RESEARCH PAPER

RELATIONSHIP BETWEEN URBANIZATION AND ROAD NETWORKS IN THE LOWER NORTHEASTERN REGION OF THAILAND USING NIGHTTIME LIGHT SATELLITE IMAGERY

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ABSTRACT. The objective of this research on the relationship between urbanization and road networks in the lower Northeastern region of Thailand was to compare the urban area in 2006, 2013 and 2016 using nighttime light satellite images from the National Oceanic and Atmospheric Administration (NOAA), acquired by the Defense Meteorological Satellite Program (DMSP/OLS) and the Suomi National Polar-orbiting Partnership (Suomi NPP). After that the relationship between urbanization and road network was identified using nighttime light satellite images from these satellites. The nighttime light data was used to determine the urbanization levels, which were then compared with Landsat 8 Satellite images taken in 2016 in order to find the Pearson correlation coefficient. The results indicated that areas with high urbanization identified from the nighttime light satellite images taken by the Suomi NPP Satellite had a day/night band reflectance of 172-255 indicated and were located primarily along the roads. The analysis of these data suggested that urbanization has a significantly positive relationship with the road network at 0.01 level, with R^2 values of 0.800 for urbanization and 0.985 for the road network.

KEYWORDS: nighttime light satellite image, urbanization, road network, lower Northeastern region Thailand, Remote Sensing

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INTRODUCTION

The patterns of land utilization are rapidly changing, significantly affecting people's lifestyles in terms of the economy, society, and the environment (Taati et al. 2015; Heagzy and Kaloop 2015; Waiyasusri and Wetchayont 2020; Zaman et al. 2020). Therefore, the application of remote sensing to monitor, verify and predict land use becomes crucial to monitor, verify and predict land use trends, especially in urban and built-up areas (Ping et al. 2011; Ma and Li 2018; Halder et al. 2021) There are many instruments suitable for this matter, including remote-controlled pilotless aircraft, or drones, and satellite images from natural resource satellites, hyperspectral satellites, etc. (Liu & Yang 2015; Robert Behling et al. 2015). However, the images taken by natural resource satellites are quite large due to the different types of sensors they use, therefore, for studying urbanization it is recommended to use images taken by meteorology satellites (Zhou et al. 2015; Nguyen et al. 2019) In addition, one of the limitations is the long time it takes for satellite to orbit the Earth and then come back to take another picture of the same area, resulting in the lack of data during period. However, the VIIRS/DNB data is currently available to the public from a number of sources, including the Google Earth Engine and Earth Observation Group, Colorado School of Mines. (Puttanapong et al. 2020; Colorado School of Mines 2021)

The study of urban expansion using meteorology satellite images is based on the collection of nighttime light images taken by a satellite of the Defence Meteorological Satellite Program (DMSP) with the Operational Line Scan (OLS) system (hereinafter referred to as the "DMSP/OLS Satellite") from the United States of America (Amaral et al. 2006; Min Zhao 2020), and a satellite of the Suomi National Polar-orbiting Partnership (Suomi NPP) with Visible Infrared Imaging Radiometer Suite (VIIRS) instruments and a Day/Night Band (DNB) sensor (hereinafter referred to as the "Suomi NPP Satellite") from Japan (Ma et al. 2014; Bennett and Smith 2017). Both satellites collect nighttime light reflectance data for monitoring urbanization (Tong et al.2018). This remote sensing of nighttime light was, applied in the study of urban economic trends and urbanization by Zheng et al (2019) and Zhao et al (2020). In addition, Hasi Bagan & Yoshiki Yamagata (2015) used nighttime satellite images to analyze urban growth, population density, land utilization, and population in Japan from 1990 to 2006. Their results indicated a significant relationship between the land use data, especially in urban and built-up areas, and population. Nighttime light satellite images show illumination in areas of high urbanization and population density (Bagan and Yamagata 2015). Therefore, this methodology could be applied to study urbanization using meteorology satellite images, which are a better instrument for this purpose than other types of satellite images.

In Thailand, there have been many studies on the use of nighttime light and day-night bands. For example, Puttanapong et al. (2020) used nighttime light satellite images from DMSP OLS and Suomi VIIRS to predict the distribution of poverty in Thailand. Nighttime light images were used as one of the geospatial parameters in this prediction. Furthermore, Tepinta (2020) studied the spatial effect of road density on urbanization in Thailand using data from DMSP OLS and the VIIRS project from the Google Earth engine. The results of this study showed a statistically significant correlation between road density and nighttime light (Tepinta 2020).

Furthermore, nighttime light satellite images were used to analyze the spatial cluster of leptospirosis in Thailand during the period from 2013 to 2015. In the study, nighttime light images were used as one of the environmental factors providing a statistically significant contribution to predicting this disease (Luenam and Puttanapong 2020).

