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Temporal Dynamics of Land Surface Temperature in Dry Season 2014 – 2015 in Lam Ha district, Lam Dong province in Central Highlands, Vietnam From LANDSAT 8 TIRS Time Series Images

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Abstract

Located in Southeast Asia, Vietnam is one of the most severely affected countries by climate change and faces to series of challenges related to climate change such as rising sea level, drought and flood. Drought is a natural phenomenon, which occurs in most regions in the world, caused immense damage in agricultural production and seriously affected on the environment. Land surface temperature is one of the most important factors in the evaluation of soil moisture to monitor drought phenomenon. LANDSAT thermal infrared images can be used to retrieve temperature. This article presents study on the application of LANDSAT 8 multi – temporal thermal infrared image for monitoring land surface temperature changes in dry season 2014 – 2015 in Central Highlands of Vietnam. The results obtained in this study can be used to create the land surface temperature distribution map and to monitor drought phenomenon.

Keywords: remote sensing, land surface temperature, drought, thermal infrared image, LANDSAT, Vietnam.

Introduction

Vietnam is likely to be one of the several countries most adversely affected by climate change. During the last 50 years, Vietnam's annual average surface temperature has increased by approximately 0,5 – 0,7 ^oC (Vietnam assessment report on climate change). Land surface temperature is important factor in global change studies, in estimating radiation budgets in heat balance studies and as a control for climate models. Land surface temperature can provide important information about the surface physical properties and climate which plays a role in many environmental processes (Mallick, 2008; Mira, 2007).

To control and monitor temperature distribution, many researchers have measured the air temperature by using land observation stations. In 1976, Yamashita used measurements of temperature using temperature sensors mounted on car, along various routes (Yamashita, 1976). This method can be both expensive and time consuming and lead to problems in spatial interpolation. Since the last of 20^{th} century, remote sensing with many advantages over traditional method has been effectively used for retrieving land surface temperature [Sundara Kumar, 2012; Mallick, 2008; Mira 2007; Garcia Cueto, 2007; Grishchenko, 2012; Marchukov, 2013]. Javed Mallick et al. (2008) used the LANDSAT 7 ETM+ thermal infrared band to estimate land surface temperature over Delhi (India) (Mallick, 2008). In 2012, Sundara Kumar et al. estimated land surface temperature to study urban heat island in Vijayawada city (India) using LANDSAT 7 ETM+ thermal infrared data (Sundara Kurma, 2012). Garcia Cueto et al (2007) found correlation between surface temperature in Mexicali (Mexico) and land use by using remote sensing data (Garcia Cueto, 2007). Sandholt I. et al (2002), Zverev A.T. and Trinh L.H. used LANDSAT thermal infrared data to monitor soil moisture based temperature vegetation dryness index (TVDI) (Sandholt, 2002; Zverev, 2015). Lu Yuan et al. (2007) used land surface temperature, which retrieve from remote sensing data to monitor dynamic drought in Guangxi (China) (Lu Yuan, 2007).

In Vietnam, some studies have estimated land surface temperature in Hanoi and Ho Chi Minh cities using LANDSAT and Aster thermal infrared data (Trinh, 2014; Tran, 2009). This paper focused on estimation and dynamics of land surface temperature in Central Highland of Vietnam using LANDSAT 8 multi-temporal infrared data.

Materials

In this study, multispectral cloud – free LANDSAT 8 OLI - TIRS data in dry season 2014 – 2015 in Lam Ha district, Lam Dong province (Central Highlands of Vietnam) was collected (Table 1). The LANDSAT 8 data was the standard terrain correction products (L1T), downloaded from United States Geological Survey (USGS – http://glovis.usgs.gov) website.

Table 1: The LANDSAT 8 data used for NDVI and temperature retrieval in the study

No.	***Data type***	***Band used for temperature***	***Band used for NDVI***	***Time of data acquisition***
1	LANDSAT 8	10, 11	4, 5	14 November 2014
2	LANDSAT 8	10, 11	4, 5	22 March 2015
3	LANDSAT 8	10, 11	4, 5	07 April 20115

LANDSAT 8 images consist of eleven spectral bands with a spatial resolution of 30 m for multispectral bands (band 1 to 7 and band 9). Spatial resolution for thermal infrared band (band 10, 11) is 100 m. Band 8 (0,500 – 0,680 μm) is the panchromatic with spatial resolution of 15 m (Table 2) (LANDSAT 8 Conversion to Radiance, Reflectance and At-Satellite Brightness Temperature).

