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Estimation of Land Surface Temperature of Chilika Lagoon Watershed and its Dependence on Terrain Properties

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A B S T R A C T

Land Surface Temperature (LST) is very important thing to understand terrestrial thermal behavior, the regional environmental change, and land atmosphere energy balance of a specific geographic area. Landsat Thematic Mapper Thermal Band has high spatial resolution, for this it has significant potency for many applications related to Land Surface Temperature. The rate of evapo-transpiration, rainfall distribution, rate of geomorphic change and distribution of biotic community is directly influenced by land surface temperature. The Chilika lagoon watershed has a unique setup of bare land, Vegetated land and water. Vegetated land and Water cover ratio is 24:62:14 significantly controlling the Distribution of LST of this Lake Watershed. Various land composition reply various response at LST. Using various software and method to build a Basic model, Land Surface Temperature is extracted from the Landsat Thematic Mapper Image. Then the land surface temperatures are compared with in situ Measurements of field survey. Then the result compare with various results of remote sensed data. Land surface temperature image also compared with various terrain types.

1. Introduction

Land Surface Temperature (LST) is very important thing to understand terrestrial thermal behavior, the regional environmental change, and land atmosphere energy balance of a specific geographic area. Landsat Thematic Mapper Thermal Band has high spatial resolution (120m), that's why it has significant potential for many applications related to Land Surface Temperature. Some researchers working with Landsat Thematic Mapper and they only use the brightness temperature at the satellite level (Mansor et al. 1994) some are using the digital number value for their specific image applications (Ritchie et al. 1990). The specific use of Land Surface Temperature extracted from Landsat TM thermal band is very few (Hurtado et al.1996). In situ measurement of a large geographical area at a time is quite difficult and expensive but using a satellite image Land surface temperature is quite easy to determine whole area

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continuous measurement (Qin et al 2001 and Sobrino et al, 2004). Some important determinants of LST are hemisphere, latitude, aspect, and elevation, Land cover composition (water, vegetation, soil, sand, rock, settlement, and industrial activity). The rate of evapo-transpiration, rainfall distribution, rate of geomorphic change and distribution of biotic community is directly influence by land surface temperature. The Chilika lagoon has a unique setup of bare land, Vegetated land and water.

As from Landsat 8 OLI image of Chilika Lagoon Watershed (figure 1) of 10th April, 2013, bare land area is 1264.30 sq km (24%), vegetated land is about 3234sq. km (62%) and water cover area is about 743.65sq. km (14%). Landmass quickly warmed and cold quickly but water body warm slowly and cools slowly, and vegetation cover normalize the temperature extremes. The weather of Chilika surroundings has a diurnal change of temperature. Maximum daily temperature is observed at 14:00 - 14:30 hr and minimum temperature is observed at 4:00- 4:30 hr. Average high temperature is about 33°C appears in the months of May-June and average low temperature is about 16 °C appears months of December. There is some regional variation in temperature in the surrounding area of Chilika lagoon. The north western part of the Chilika Lake Watershed has a granitic hilly area of height about 700m with dense forest cover, can play a local difference from the average. The eastern part of the lake Watershed composed of recently deposited fine sediment with sparse vegetation covered lowland is affected by seasonally water logging. This area seems to have moderate high temperature rather than the forest covered hilly area. The coastal part of Lake Watershed is composed of sandy spit and ridges. The 3 stepped topography of Chilika spit is the composition of partially cover dune and exposed sandy beaches. Sand ridges are forming island of middle part of lagoon and the backside of present spit with partially scrub cover. The north western rim of the lagoon Watershed composed of old denudated lateritic material buried plain with some rocky promontories extending to the lake. Bare land, Vegetated land and Water cover ratio is 24:62:14 significantly controls the Distribution of LST of this Lake Watershed. The lagoon is not much deeper, maximum depth is 3.8m seen at the dredged Channel near New mouth region of the outer channel and southern part of the lake beside Ghantashila hill. The north eastern part and middle part of the lagoon is shallower than 1m. The Water remains clear at the southern part of the lagoon throughout the year. Maximum turbidity is observed at the north eastern part of the lagoon. Salinity is maximum in outer channel zone and lower at north eastern zone. Various land composition reply various response at LST.

2. Materials and Methods

Landsat Thematic Mapper image is downloaded from the USGS Earthexplorer website. The Two images are L5140046_04620100119 and L5140046_04620100425, which are acquired on 2010-04-25 and 2010-01-19 at 10:00 AM (table 1). Then DN values of Band 6 are calibrated by Landsat Calibration Tool of ENVI 5.1. Using ERDAS Imagine 11 Model Maker to build a Basic model (figure 2) to extract Land Surface Temperature from the Landsat Thematic Mapper Image. These steps are describes briefly bellow (figure 2). Then the land surface temperatures are compared with in situ Measurements of field survey. Then the result compare with various results of remote sensed data (figure 9-14). Geological Map is prepared by ASTER image (Gad and Kusky 2007; Matar and Bamousa 2013) and land cover classification is prepared from same TM image using supervised classification method using maximum likelihood classification algorithm, Urban and rural settlements are extracted from Google Map, Aspect and Elevation layer is created from SRTM DEM, soil moisture layer is created from Same TM image. Then all layers are overlayed in ARCGIS 10.1 weighted overlay Tool. Different classes within a layer (Land Cover, Settlements, Aspect, Elevation, Geological Map, and Soil Moisture) are weighted on 5 point scale. At a 100 percent scale land cover layer get highest importance and elevation get lowest importance (table 4). Weighted overlay produces various land parcels ranging higher to lower values. Then the Land Surface Temperature and different thermal land parcel are compared.

Characteristics of Landsat 5 TM sensor

LANDSAT- 5 was launched by NASA from Vandenberg Air Force Base on March 1, 1984. Landsat 5 was an orbit satellite to collect imagery of the surface of Earth. A continuation of the Landsat Program, Landsat 5 was jointly managed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). Details of Landsat 5 Thematic Mapper is describes in bellow table (table 2)

Derivation of LST from Landsat TM imagery

Derivation of Land surface Temperature through the use of satellite image depends on various interlinked stages which are discussed below

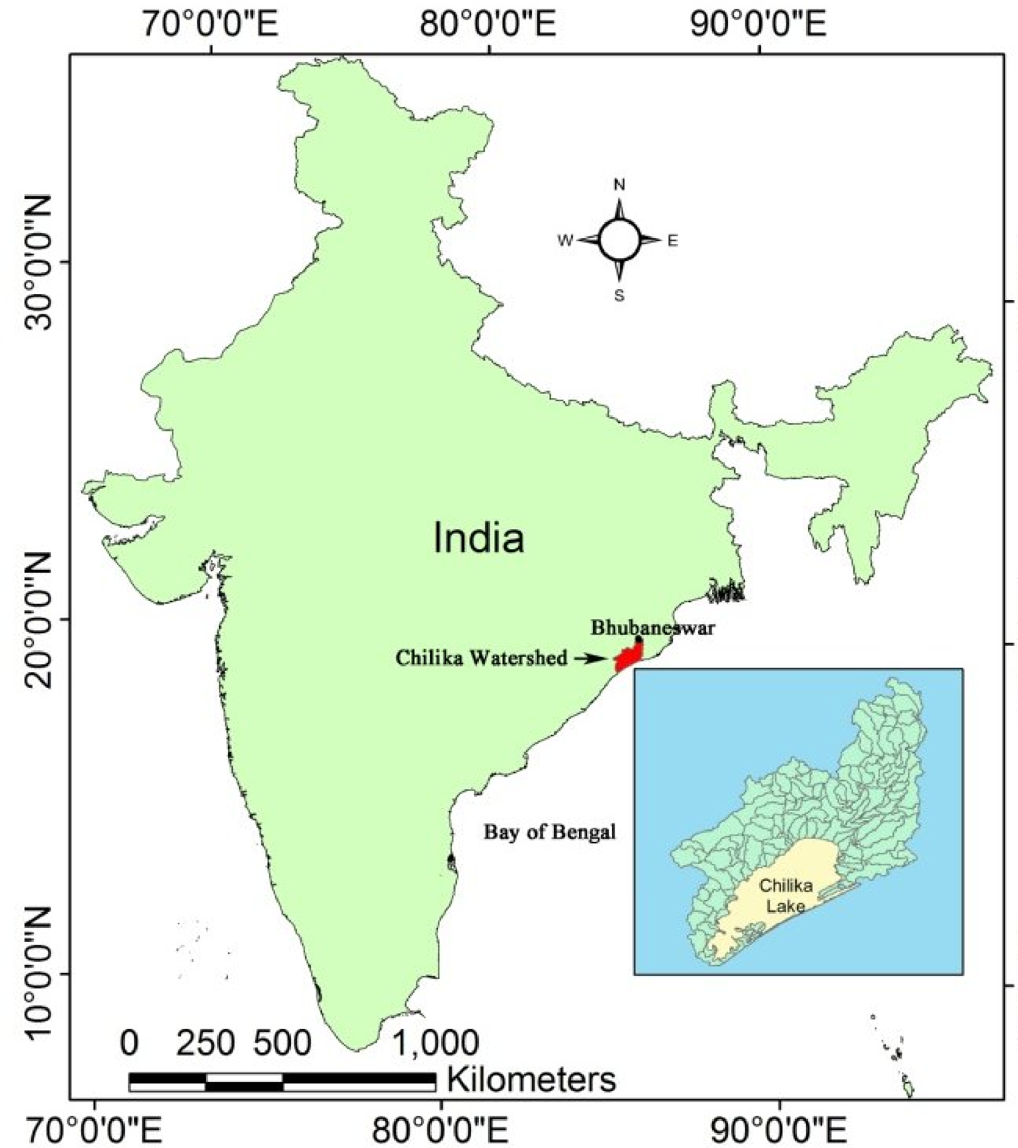

Fig. 1 Location Map of the Study area

Table 1: List of Landsat 5 Thematic Mapper images used in derivation of LST

Image ID	Path	Row	Band Used	Acquisition Date
L5140046_04620100119	140	046	Band 6	2010-04-25 at 10:00 AM
L5140046_04620100425	140	046	Band 6	2010-01-19 at 10:00 AM