The aims of this research was to study urbanization in the lower Northeastern region of Thailand using nighttime light reflectance data collected by the DMSP/OLS Satellite and day/night band reflectance collected by the Suomi NPP Satellite in 2006, 2013 and 2016. In order to analyze urban growth in the lower Northeastern region of Thailand, we aimed to identify the relationship between urbanization and road networks, which can be used to predict urban expansion and prepare an effective development plan without using natural resource satellite images.

MATERIALS AND METHODS

Study area

The study area is located in the lower Northeastern region of Thailand in the middle of the East-West Economic Corridor (EWEC), an Economic Development Program in the Greater Mekong Sub-region (GMS), connecting and promoting trade and culture among the countries in this sub-region with high commercial demand as the key for economic recovery (Ramachandran and Linde 2011; Tansakul et al. 2013; Leisz et al. 2016). The studied territory covers a vast area of 115,402.41 square kilometers, or 22.49% of the country, serves as the gateway to the east border of Thailand, and comprises 12 provinces: Chaiyaphum, Nakhon Ratchasima, Khon Kaen, Maha Sarakham, Kalasin, Roi Et, Yasothon, Ubon Ratchathani, Amnat Charoen, Surin, Si Sa Ket and Buri Ram, as presented in Figure 1.

Thailand's highways

Thailand's highways consist of five levels, particularly special, national, rural, local, and concession highways. National highways also classify into four levels, which are indicated by the number of digits in the highway markers. For example, a single-digit number indicates the main highway that connects to Bangkok, Two digits indicate a principal highway within a region, three digits indicate a secondary regional highway, four digits indicate an intra-province highway connecting a provincial capital to its districts. This study used road network data that included only national highways of the main principal regional, and secondary regional highways.

Fig. 1. Map of the Lower Northeastern Region of Thailand

DATA

Nighttime light images taken by the DMSP/OLS and Suomi NPP meteorology satellites were collected for the analysis of urban and built-up areas, along with the images taken by the Landsat 8 and Sentinel-2 satellites for comparison. These images were then analyzed together with road network data in Thailand using Geographic Information Systems (GIS), as presented in Table 1.

Defense Meteorological Satellite Program (DMSP/OLS)

Defense Meteorological Satellite Program (DMSP) is a program of lower orbit satellites initiated by the United States Department of Defense and managed by the United States Space Force. DMSP is primarily engaged in environmental surveys and monitoring, especially meteorology. DMSP satellites have 7 types of important sensor systems: OLS- Operational Linescan System, SSM/I- Microwave Imager, SSMT/2- Atmospheric Water Vapor Profiler, SSJ/4- Precipitating Electron and Ion Spectrometer, SSM/T- Atmospheric Temperature Profiler, SSIES- Ion Scintillation Monitor, and SSM – Magnetometer. The annual DMSP-OLS NTL composites (i.e., yearly average NTL intensity) from 1992 to 2013 were obtained from the National Oceanic and Atmospheric Administration's National Geophysical Data Center (NOAA/NGDC). The data values range from 0 to 63, (as presented in Table 2.) with 0 representing the background noise. (Lu et. al. 2019)

Suomi National Polar-orbiting Partnership (Suomi NPP)

The Suomi National Polar-orbiting Partnership or Suomi NPP is a weather satellite operated by the United States National Oceanic and Atmospheric Administration (NOAA). Suomi NPP has 5 types of systems for collecting the images: Visible Infrared Imaging Radiometer Suite (VIIRS), Ozone Mapping and Profiler Suite (OMPS), Clouds and the Earth's Radiant Energy System (CERES), Cross-track Infrared Sounder (CrIS), and Advanced Technology Microwave Sounder (ATMS). The Visible Infrared Imaging Radiometer Suite (VIIRS) is the largest instrument aboard NPP. It collects radiometric imagery of the land, atmosphere, ice, and ocean in visible and infrared wavelengths (Keck 2011). Furthermore, VIIRS has a day/night band to detect low levels of visible/near-infrared radiance at night from sources on or near the Earth's surface, which allows to identify lightning flashes from urban areas.

Relationship between DMSP/OLS and Suomi NPP Satellites

The preparation of nighttime light satellite images taken by the DMSP/OLS and Suomi NPP Satellites in 2013 included image analysis to crop the study area and GIS analysis to adjust their reflectance values. The data values ranged from 0 to 63 (64 values) for the DMSP/OLS Satellite (Xiao et al. 2014; Cao et al. 2014; Sun et al. 2020; Gibson and Boe-Gibson 2021), and from 0 to 255 (256 values) for the Suomi NPP Satellite (Stokes and Seto 2019; Sun et al. 2020). Therefore, reclassification of the value was required (Zheng et al. 2019) to divided them into four levels: no urbanization, low urbanization, moderate urbanization, and high urbanization, as presented in Table 2.