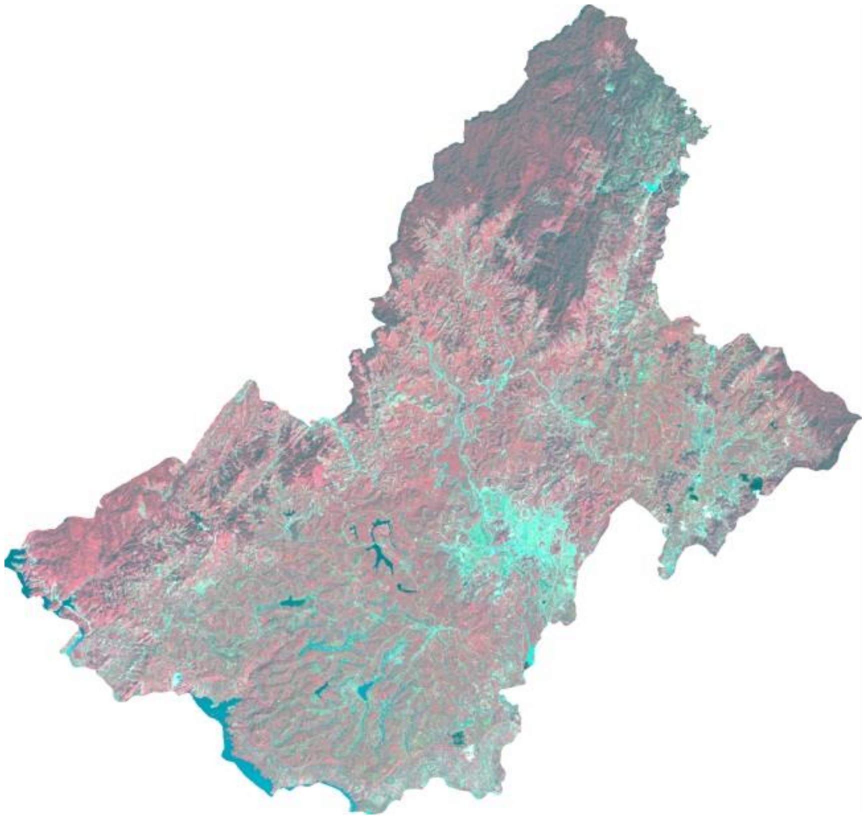

Fig. 1. LANDSAT 8 multispectral image in Lam Ha district, 14 November 2014, RGB composite = NIR:RED:GREEN

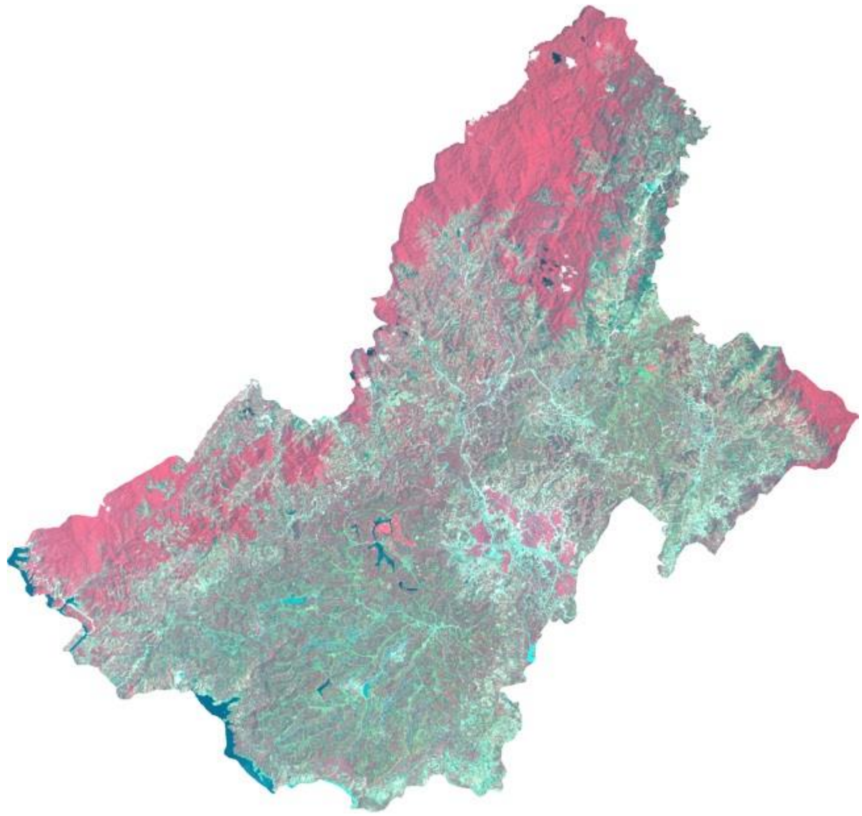

Fig. 2. LANDSAT 8 multispectral image in Lam Ha district, 22 March 2015, RGB composite = NIR:RED:GREEN

