RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 10 | Issue 2 | October, 2017 | 354-359
e ISSN–0976–7223 ■ Visit us : *www.researchjournal.co.in* ■ **DOI: 10.15740/HAS/IJAE/10.2/354-359**

Land surface temperature estimation using split window approach over US Nagar district of Uttarakhand state, India

■ **DANIEL PRAKASH KUSHWAHA, VIJAY KUMAR SINGH AND TARATE SURYAKANT BAJIRAO**

Received : 21.04.2017; **Revised :** 27.07.2017; **Accepted :** 11.08.2017

See end of the Paper for authors' affiliation

Correspondence to :

DANIEL PRAKASH KUSHWAHA
Department of Soil and Water Conservation Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. NAGAR (UTTARAKHAND) INDIA
Email : danielprakash45499@ gmail. com

■ **ABSTRACT :** To estimate land surface temperature (LST) has an important role for agriculture as well as global change of climate, growth of vegetation and glacier melting. It combines the results of all surface atmosphere interactions and energy fluxes between the surface and the atmosphere. Now-a-days, estimation of temperature of land surface is being calculated with the help of satellite images containing thermal infrared band. Though land surface temperature derived from satellite, could be a beneficial complement to conventional land surface temperature data sources. This research, proposed a methodology for determining land surface temperature through using a structured mathematical algorithm *viz.*, split window (SW) algorithm. Split window algorithm has been used on LANDSAT 8 with operational land imager *i.e.* OLI sensor and thermal infrared sensor *i.e.* TIRS dataset of Udham Singh Nagar district. TIRS shows two thermal bands *i.e.* band 10 and band 11. SW approach requires brightness temperature value of both band 10 and band 11 as well as land surface emissivity which is calculated from OLI bands *i.e.* NIR and Red, for the estimation of land surface temperature. The spectral radiance was determined using thermal infrared bands *i.e.* band 10 and band 11. Emissivity was calculated by using normalized difference vegetation index *i.e.* NDVI threshold technique for which OLI bands 2, 3, 4 and 5 were utilized. SW approach uses brightness temperature of two bands of thermal infrared, mean and difference in land surface emissivity for estimating land surface temperature. In this paper, 6 Dec. 2015 date was selected as an example to show the approach of using SW technique to estimate the LST of Udham Singh Nagar district of Uttarakhand state in India.

■ **KEY WORDS :** Split window approach, Fractional vegetation cover, Land surface emissivity, Land surface temperature

■ **HOW TO CITE THIS PAPER :** Kushwaha, Daniel Prakash, Singh, Vijay Kumar and Bajirao, Tarate Suryakant (2017). Land surface temperature estimation using split window approach over US Nagar district of Uttarakhand state, India. *Internat. J. Agric. Engg.*, **10**(2) : 354-359, **DOI: 10.15740/HAS/IJAE/10.2/354-359.**

Land surface temperature (LST) is very important environmental parameter to be studied. The meaning of land surface temperature is the temperature of earth surface when we directly contact with it. It is also called skin temperature of the earth surface. LST is one of the important factors in global climate change, vegetation growth and glacier melting. The study of the LST is very crucial in monsoon prone areas. When it rises it causes environmental imbalance situation such as melting in glacier, reduction in vegetation, and change in climatic condition of monsoon areas leading to unpredictable rainfall. The semi-urban areas which are in development stage, are a focal point for social and economic activities and due to which, these are closely related to daily life of human being (Mirzaei and Haghighat, 2010 and Madlener and Sunak, 2011).

Attention is more and more being given to the pursuit of more comfortable living conditions in semi-urban areas in the face of increasing urbanization. Due to which our interests are growing in the factors that impact on human ease and well being in cities (Oke, 1982; Quattrochi and Luvall, 1999; Kleerekoper *et al.*, 2012; Gago *et al.*, 2013; Santamouris, 2013 and Xiaokang Kou *et al.*, 2016). Poor air quality is also responsible for increment in temperature of the earth (Sarrat *et al.*, 2006) and finally it can boost the energy requirement of an area (Santamouris *et al.*, 2001; Kondo and Kikegawa, 2003; Kolokotroni *et al.*, 2007; Mirzaei and Haghighat, 2010; Kolokotroni *et al.*, 2012 and Ema *et al.*, 2016). Increment in temperature can even contribute to human mortality rates, with thousands of heat-related deaths in every year (Cleveland, 2007; Ashley and Lemay, 2008 and Gosling *et al.*, 2009) and it has been directly linked to adverse impacts on human health (Tan *et al.*, 2010 and Cheung and Hart, 2014).

