International Journal of Engineering and Geosciences
https://dergipark.org.tr/en/pub/ijeg
e-ISSN 2548-0960

# Investigation and modeling of physical development of urban areas and its effects on light pollution using night light data

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**Keywords**
VIIRS
NPP
Light Pollution
Physical Development
GIS

Research Article
DOI: 10.26833/ijeg.976495

Received: 08.11.2021
Accepted: 15.02.2022
Published: 13.04.2022

**Abstract**

The expansion of urbanization and unbalanced urban growth has attracted the attention of many urban planners and decision makers to the issues and consequences of urban population growth. In general, monitoring how urban areas are developed on a large scale is very important in order to plan urban development. However, in most cases, the lack of basic information in this area, especially in developing countries is one of the main obstacles to achieve this. With the development of human civilization and urbanization, the demand for artificial light has increased and this growth will continue. Found. Due to its lack of direct impact on daily life, light pollution has remained largely unknown and has rarely been studied. In this regard, the role of remote sensing techniques and data in identifying changes in the physical development of cities and changes in the amount of light is clearer than other methods. Using VIIRS satellite imagery, other satellite, digital and GIS data can measure and measure the physical growth of cities as well as the spatial and temporal distribution and extent of this type of pollution, and can even manage the risk of this pollution and Reach zoning. High-risk and dangerous areas. In this study, NPP images, travel time layer of Landsat 7 and 8 images have been used, which have been analyzed with the help of remote sensing and GIS techniques. The time frame considered in this study is 2012 to 2020.

## 1. Introduction

The world is urbanizing rapidly. The process of urbanization in different parts of the world is the result of interactions between various factors, including social, economic, political, geographical and cultural, and has had consequences. Pollution is one of the most important consequences of urban civilization. Of the various types of pollution, light pollution may be one of the emerging pollutants in the field of environmental damage. Despite the introduction in recent years, this pollution continues to grow due to poor urban management. Disrupting or causing adverse effects on the environment and the health of organisms is called pollution. Light pollution is a type of pollution that is called over-illumination of an environment by artificial light. This pollution is a branch of environmental studies that has become important in the last two decades, and experts have begun studies due to the effects that this pollution causes on humans and nature, especially animals. Therefore, identification and zoning of areas sensitive to light pollution in order to assess the environment of these areas seems necessary. Recently, advances in data collection and sharing in many aspects of urban life have provided us with better clues about the characteristics of cities [1-3]. In this regard, the effectiveness of remote sensing techniques and data in detecting changes, whether physical or optical changes, has been more than other methods. Night light observations through remote sensing allow us to evaluate human activities. In this study, we will follow a new multi-stage approach to examine the rate of physical growth of cities and light pollution in them. The main purpose of this study is to evaluate the efficiency of satellite remote sensing (NTL) to determine the causes of changes and various factors affecting the development and growth of urban areas and light pollution and to make a comparison between Tehran and Tabriz cities.

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**Cite this article**

Bagheri, S., Karimzadeh, S., & Feizizadeh, B. (2023). Investigation and modeling of physical development of urban areas and its effects on light pollution using night light data. International Journal of Engineering and Geosciences, 8(1), 98-110

## 2. Material, Methods and Case Studies

In order to study the physical development of cities and light pollution, we use two remote sensing data classes: built-up area and night lights. We also use travel time based on openly available street maps. Some authors such as [4-6] used these data in their studies. In this study, Landsat 7, Landsat 8 satellite images, VIIRS night light images and travel time raster images were used. Landsat 7 images were used to produce the ground cover layer in 2012 and Landsat 8 images were used for the years 2013 to 2020. The night light images for the years 2012 to 2020 are all for the SOUMI NPP satellite VIIRS sensor. The Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) collects global low-light imaging data that have significant improvements over comparable data collected for 40 years by the DMSP Operational Linescan System. One of the prominent features of DNB data is the detection of electric lighting present on the Earth's surface. Most of these lights are from human settlements. VIIRS collects source data that could be used to generate monthly and annual science grade global radiance maps of human settlements with electric lighting. There are a substantial number of steps involved in producing a product that has been cleaned to exclude background noise, solar and lunar contamination, data degraded by cloud cover, and features unrelated to electric lighting (e.g., fires, flares, volcanoes), [7]. The flow chart of the adopted methodology is depicted in Figure1. In this study, we will go through three steps to measure urban growth: the first step is to produce land cover, the second step is to classify the night light image, and the third step is to calculate travel time. Each of these steps has its own processing. Each of these datasets has advantages and disadvantages that. For example, Landsat provides the free optical remote sensing imagery of medium resolution (30m). Surface classification using Landsat is limited by cloud obscuration, the similarity of radiance signatures among surface types and incomplete training data. Another problem with land cover is the occurrence of gaps when we focus on one class (built up in the present study). Unlike Landsat, the Nighttime Light (NTL) products do not show any gaps over a city area. However, due to their large pixel size, NTL products provide ambiguous information at the edges of the cities and on coastlines. Travel time provides evidence on the connectivity of a city but not whether this is associated with population so it cannot define urban extent alone. If logically combined, show the physical growth of the city. The algorithm used in this study is called BUNTUS (ground cover, night light and travel time) algorithm [8], which will use remote sensing and GIS techniques to calculate the physical growth of the city. We will also use the Google Earth Engine system to check the amount of light pollution. In the following, we will show our study areas and explain each step separately and examine their composition and the final result. The general framework of the work is shown in Figure 1.

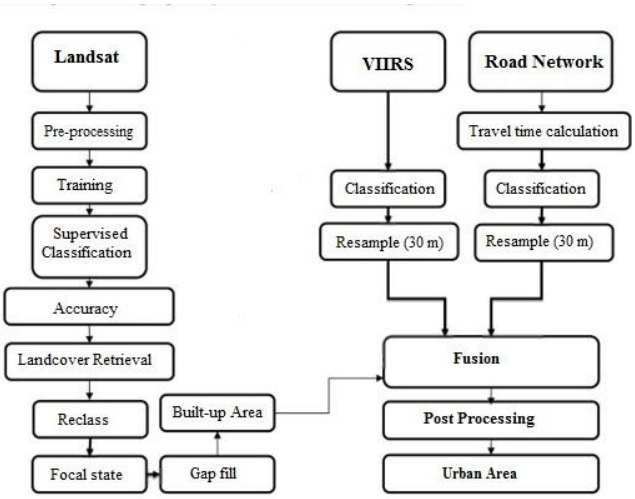


**Figure 1.** Methodology flowchart of fusion of Landsat, Nighttime light product of Visible Infrared Imaging Radiometer Suite (VIIRS) and travel time

### 2.1. Case Studies

In this study, we selected two metropolises of Iran, namely the cities of Tehran and Tabriz as study areas (see Figure 2) to examine the various aspects of the BUNTUS algorithm on them and to challenge the progress of light pollution. The figure 2 shows the study areas.

### 2.2. Land Cover Classification

Landsat Enhancement Thematic Mapper (ETM) and Landsat Operational Line Imager (OLI) images were used to produce the land cover map. ETM images were used to map the land cover for 2012 and Landsat 8 images for 2013-2020. First, the necessary preprocessions such as radiometric correction and atmospheric correction were performed in ENVI image review software, then the images were classified using SVM method. Initially, each image was classified into four classes of built-up areas, water, plants, and soil, and then we categorized those four classes into two classes to extract urban built-up and non-built-up areas. In selecting the training data, Google Earth was used to classify it correctly.

#### 2.2.1. Accuracy Assessment

Error matrix method was used to evaluate the classification accuracy. A confusion matrix is a summary of prediction results on a classification problem. The results showed that the accuracy of the four classified classes was between 85 and 90%.

#### 2.2.2. Urban Area Generation

The land cover produced had 4 classes. The higher number of classes minimizes the effect of mixed pixels. In order to separate built-up and non-built-up urban areas, we divided the 4 classes into two classes. A value of 1 was assigned to build areas and a value of 0 was assigned to non-built-up areas. Since our main focus was on built-up areas, we re-evaluated the accuracy of the two classes. Our two-class classification was more than 90% successful in all datasets. Finally, Focal Statistics analysis

was performed on a two-tier image in ArcGIS software and the ground cover layer was ready to be collected with other data.

### 2.3. Nighttime Light Data Processing

Nighttime light (NTL) satellite images are a class of remote sensing products, globally available for multiple years. The global open-source night light images are available from two sensors; The Operational Line scan System (OLS) instrument mounted on the United States Air force Defense Meteorological System Program (DMSP) and the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor mounted and flown on NASA/NOAA Suomi-National Polar-Orbiting Operational Environmental Satellite System (SNPP) [8]. In this research, we use VIIRS images and various strategies. To find the DN threshold for urban areas for multivariate analysis, we categorized NTL images into five classes to establish the relationship between DN and ground cover. We categorized the VIIRS datasets into five classes at their native resolutions of 742 meters. Figures 3 and 4 show the NTL classified image map of Tehran and Tabriz.

