. Thermal data analysis has provided the surface temperature of each land cover units of every month. A Remarkable difference has been found in the temperatures of different land cover units like agricultural land, Built-up, bare and forest land. This difference is because of their different emissivity. Correlation plot has been made in between the atmospheric temperature and LST showing $R^2 = 0.92$.*

Keywords: *Land surface temperature, Land use/ land cover mapping, Thermal mapping, LANDSAT-8, ArcGIS*

1. Introduction

Land Surface Temperature (LST) is defined as the temperature at interface between the Earth's surface and its atmosphere (1) Land Surface temperature have wide application in many environmental models, viz; energy and water exchange between atmosphere and surface, numerical weather prediction, global ocean circulation, climatic variability (2). LST is a key parameter in land surface processes, not only, because of having climatic importance, but also due to its control of the sensible and latent heat flux exchange (3, 4). LST is also used in models of vegetation stress (5-7). Due to the strong heterogeneity of land cover classes such as vegetation, surface roughness, soil and topography LST changes rapidly in space as well as in time (8, 9). Because of the relatively small network of in situ observations and its relatively large spatial variability, LST is commonly measured on a regional or global basis with satellite retrievals. Therefore, it requires measurements with detailed spatial and temporal sampling. On the availability of large scale satellite derived LST data, near surface air temperature measurements can be predicted (10-12). LST data is very important for monitoring the temperature of different land use land /cover classes. It is often used for checking and predicting of crop yield (13).

The thermal properties of earth and atmosphere is effecting on LST drastically. Satellite based thermal infrared data is directly linked to the LST through the radiative transfer equation. Retrieval of the LST from thermal remote sensing data has attracted much attention and its history dates back to the 1970s (14). Technological advancement in remote sensing techniques provides a unique possibility for assessing the LST on global scale with high spatial and temporal resolution. Remote sensing helps in understanding of spatiotemporal land cover changes in relation to the basic physical properties in terms of the surface radiance and emissivity data. Since the 1970s, satellite derived surface temperature data have been utilized for regional climate analyses on different scale. The advantages of using remotely sensed data are availability of high resolution data, consistent and repetitive coverage and capability of measurements of earth surface conditions (15). Thermal infrared (TIR) sensors are able to obtain quantitative information of surface temperature across the different land use/land cover categories. LANDSAT 8 has open new possibilities to understand the various events on earth's surface. Many studies were conducted used LANDSAT satellite data series for retrieving of land surface temperature and urban heat monitoring (16-21). For quantifying the LST & urban heat island (UHI) there are many available thermal infrared sensors viz; Geostationary Operational Environmental Satellite (GOES), NOAA-Advanced Very High Resolution Radiometer (AVHRR), Terra and Aqua- Moderate Resolution Imaging Spectroradiometer (MODIS). High resolution data from the Terra-Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) has a 90 m resolution and Landsat-7 Enhanced Thematic Mapper (ETM+) and Landsat-8 TIRS having resolution of 100 m in thermal region.

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LST is very sensitive to vegetation and soil moisture, hence it can be used to detect land use/land cover changes, such as tendencies towards urbanization, desertification etc.

Remote sensing derived surface emissivity has two major benefits: 1) using as an input for accurate land surface-temperature estimates, particularly for low-resolution sensors and 2) for terrestrial and planetary geologic studies, for example, for mineral mapping (22) which can be dealt from multispectral/hyperspectral thermal data. Thermal remote sensing has application in groundwater management studies such as demarcation of groundwater potential zones. Little work has been noted using thermal remote sensing for delineation of groundwater potential zones (23 & 24). They have observed that great contrast resulted in the surface temperature of groundwater discharging zones and non-discharging zones. Groundwater discharge zones are acting as heat sources in winter season and heat sinkers in summer season (25). In the study using thermal data for retrieving the LST of different land cover surfaces and their comparison has been drawn with the atmospheric temperature.