Urban and built-up areas were identified from nighttime light satellite images by calculating the digital number of DMSP/OLS and Suomi NPP Satellite images taken in 2013 and employing GIS to convert raster data into a vector before dissolving the reflectance values of the same level to reduce data redundancy. The nighttime light areas in each province were then calculated and identified. Analysis of the Relationship between Urban Land Utilization and Road Networks Using Landsat 8 Satellite Images Urbanizations characteristics were identified by analyzing the road network in Landsat 8 Satellite images taken in 2016 using a band composition method for quality detection before cropping the selected areas. Reflectance value adjustments and geometric corrections were required in order to calculate the Normalized Difference Built-up Index (NDBI) (Zha et al. 2003; Chen et al. 2006; Zhang and Jia 2013; Bhatti and Tripathi 2013) using the equation below:

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR} \quad (1)$$

Whereas: NDBI = Normalized Difference Built-up Index

SWIR = Shortwave Infrared Reflectance

NIR = Near Infrared Reflectance

Sentinel-2 Satellite images were used for the geometric correction of the Landsat 8 satellite images in order to identify the area of urban land utilization, while NDBI was used to verify the accuracy of all urbanization levels. The accuracy of Landsat 8 Satellite images was verified by

Table 1. Data used in this study

Description	Year	Source
Nighttime Light Satellite Images Taken by Defense Meteorological Satellite Program (DMSP/OLS)	2006 and 2013	National Oceanic and Atmospheric Administration (NOAA), USA
Nighttime Light Satellite Images Taken by Suomi National Polar-orbiting Partnership (Suomi NPP)	2013 and 2016	National Oceanic and Atmospheric Administration (NOAA), USA
Satellite Images Taken by Landsat 8 Satellite	2016	U.S. Geological Survey, USA
Road Network	2016	Department of Highways, Thailand

Table 2. Day/Night Band Reflectance from DMSP/OLS and Suomi NPP Satellite Images

Urbanization Level	DMSP/OLS	Suomi NPP
No Urbanization	0 - 10	0 - 43
Low Urbanization	11 - 24	44 - 99
Moderate Urbanization	25 - 53	100 - 215
High Urbanization	54 - 63	216 - 255

Cohen's kappa coefficient. Fishnet grids were then drawn on the urban land utilization images and nighttime light satellite images before combining them with the nighttime light images taken by the Suomi NPP Satellite and selecting only the overlaying parts showing high urbanization.

Analysis of the Relationship between Urbanization and Road Network Using DMSP/OLS and Suomi NPP Satellite Images

Road network data overlaid with the nighttime light images taken by Suomi NPP Satellite was selected to analyze the relationship between urbanization and road network using the Pearson correlation coefficient, which was calculated using the equation 2

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \quad (2)$$

Where: r_{xy} = Correlation Coefficient

N = Total Number of Data

X = Nighttime Light Satellite Images Taken by Suomi NPP Satellite in 2016

Y = Urban and Built-Up Area, and Transport Network

RESULTS

Comparison of Urban Expansion in the Lower Northeastern Region estimated from Nighttime Light Satellite Images Taken by the DMSP/OLS and Suomi NPP Satellites in 2006, 2013, and 2016.