Table 2 : Characteristics of the Landsat 5 TM Sensor

Launched	March,1984
Decommissioned	June, 2013
Altitude	705 km
Sensor	TM
Spatial Resolution	Band 1 to 5,7 (30 m) and Band 6 (120 m)
Spectral Resolution	Band 1 – 0.45-0.50 Blue
	Band 2 – 0.52-0.60 Green
	Band 3 – 0.63-0.69 Red
	Band 4 – 0.78-0.90 Near Infrared
	Band 5 – 1.55-1.75 Short wave Infrared
	Band 6 – 10.4-12.5 Thermal Infrared
	Band 7 – 2.08-2.57 Short wave Infrared
Temporal Resolution	16 days
Swath	185 km
Period	99 minutes
Inclination	98.2^0

Spectral Radiance

The extraction of surface temperature from thermal band of the Landsat TM data involves. First the digital numbers (DNs) of the thermal band were converted to spectral radiance using the following equation (NASA 2010) -

$$L_\lambda = \frac{(\mathrm{LMAX}_\lambda - \mathrm{LMIN}_\lambda)}{(\mathrm{QCALMAX} - \mathrm{QCALMIN})} \times (\mathrm{QCAL} - \mathrm{QCALMIN}) + \mathrm{LMIN}_\lambda$$

Where,

L_λ = Spectral radiance

LMIN_λ = The minimum value of spectral radiance at band i ($wm^{-2}\,sr^{-1}\,\mu m^{-1}$).

LMAX_λ = The maximum value of spectral radiance at band i.

QCAL MAX =The maximum value of Qcal (DN = 255).

QCAL MIN = The minimum value of Qcal (DN = 1).

QCAL = DN value at band i.

Radiant Temperature:-Thermal infrared data (band 6) of the Landsat TM can also be converted from spectral radiance ($L\lambda$) to radiant temperature (T_R) directly by the following equation-

$$TR = \frac{K_2}{\ln k_1 / L\lambda + 1}$$

TR = the radiant temperature at the satellite sensor (K).

$L\lambda$ = the spectral radiance of TIR band.

K1 = the calibration constant 1 for Landsat TM (607.76 wm-2 sr-1 m-1)

K2 = the calibration constant 2 for Landsat TM (1260.57 K)

The radiant temperature is based on the blackbody hypothesis. In reality, however, the correction for spectral emissivity is needed for the estimating the surface temperature of a target objects.

Kinetic Temperature

From the radiant temperature (TR) can be converted into kinetic temperature (TK) by using following equation-

$$\mathrm{TK} = \frac{\mathrm{TR}}{\varepsilon_1/4}$$

Where,

TK = kinetic temperature.

TR = radiant temperature.

ε = spectral emissivity.

Normalized Different Vegetation Index (NDVI)

its measures the greenness of the environment and the amount of vegetation. The NDVI is computed form the following equation-

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

Where,

NIR is the near infrared radiance from band 4 and RED is the red radiance from band 3 of Landsat TM. Distribution of NDVI in linear way, converting the NDVI image on positively by using the following equation-

$$\frac{(\mathrm{NDVI} + 1)}{2}$$

Surface Emissivity

Although several methods exist for the estimation of spectral emissivity, here we use NDVI (Normalized

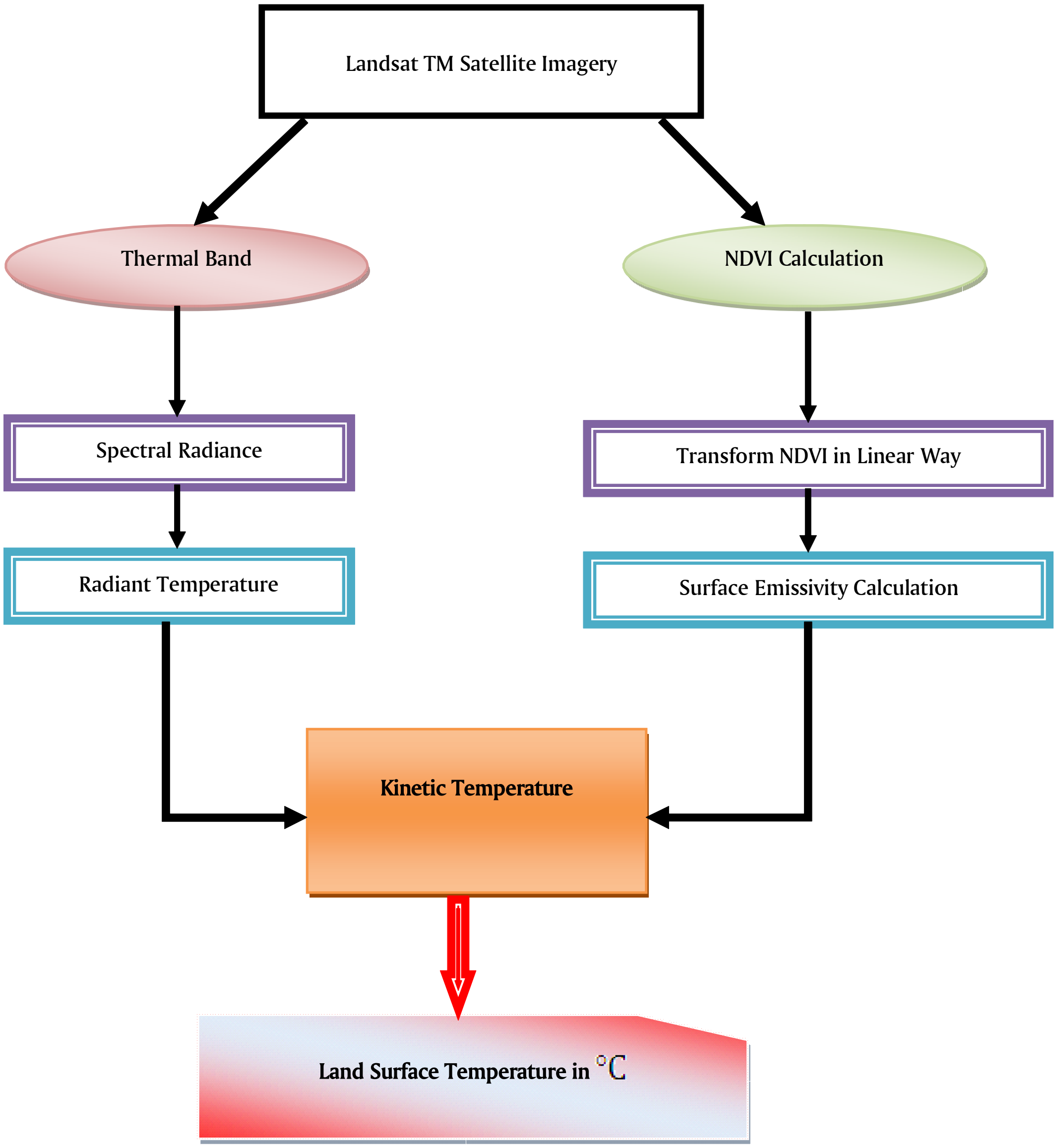

Fig. 2 Derivation of LST from Landsat TM imagery

Different Vegetation Index). To calculate the emissivity by using the following equation-

$$\varepsilon = a + b \times \ln(\text{NDVI})$$

Where,

NDVI and ε are average thermal emissivity and average normalized difference vegetation index for individual surface covers respectively, they are two constant such as **a** and **b** (a = 1.0094 and b = 0.047 for a correlation coefficient of 0.941 at 0.01 level of significance).

Temperature in °C

Conversion kinetic temperature to land surface temperature in degree Celsius by using following equation-

$$\text{LST} = (\text{TK} - 273)$$

Where,

LST = the land surface temperature.

TK = kinetic temperature.