1.1 Study Area

Kandaihimmat Watershed with an area of 166.58 km^2 is located adjacent to the left bank of the Tawa River Hoshangabad District, Madhya Pradesh (India). The watershed basin is characterized by a vast alluvial plain. The study area falls in Survey of India (SOI) Toposheet No. 55 F/14, between latitude (22^0 30' 00"- 22^0 40' 00" N) and longitude (77^0 45' 00" - 78^0 00' 00" E). The watershed name (Kandaihimmat) is assigned on the basis of village name close to outlet of the watershed located adjacent to left bank side of Tawa River. The watershed is covered by thick alluvium which is highly supporting the agricultural practices in the region. The study area is characterized by dry hot summer and dry cold winter. The maximum temperature is recorded in the month of May is 42 ^{0}C and minimum during the month of January is 11 ^{0}C. Mean annual rainfall is above 1200 mm and is mostly receiving in monsoon season. The location Map of the study area is given in (Fig.1).

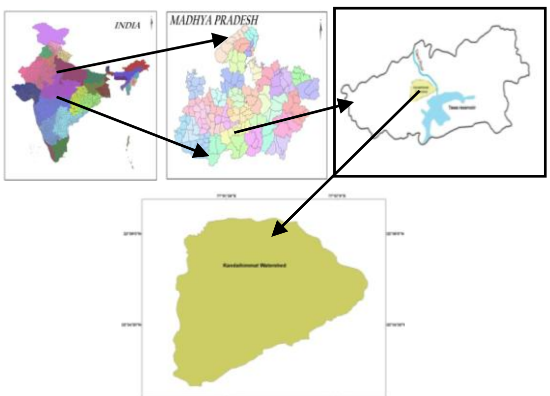

***Figure 1**: Location Map of Study Area*

1.2 Lithology

Lithologically, the study area comprises of rocks represented by conglomerate and gravel/silty sand of Hirdepur formation, Quartenary group of Pleistocene age. Some small patches of sandstone, basalt lava flows and Granite are also found along the foot hills of Satpura range towards southern part. The northern part is covered by Non-calcareous silt, sand & clay of Ramagarh formation of Holocene period. A part adjacent to the Tawa left bank canal contains sand, gravel & conglomerate with flood plain alluvial deposits comprising of silt, fine sand with lenses of clay, silt gravel and conglomerate (DRM of GSI, 1st Edition 2002). The thickness of the alluvial deposits as exposed along the banks of the rivers usually does not extend 35 m. The slope is generally steep at the foothills of Satpura range, but moderate to gentle towards north.

2. Materials and Methods

Mathematical algorithms developed (26) were used to derive the land surface temperature from LANDSAT-8 thermal data in ArcGIS software. LANDSAT-8 data during 23 Jan. 2016, 08 Feb.2016, 11March 2016 and 12 April 2016 has been taken from USGS Earth Explorer website free of charge. TIRS band 10 of the satellite data was processed to derive the LST. Bands 2, 3, 4 & 5 of the Landsat-8 data were analyzed for land use / land cover mapping by supervised classification using the maximum likelihood classification algorithm of ArcGIS software. Calculating of LST, from Landsat-8 satellite imagery in ArcGIS raster processing involving following steps:

1. Conversion of Satellite Digital number (DN) into Radiance by:

$$L\lambda = M_L * Q\text{cal} + A_L - O_i, \quad (1)$$

Where, M_L represents the band-specific multiplicative rescaling factor, Qcal is the Band 10 image, A_L is the band-specific additive rescaling factor, and O_i is the correction for Band 10.

2. Conversion of Radiance to At-Sensor Temperature by:

$$\text{BT} = \text{K2} / \ln [(K1/L\lambda) + 1] - 273.15 \quad (2)$$

Where, K_1 and K_2 stand for the band-specific thermal conversion constants from the metadata.

3. Conversion of Satellite Brightness Temperature (BT) into LST by:

$$T_s = \text{BT} / \{1 + [(\lambda \text{BT}/\rho) \ln \varepsilon\lambda]\} \quad (3)$$

Where T_s is the LST in Celsius (°C), BT is at-sensor BT (°C), λ is the wavelength of emitted radiance (for which the peak response and the average of the limiting wavelength (λ =10.895), ε_λ is the emissivity calculated.