Now-a-days, LST is being calculated by using different images of satellite which are containing thermal infrared (TIR) band. Therefore, with the help of satellite images LST could be a useful complement to traditional LST data sources. TIR remote sensing technique has become one of the important means to study the thermal characteristic of land surface. In this paper, split window (SW) approach is used to calculate LST. In this study, we are using two thermal bands *i.e.* band 10 and band 11 in LANDSAT 8 images and we have used moderate resolution LANDSAT 8 bands (30m). During the estimation of LST, we required operational land imager (OLI) sensor bands (which are from band number 2 to band number 5) for determining land surface emissivity (LSE) with the help of fractional vegetation cover (FVC). SW approach combined brightness temperature of band number 10 and 11 with LSE to estimate LST for each ground pixels vector.

METHODOLOGY

Study area and data used :

US Nagar is a famous district of the Uttarakhand state, it is in the tarai region of Kumaon divison. Total geographical area of this district is about three thousand fifty five sq. km. and in aerially it ranks ninth in its own state. It is situated between latitude 28° 53' N to 29° 23' N and and longitudes 78° 45' E to 80° 08' E. The study area falls in survey of India (SOI) Topo sheet (Quadrangle Maps) Nos. 53K, O, P and 62D. The overall literacy rate is 64.86%. Agriculture is the primary occupation of the people as it justifies the title of "Chawal ki Nagari". About 64% of the total work force involved in farming. Total areas under *Rabi*, *Kharif* and *Zaid* crop are 97973, 139928 and 8580 ha, respectively.

Landsat-8 is one of the Landsat series of NASA. The data of Landsat-8 is available in Earth Explorer website at free of cost. In the present study, the TIR band number 10 and 11 were used to estimate brightness temperature and OLI spectral bands 2, 3, 4 and 5 were used to determine normalized difference vegetation index (NDVI). Landsat-8 provides metadata of the bands such as thermal constant, rescaling factor value etc., which can be used for calculating LST. In 2013, the new Landsat series was lunched which is called Landsat data continuity mission (LDCM) or simply Landsat-8. This new generation included the new TIR sensor (TIRS). Its resolution has been given in Table A. The major difference between the new TIRS and the thematic mapper (TM) or enhanced thematic mapper (ETM) sensors is the existence of two thermal infrared bands in the atmospheric window between 10 and 12 µm.

Table A : Sensors and their resolutions

Sensor	No. of bands	Resolution (m)	Path/Row	Date of acquisition
Operational land imager (OLI)	9	30	145/040	6th Dec 2015
Thermal infrared sensor (TIR)	2	100		

Environment for visualizing images (ENVI) is a image processing software and has been used in this study. ENVI combines a number of scientific algorithms, a lot of which are contained in automated, wizard-based approach that walks users through complex tasks. SW approach uses brightness temperature of two bands of TIR, mean and difference in LSE for estimating LST of an area. The SW approach uses the following algorithm;

$$LST = TB_{10} + C_1 (TB_{10}-TB_{11}) + C_2 (TB_{10}-TB_{11})^2 + C_0 + (C_3+C_4e_w)(1- £) + (C_5+C_6e_w) a£ \quad (1)$$

where, LST is in ^{0}K, from C_0 to C_6 are split window co-efficient values (Skokovic *et al.*, 2014; Sobrino *et al.*, 1996 and 2003 and Zhao *et al.*, 2009) given in Table B, TB_{10} and TB_{11} are brightness temperature in ^{0}K of band 10 and band 11, respectively, ε is mean LSE of TIR bands, e_w is the atmospheric water vapor content (g/cm^3) and Δε is difference in LSE.