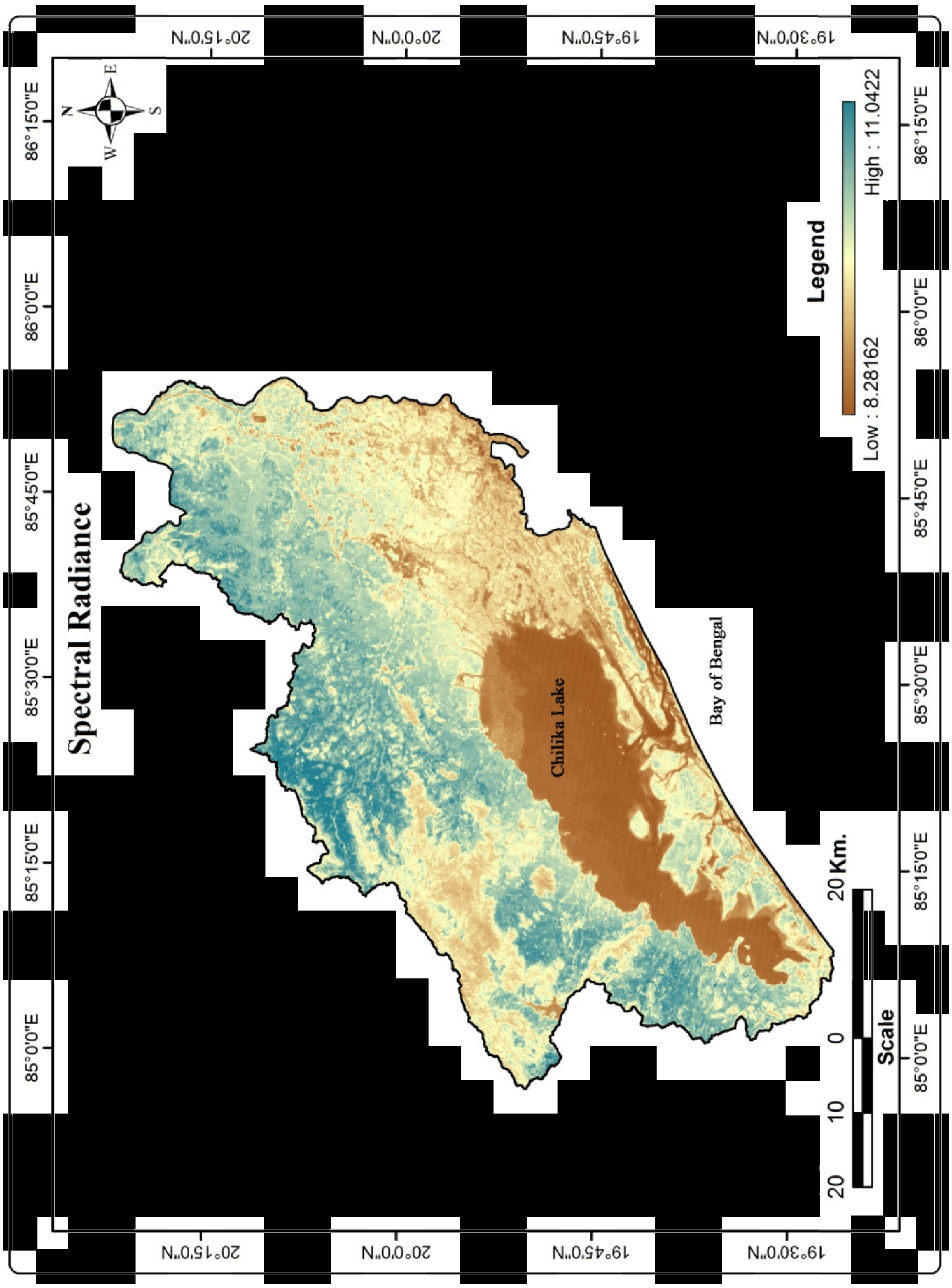

Fig. 3 Spectral Radiance map of Chilika Watershed

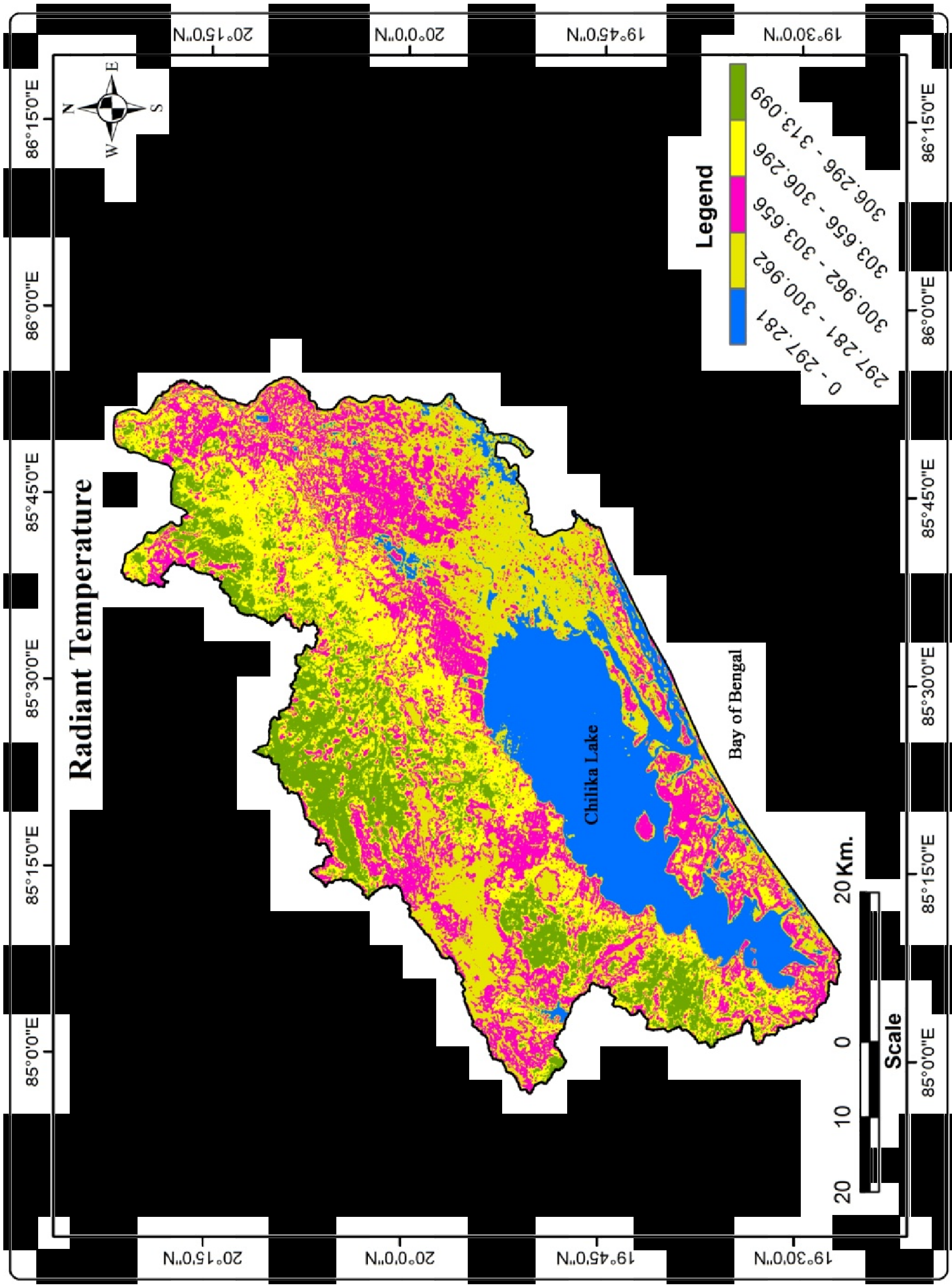

Fig. 4 Radiant Temperature map of Chilika Watershed

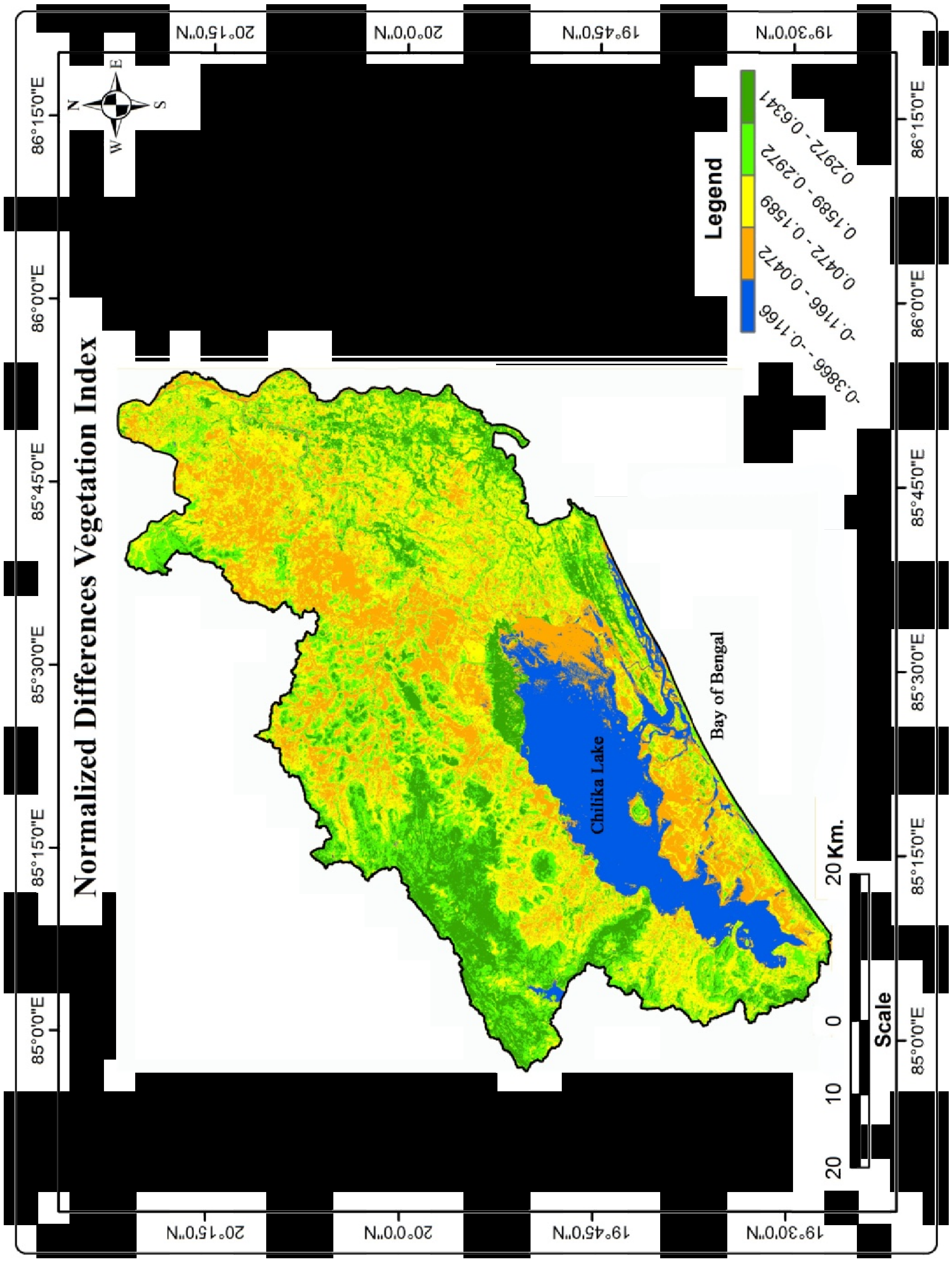

Fig. 5 NDVI map of Chilika Watershed

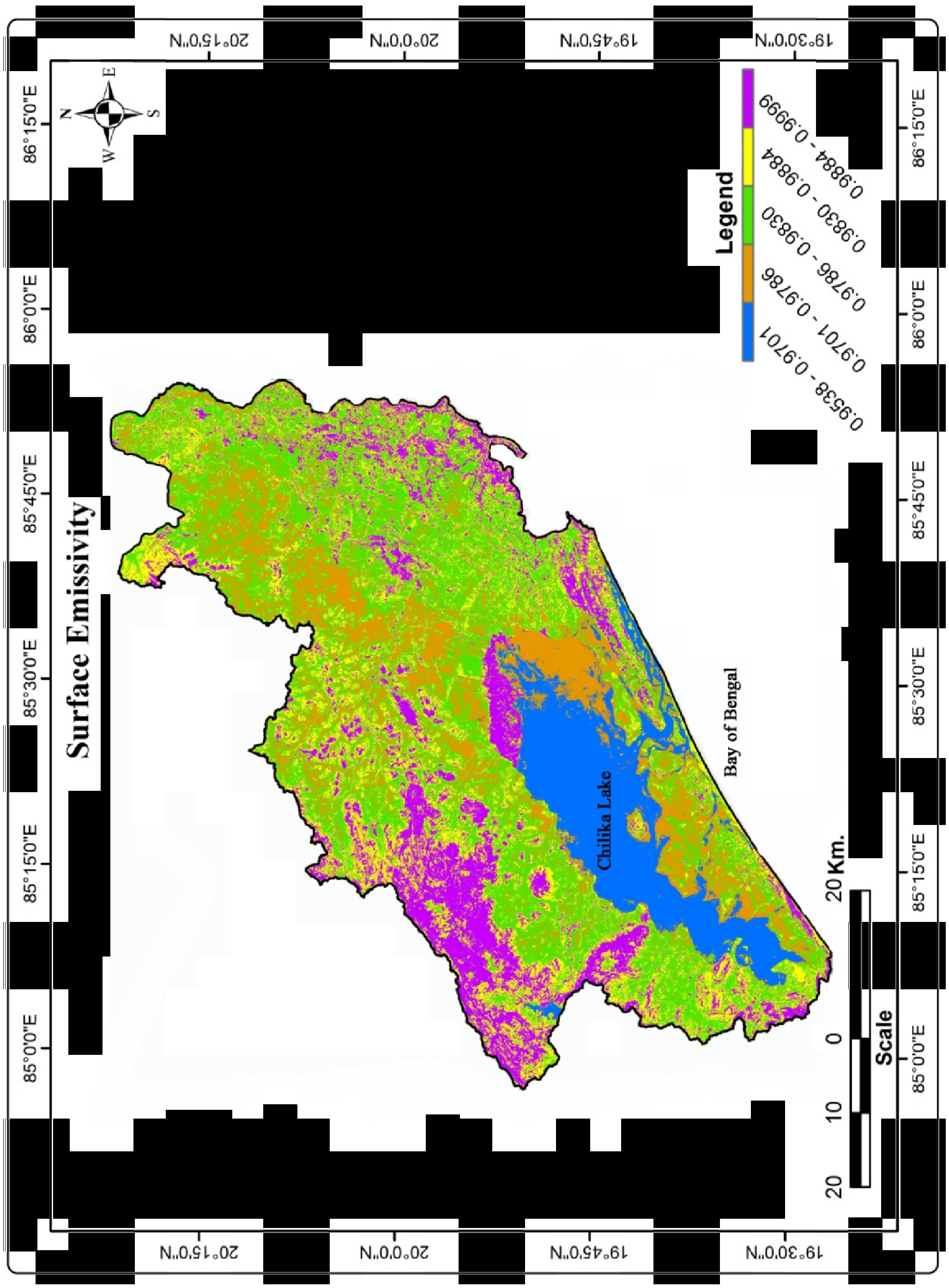

Fig. 6 Surface emissivity map of Chilika Watershed

3. Result and Discussion

After the processing of satellite images using several methods, derivation of LST has been accomplished. Result shows the land surface temperature of this region ranges Between 25^0 C - 41^0 C at 10:05 AM on 25th April 2010 and 15^0 C - 28^0 C at 10:00 AM on 19th January 2010 (figure 7-8). For checking the result five in-situ points based temperature measurement of that time is used. The Land Surface Temperature variation between the in-situ and the extracted ones are less than $\pm 0.8°C$ (table 3). Correlation between in-situ and remotely sensed temperature is +0.96. Point based measurement is efficient because an information of thermal image is average of 120 sq. meter emission of the terrain. Sometimes a single pixel coverage area of a terrain is covered by various land cover types that can cause a mixture and create little difference from the actual. It means that Landsat TM derived land surface temperature is efficient to estimate land surface temperature of wide geographic area. The influence of the surface on the overlying atmosphere is depends on various factors. In comparison with the overlay analysis of various terrain properties (figure 9-14), it has shown that temperature response zones are moderate to highly correlated (figure 15). Vegetation cover and water body are very important factors for controlling the Land surface Temperature. In barren surfaces there is a great temperature variation. For a non vegetated surface, soil moisture is the chief determinant factors of surface albedo and temperature. In the Chilika Lake watershed the colluvium plain land seems to be high temperature value in overlay result, because of non vegetated dry land and presence of laterite exposure. An un-vegetated rocky hillock also shows the high temperature value. Sandy beaches, bars, beach-ridges, non- vegetated dune faces shows high temperature because of the heating effect of dry unconsolidated sand. Urban settlement area of Bhubaneswar city also shows high temperature value in overlay analysis as well as also in satellite derived LST image. Because of high specific heat and thermal conductivity of water