Using these thresholds, we classified VIIRS data into two classes: for the city of Tehran, the range is between 0 - 26.6 class one, which is not related to the built-up areas, and the value of 0 is assigned to it, and the range is between 26.6 - 149.25 is the second class, which is related to urban areas and the value of 1 is assigned to it. For the city of Tabriz, the range between 0 - 22.99 is class one (unbuilt areas, and has a value of 0), and the range between 22.99 - 168.64 is the second class (built areas of the city), to which value one is assigned. Figures 5 and 6 show Two-class night light image map for Tehran and Tabriz for 2020.

### 2.4. Travel Distance Raster Creation

Meaning of travel time is usually specified period of time spent in traveling at work or from the entrance of a business establishment to the place where work is actually done (as in portal-to-portal travel or deadheading) for which compensation may be demanded or paid. The road network provides a third view of the urban area as it measures the connection of space. Therefore, complete and accurate geographic road network data is a valuable data set. Open Street Maps (OSM) provide the spatial data of the road network globally and at no cost [8]. In the present study, we used OSM data because they are readily available. To create the travel distance layer, the OSM platform and ORS command in QGIS software were used. This tool calculates the travel time by introducing the city center to it, without considering any restrictions such as traffic, and based on the speed considered in each route. Finally, the final layer became a raster in ArcGIS software. Figure 7 and 8 show Travel distance raster map for Tehran and Tabriz.