Beside this, air temperature of the study area on satellite passage time over the area has been taken from online web.www.accurateweather.com and has kept constant for each land cover unit.

3. Results and Discussions

3.1 Land Surface temperature (LST) Retrieval

LANDSAT-8, Thermal Band (band 10) data during 23 Jan. 2016, 08 Feb.2016, 11March 2016 and 12 April 2016 was processed to evaluate the Land Surface Temperature (LST) of the watershed which is under investigation. Land surface temperature map (Fig.2a-d) of each studied period were prepared in ArcGIS showing the spatial distribution of land surface temperature of each land cover unit on the particular date and time. Different thermal signatures found in the watershed on same date showing because of presence of different land cover surfaces with their varying physical properties. Maximum surface temperature was observed in bare and built-up surfaces while least temperature in dense vegetative areas (Agriculture/Forest). Furthermore, it has been tried to compare the land surface temperature with the air temperature on the same date and time of satellite over pass from the area. It has been found that at some observation points land surface temperature and air temperature has shown similarity or little variation but at most places showing a remarkable temperature difference. This temperature difference is found because of their varying land cover properties and of different surface emissivity of the materials. Therefore, it can be said that some surface materials of earth showing direct response with the air temperature and observed similarity in temperature. Some materials are showing variation because of their varying thermal properties such as emissivity, thermal inertia, transmission and absorption capacities. Therefore, it has been observed that air temperature and land surface of an area should not be same. Land surface temperature is variable phenomenon depending on the properties and characteristics of the land surface materials.

3.2 Land Use / Land Cover Analysis

Landsat-8 satellite imagery bands 2-5 were used to derive the land use / land cover units present in the study area during observation period, by supervised classification using the maximum likelihood classification algorithm of ArcGIS. The five major land cover classes observed in the study area include; (1) Built-up areas (2) Bare land, (3) Agricultural (including standing crop) (4) forest cover and (5) Grass & Scrub land. These land use classes were also verified during field checks. Furthermore, Land use/land cover maps of the study have been prepared are shown in (Fig.3 a-d).

3.3 LST with Atmospheric temperature

The minimum and maximum land surface temperature of each land cover unit was calculated, which is shown in (Table1). The different land cover units are showing different thermal signatures because of their different thermal and physical properties of the materials. Also atmospheric temperature on the same date and time of satellite over pass from the study area has been noted and kept constant for each land cover unit of the study area. The maximum temperature contrast was found in summer and winter times. The satellite derived maximum surface temperature was seen in April in built-up, bare and grass lands, 39, 40 and 44°C respectively while the maximum air temperature recorded was 44^0C at that particular time of satellite passage from the study area. Other hand minimum surface temperature of 17, 19, 20 & 23^0C derived from satellite was found in January where air temperature was recorded 20°C. In the study it has been observed that surface temperature of land cover features have direct relation with air temperature as the air temperature was increasing timely similarly the surface temperature of objects are also showing positive response towards it. After computing the surface temperature and air temperature of each land cover unit present at the studied time there correlation were made. Relationship has been established between the satellite derived LST and atmospheric temperature have shown a good positive correlation r^2=0.92 which is shown in Fig.4.

4. Conclusions

LST have worldwide importance and have wide application in many fields such as for hydrological, climatic and land use/ land cover mapping and urban heat monitoring etc. In the study, Landsat-8 satellite Band 10 data during 23 Jan. 2016, 08 Feb.2016, 11March 2016 and 12 April 2016 have been processed for thermal analysis. Thermal analysis has provided the land surface temperature of each land cover unit present in the area. LST maps were prepared showing the spatial distribution temporal distribution of surface temperature in the study area. LU/LC mapping were also done for describing the different land cover units of watershed. Furthermore, correlation has been made in between satellite derived LST and air temperature. A remarkable difference has been found in temperature of different earth surfaces like, agricultural land, built-up land, bare land and forest cover, because of different their emissivity and properties of the materials. Huge temperature contrast was seen in winter (January) and summer (April) time in which the maximum temperature was 24^0C & 48^0C respectively. Therefore, we can say that deriving LST from satellite data will help in studies having climatic as well as agriculture importance and observing the temporal changes results in surface covered materials of the earth.