Table B : SW constant values

Split window constants	Value
C_0	-0.268
C_1	1.378
C_2	0.183
C_3	54.300
C_4	-2.238
C_5	-129.200
C_6	16.400

Brightness temperature (T_B): is the microwave radiation radiance traveling upward from the top of Earth's atmosphere. Te calibration process has been done for converting thermal DN values of thermal bands of thermal infrared to T_B. The top of atmospheric (TOA) spectral radiance of (Lλ) was needed for finding T_B of an area. T_B for both the TIR bands was determined by using the following formula;

$$TB = \frac{K_2}{Ln\left[\left(\frac{K_1}{L\lambda}\right) + 1\right]} \quad (2)$$

where, K_1 and K_2 are thermal conversion constant and it varies for both TIR bands, Lλ is TOA spectral radiance and it was determined by multiplying multiplicative rescaling factor (MRF), which is 0.000342, of TIR bands with its corresponding TIR band and adding additive rescaling factor (ARF), which is 0.1, with it.

$$L\lambda = M_L \text{ x } Qcal + A_L \quad (3)$$

where, Lλ is in watts per (m^2 x srad x μm), M_L is band specific MRF (radiance multi band 10 or 11), Q_{cal} is band 10 or 11 image and A_L is band specific ARF (radiance add band 10 or 11). To find LST it is necessary to calculate the LSE of the region. LSE was estimated using NDVI threshold method and formula is given below;

$$LSE = \varepsilon_s \text{ (1-FVC)} + \varepsilon_v \text{ x FVC} \quad (4)$$

where, ε_s and ε_v are the soil and vegetative emissivity values of the corresponding bands. Emissivity values are given in Table C.

Table C : Emissivity of bands

Emissivity	Band 10	Band 11
ε_s	0.971	0.977
ε_v	0.987	0.989

Here FVC was estimated for a pixel and FVC for an image was calculated by

$$FVC = \frac{NDVI - NDVIs}{NDVIv - NDVIs} \quad (5)$$

Where, NDVIs is NDVI re-classified for soil NDVIv is NDVI re-classified for vegetation. OLI bands 2, 3, 4 and 5 may be layer stacked and NDVI is estimated using ENVI IP software. The output value of NDVI ranges between -1 and +1, it may vary from one region to other. To get NDVIs and NDVIv, the NDVI image was reclassified into soil and vegetation, the classified data were used to find out FVC. After generating LSE for both the bands of TIR, the mean and difference LSE was found as;

$$\varepsilon = \frac{(\varepsilon_{10} + \varepsilon_{11})}{2} \quad (6)$$

$$\Delta\varepsilon = \varepsilon_{10} - \varepsilon_{11} \quad (7)$$

where, ε_{10} and ε_{11} are LSE of band 10 and 11, respectively. Finally, the LST in ^{0}K was determined using SW approach.

Atmospheric water vapor content (e_w) :

Water vapor content of region is the function of relative humidity (RH). Relative humidity is available at many observatories. In this study, weather forecasting website *worldweatheronline.com* has been used and got the RH, absolute pressure and temperature of the present day and present time when satellite passed over the region. Although values of the present time RH, absolute pressure and temperature is not available on above mentioned website, so to get the values of the present time RH, absolute pressure and temperature at which study has been performed, interpolation technique has been used and following steps are needed for this;

Equilibrium vapor pressure (e^*_w) :

The below formula was used to determine the e^*_w;

$$e^*_w = (1.0007 + 3.46 \text{ x } 10^{-6} \text{ P}) \text{ x } (6.1121) e^{\left(\frac{17.502 * T}{240.97 + T}\right)} \quad (8)$$

where, T is the dry bulb temperature expressed in

°C, P is the absolute pressure in mili-bar and e^*_w is in mili-bar. This formula was given by Buck. Atmospheric water vapor content is measured in hecta-pascal or in mili-bar. To convert it into gram per cube centimeter, a constant 0.098 is multiplied in the mili-bar value of water vapor content. Water vapor content has been calculated using the following relationships;

$$RH = \left[\frac{e_w}{e_w^*}\right] x\,100 \qquad (9)$$

■ RESULTS AND DISCUSSION

In this study, LST was calculated by applying a SW structured mathematical algorithm and it has been described in earlier methodology. SW uses brightness temperature of TIR band 10, TIR band 11, mean and difference in LSE for estimating LST of an area. The values of thermal conservation constants *i.e.* K_1 and K_2 and rescaling factors *i.e.* M_L and A_L have been given in Table 1 and 2, respectively for band 10 and band 11 and these values are obtained from the metadata file of the imagery provided by the image provider website *i.e.* *https://earthexplorer.usgs.gov*

Table 1 : Values of thermal conservation constants

Thermal conservation constants	Band 10	Band11
K_1	0774.885	0480.888
K_2	1321.079	1201.144

Table 2 : Values of rescaling factor

Rescaling factor	Band 10	Band 11
M_L	0.000342	0.000342
A_L	0.1	0.1

To calculate LSE, it is very important to calculate FVC and it is dependent on NDVI of soil as well as of vegetation and its values have been determined by the *Quick Stats* option of the ENVI 4.7 image processing software and given in Table 3. For calculating the value of e_w, we have used the values of RH, absolute pressure and temperature of the day (6th December 2015) and time (10:42:48) when satellite passed over the study area by applying the Equations 2.8 and Equation 2.9 and it has been given in Table 4.