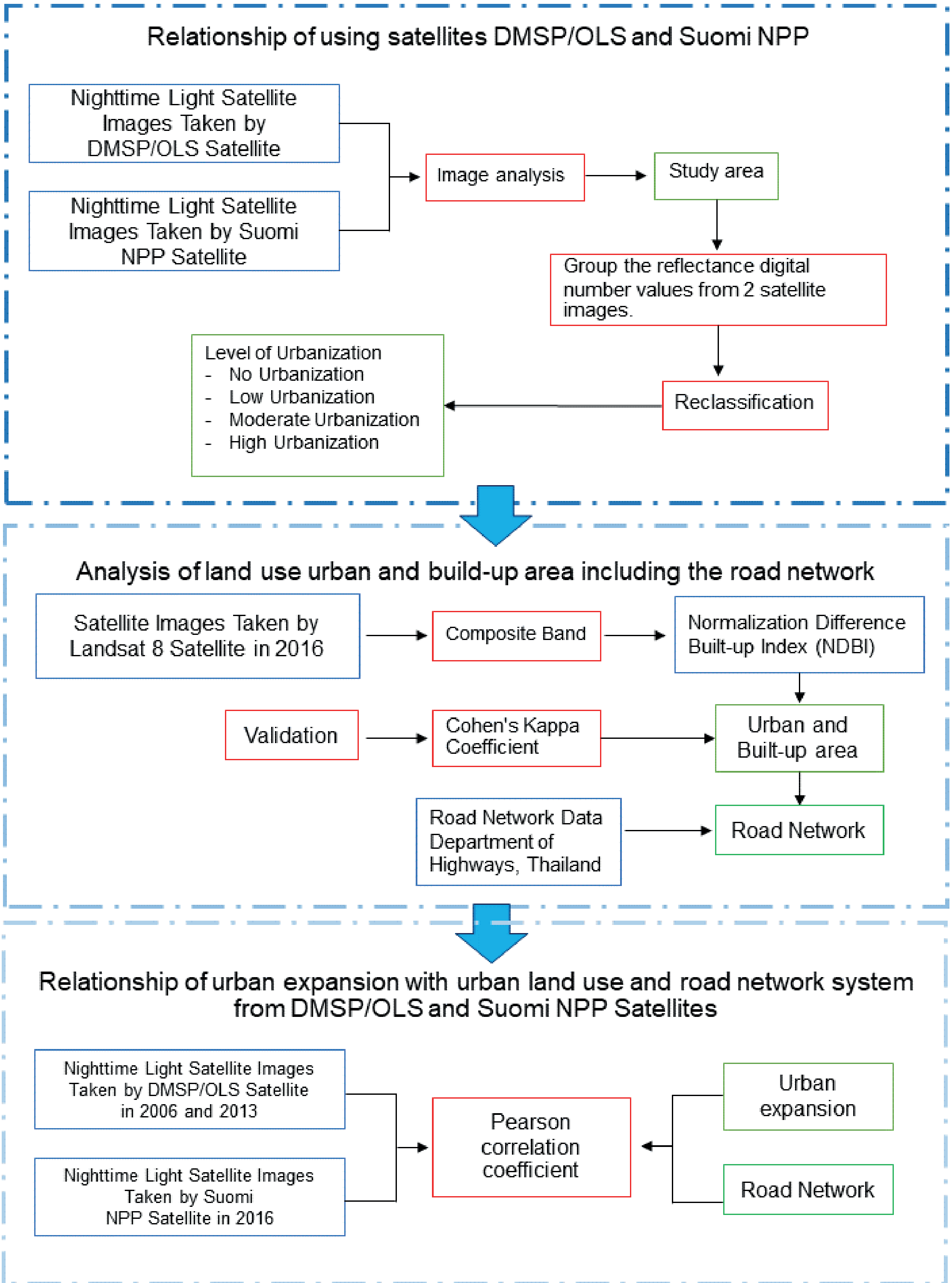

Fig. 2. Research Process

The results indicated that, according to the nighttime light satellite images taken by the DMSP/OLS Satellite, urbanization within the lower Northeastern region of Thailand increased every year as presented in Table 3.

The analysis showed that the area with high urbanization identified from the nighttime light reflectance data collected by the DMSP/OLS Satellite increased from 1,249.02 square kilometers in 2006 to 3,950.37 square kilometers in 2013. In addition, the nighttime light reflectance data collected by the Suomi NPP Satellite showed that by 2016, the urban area increased even further, reaching 13,829.02 square kilometers. This increase in urbanization was observed in all the provinces as presented in Figure 4, and the top 3 provinces with the highest urbanization were Nakhon Ratchasima, Khon Kaen, and Ubon Ratchathani, as presented in Figures 3 and 4 as well as Table 4.

Table 3. Urbanization in the Lower Northeastern Region of Thailand based on Nighttime Light Satellite Images

Urbanization Level		2006	2013	2016
No Urbanization	Day/Night Band Reflectance	0-10		
	Area (km²)	384,308.55	375,201.72	77,554.25
Low Urbanization	Day/Night Band Reflectance	11-24		
	Area (km²)	7,867.53	30,296.43	33,855.5
Moderate Urbanization	Day/Night Band Reflectance	25-53		
	Area (km²)	3,138.75	8,855.73	23,598.5
High Urbanization	Day/Night Band Reflectance	54-63		
	Area (km²)	1,249.02	3,950.37	13,829.02