and the expenditure of energy for evaporation, wetter surface seems to be general cooler than dry land and is free from extremity of weather. Water saturated soil such as in swamps and marshes is almost as effective as water in suppressing temperature changes, for this reason dense phragmites covered north eastern fringe and marshy eastern side of lake watershed is cooler than other region. Dense vegetation cover tends to control temperature changes since it contains some water and also insulates against heat transfer ground and atmosphere. Prevailing wind is also a factor in temperature controls. Lake margin and island's temperature also controlled by lake wind. Temperature normally decreases with increasing altitude throughout the troposphere. This decrease of temperature with altitude at the rate of 6.4°C/ Km is defined as lapse rate. This lapse rate happens on the north eastern hilly terrain of the watershed. Seasonal control is also observed in this watershed. The water seems hotter than vegetation zone in January and colder in April. Bare soil, Sand and rock covered area display the maximum temperature in both seasons. Landsat Thematic Mapper captures the thermal image continuously at 16 day interval since 1982. Landsat Thematic Mapper image is free of cost and if continuously captured image is used for biophysical modeling and time series analysis it will be very helpful to researchers. Users have to be sincere about appropriate radiometric calibration of the thermal image.

4. Conclusion

Remotely sensed land surface temperature measurement method is reflecting the Actual temperature Scenario of a wide geographic region. It is helpful to asses various thermal zone of the area. In-situ temperature measurement technique also helpful to measure land surface temperature but this measurement are point station basis and not continuous. Thermal Image Based continuous land surface temperature is used for various biophysical modeling of the environment.

The terrain thermal properties are reflected as very contrasting with the spatial variation of bare rock and sandy surfaces, vegetated surface, swampy moisture surface, saturated soils, build up area coverages, and differences in surface elevations in such LST study for the case of Chilika Lagoon during summer months. However in the winter months the water bodies and wet soils seem hotter than the vegetated zones. Thus on the basis of temperature scenario the terrain classes can be studied with biophysical modeling of an area.