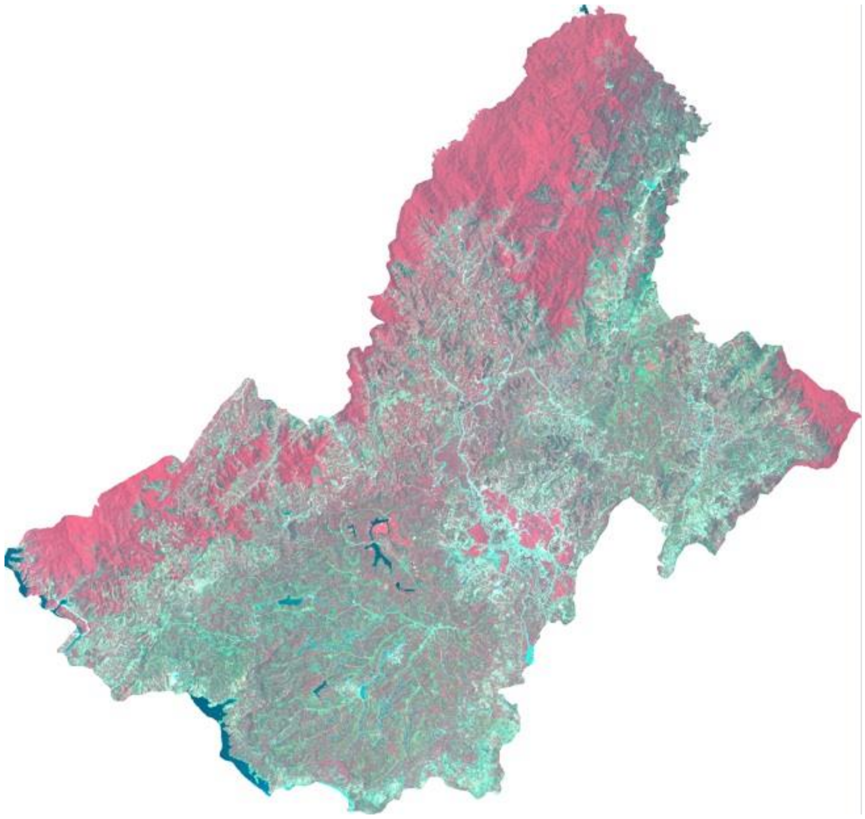

Fig. 3. LANDSAT 8 multispectral image in Lam Ha district, 07 April 2015, RGB composite = NIR:RED:GREEN

Table 2: LANDSAT 8 OLI-TIRS characteristics

No.	***Band***	***Wavelength (μm)***	***Spatial resolution (m)***
1	Coastal/Aerosol	0,433 – 0,453	30
2	Blue	0,450 – 0,515	30
3	Green	0,525 – 0,600	30
4	Red	0,630 – 0,680	30
5	NIR	0,845 – 0,885	30
6	MIR	1,560 – 1,660	30
7	MIR	2,100 – 2,300	30
8	PAN	0,500 – 0,680	15
9	Cirrus	1,360 – 1,390	30
10	TIR	10,30 – 11,30	100
11	TIR	11,50 – 12,50	100

Methodology

To calculate land surface temperature, in first step, OLI and TIRS band data must be converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file (LANDSAT 8 Conversion to Radiance, Reflectance and At-Satellite Brightness Temperature):

$$L_\lambda = M_L . Q_{cal} + A_L, \qquad (1)$$

where:

L_λ - TOA spectral radiance (Watts/(m2 * srad * μm)),

M_L - Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number),

A_L - Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number),

Q_{cal} - Quantized and calibrated standard product pixel values (DN).

Table 3: LANDSAT 8 TIRS spectral radiance M_L, A_L dynamic ranges

No.	***Data type***	***Band***	***M_L***	***A_L***
1	LANDSAT 8 TIRS	10	$3{,}3420.10^{-4}$	0,10000
2	LANDSAT 8 TIRS	11	$3{,}3420.10^{-4}$	0,10000

In second step, the LANDSAT thermal band data can be converted form spectral radiance to brightness temperature using following equation (LANDSAT 8 Conversion to Radiance, Reflectance and At-Satellite Brightness Temperature):

$$T = \frac{K_2}{\ln(\frac{K_1}{L_\lambda}+1)}, \qquad (2)$$

where:
T – At satellite brightness temperature (K),
K_1 – Calibration constant 1 [W/(m².sr.μm)],
K_2 – Calibration constant 2 [K].