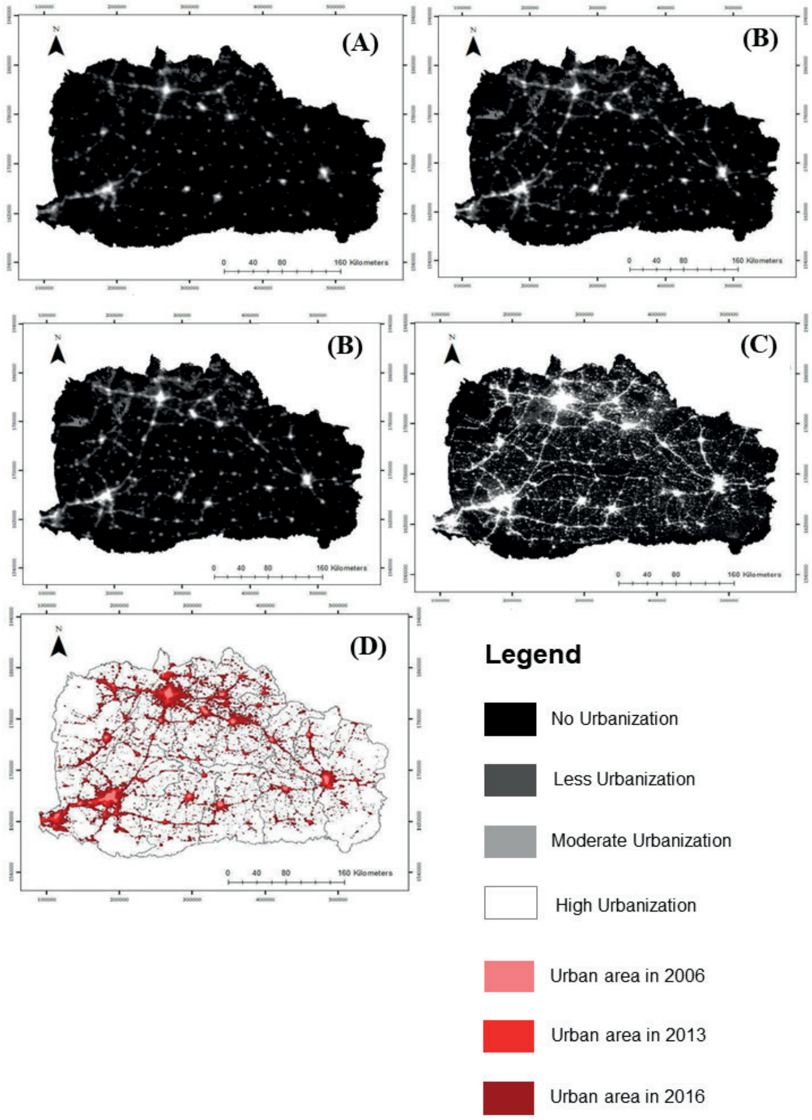

Fig. 3. Night time Light Satellite Images and Urban Expansion in 2006, 2013 and 2016 (A)DMSP/OLS Satellite Image in 2006, (B) DMSP/OLS Satellite Image in 2013, (C) Suomi NPP Satellite Image in 2016, and (D) Urbanization map base on Nighttime Light Satellite Images

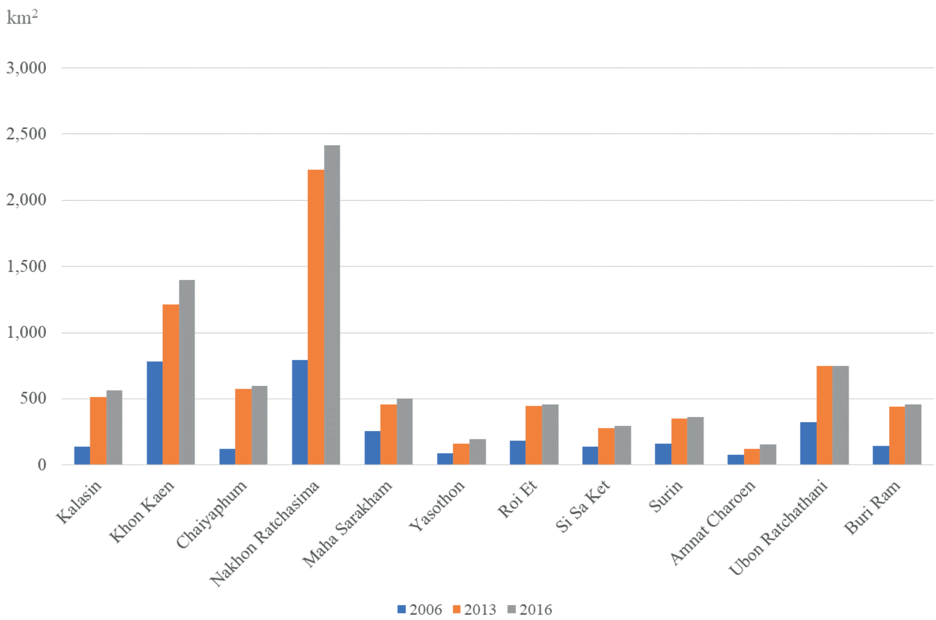

Fig. 4. Urban Area per province based on Nighttime Light Satellite Images

Table 4. Urban Area per province based on Nighttime Light Satellite Images

Province	Urban Area (km^2)		
	2006	2013	2016
Kalasin	137.70	513.54	564.25
Khon Kaen	782.46	1,215.00	1,400.00
Chaiyaphum	120.69	557.53	599.25
Nakhon Ratchasima	793.80	228.31	2,418.00
Maha Sarakham	258.39	456.84	501.00
Yasothon	89.10	160.38	193.00
Roi Et	183.06	447.93	456.00
Si Sa Ket	138.51	277.02	296.25
Surin	162.00	349.11	365.00
Amnat Charoen	76.95	124.01	153.25
Ubon Ratchathani	324.00	746.01	750.75
Buri Ram	143.37	442.26	460.00

Relationship between Urbanization and Road Network

Urbanization was divided into four levels: no urbanization, low urbanization, moderate urbanization, and high urbanization. After that nighttime light reflectance data collected by the Suomi NPP Satellite was analyzed to find the relationship between urbanization and road network area, which is presented in Table 5.

