CHAPTER - 2

MATERIALS AND METHODOLOGY

2.1 SATELLITE DATA AND ITS SPECIFICATIONS

The multispectral remote sensing images from the MODIS and Landsat satellite data have been used in this study. These satellite sensors also provide the thermal images which can be useful to study the thermal behaviour of earth surface features.

2.1.1 MODIS satellite data

The first MODIS sensor onboard the Terra (EOS AM-1) spacecraft was launched in the Earth's orbit by National Aeronautics and Space Administration (NASA) successfully on December 18, 1999. The satellite moves in a near-polar circular orbit at a distance of 705 km from the Earth surface and passes the equator at a local time of 10:30 a.m. on the side of the Earth illuminated by the sun. The MODIS instrument has 36 spectral bands in the wavelength ranging from 0.4 µm to 14.4 µm at varying spatial resolutions i.e. 2 bands at 250 m, 5 bands at 500 m and 29 bands at 1000 m. It has a radiometric resolution of 12 bits and temporal resolution of 1-2 days.

MODIS data provides various atmospheric corrected land products, from which the surface reflectance products and the land surface temperature products have been used for study. MOD09A1 is the surface reflectance product which provides 8-day composite surface reflectance values of 7 bands at a spatial resolution of 500 m. MOD11A1 and MOD11A2 are the LST products which provide LST images at a spatial resolution of 1 km. These satellite images are obtained from the USGS LPDAAC (Land Processes Distributed Active Archive Center) website i.e. https://lpdaac.usgs.gov/.

Table 2.1 Specification of MODIS surface reflectance product (MOD09A1)

MOD09A1 bands specification	
No of Bands	Wavelengths
Band 1	0.62 – 0.67 µm (Red)
Band 2	0.84 –0.88 µm (NIR)
Band 3	0.46 – 0.48 µm (Blue)
Band 4	0.55 - 0.57 µm (Green)
Band 5	1.23 – 1.25 µm (NIR)
Band 6	1.63 – 1.65 µm (SWIR-1)
Band 7	2.11 – 2.16 µm (SWIR - 2)

2.1.2 Landsat satellite data

The Landsat program is a series of Earth-observing satellite missions launched in 1972 and is controlled jointly by NASA and the U.S. Geological Survey. This provides the world's longest continuously-acquired collection of remote sensing data for land surfaces from space at a moderate-resolution. These satellites move in a near-polar orbit at a distance of 917 km from the Earth surface and passes the equator at a local time of 9:30 to 10:00 a.m. on the side of the Earth illuminated by the sun.

Table 2.2 Band specification of Landsat-5 satellite data

Bands	**Wavelength range**	**Spatial Resolution**
Band 1	0.45 – 0.52 µm (Blue)	30 m
Band 2	0.52 –0.60 µm (Green)	30 m
Band 3	0.63 – 0.69 µm (Red)	30 m
Band 4	0.77 - 0.90 µm (NIR)	30 m
Band 5	1.55 – 1.75 µm (SWIR-1)	30 m
Band 6	**10.4 – 12.5 µm (TIR)**	**120 m**
Band 7	2.09 – 2.35 µm (SWIR - 2)	30 m

Table 2.3 Band specification of Landsat-8 satellite data

Bands	**Wavelength range**	**Spatial resolution**
Band 1	0.43 – 0.45 µm (Aerosol)	30 m
Band 2	0.45 – 0.51 µm (Blue)	30 m
Band 3	0.53 – 0.59 µm (Green)	30 m
Band 4	0.63 – 0.67 µm (Red)	30 m
Band 5	0.85 – 0.88 µm (NIR)	30 m
Band 6	1.56 –1.65 µm (SWIR-1)	30 m
Band 7	2.10 - 2.29 µm (SWIR-2)	30 m
Band 8	0.50 – 0.67 µm (Panchromatic)	15 m
Band 9	1.36 –1.38 µm (Cirrus)	30 m
Band 10	**10.6 – 11.2 µm (TIR-1)**	**100 m**
Band 11	11.5 – 12.5 µm (TIR-2)	100 m

Landsat Level 1 data proucts are radiometric, geometric and terrain corrected. Landsat data do not contain bands required for atmospheric correction, hence the AOT (aerosol optical thickness), ozone and water vapour bands ontained from MODIS data was used for atmospheric correction on Landsat Level-1 data products. Landsat Collection-1 Higher Level data products provides the atmospheric corrected surface reflectance data and can be obtained from the US Geological survey website i.e. https://earthexplorer.usgs.gov/. Landsat-5 and Landsat-8 data have been used in this study. Landsat-5 data was launched in March,1984 and provided land surface data until June, 2013. It has a radiometric resolution of 8-bits and temporal resolution of 16 days. There are 7 bands whose specification is provided in Table 2.2. Landsat-8 data was launched in February 2013 and it continues to acquire land surface data from space. It has a radiometric resolution of 12-bits and temporal resolution of 16 days. There are 11 bands whose specification is provided in Table 2.3.