Table 4: LANDSAT 8 thermal band calibration constants

No.	***Data type***	***Band***	***K_1 (W/(m².sr.μm))***	***K_2 (Kelvin)***
1	LANDSAT 8	10	774,89	1321,08
2	LANDSAT 8	11	480,89	1201,14

For determining land surface temperature from LANDSAT data, values of surface emissivity is needed. In this paper, the surface emissivity is determined by using method based on NDVI image, which proposed by Valor and Caselles (1996) by following equation (Valor, 1996):

$$\varepsilon = \varepsilon_v.P_v + \varepsilon_s(1-P_v), \qquad (4)$$

where:
ε – Surface emissivity,
ε_v, ε_v – Emissivity of pure vegetation covers and pure soil areas, respectively.
P_v - The percentage of vegetation in one pixel, which calculated by equation:

$$P_v = \left(\frac{NDVI - NDVI_{soil}}{NDVI_{veg.} - NDVI_{soil}}\right)^2, \qquad (5)$$

Where NDVI – normalized difference vegetation index, which can be calculated by equation:

$$NDVI = \frac{NIR - RED}{NIR + RED}, \qquad (6)$$

Where RED and NIR – the spectral reflectance in red and near – infrared band, respectively.

In last step, land surface temperature can be calculated by following equation (Grishchenko, 2012; Trinh, 2014; Marchukov, 2013; Sundara Kurma, 2012):

$$LST = \frac{T}{1+(\frac{\lambda.T}{\rho})*\ln\varepsilon}, \qquad (7)$$

where T - brightness temperature (K°), λ – wavelength (11,5 μm), ε – land surface emissivity, $\rho = \frac{h.c}{\sigma}$, h – Plank's constant ($6{,}626.10^{-34}$ J.sec), c – velocity of light ($2{,}998.10^{8}$ m/sec), σ – Stefan Boltzmann's constant, which is equal to $5{,}67.10^{-8}$ Wm^{-2} K^{-4}.

Results and Discussion

The Lam Ha district is located in the Northern of Lam Dong province in the Central Highlands of Vietnam. The area is bounded by 11°55'26"N latitude and 108°11'31"E longitude. The district covers an area of 978,52 km² and had a population of 133679 people (http://lamdong.gov.vn). The altitude of the surface of the Lam Ha district ranges from 497 m on the Phi Co village (Ro Men area) to 1998 m on the Hon Nga mountain. Located in the tropical savanna, the climate in the Central Highlands of Vietnam is divided into two seasons: the rainy season from May until October and the dry season from November to April, while March and April are the warmest and driest months. This is one of the most regions severely affected by climate change in Central Highlands of Vietnam.

The reflectance values for red and near infrared channels of LANDSAT 8 data was used to calculate normalized difference vegetation index (NDVI). The NDVI images are shown in Fig. 4 – 6 below. For determining surface emissivity by this methodology, values of soil and vegetation emissivity are needed. This study has been used more than 150 training samples for bare soil and vegetation cover areas to calculate normalized difference vegetation index (NDVI). Finally, NDVI for pure soil and pure vegetation cover of study area equal 0,122 and 0,505, respectively. Emissivity of pure soil and pure vegetation cover areas are calculated using method of Van de Griend by following equation (Van de Griend, 1993):

$$\varepsilon = 1,0094 + 0,047.\ln(NDVI). \quad (8)$$

Emissivity of pure soil and pure vegetation cover areas identified by using this method equal 0,911 and 0,977 respectively. Basing on the NDVI values of difference land use classes, emissivity image was prepared using method of Valor and Caselles by assigning values as 0,911 for soil areas and 0,977 for vegetation areas.

$$\varepsilon = \varepsilon_v.P_v + \varepsilon_s(1-P_v) = 0,977.P_v + 0,911(1-P_v) = 0,66.P_v + 0,911. \quad (9)$$