Acknowledgement

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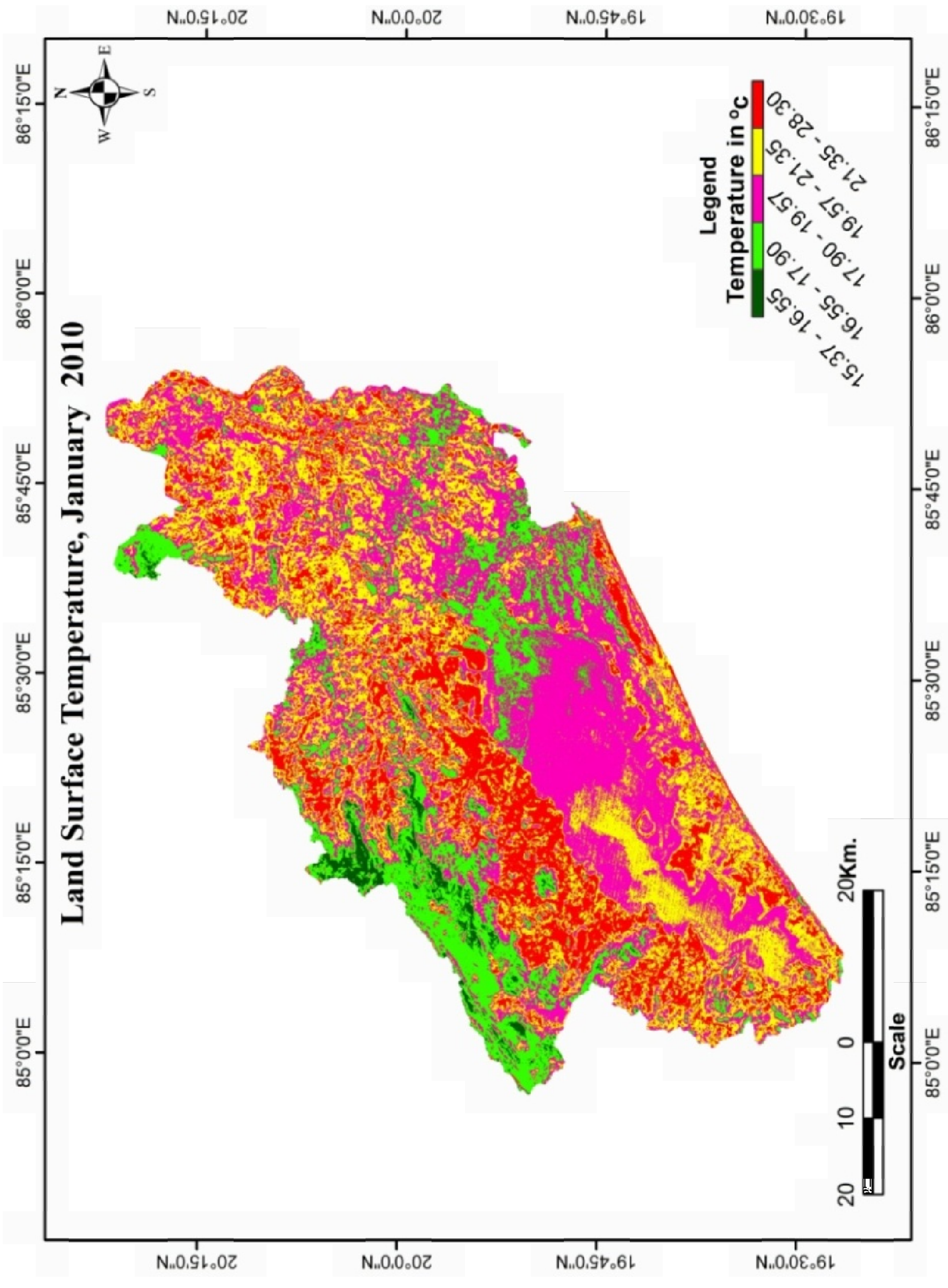

Fig. 7 LST map of January, 2010 of Chilika Watershed

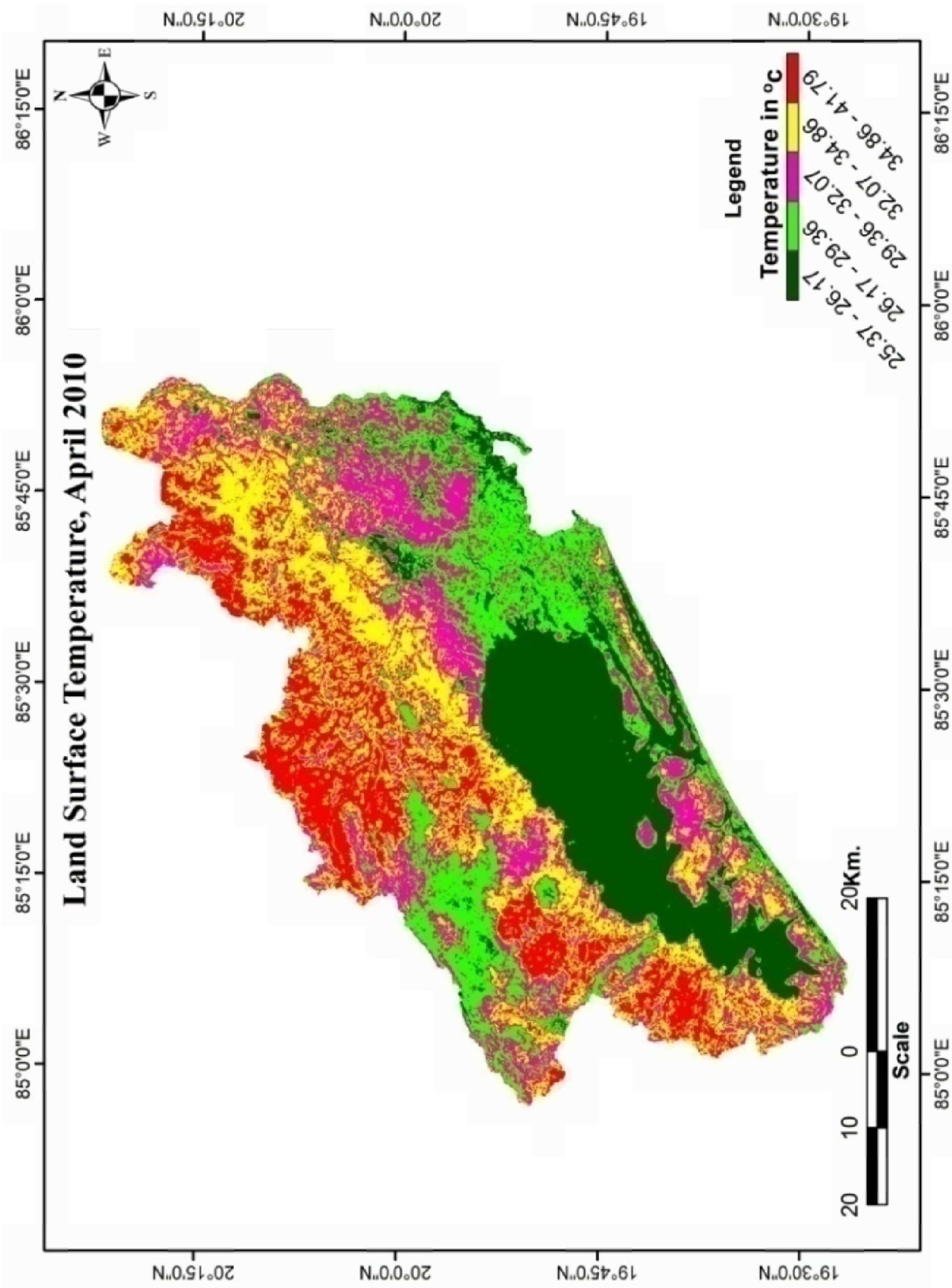

Fig. 8 LST map of April, 2010 of Chilika Watershed

Table 3: Comparison of LST using ground based and satellite based measurement

Weather Station/ Survey Area	Location	Date and Time	Observed Temperature (Automatic Weather Station/Digital Thermometer)	Satellite Sensed Temperature	Difference (°C)
INS Chilka, Khurda	Latitude: 19.67 N Longitude: 85.18 E	10:00 am 2010-01-19	24.95	24.36	-0.59
INS Chilka, Khurda	Latitude: 19.67 N Longitude: 85.18 E	10:00 am 2010-04-25	32.09	32.17	0.08
B.D.O.- Panchayat Samithi Office- TANGI	Latitude: 19.92 N Longitude: 85.39 E	10:00 am 2010-01-19	27.39	27.87	0.48
B.D.O.-Panchayat Samithi Office- TANGI	Latitude: 19.92 N Longitude: 85.39 E	10:00 am 2010-04-25	34.38	34.40	0.02
B.D.O.-Panchayat Samithi Office- KANAS	Latitude: 20.00 N Longitude: 85.65 E	10:00 am 2010-01-19	21.32	21.15	-0.17
B.D.O.-Panchayat Samithi Office- KANAS	Latitude: 20.00 N Longitude: 85.65 E	10:00 am 2010-04-25	32.78	31.98	-0.8
Chilika Lake	Latitude: 19.72N Longitude: 85.36E	10:00 am 2010-01-19	19.55	19.03	-0.52
Krushnaprasad King Palace	Latitude: 19.64N Longitude: 85.26E	10:00 am 2010-04-25	34.32	34.63	0.31