The results showed that urban areas are located along Highway No. 2 (Mittraphap Road) and Highway No. 230 in Khon Kaen, Highway No. 231 in Ubon Ratchathani, Highway No. 232 in Roi Et, Highway No. 288 in Buri Ram, and Highway No. 290 in Nakhon Ratchasima, all of which are ring roads. The analysis of nighttime light reflectance indicated a high concentration of residences, shopping malls, commercial buildings and other economic activities along the roads in each province, resulting in high nighttime light reflectance values, as presented in Figure 5.

Table 5. Urbanization Level and Road Network

Urbanization Level	Day/Night Band Reflectance	Road Area (km^2)
No Urbanization	0-43	0.44
Less Urbanization	44-99	0.58
Moderate Urbanization	100-215	0.84
High Urbanization	216-255	2.06

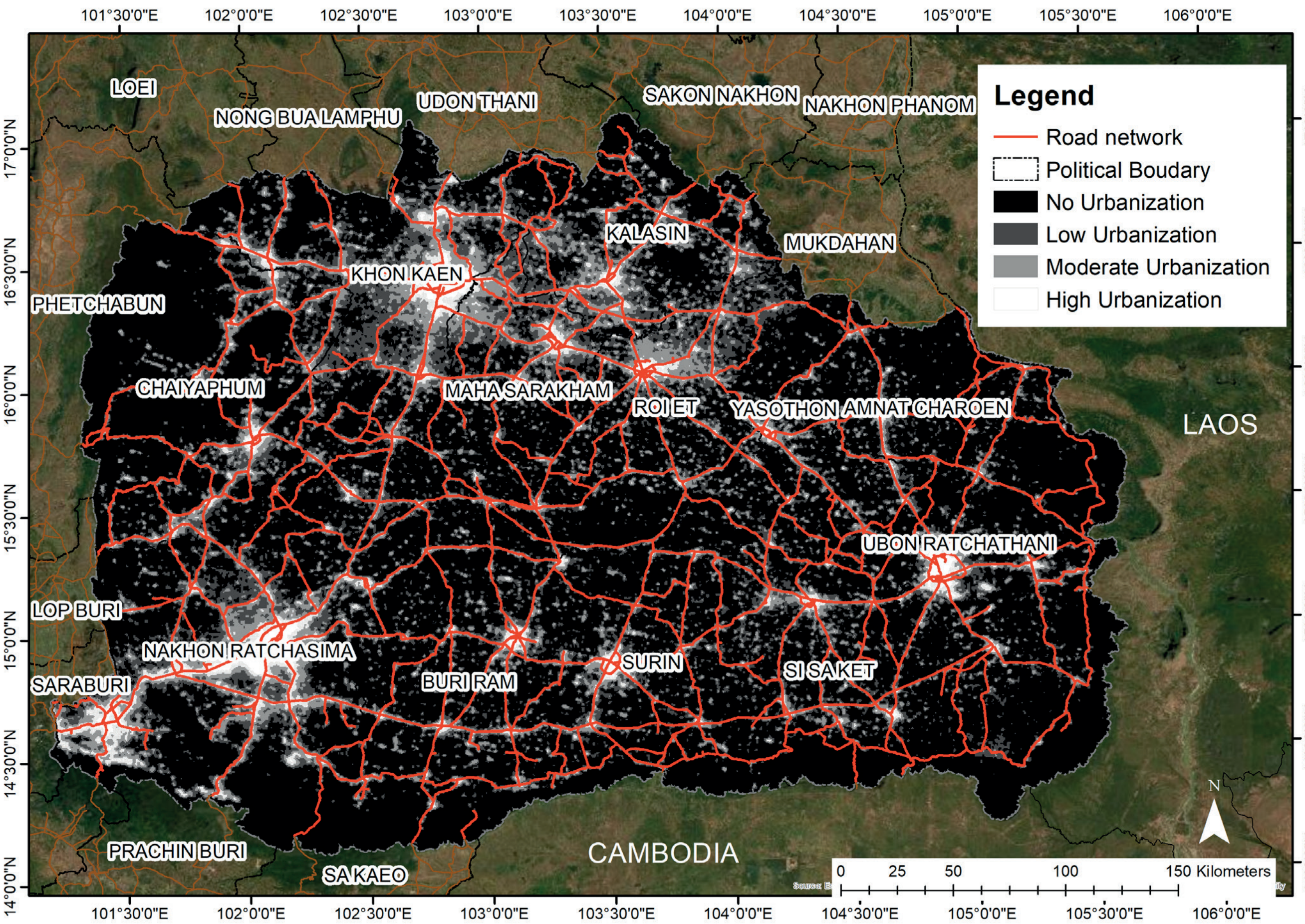

Fig. 5. Road Network and Urbanization base on Nighttime Light Data Acquired by Suomi NPP Satellite in 2016

The Pearson correlation coefficient was calculated found and the correlation was found to be significant at 0.01 level. The data of nighttime light reflectance, urban and built-up areas, and road network are presented in Table 6.