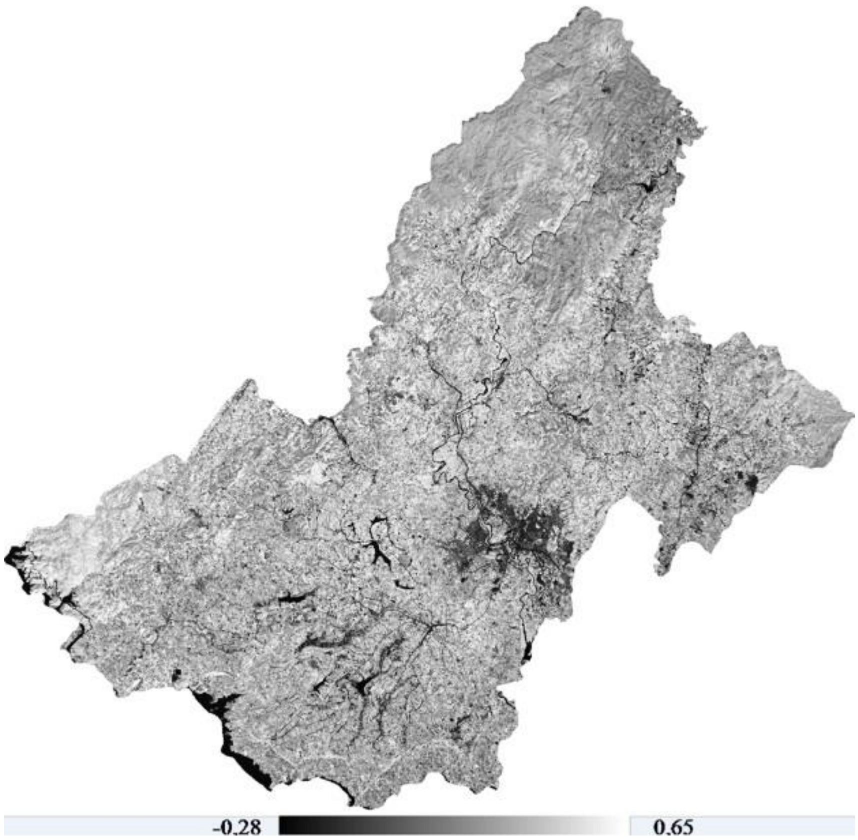

Fig. 4. NDVI image of Lam Ha district, 14 November 2014

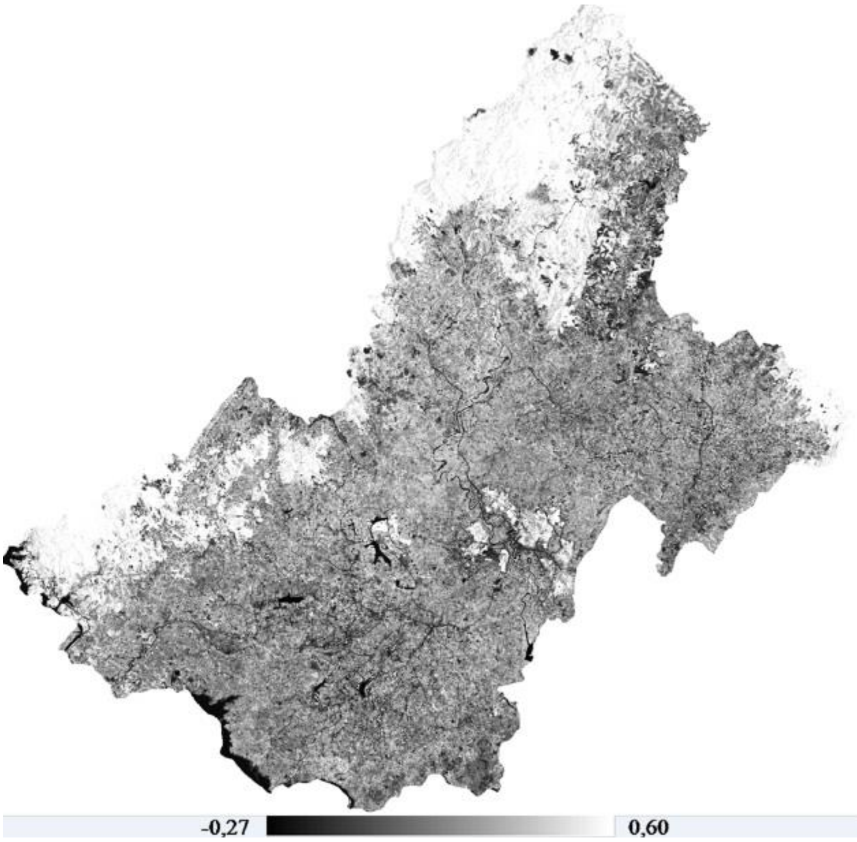

Fig. 5. NDVI image of Lam Ha district, 22 March 2015

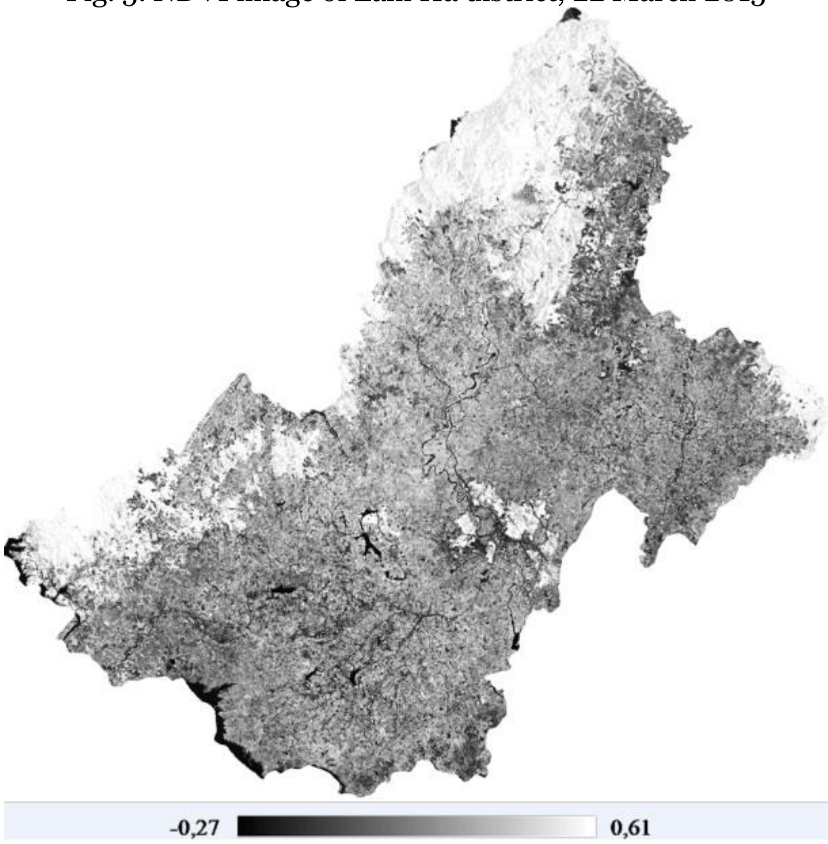

Fig. 6. NDVI image of Lam Ha district, 07 April 2015

From brightness temperature and land surface emissivity images, the land surface temperature image was obtained by developing a program in C++. The land surface temperature distribution map of the study area displays the different zone of temperatures. The density sliced image shows nine temperature zones that represents greater than 34, 32 – 34, 30 – 32, 28 – 30, 26 – 28, 24 – 26, 22 – 24, 20 – 22 and less than 22 °C respectively.

Figures from 7 to 9 show the spatial distribution of land surface temperature of LANDSAT 8 data in dry season 2014 – 2015. The land surface temperature ranged from 14,3 to 39,1°C in 14 November 2014; 9,8 to 47,1°C in 22 March 2015 and 13,5 to 48,8°C in 07 April 2015. The study shows that, in the early dry season 2014 – 2015, the most part of study area (73,99% of total area) had land surface temperature in range 24 to 30°C. While at the end of dry season, the most part of study area (73,06% in March, 66,76% in April) had land surface temperature greater than 30 °C. The high land surface temperature area (greater than 34°C) was found in increasing order 99,73 ha in November 2014 to 37366,81 ha in March 2015 and 23225,34 ha in April 2015 (Table 5). Using hydro-meteorological data and the results obtained in this study can be confirmed that March is the hottest time of dry season in Central Highlands of Vietnam.

Besides, the high land surface temperature distributed in area with small vegetation coverage. While the area with full vegetation coverage in northern of study area has much lower land surface temperature.

Table 5: Temporal dynamics of land surface temperature in Lam Ha district, Lam Dong province, Central highlands of Vietnam

No.	***Temperature (°C)***	***Area***					
		14 November 2014		***22 March 2015***		***07 April 2015***	
		Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
1	< 20	585,90	0,60	161,91	0,17	79,12	0,08
2	20 – 22	8207,90	8,39	1941,27	1,98	193,40	0,20
3	22 – 24	14309,67	14,62	6050,74	6,18	3718,05	3,80
4	24 – 26	16650,94	17,02	6516,13	6,66	9065,07	9,26
5	26 – 28	37919,73	38,75	5551,91	5,67	7843,77	8,02
6	28 – 30	17830,67	18,22	6142,63	6,28	11625,52	11,88
7	30 – 32	1891,58	1,93	12561,07	12,84	21245,89	21,71
8	32 – 34	356,28	0,36	21560,03	22,03	20856,33	21,31
9	> 34	99,73	0,10	37366,81	38,19	23225,34	23,74