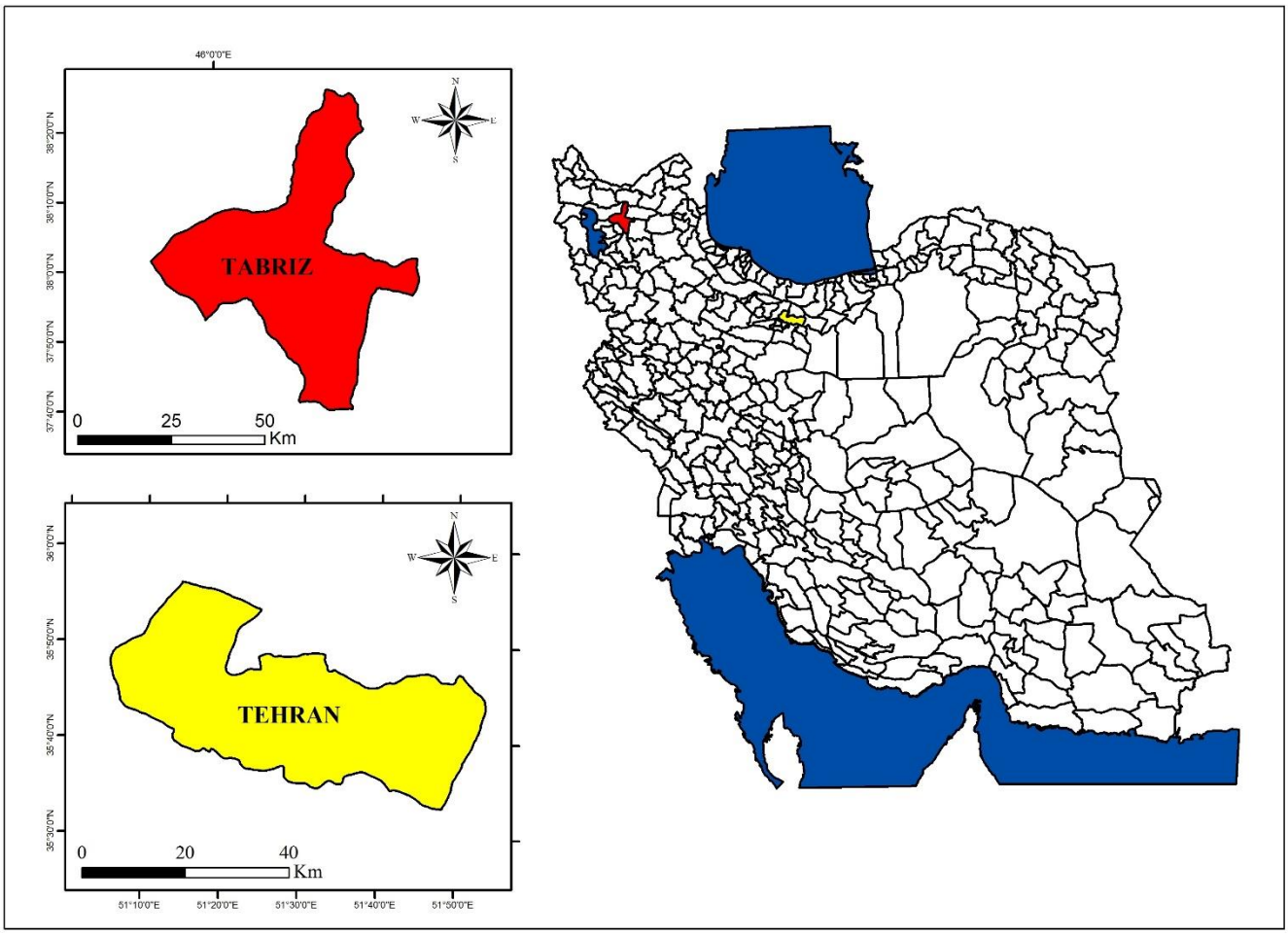


**Figure 2.** Study area

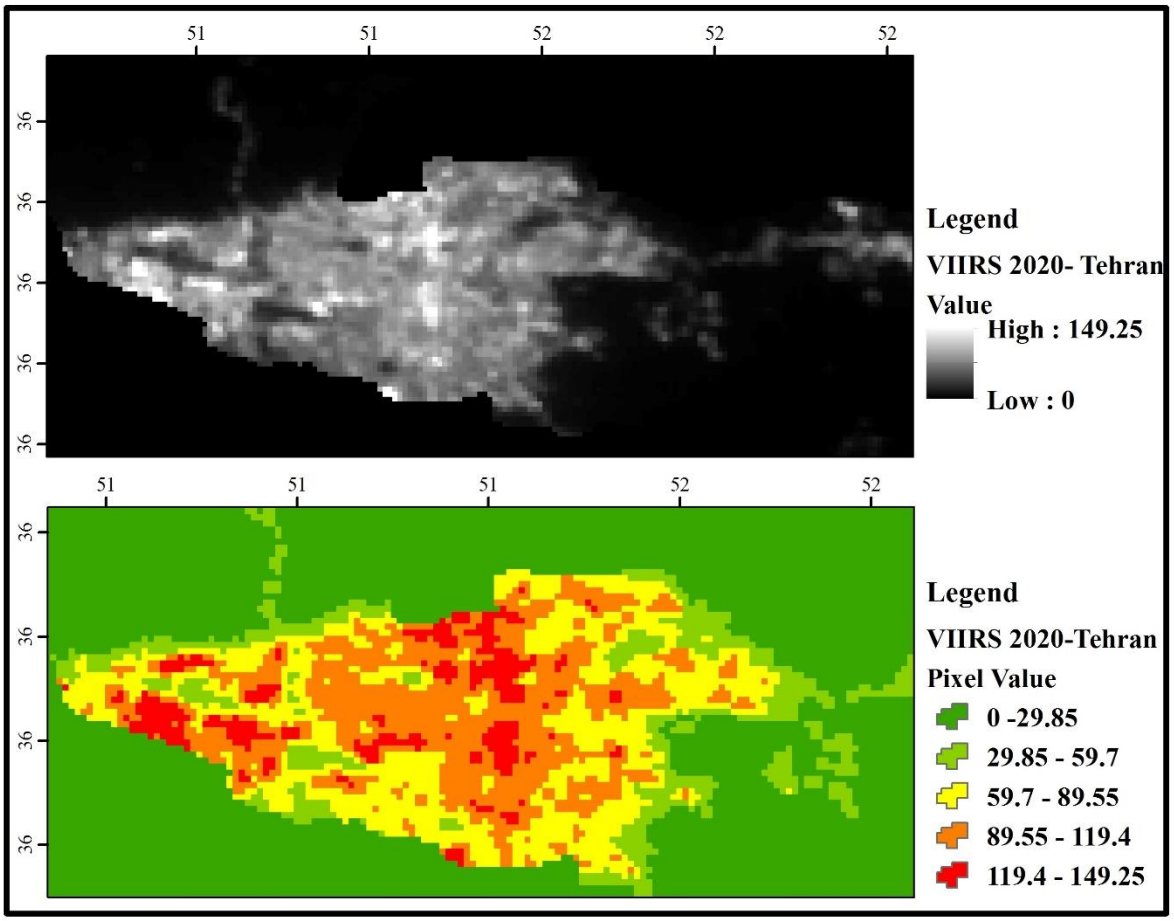


**Figure 3.** Classified NTL image map of Tehran

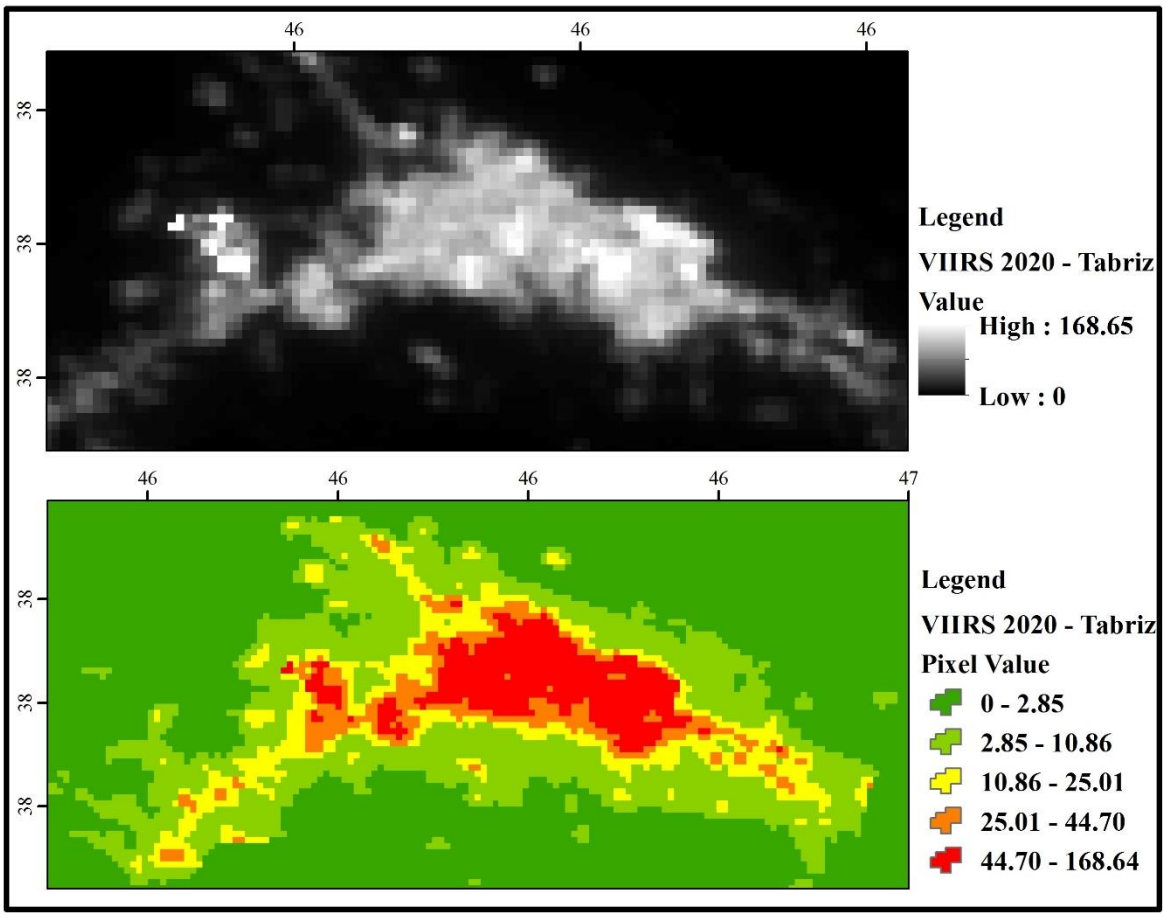


**Figure 4.** Classified NTL image map of Tabriz

### 2.5. Fusion of Datasets

After generating three rasters, namely the ground cover layer, the travel time raster, and the night light image, we merged these three layers. A simple sum of three raster is generated according to the following formula:

DNout = DNB + DNNTL + DNTT

Finally, in order to extract the urban boundary, we divided the generated layer into two classes according to the logical threshold. We then selected the largest adjacent urban area, which included the urban core, and converted it to a data vector polygon. Then we adapted it to Google Earth images. These steps are shown in the figure below, respectively. Figure 9 and 10 show Fusion of three datasets (DNTT, DNB, DNNTL) for Tehran and Tabriz in 2020.