2.2 CALCULATION OF SPECTRAL INDICES

SI refers to the mathematical equation determined using the combinations of spectral reflectance values from two or more wavelength bands in an image. This signifies the relative abundance of a particular earth surface feature of interest. The mathematical equations used for the calculation of different SI are shown in the Table 2.4.

The vegetation indices used in the study uses reflectance values from mainly NIR and Red band. Vegetation shows very high reflectance values in the NIR band and very low reflectance values in case of Red band. This helps in determining the relative abundance of vegetation present in an image using the vegetation indices. The built-up or soil indices uses reflectance values from mainly SWIR band. The built-up and the dry bare soil areas shows higher reflectance values in SWIR band as compared to the NIR and visible band. This enables the determination of relative abundance of built-up of dry bare soil land covers in a region. The water index uses reflectance values from green and NIR band. The reflectance value of water is higher in the visible region and negligible in the NIR band which helps to determine the areas with relative abundance of water in an image.

Table 2.4 Equations used for the calculation of spectral indices

Spectral Indices	Equations
Normalized Difference Vegetation Index (NDVI)	$\frac{NIR - RED}{NIR + RED}$
Enhanced Vegetation Index (EVI)	$2.5 \frac{NIR - RED}{NIR + 6 \times RED - 7.5 \times BLUE + 1}$
Soil Adjusted Vegetation Index (SAVI)	$1.5 \times \frac{NIR - RED}{NIR + Red + 0.5}$
Modified Soil Adjusted Vegetation Index (MSAVI)	$0.5 \times \left[(2 \times NIR + 1) - \sqrt{(2 \times NIR + 1)^2 - 8 \times (NIR - Red)}\right]$
Normalized Difference Built-up Index (NDBI)	$\frac{SWIR1 - NIR}{SWIR1 + NIR}$
Urban Index (UI)	$\frac{SWIR2 - NIR}{SWIR2 + NIR}$
Normalized Difference Soil Index (NDSI)	$\frac{SWIR2 - GREEN}{SWIR2 + GREEN}$
Built − up Index (BI)	$\frac{(SWIR1 + Red) - (NIR + Blue)}{(SWIR1 + Red) + (NIR + Blue)}$
Normalized Difference Water Index (NDWI)	$\frac{GREEN - NIR}{GREEN + NIR}$

2.3 CLASSIFICATION OF IMPERVIOUS SURFACE FRACTION

A NSMA method given by Wu (2004) was used for classification of ISF from the mixed spectrum which was modelled as a linear combination of vegetation-impervious-soil (V-I-S) endmembers. Impervious surfaces consist of high and low albedo surfaces which show higher spectral variability. The four-endmember NSMA approach, used in the study, was modelled as a linear combination of vegetation, high albedo impervious surface, low albedo impervious surface and soil. First, the reflectance bands of original Landsat 8 data were normalized.

$$\overline{R}_b = \frac{R_b}{m} \times 100 \tag{2.1}$$

where $m = \frac{1}{n}\sum_{b=1}^{n} R_b$ is the average reflectance in a pixel, $\bar{R}_b$ is the normalized reflectance for band b, R_b is the original reflectance of band b and n is the total number of bands. Further, LSMA approach was used for calculation of fractions of the four endmembers contained in a pixel (Wu & Murray, 2003). This is an image processing approach used for sub-pixel classification of land cover. The endmembers are determined by visual interpretation from the pure land covers from the Landsat data. The linear mixture model is represented as

$$\overline{R}_b = \sum_{i=1}^{n'} \bar{f}_i \overline{R}_{i,b} + e_b \tag{2.2}$$

where $\sum_{i=1}^{n'} \bar{f}_i = 1$ and $\bar{f}_i \geq 0$; $\bar{f}_i$ is the fraction of endmember i, $\bar{R}_{i,b}$ is the normalized reflectance of endmember i in band b, n' is the number of endmembers and e_b is the residual. The fraction is determined using a least squares method by minimizing the residual e_b. The low albedo impervious surface and waterbodies shows similar reflectance values. The high albedo impervious surfaces and sandy areas show similar reflectance values.

Hence, the waterbodies and sandy areas were masked out from the image for the LSMA classification.

2.4 ESTIMATION OF LST FROM LANDSAT DATA

Thermal band of Landsat data provides pixel values in the form of DN. There are various steps involved in estimation of LST from Landsat data (Essa et al., 2012). DN was first rescaled into Top of atmosphere radiance (TOA) using Equation 2.3.

$$L_\lambda = M_L \times DN + A_L \tag{2.3}$$

Where, M_L and A_L are multiplicative and additive rescaling factor for thermal bands obtained from metadata file. This TOA radiance includes contribution from atmosphere as well as land targets as shown in Figure 2.1.