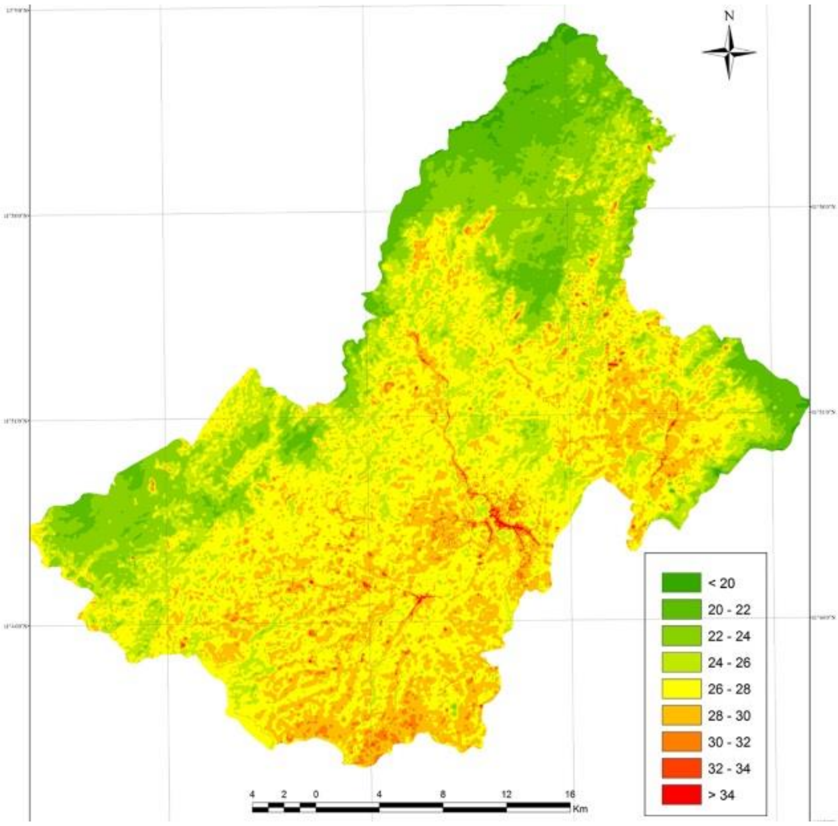

Fig. 7. Spatial distribution of land surface temperature over study area using LANDSAT 8 data, 14 November 2014

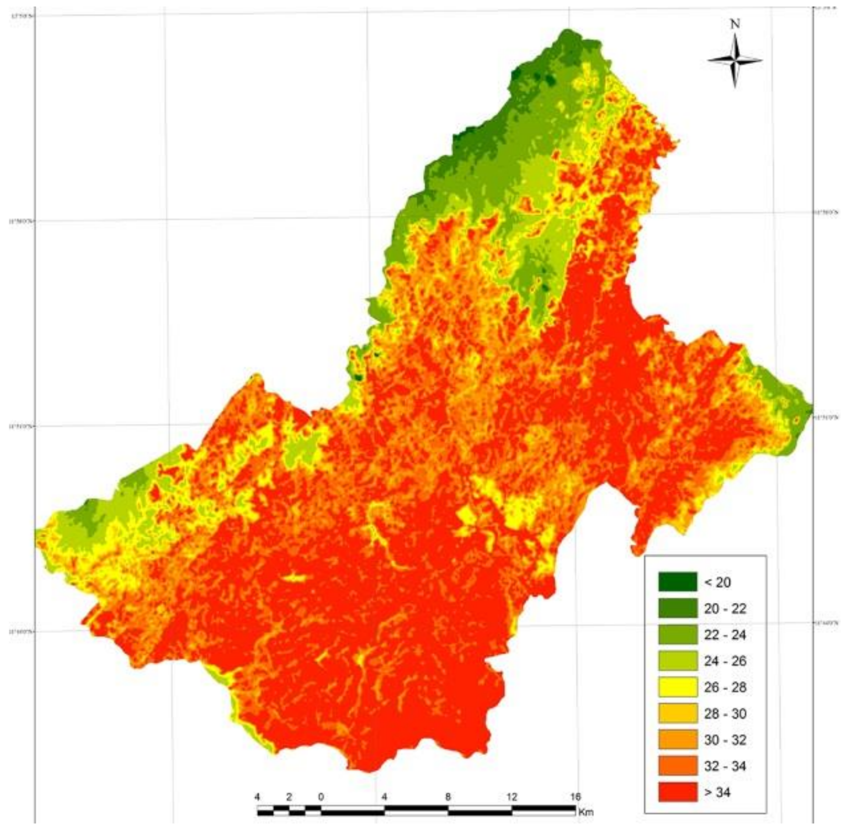

Fig. 8. Spatial distribution of land surface temperature over study area using LANDSAT 8 data, 22 March 2015