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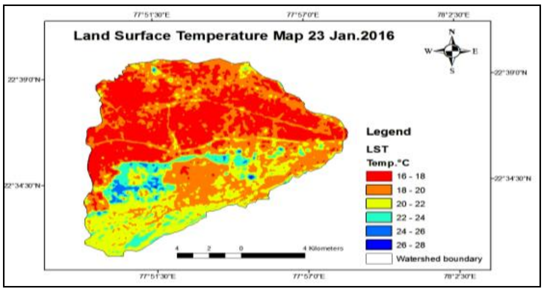
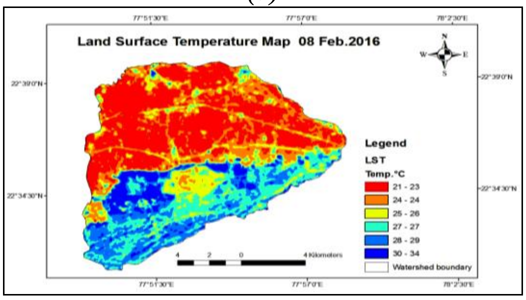


(a)



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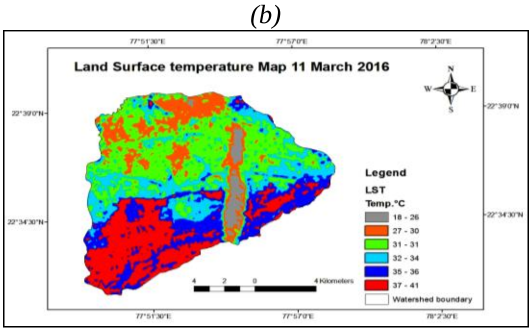

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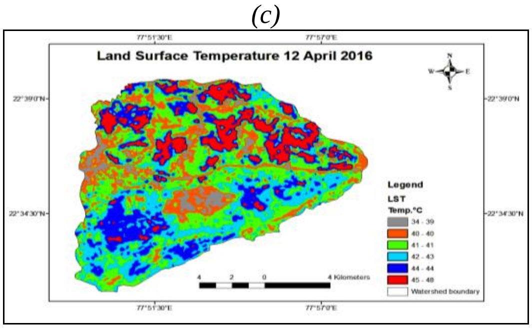
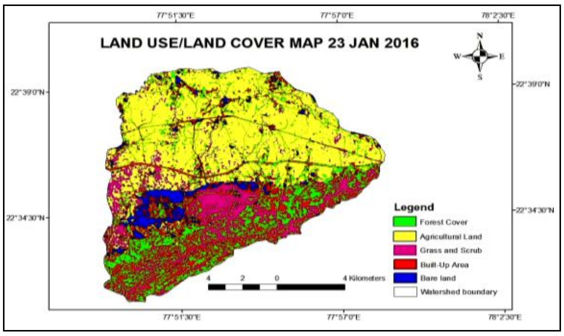
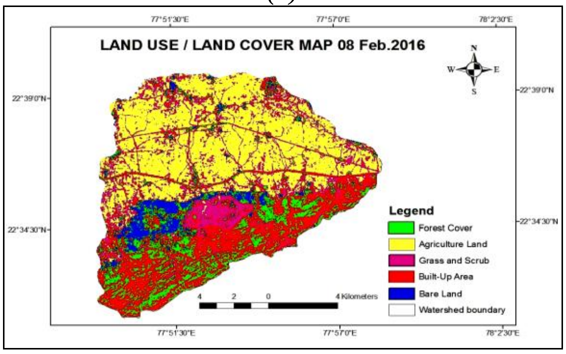