The relationship between the area of urban land use and nighttime light satellite images was found with a correlation coefficient (r) of 0.800. Data from the Department of Highways in Thailand was then used for further analysis. The correlation coefficient (r) between nighttime light satellite images and road network area was found to be 0.985, indicating a significant relationship, as presented in Figures 6 and 7.

Table 6. Comparison of Urban and Built-Up Area Expansion in 2016

Province	Urban or Built-Up Areas in 2016 (km^2)		
	Road Network	Suomi NPP	Landsat 8
Kalasin	0.122	564.25	2,546.53
Khon Kaen	0.410	1,400.00	4,207.02
Chaiyaphum	0.122	599.25	4,371.57
Nakhon Ratchasima	0.485	2,418.00	8,251.13
Maha Sarakham	0.110	501.00	2,288.51
Yasothon	0.092	193.00	1,545.05
Roi Et	0.142	456.00	3,045.25
Si Sa Ket	0.084	296.25	3,689.64
Surin	0.120	365.00	3,726.93
Amnat Charoen	0.057	153.25	1,244.63
Ubon Ratchathani	0.202	750.75	6,375.53
Buri Ram	0.120	460.00	4,439.18

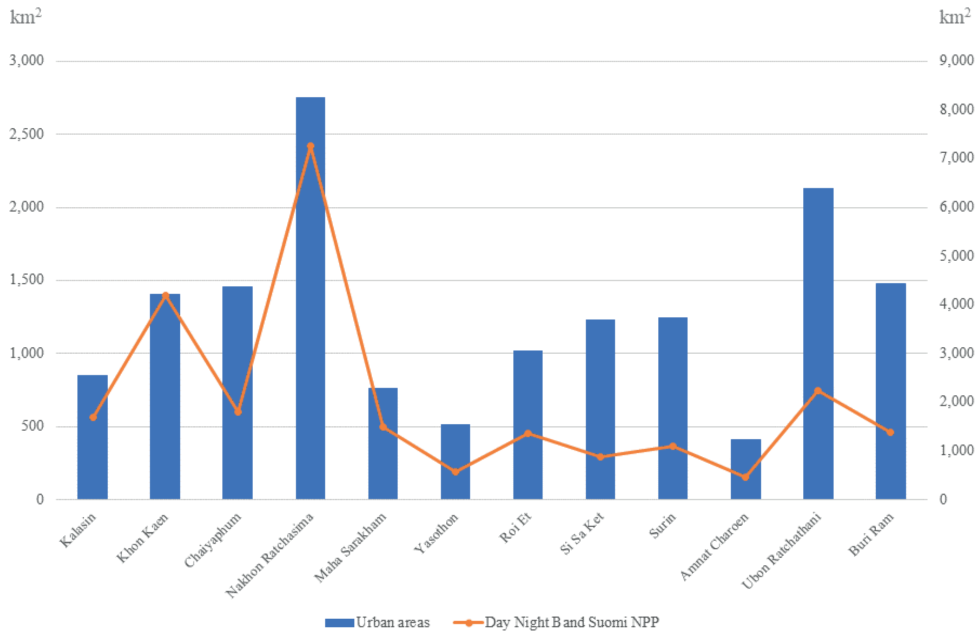

Fig. 6. Relationship between Day/Night Band Captured by Suomi NPP Satellite and Urban Area according to Landsat 8 Data in 2016