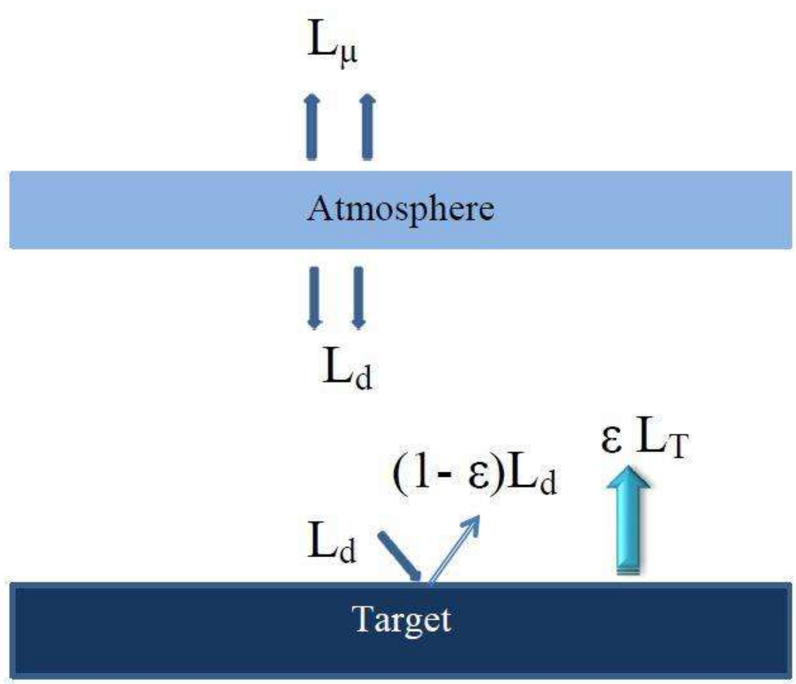

Figure 2.1 Interaction of radiation from atmosphere and land targets

TOA radiance was corrected by removing atmospheric effects in thermal region using radiative transfer equation as shown in Equation 2.4.

$$L_\lambda = \varepsilon \, \tau \, L_T + L_\mu + \tau(1 - \varepsilon) \, L_d \tag{2.4}$$

Here, L_μ is the upwelling radiance which is the radiance that reaches the sensor directly after reflecting from the atmosphere. L_d is the downwelling radiance which is the radiance that gets transmitted from the atmosphere and reaches the Earth surface. The third term in the Equation 2.2 represents the part of L_d that gets reflected from the earth's surface and then reaches the sensor after transmission from the atmosphere. The first term in the Equation 2.2 represents the radiance emitted from the earth surface and after transmission from the atmosphere reaches the sensor. This emitted radiance from the earth surface, also known as surface leaving radiance, is useful for the estimation of LST.

Table 2.5 Land surface emissivity determination using NDVI

NDVI	**Land surface emissivity**
NDVI < -0.185	0.995
-0.185 < NDVI < 0.157	0.970
0.157 < NDVI < 0.727	1.0094 + 0.047 × ln (NDVI)
NDVI > 0.727	0.990

The atmospheric parameters like transmission (τ), upwelling radiance (L_μ) and downwelling radiances (L_d) values were obtained from an atmospheric correction tool developed by Barsi et al. (2005) and is available at http://atmcorr.gsfc.nasa.gov/ only for Landsat 4-5, 7 and 8 satellite images and the land surface emissivity values were estimated using NDVI (Van de Griend and Owe, 1993). Emissivity can be estimated using NDVI values only for the range of 0.157 to 0.727. The other NDVI values were divided into three classes and emissivity values were given as shown in the Table 2.5. These values were assigned based on the past studies. When NDVI is less than -0.185, the land cover is mostly water. The NDVI values between -0.185 to 0.157 resembles mainly urban or bare land and when NDVI is greater than 0.727, it is completely vegetated land (Zhang et al., 2006).

Then, the radiative transfer equation was used for the determination of surface leaving radiance (L_T) as given by Equation 2.5.

$$L_T = \frac{L_\lambda - L_\mu - \tau \times (1 - \varepsilon) \times L_d}{\tau \times \varepsilon} \tag{2.5}$$

Then, the surface leaving radiance was converted into LST using Planck's radiation law as given in Equation 2.6.

$$T_s = \frac{K_2}{ln\left(1 + \frac{K_1}{L_T}\right)} \tag{2.6}$$

Where, K_1 and K_2 are thermal constants obtained from the metadata file. The value of K_1 and K_2 for Landsat-5 data are 607.76 W cm^{-2} sr^{-1} μm^{-1} and 1260.56 deg K, respectively and that of Landsat-8 data were 774.89 W cm^{-2} sr^{-1} μm^{-1} and 1321.08 deg K, respectively.