(d)

Figure (2a-d): *Spatial distribution of Land Surface Temperature*



(a)



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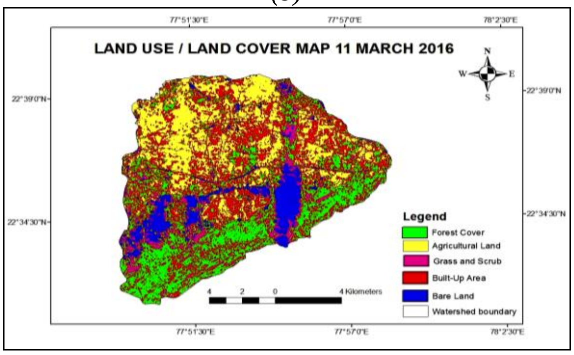

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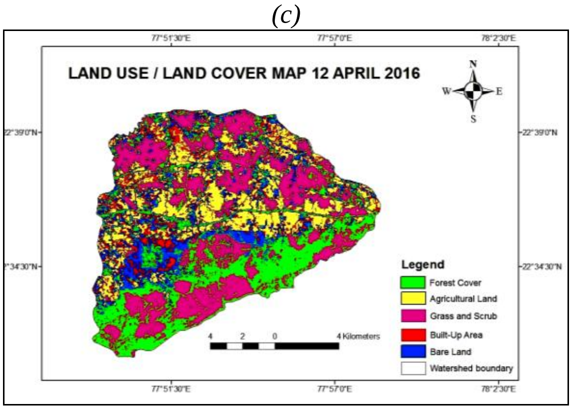

(d)

Figure (3a-d): *Land Use / Land Cover Map*

Table 1: *Satellite derived LST and atmospheric temperature in different land cover units*

Imagery Date	**LU/LC**	**LST**		**Air Temp. (^{0}C)**
		Min. (^{0}C)	**Max. (^{0}C)**	
23 Jan. 2016	Forest	17	19	20
	Agricultural land	16	17	20
	Grass & scrub	19	20	20
	Built-up	20	23	20
	Bare land	23	24	20
08 Feb. 2016	Forest	20	22	28
	Agricultural land	26	28	28
	Grass & scrub	28	33	28
	Built-up	22	24	28
	Bare land	24	26	28
11 March 2016	Forest	35	35	33
	Agricultural land	26	30	33
	Grass & scrub	33	35	33
	Built-up	35	41	33
	Bare land	18	26	33
12 April 2016	Forest	42	44	44
	Agricultural land	40	42	44
	Grass & scrub	42	44	44
	Built-up	39	40	44
	Bare land	33	39	44

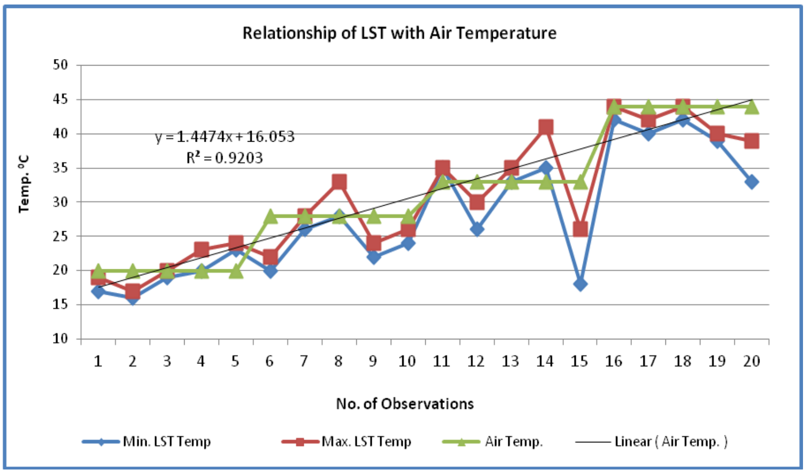

Figure 4:*Correlation Plot of Satellite derived LST with Air Temperature*