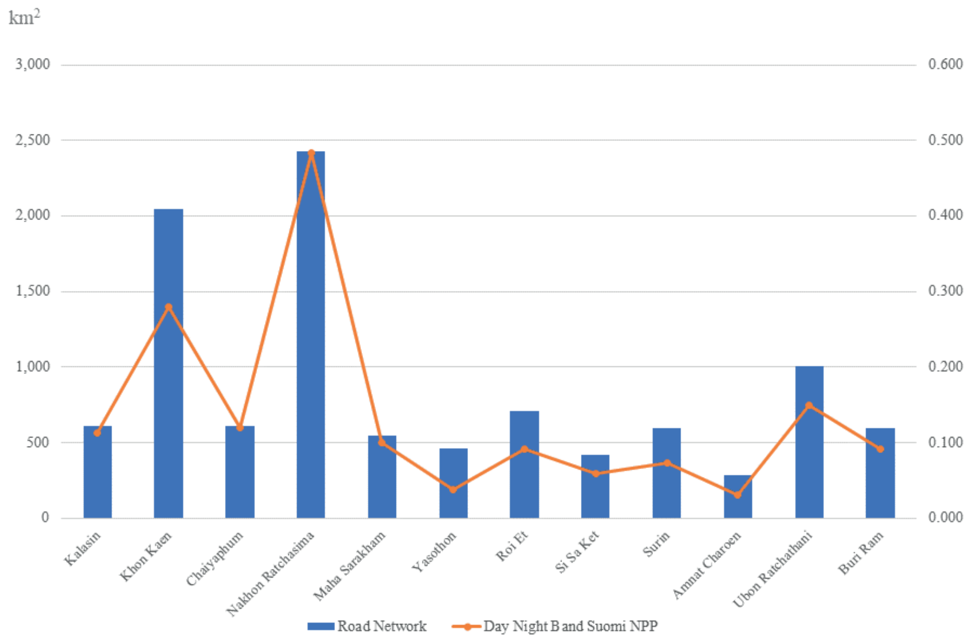

Fig. 7. Relationship between Day/Night Band Captured by Suomi NPP Satellite and Road Network in 2016

DISCUSSION

The nighttime light satellite images taken by DMSP/OLS and Suomi NPP satellites in the lower Northeastern region of Thailand during 2006-2016 can be applied to study the urban area and building expansion over this period (Amaral et al. 2006; Min Zhao 2020; Ma et al. 2014; Mia M. Bennett 2017; Q. Zheng et al. 2019) and replace the analysis using the images from natural resource satellites. This type of analysis can be applied to the regional level as well (Bagan & Yamagata 2015). It was found that the top 3 provinces with the highest urbanization were Nakhon Ratchasima, Khon Kaen and Ubon Ratchathani, the corresponds with the road network expansion surrounding the city centers, which are the key economic areas that include residences, shopping malls, markets, and other related activities (Keeratikasikorn 2018). Moreover, this relationship between the road network and urban areas via the nighttime light images was confirmed using correlation statistics (Tepinta 2020; Sangkasem and Puttanapong 2020). R-square value of the relationship between urbanization and nighttime light satellite images was 0.800, while for one of the relationships between the road network and nighttime light satellite images it was 0.985, which can be considered very high. Therefore, the results of this study can be useful for the agencies that work on monitoring and studying urbanization as well as the relevant local administrative authorities.

The results of this study also showed some patterns of urban development in Thailand. It was found that urban areas will develop primarily from city centers, with the development poles being shopping malls, government offices, stadiums, and other urban areas of high economic activity. For example, Nakhon Ratchasima and Khon Kaen are provinces that developed around their city centers in the past. This happened because the government established a number of regional government centers in the country. In addition, universities such as Khon Kaen University, and the Rajamangala University of Technology Isan were also established in order to spread higher education into many regions. As a result of such policies, the cities in both provinces have grown considerably. There is also a rapid increase in population and buildings, in Ubon Ratchathani province which has a large area and is located adjacent to Laos and Cambodia. As a result, the expansion of urban areas here occurs mainly from economic development, especially the migration of agricultural workers into the city. Furthermore, an interesting urban expansion pattern was found in this study for Buriram Province, which was associated with the expansion of the city due to the construction of internationally recognized sports facilities, such as football stadiums, and racing tracks that took place in 2014. Therefore, other provinces in the region need to rely on the development of the economy and the infrastructure of the cities for their further growth.

CONCLUSIONS

During this study, while analyzing urban expansion in the lower Northeastern region of Thailand using the nighttime light satellite images taken by the DMSP/OLS and Suomi NPP Satellites, it was found that the data captured by both satellites required conversion in order to obtain compatible values. It was also concluded that nighttime light satellite images taken by the Suomi NPP Satellite were better for the analysis of urban expansion because the DMSP/OLS Satellite data was only available until 2013. Consequently, images from the Suomi NPP, launched in 2011, were required afterwards.

From this study, it can be concluded that (1) urban expansion was analyzed using the nighttime light satellite images taken by the Suomi NPP Satellite and compared with the Landsat 8 Satellite image, which were used to calculate the NDBI, and identify the relationship between the urban area and nighttime light satellite images using the correlation coefficient, it was found that this relationship was highly significant with a coefficient value of 0.800; and (2) the relationship between urbanization and road networks areas was analyzed using the correlation coefficient and it was found that this relationship was also highly significant with a coefficient value of 0.985. The urban and built-up areas can be easily identified from the nighttime light satellite images using the methods employed in this study, as well as compared to the results obtained from the natural resource satellite images.

The present study had two limitations. The first limitation was that the correlation coefficient is only a rough statistical test, future studies regression, and machine learning should be used to analyze the data. The second limitation was that the number of observations used in this study was very small, and a larger area should be chosen for future studies.

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