Table 3 : NDVI values for soil and vegetation

NDVI for soil	0.000993
NDVI for vegetation	0.354073

Table 4 : Calculation for water vapor content (e_w) of the day 6th December 2015 at 10: 42: 48 of IST

Parameters	Values
Temperature (T) (Recorded)	21 ^{0}C
Relative humidity (RH) (Recorded)	41 %
Absolute pressure (P) (Recorded)	1019 milibar
Equilibrium vapor pressure (e^*_w) (Calculated)	24.965 milibar
Atmospheric water vapor content (e_w)(Calculated)	1.0031 g/cm^3

The flow steps which have been considered to calculate final value of LST in ENVI 4.7 software with the help of TOA radiance, T_B, NDVI, FVC, LSE, mean of LSE and difference of LSE using the Equations 1 through 7 and Tables C through 3 have been given systematically in Table 4. Colour mapping green-blue-red-white in ENVI software has been used to give the different colors to all the temperature ranges *i.e.* green, purple, red, white and black to show the LST of different regions of the US Nagar district. LSE for band 10, band 11 of LANDSAT 8 (without ENVI colour mapping) and LST (with ENVI colour mapping) of US Nagar district has been shown in Fig. 1, 2 and 3, respectively.

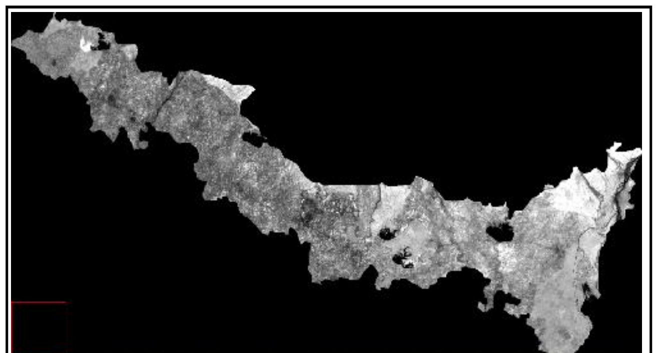

Fig. 1 : LSE for band 10

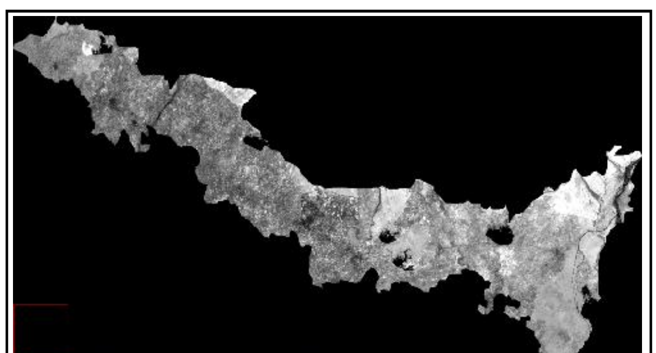

Fig. 2 : LSE for band 11

Table 5 : Systematic calculations of LST with ENVI software

Systematic steps	Parameter	Generalized formula		Formula used in band math of ENVI software	
		Band 10	Band 11	Band 10	Band 11
1	TOA Radiance	3.3420e-4×(B_{10})+0.1000	3.3420e-4×(B_{11})+0.1000	3.3420e-4×float(b_{10})+0.1000	3.3420e-4×float(b_{11})+0.1000
2	Brightness temp. (T_B)	1321.079/alog(774.885/(TOA of B_{10})+1)	1201.144/alog(480.888 /(TOA of B_{11})+1)	1321.079/alog(774.885/float(TOA of B_{10})+1)	1201.144/alog(480.888 /float(TOA of B_{11})+1)
3	NDVI	((NIR)-(R))/((NIR)+(R))		(float(b_5)-float(b_4))/(float(b_5)+float(b_4))	
4	FVC	((NDVI)-(0.000993))/(0.354073-0.000993))		(float(NDVI)-(0.000993)/(0.354073-0.000993))	
5	LSE	(0.971× (1-(FVC of B_{10}))+0.987× (FVC of B_{10})	(0.977× (1-(FVC of B_{11}))+0.989× (FVC of B_{11})	(0.971× (1-float(FVC of B_{10})))+0.987×float(FVC of B_{10})	(0.977× (1-float(FVC of B_{11})))+0.989×float(FVC of B_{11})
6	Mean of LSE	((LSE of B_{10})(LSE of B_{11}))/2		(float(LSE of B_{10})+float(LSE of B_{11}))/2	
7	Difference of LSE	(LSE of B_{10})-(LSE of B_{11})		float(LSE of B_{10})-float(LSE of B_{11})	