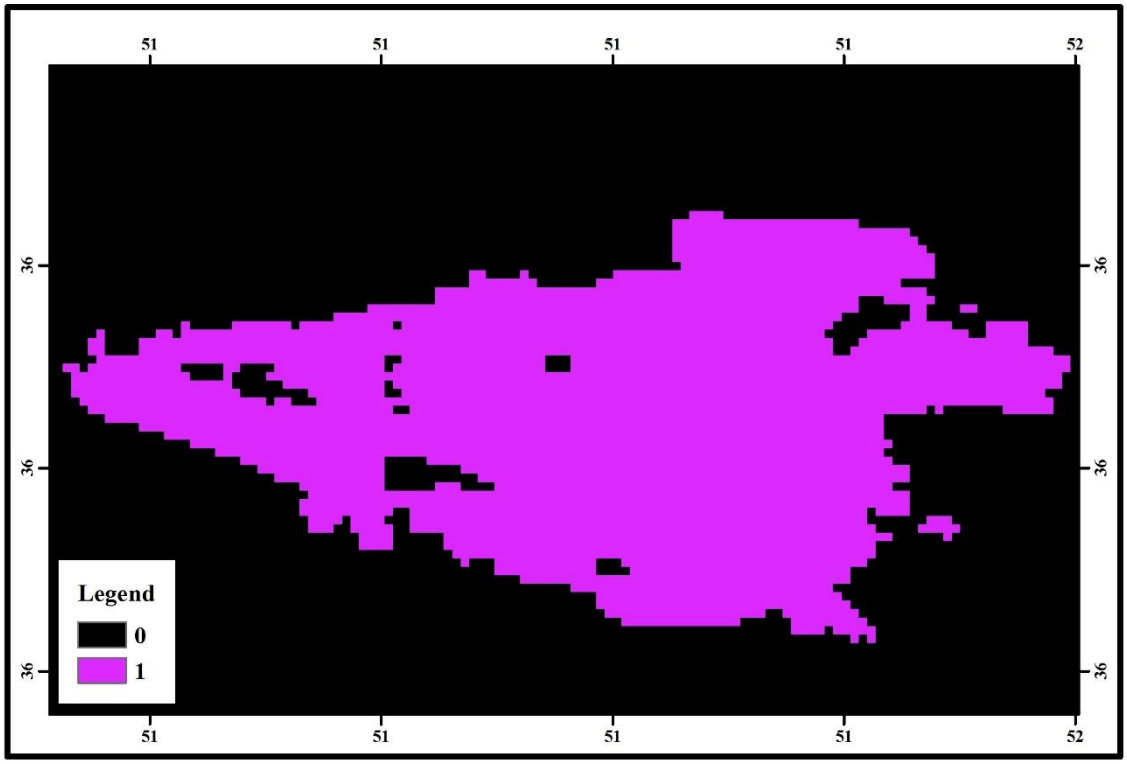


**Figure 5.** Two-class night light image map for Tehran for 2020

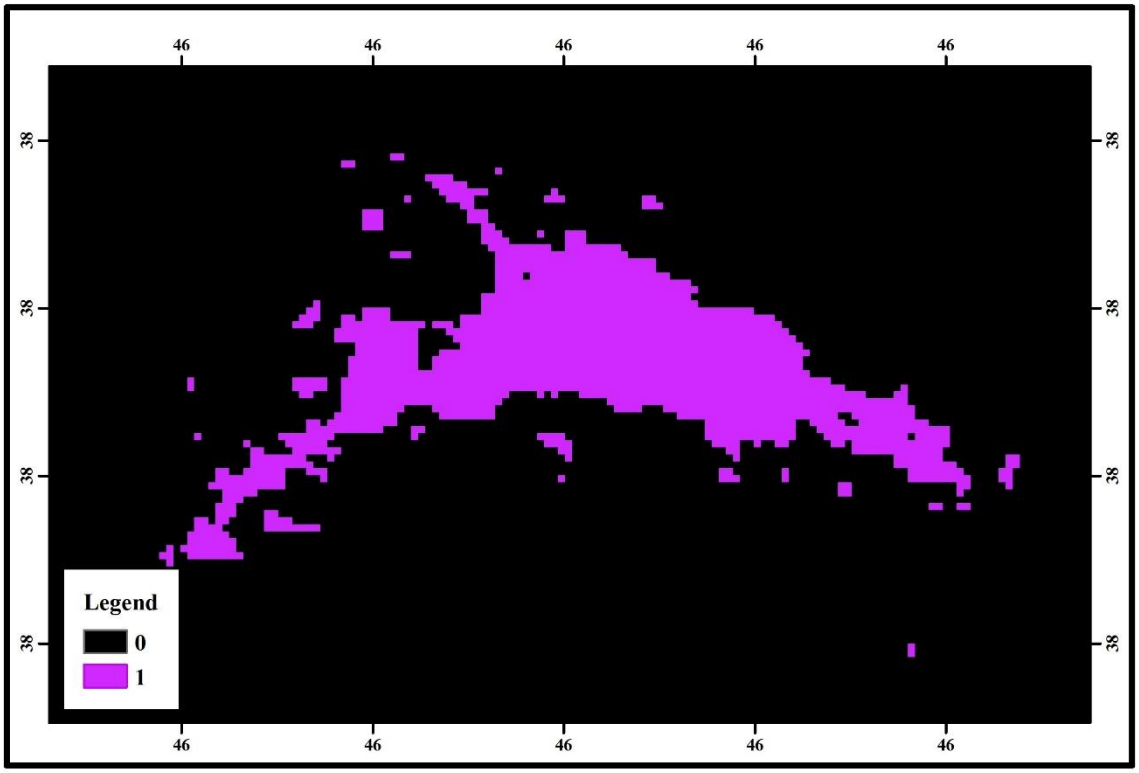


**Figure 6.** Two-class night light image map for Tabriz for 2020

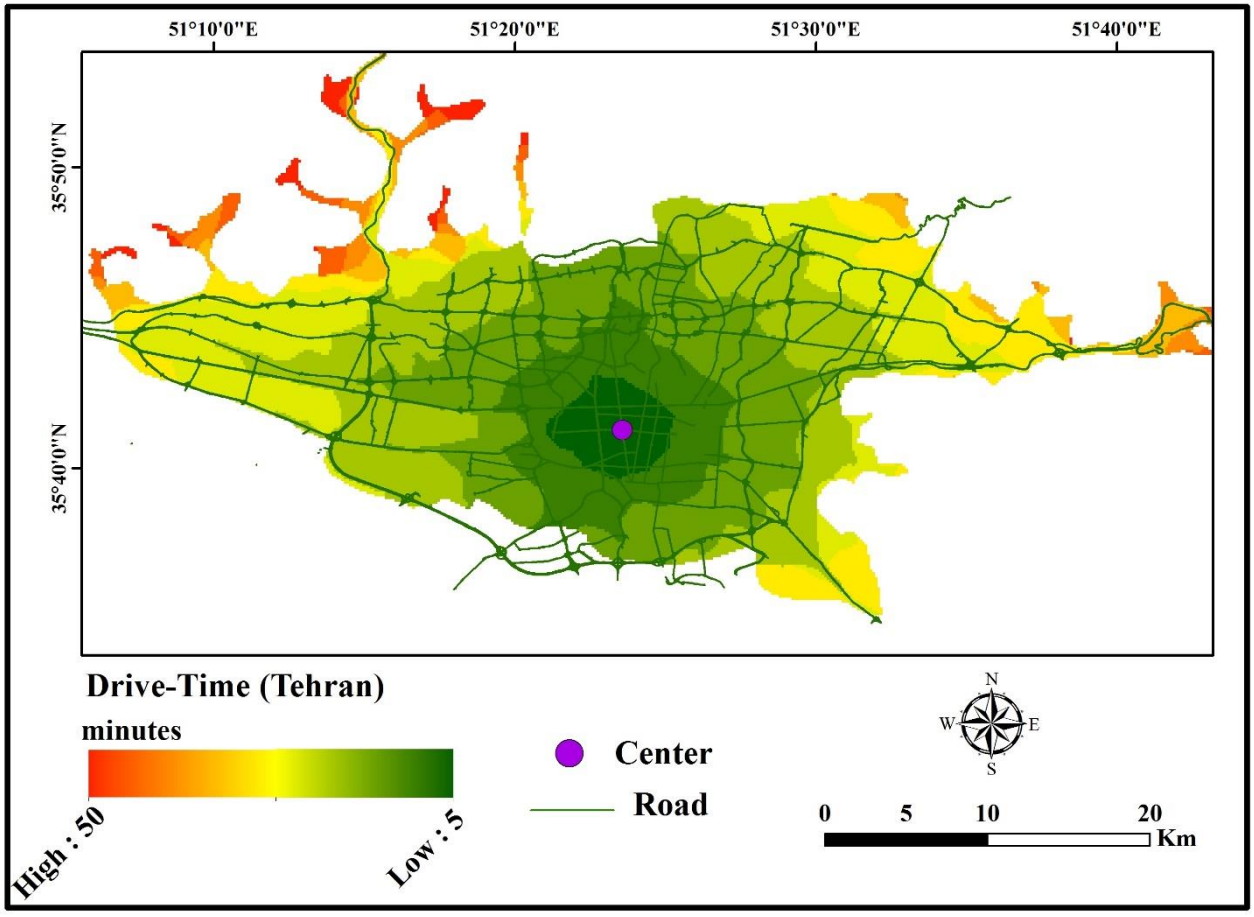


**Figure 7.** Travel distance raster map for Tehran

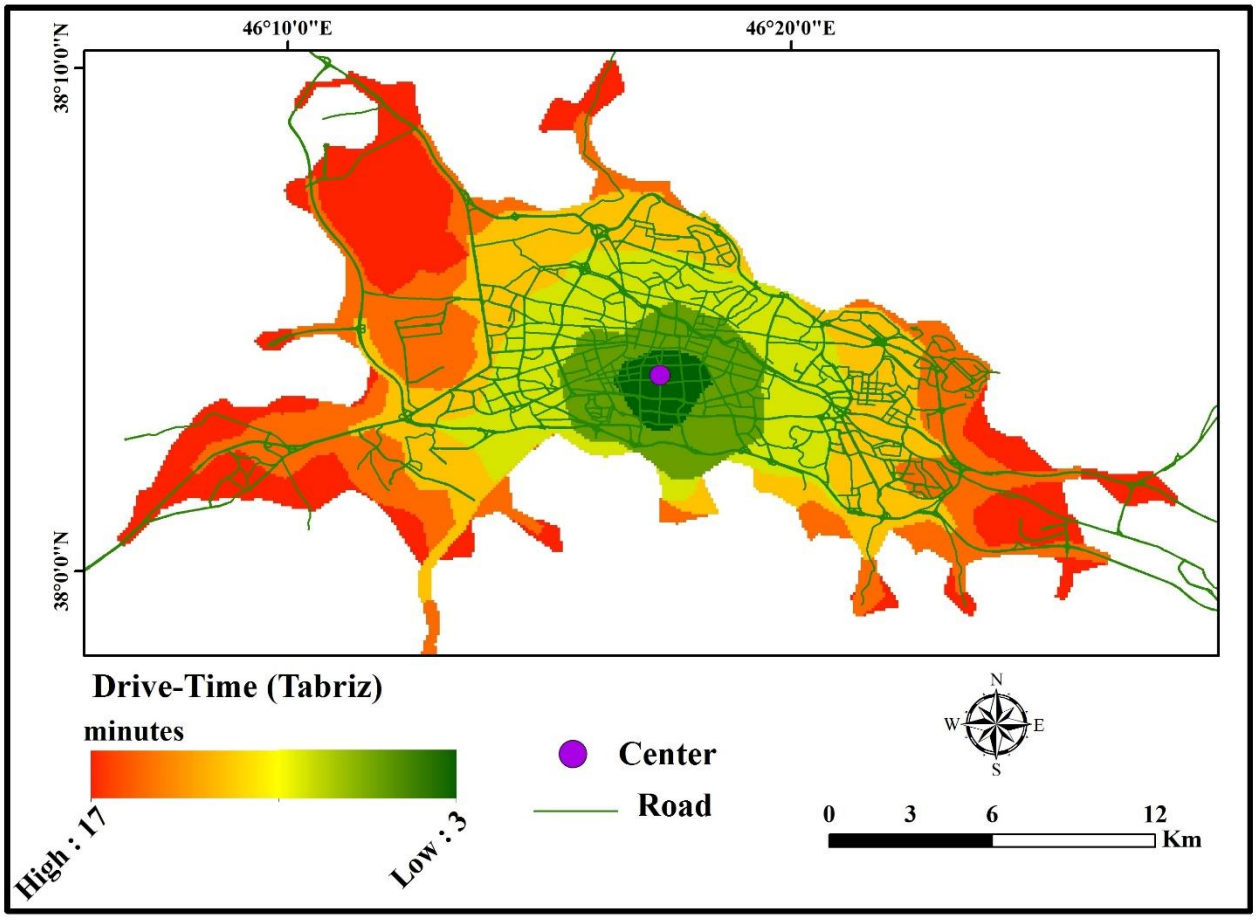


**Figure 8.** Travel distance raster map for Tabriz

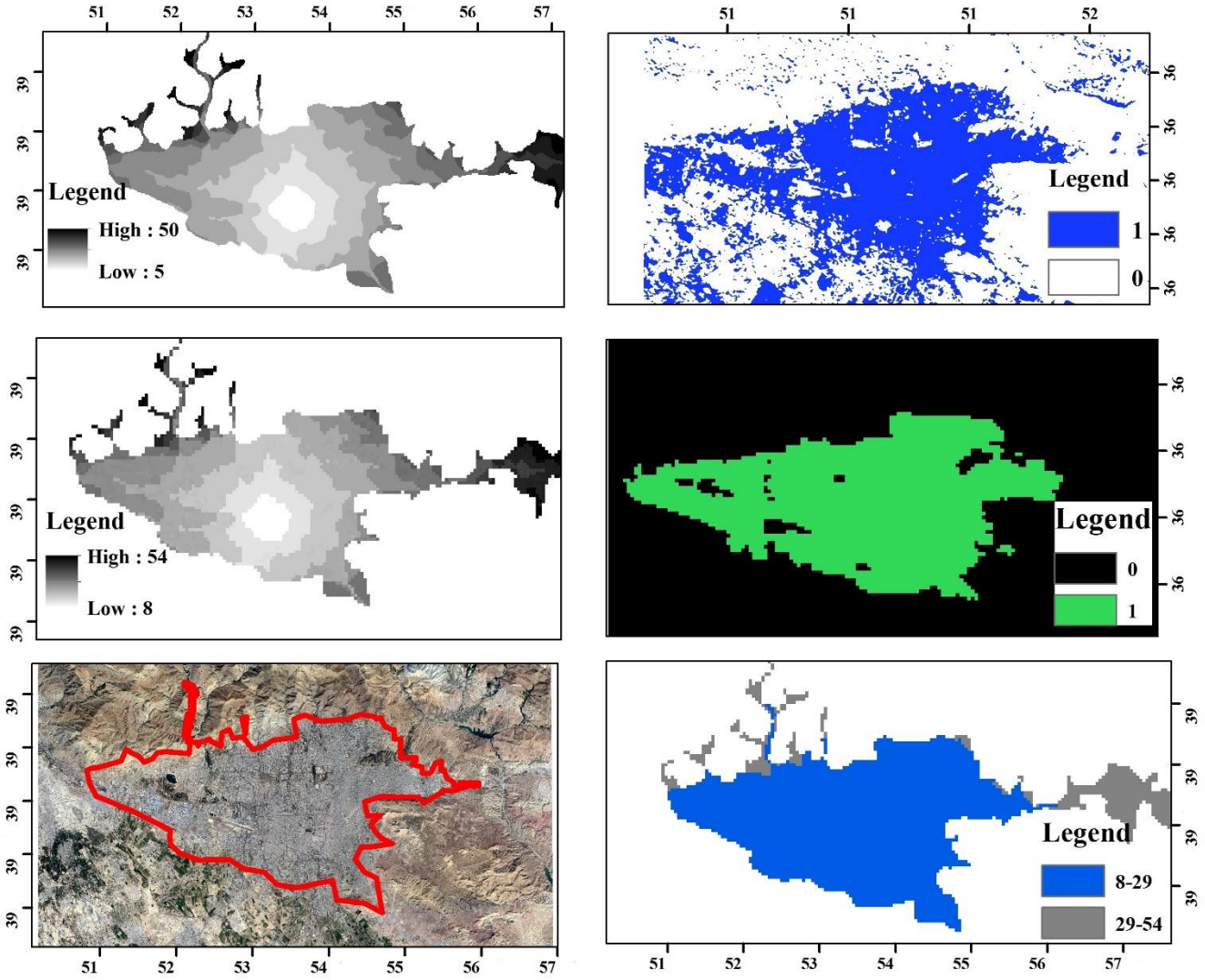


**Figure 9.** Fusion of three datasets (Tehran in 2020). Plate (A) represents the travel time raster (DNTT), plate (B) represents the built-up area (DNB), plate (C) represents the Nighttime Light classified raster (DNNTL), plate (D) represents the fusion of all three datasets (DNout), plate (E) represents the classified sum with a threshold value 1.5, and plate F represents the largest contiguous urban area boundary

### 2.6. Light pollution

In the astronomical classification of the sky, there are three categories: dark, marginal and catastrophic. According to the evidence, the capital sky is in the category of a catastrophic sky. What is more important than air pollution, improper and uncontrolled expansion of cities, widespread and uncontrolled use of non-standard lamps, lack of awareness of people in the correct use of light and its means of production and incorrect policies of urban management in using street lighting and Passages have placed Tehran at the top of Iran's polluted cities in terms of light pollution [9]. In order to calculate the level of pollution in the two cities studied, Google earth Engine software was used.

The results obtained in this study also show an increasing trend of light pollution in Tehran and Tabriz between 2012 and 2020. As you can see, in 2012, the central centers of Tehran had moderate light pollution, while in 2020, the amount of light pollution in the central and western regions has increased. Billboard lights, street and highway lights, lighting of urban elements such as flags, statues, stairs, etc., lighting of buildings and towers, recreational places, etc. are among the causes of light pollution. And every year we see a sharp increase in these cases. Figure 9 shows Night light images for Tehran for 2012 and 2020. Also Figure 12 and 13 show Graph of changes in light pollution in Tehran and Tabriz between 2012 and 2020.

Due to the increasing expansion of urbanization and the consequences of urbanization of cities and uncontrolled migration of light has also increased. Although this pollution is not comparable in appearance and sight to the naked eye, but it is an unfortunate environmental reality that lurks in the health of creatures and humans. By using new methods and techniques for measuring the distance, these contaminants can be mapped and appropriate measures can be taken to deal with and reduce them. If in an area with a high degree of light pollution and its negative effects on humans, it may be possible to prevent or relocate endangered individuals and organisms [9].