Table 4: Weightage of various subclass and terrain thermal properties layer during summer months of Chilika watershed

Terrain Properties	Sub Classes	Individual Class Weightage	Percentage of Layer Weightage
Surface Geology	Precambrian Granitic Rock	4	20
	Colluvium Plain	3	
	Sandy Spit Ridges	5	
	Mahanadi New Alluvium	2	
	Lagoon Proper	1	
Major Land cover	Bare Soil	5	25
	Vegetation	3	
	Water	1	
Elevation	Less than 500 m	5	10
	Greater than 500m	3	
Aspect	Southern	5	15
	Northern	3	
	Rest part	1	
Settlement	Urban Settlement	5	15
	Rural Settlement	3	
	Rest part	1	
Soil Moisture Content	Very Dry Soil	5	15
	Dry Soil	4	
	Intermediate	3	
	Wet Soil	2	
	Saturated Soil	1	

Various Terrain Properties as Determinant factors of Land Surface Temperature

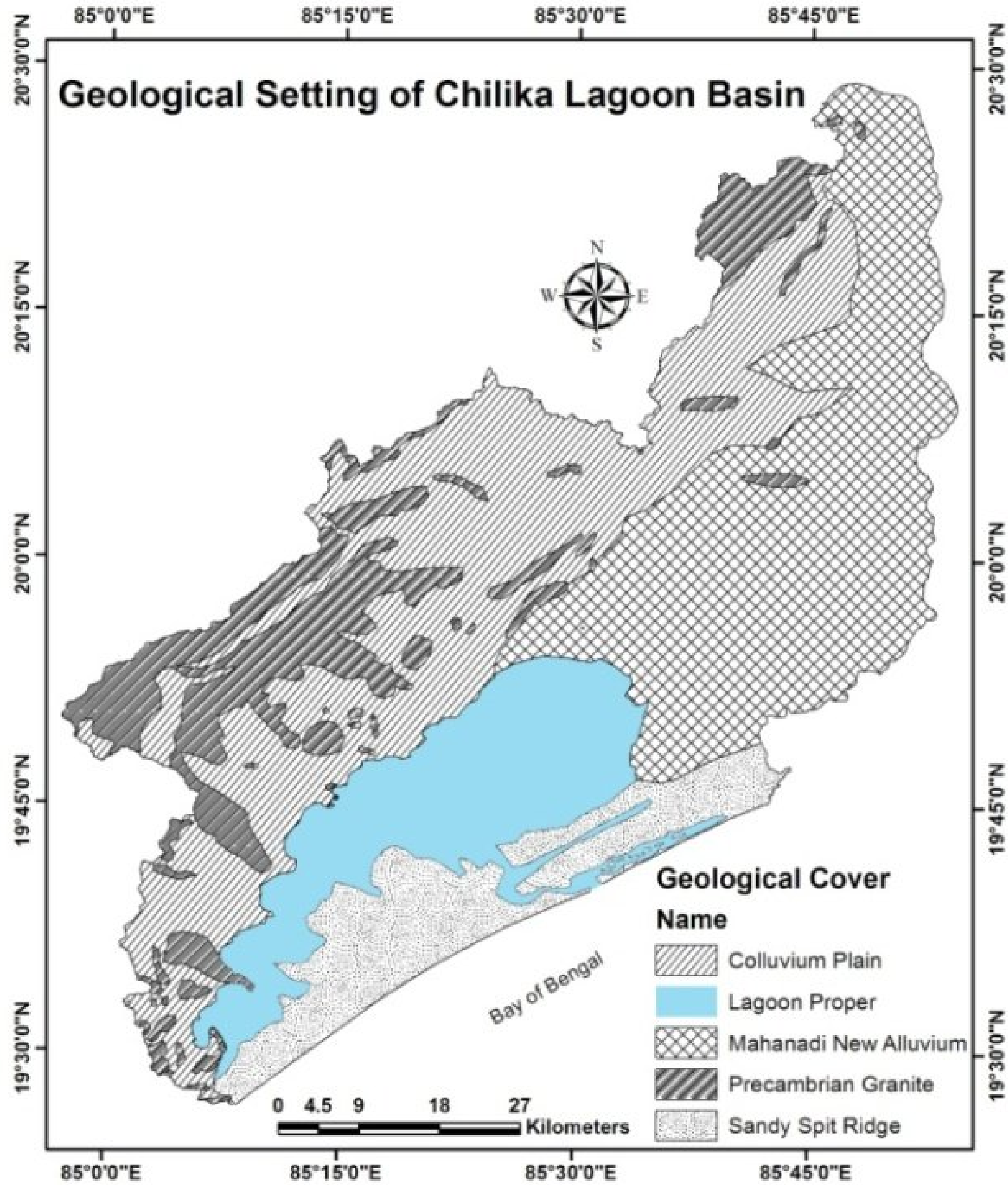

Fig. 9 Geological Map of Chilika watershed

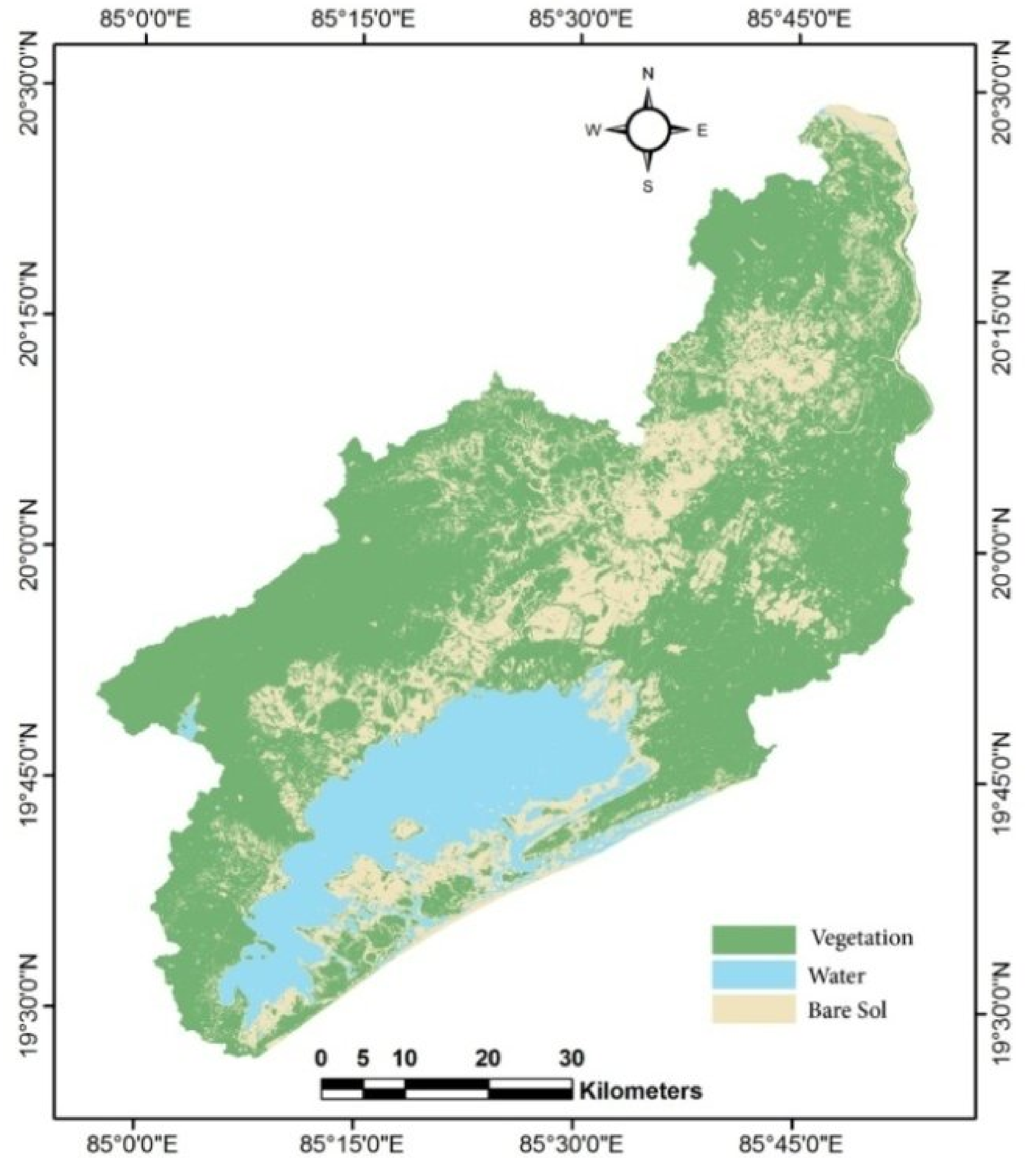

Fig.10 Land Cover Map of Chilika watershed

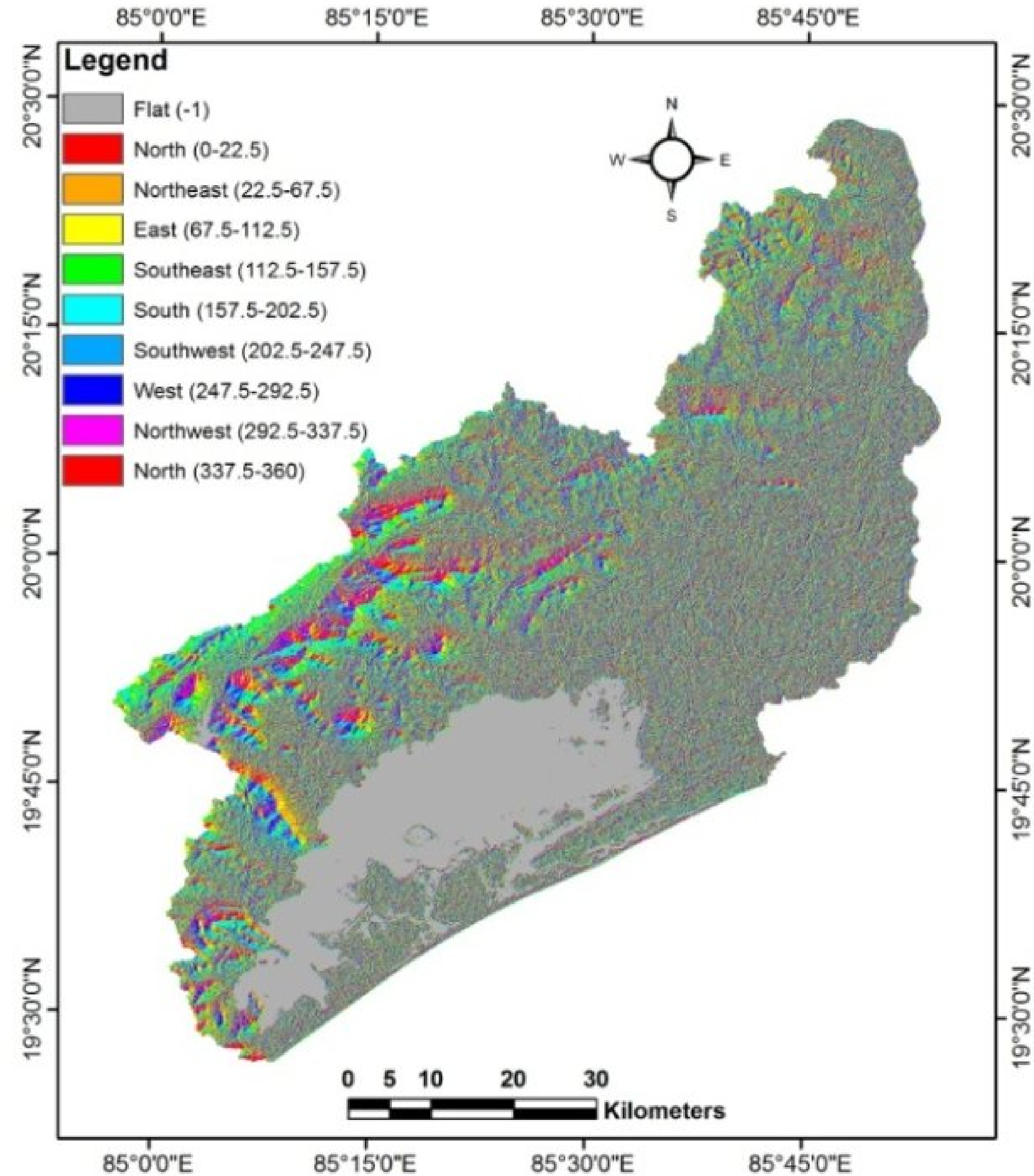

Fig. 11 Aspect Map of Chilika watershed.