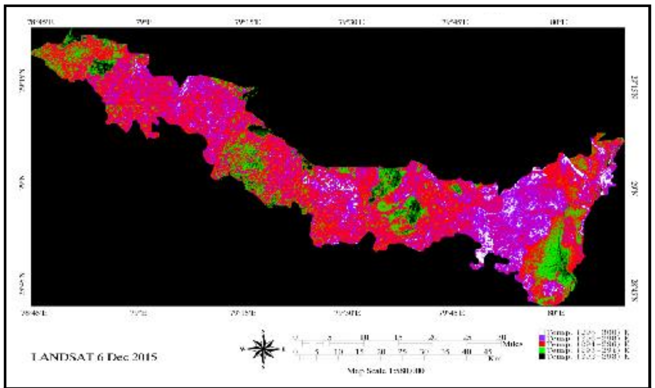

Fig. 3 : Land surface temperature of Udham Singh Nagar

Summary and conclusion :

In this paper we proposed a methodology for retrieving LST of US Nagar district, Uttarakhand, by applying a structured mathematical algorithm *viz.*, SW approach. S algorithm is used on LANDSAT 8 OLI sensor and TIRS sensor dataset. TIRS exhibit two thermal bands 10 and 11. SW approach requires T_B value of both band 10 and 11 as well as LSE which has been calculated from OLI bands (*i.e.* NIR and Red) for estimation of LST. The spectral radiance was estimated using TIR bands 10 and 11. Emissivity was calculated with the help of NDVI threshold technique for which OLI bands 2, 3, 4 and 5 were used. SW approach used T_B of two bands of TIR, mean and difference in LSE for estimating LST.

There are following conclusions are drawn from the results of the study;

– The study clearly reveals that as the region had more vegetative cover therefore, the LST in part was low and the surrounding area with barren lands, uncultivable land and urban areas experienced high LST value.

– The maximum and minimum temperature was found to be 300 ^{0}K and 292 ^{0}K, respectively in US Nagar on 6th December 2015.

– There is a temperature difference of 8 ^{0}K in maximum and minimum temperature of US Nagar on 6th December 2015.

– The output reveals that LST is high in the barren regions whereas it was low in the hilly regions because of vegetative cover.

– As the SW approach uses both the TIR bands (*i.e.* band 10 and band 11) and OLI bands 2, 3, 4 and 5, therefore, LST generated using them is more reliable and accurate.

– Finally, it was concluded that SW approach can be used for estimating LST using LANDSAT 8 imagery which is having multiband OLI and TIR images.

Acknowledgement :

The authors wish to acknowledge Dr. A. S. Nain, Professor and head, Department of Agro-meteorology, GBPUAT, Pantnagar for providing laboratory facilities and useful guidance. Authors are also thankful to his university seniors for providing support and help whenever we need.

Authors' affiliations:

VIJAY KUMAR AND TARATE SURYAKANT BAJIRAO, Department of Soil and Water Conservation Engineering, Gobind Ballabh Pant University of Agriculture and Technology, Pantnagar, U.S. NAGAR (UTTARAKHAND) INDIA

Email : vijaysinghswce@gmail.com; taratesuryakant01@gmail.com

REFERENCES

Cheung, C. and Hart, M. (2014). Climate change and thermal comfort in Hong Kong. *Internat. J. Biometeorol.*, **58**(2): 137–148.

Cleveland, C. (2007). Heat Island Encyclopedia of Earth.