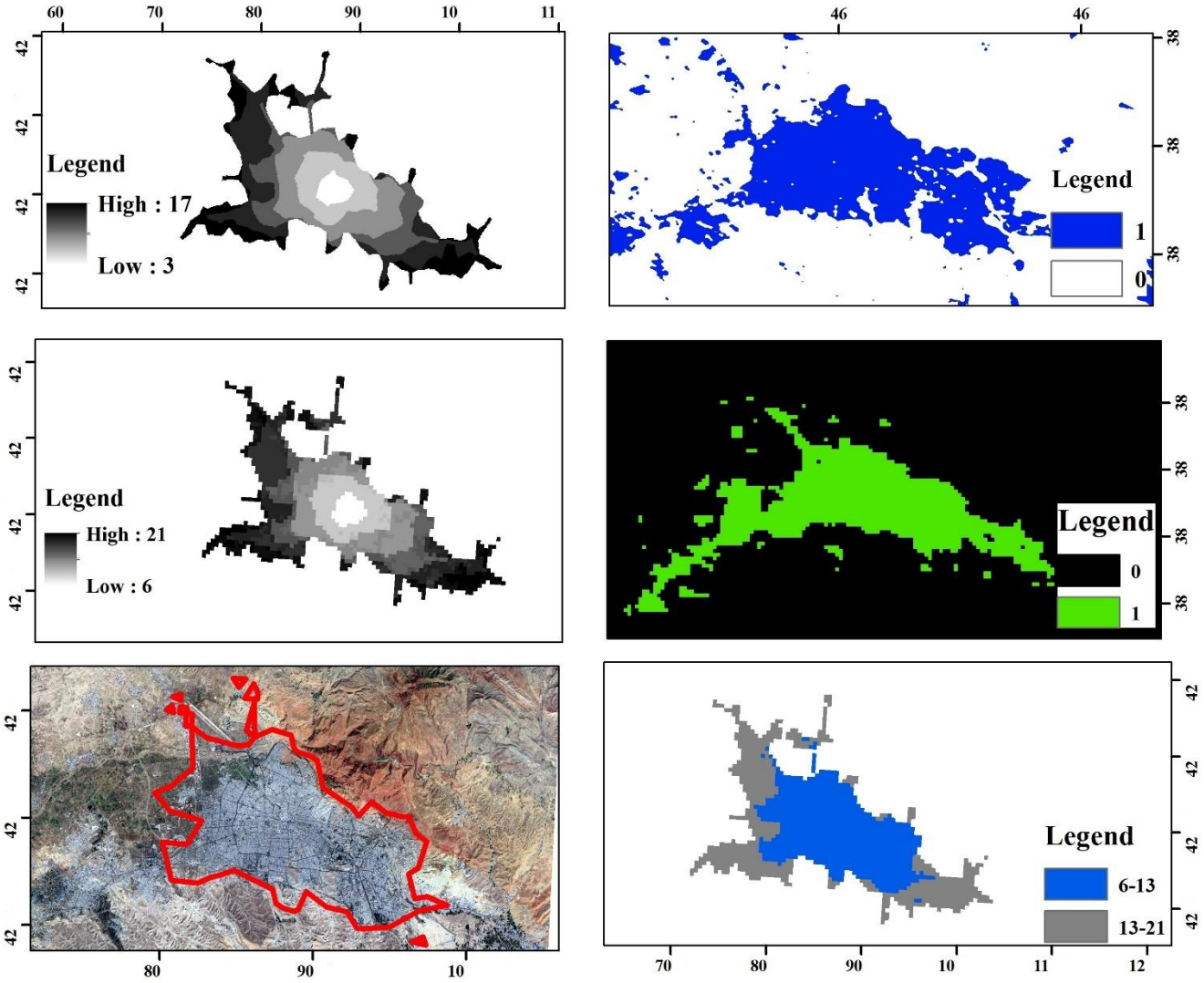


**Figure 10.** Fusion of three datasets (Tabriz in 2020). Plate (A) represents the travel time raster (DNTT), plate (B) represents the built-up area (DNB), plate (C) represents the Nighttime Light classified raster (DNNTL), plate (D) represents the fusion of all three datasets (DNout), plate (E) represents the classified sum with a threshold value 1.5, and plate F represents the largest contiguous urban area boundary

## 3. Results

### 3.1. BUNTUS validation

A little direct validation of BUNTUS is difficult. No other dataset has a separation of time and place for complete comparison. More seriously, the definition of urban sprawl is arbitrary [8]. Our task is to capture urban dynamism. Therefore, we can compare the ranking size of changes from BUNTUS and other datasets. The most commonly used method is direct comparison with urban images. The following figures show the BUNTUS borders of Tehran and Tabriz cities from 2012 to 2020 on Google Earth images, respectively. The maps below show the changes of the urban border in this period in these two cities well. The city of Tehran has expanded from the east and north to other urban areas. The city of Tabriz has also had a gentle growth in all directions. Figures 14 and 15 show the changes in the border between Tehran and Tabriz between 2012 and 2020.

### 3.2. Urban expansion

The following figures are useful for understanding how urban areas grow over time. For example, the city of Tehran shows more growth on the north side and on the northeast and northwest sides, and the city of Tabriz has been accompanied by growth in almost all directions, albeit with a gentle slope. Figure 16 Shows Boundaries of the urban area of Tehran and Tabriz (2012-2020).