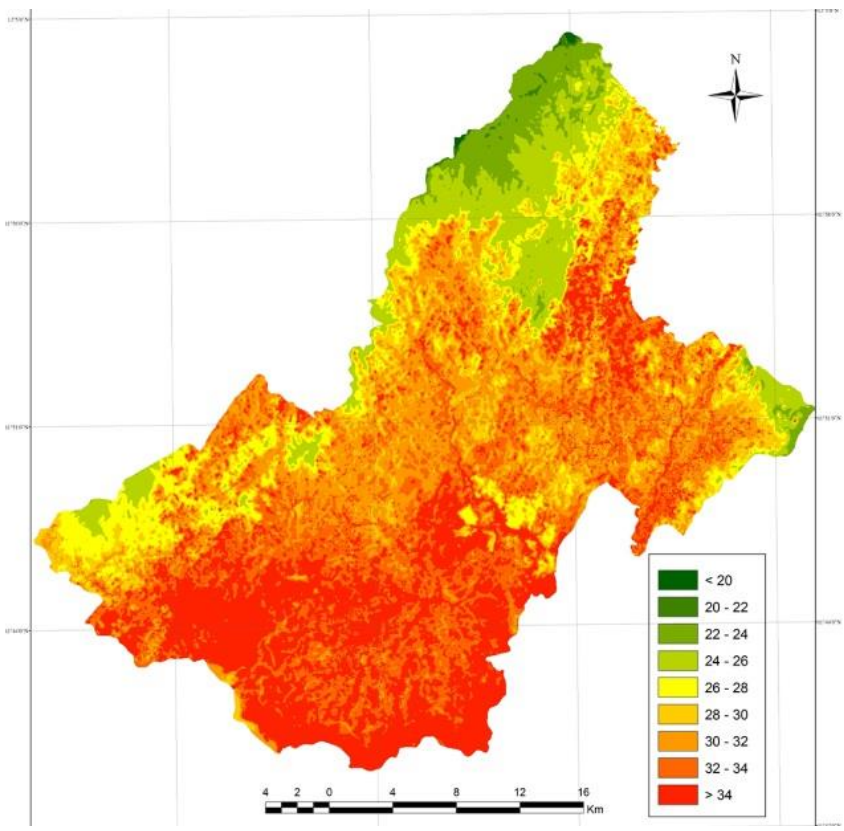

Fig. 9. Spatial distribution of land surface temperature over study area using LANDSAT 8 data, 07 April 2015

Conclusion

Land surface temperature is one of the most important factors in climatology studies and human – environment interactions. Besides, land surface temperature is also an important factor when monitoring soil moisture. Ground-based observations reflect only thermal condition of local area around the station and in fact cannot establish the number of meteorological stations with expected density due to the high cost. Remote sensing technology with advantages such as wide area coverage and short revisit interval has been used effectively in the study of land surface temperature distribution. The study indicates how to estimate surface temperature using LANDSAT 8 thermal infrared data. With 100m spatial resolution, LANDSAT 8 thermal infrared image performance applications in the region study. The results obtained in the study can be used as the reference for land use planning and the solution to the reduction of climate change effects.

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УДК 572

Динамика поверхностной температуры в сухом сезоне 2014–2015 в районе Лам Ха, провинции Лам Донг в центральном нагорье Вьетнама по данным серии тепловой инфракрасной съемки LANDSAT 8

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Аннотация. Вьетнам, расположенный в Юго-Восточной Азии, является одной из стран, наиболее сильно пострадавших от изменений климата и сталкивается с рядом проблем: повышение уровня моря, засухи и наводнения. Засуха, являющаяся естественным явлением, происходящим в большинстве регионов мира, вызывает огромный ущерб в сельскохозяйственном производстве и оказывает значительное влияние на окружающую среду. Температура поверхности является одним из важных фактров при оценке влажности почвы и может быть использована для мониторинга засухи. Тепловая ИК съемка LANDSAT может быть эффективно использована для определения температуры земной поверхности. Настоящая работа посвящена исследованию по применению данных серий разновременной тепловой ИК съемки LANDSAT 8 для мониторинга поверхностной температуры в засушливом сезоне 2014-2015 гг. в Центральном нагорье Вьетнама. Полученные результаты могут быть использованы для создания карт пространственного распределения температуры земной поверхности и мониторинга засушливых периодов.

Ключевые слова: дистанционное зондирование, поверхностная температура, засуха, тепловая инфракрасная съемка, LANDSAT, Вьетнам.