Ema, K., Nengah, S. J. and Widiatmaka (2016). Satellite-based land surface temperature estimation of Bogor municipality, Indonesia. *Indonesian J. Electrical Engg. & Computer Sci.*, DOI: 10.11591/ijeecs.v2.i1, **2** (1): 221-228.

Gago, E.J., Roldan, J., Pacheco-Torres, R. and Ordonez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable & Sustain. Energy Reviews*, **25**(0): 749–758.

Gosling, S., Lowe, J., McGregor, G., Pelling, M. and Malamud, B. (2009). Associations between elevated atmospheric temperature and human mortality: a critical review of the literature. *Climatic Change*, **92**(3-4) : 299-341.

Kleerekoper, L., Van-Esch, M. and Salcedo, T.B. (2012). How to make a city climate- proof, addressing the urban heat is land effect. *Resour., Cons. & Recyc.*, **64**(0): 30–38.

Kolokotroni, M., Zhang, Y. and Watkins, R. (2007). The London Heat Island and building cooling design. *Solar Energy*, **81**(1): 102–110.

Kolokotroni, M., Ren, X., Davies, M. and Mavrogianni, A. (2012). London's urban heat island: Impact on current and future energy consumption in office buildings. *Energy & Buildings*, **47**(0) : 302–311.

Kondo, H. and Kikegawa, Y. (2003). Temperature variation in the urban canopy with anthropogenic energy use. *Pure & Appl. Geophys.*, **160**(1–2) : 317–324.

Li, Z.L., Wu, H., Wang, N., Qiu, S., Sobrino, J.A., Wan, Z., Tang, B.H. and Yan, G. (2013). Land surface emissivity retrieval from satellite data. *Internat. J. Remote Sensing*, **34** :3084-3127.

Madlener, R. and Sunak, Y. (2011). Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management. *Sustain. Cities & Soc.*, **1**(1): 45-53.

Mirzaei, P.A. and Haghighat, F. (2010). Approaches to study Urban Heat Island, Abilities and limitations. *Building & Environ.*, **45**(10): 2192–2201.

Oke, T.R. (1982). The energetic basis of the Urban Heat-Island. *Quarterly J. Royal Meteorol. Soc.*, **108**(455): 1–24.

Quattrochi, D.A. and Luvall, J. C. (1999). Thermal infrared remote sensing for analysis of landscape ecological processes: Methods and applications. *Landscape Ecol.*, **14**(6): 577–598.

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C. and Argiriou, A. (2001). On the impact of urban climate on the energy consumption of buildings, *Solar Energy*, **70**(3): 201–216.

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island-A review. *Solar Energy*, **82**(1): 301–312.

Sarrat, C., Lemonsu, A., Masson, V. and Guedalia, D. (2006). Impact of urban heat island on regional atmospheric pollution. *Atmospheric Environ.*, **40**(10): 1743–1758.

Skokovic, D., Sobrino, J. A., Jimenez-Munoz. J. C., Soria. G., Julien. Y., Mattar, C. and Jordi Cristobal (2014). Calibration and Validation of Land Surface Temperature for Landsat 8 – TIRS Sens. *Land Product Validation and Evolution*, ESA/ ESRIN Frascati (Italy): 6-9, January 28-30,.

Sobrino, J.A., Li, Z.L., Stoll, M.P. and Becker, F. (1996). Multi-channel and multi-angle algorithms for estimating sea and land surface temperature with ATSR data. *Internat. J. Remote Sensing*, **17**: 2089–2114.

Tan, J., Zheng,Y., Tang, X., Guo, C., Li, L. and Song, G. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *Internat. J. Biometeorol.*, **54**(1): 75–84.

Xiaokang Kou, L.J., Yanchen, B., Shuang, Y. and Linna, C. (2016). Estimation of land surface temperature through blending MODIS and AMSR-E data with the Bayesian Maximum Entropy Method. *Remote sensing*, **108**(5): 1-17, DOI: 10.3390/rs8020105.

Zhao, S., Qin, Q., Yang, Y., Xiong, Y. and Qiu, G. (2009). Comparison of two Split-Window Methods for Retrieving Land Surface Temperature from MODIS Data. *J. Earth Syst. Sci.*, **118**(4): 345- 353.

WEBLOGRAPHY

Ashley, E. and Lemay, L. (2008). Concrete's contribution to sustainable development, from http://*www.specifyconcrete.org*/assets/docs/Concretes 20% Contribution to Sustainable Development.pdf.

https://*earthexplorer.usgs.gov*