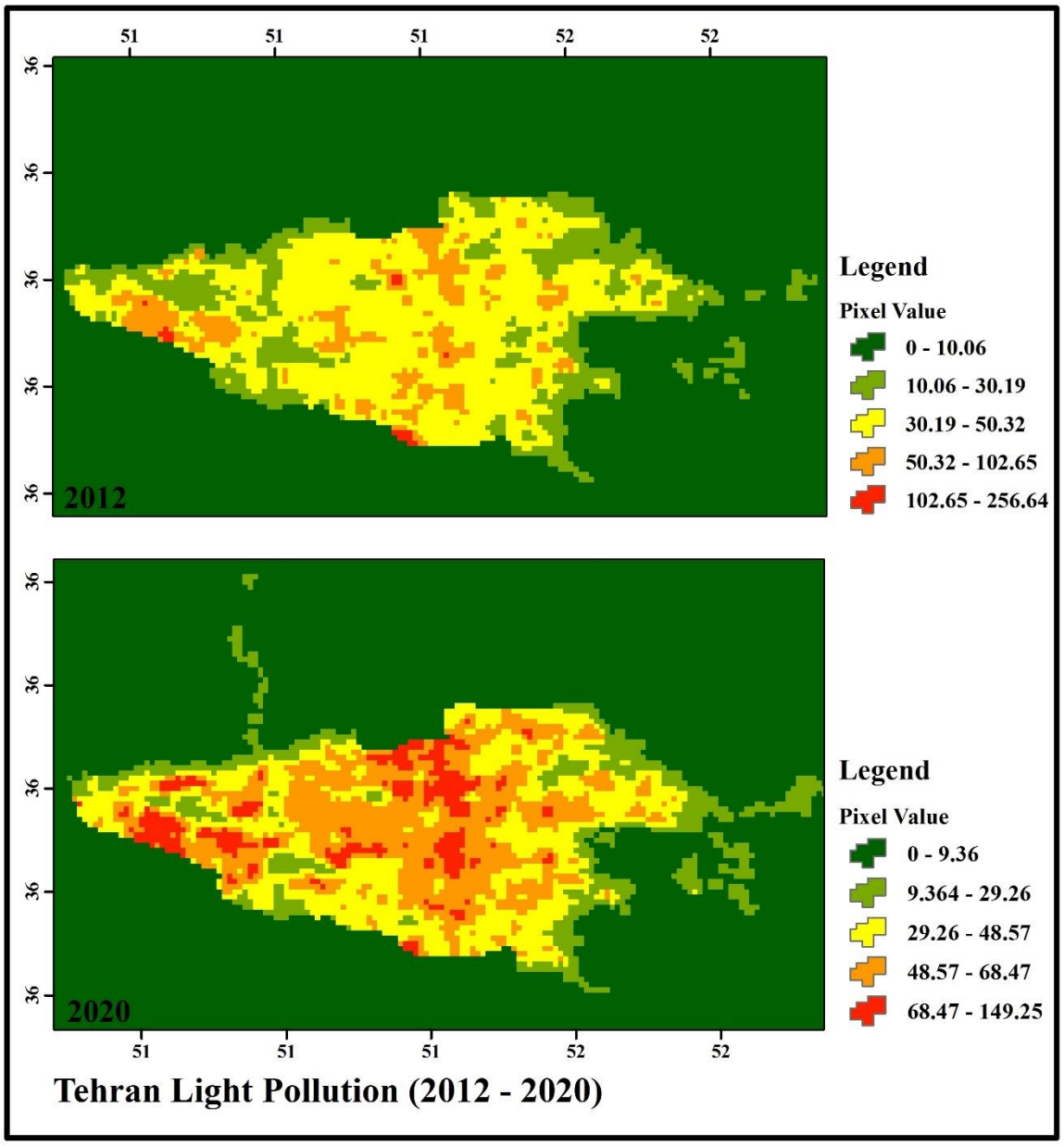


**Figure 11.** Night light images for Tehran for 2012 and 2020

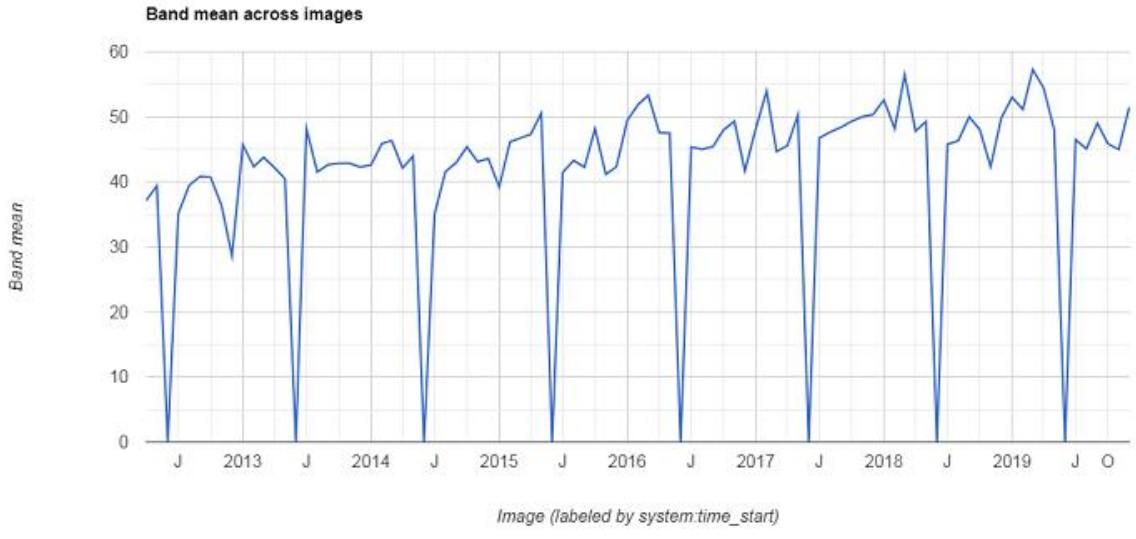


**Figure 12.** Graph of changes in light pollution in Tehran between 2012 and 2020

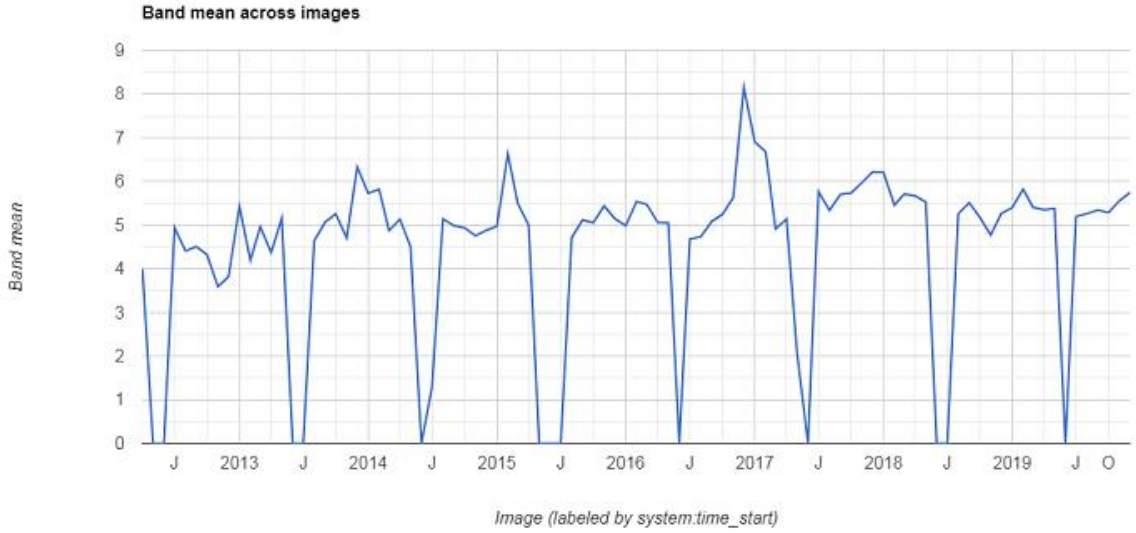


**Figure 13.** Graph of changes in light pollution in Tehran between 2012 and 2020

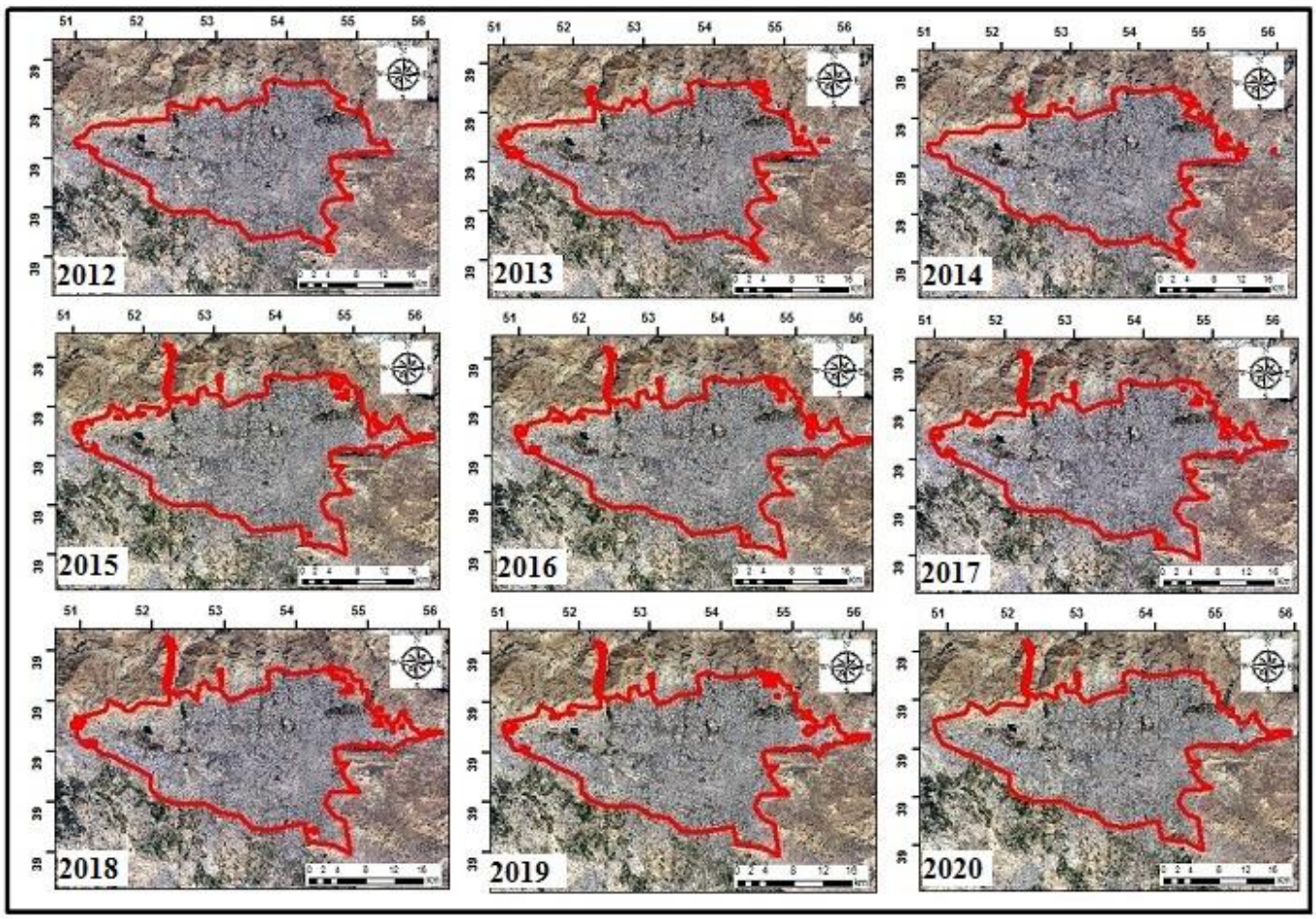


**Figure 14.** Built-in areas, night light image and travel time raster for urban size borders (BUNTUS) Tehran on Google Earth images from 2012 to 2020