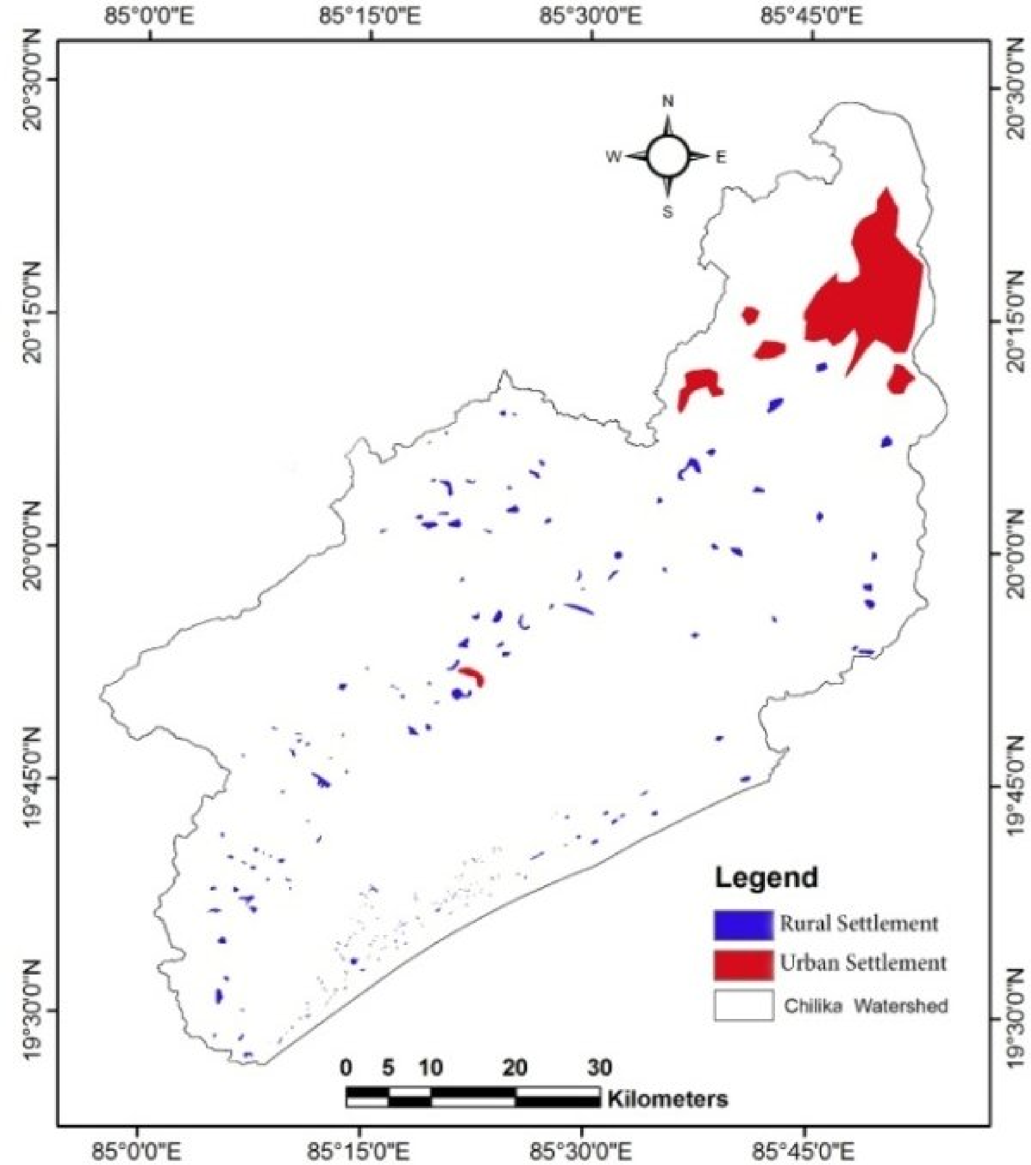

Fig. 12 Settlement Map of Chilika watershed

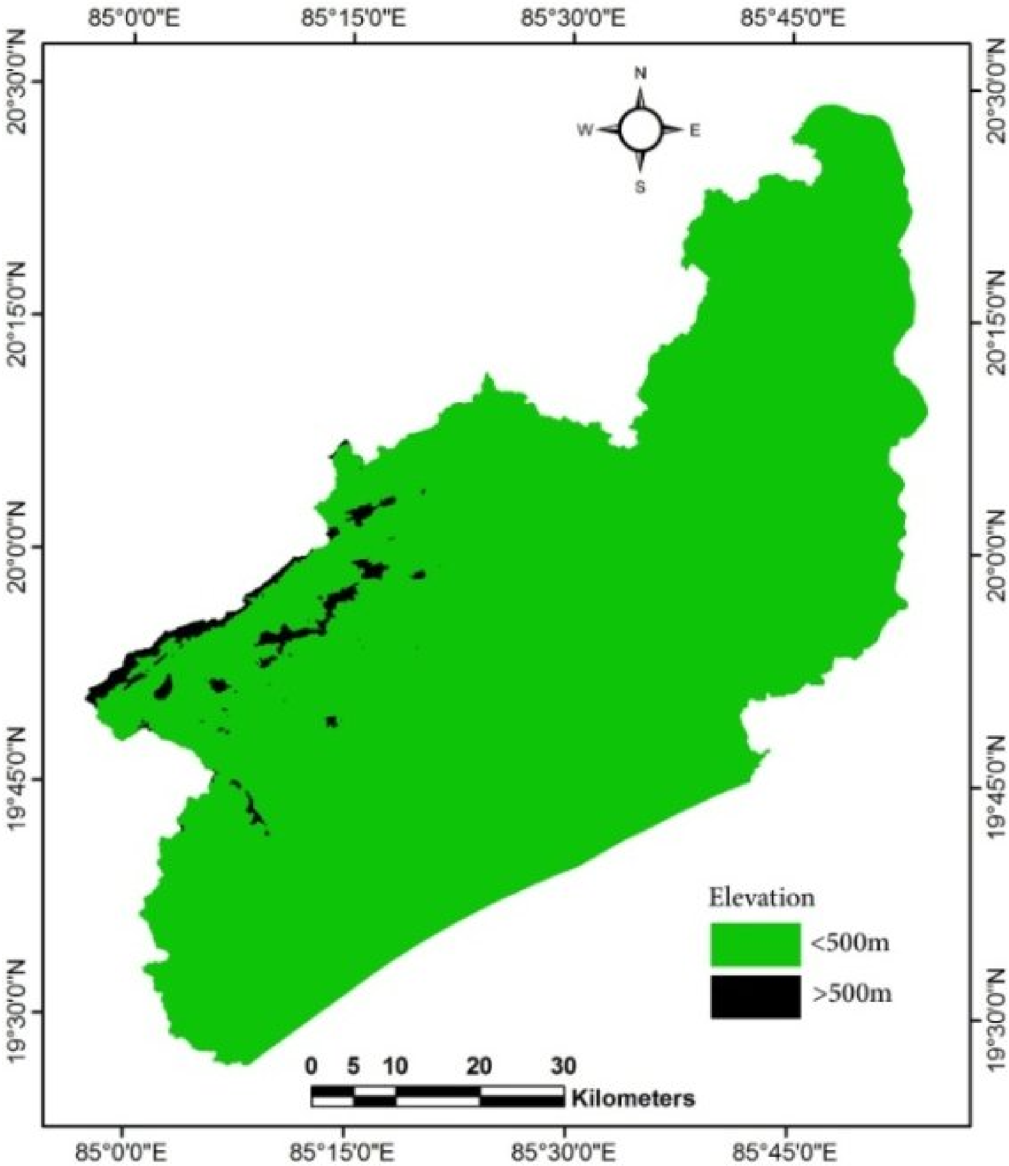

Fig. 13 Relief Map of Chilika watershed

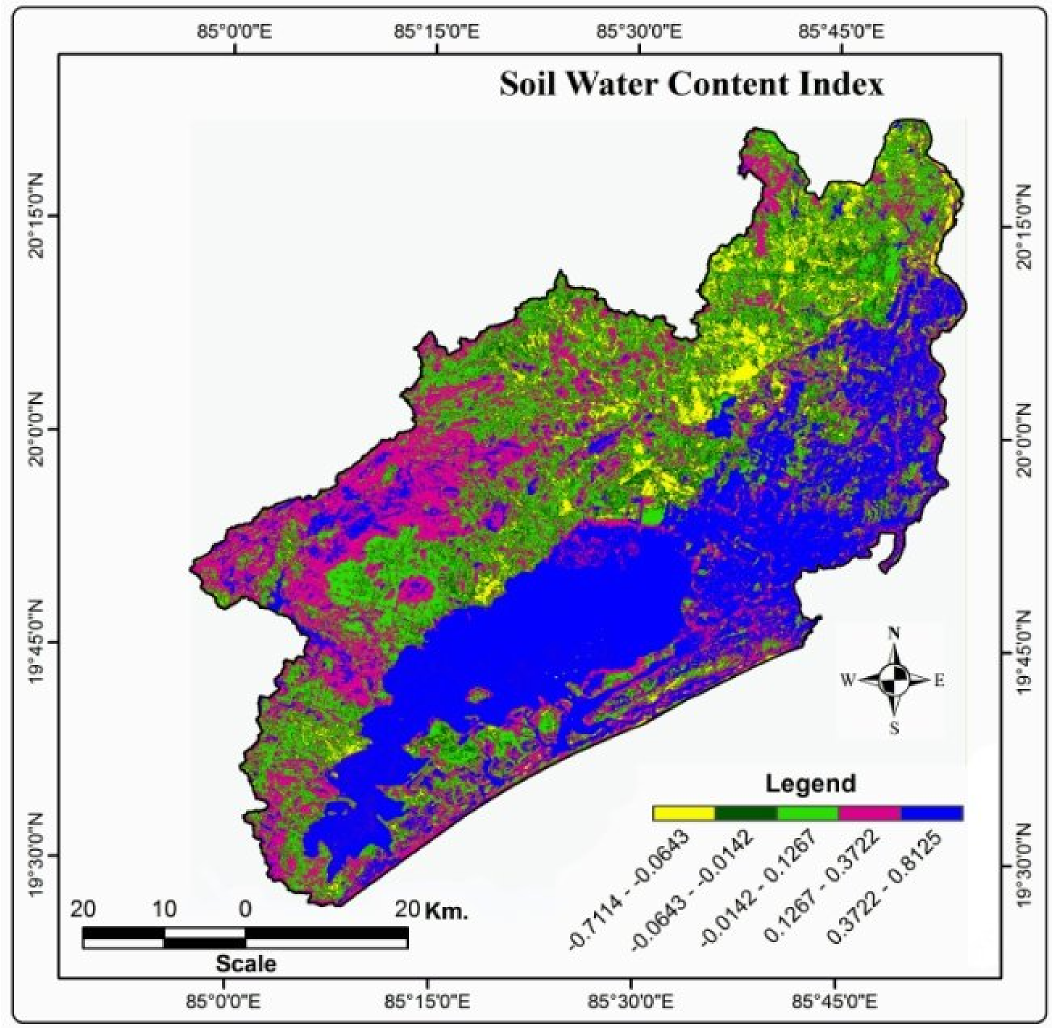

Fig. 14 Soil water content map of Chilika watershed

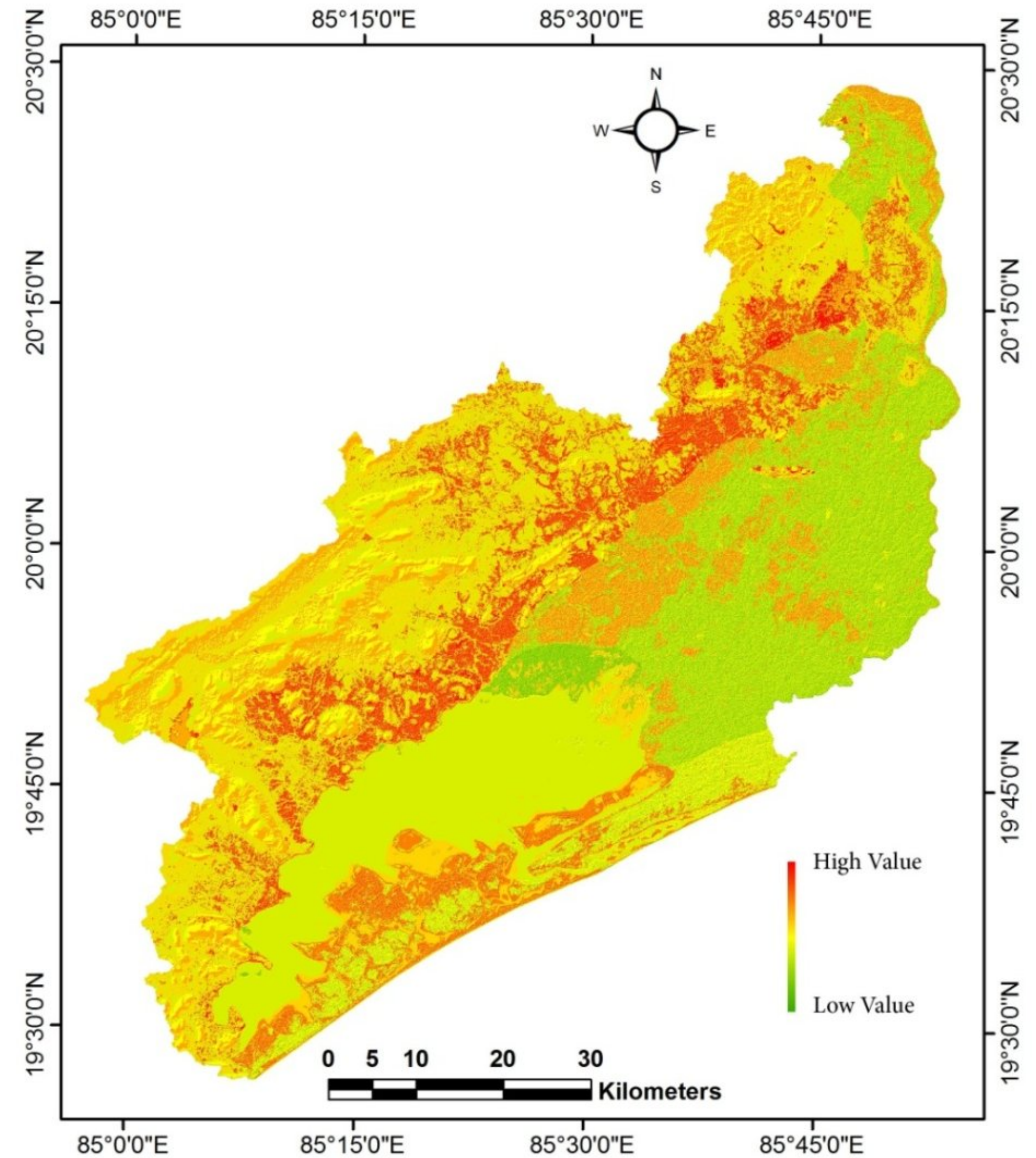

Fig. 15 Overlay map of various determinate terrain properties controlling land surface temperature of Chilika Lake Watershed

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