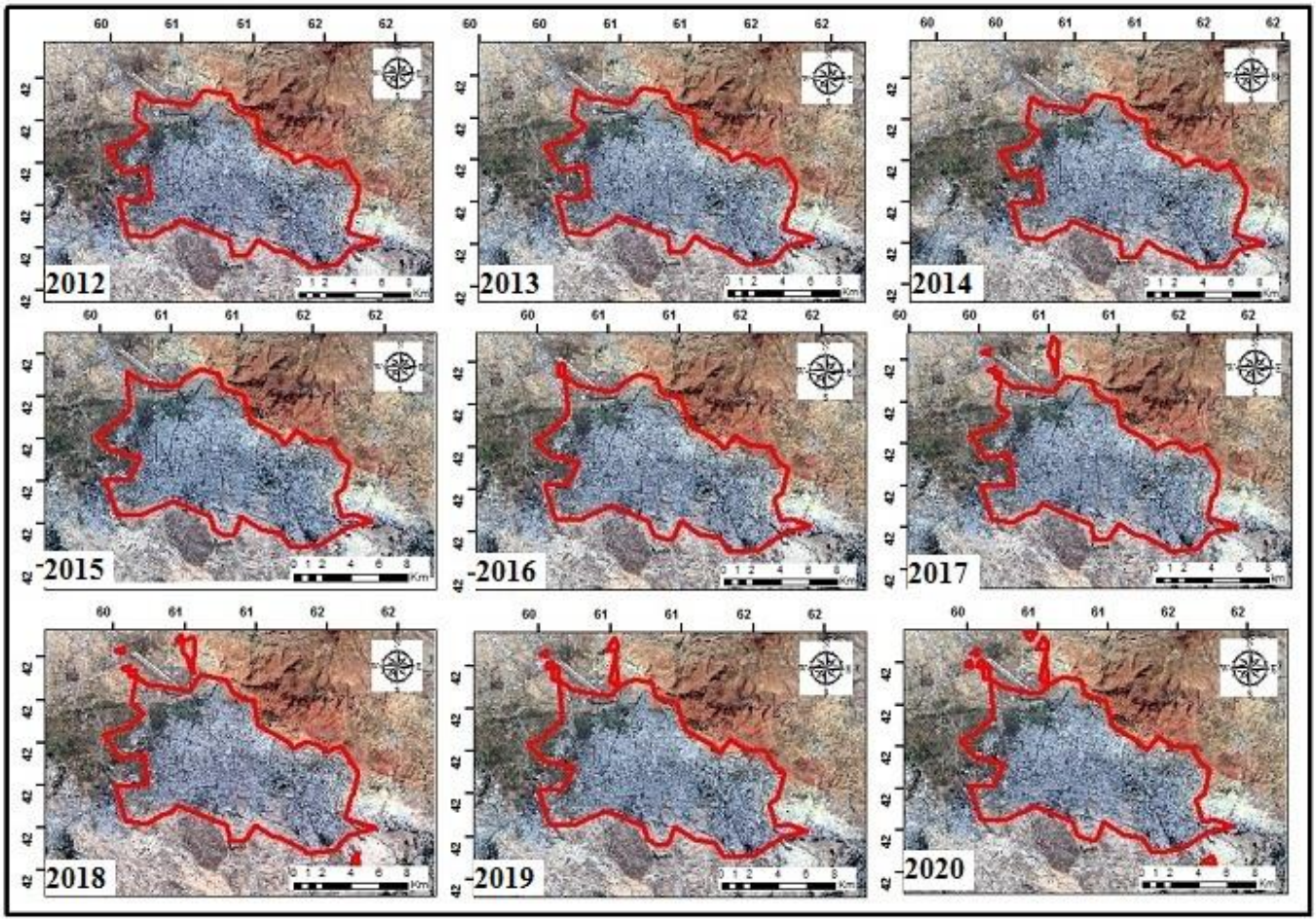


**Figure 15.** Built areas, night light image and travel time raster for Tabriz city size borders (BUNTUS) on Google Earth images from 2012 to 2020

Generally, urban area does not shrink except during war or natural disasters. We can take advantage of this fact by making the boundary calculation purely additive, i.e., once a pixel is included in a city it remains there. Figure (17) shows the area diagram of Tehran and Tabriz cities from 2012 to 2020. The chart, for both cities, shows continuous annual growth, and only the city of Tehran in 2014 showed more growth than other years. Figure 17 Shows Urban area versus year plot for Tehran and Tabriz.

## 4. Discussion

T Considering the performance of various algorithms and analyzes regarding the study and modeling of physical growth in the studied cities and its effect on light pollution, we saw that the results showed continuous growth, but with a gentle slope in the studied cities. his program should be kept in mind when evaluating the usefulness of a data set such as BUNTUS. This is true for any urban data set because no single definition is sufficient for all applications, even if there is data to determine it. Our task here is to define an algorithm that is strong, consistent, and efficient enough to define global urban dispersion trends for many cities over decades [8]. The results of this study showed that the metropolises of Tehran and Tabriz did not have significant physical growth in this period. The metropolitan area of Tehran has increased by about 66 square kilometers in this 9-year period and the city of Tabriz by about 5 square kilometers. One of the limitations that can be mentioned is that the BUNTUS algorithm depends on the quality of the data and if the data is of lower quality, the result will be less accurate. For example, due to the unavailability of cloudless satellite imagery, the accuracy of classification made for some areas and years is reduced. Also, the presence of chat in Landsat 7 images for 2012 creates many problems. Although this problem can be largely solved, some processes such as classification on these images are very time consuming and slow. Another limitation is the difference in resolution of the different data sets, resulting in mixed pixels. Though we tried to minimize the effect of mixed pixels when dealing with the coarser resolution datasets by resampling, they still play a role smaller scale. Regarding light pollution, due to its increase from 2012 to 2020, especially in the central parts of the city, plans should be made to reduce or control this type of pollution, which has a great impact on humans, animals, plants, energy.

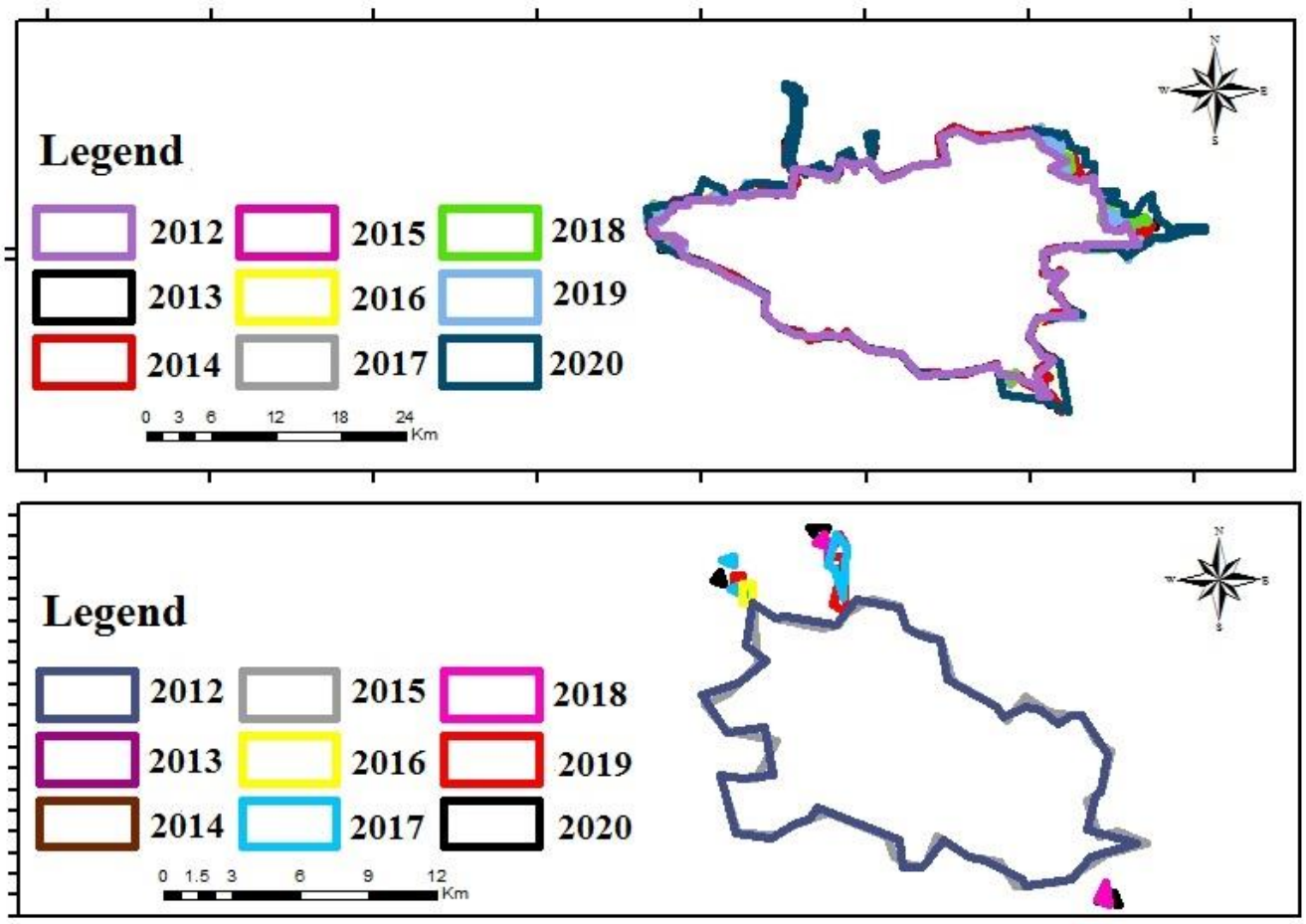


**Figure 16.** Boundaries of the urban area of Tehran and Tabriz (2012-2020)


**Figure 17.** Urban area versus year plot

## 5. Conclusion and Suggestions

With advances in NTL satellite sensors and technologies, NTLs viewed from satellites have emerged as unique geographic data products that measure the brightness of light observed at night from space. This study proposes a set of NTL urban dispersion indices that intend to use quantitative DN values to quantify urban dispersion. These NTL indicators can provide a general idea of urban sprawl and are very easy to calculate, especially for a large group of areas. In this study, efficient methods and algorithms for studying and modeling the physical development of urban areas and the effect of light pollution were investigated. The results

showed that by combining Landsat information, night light image and travel time information, urban growth trend can be studied with high accuracy. This method is relatively robust to the quality and availability of data variables and a fully automatic and general algorithm. The results of the studies on the studied cities showed that the cities of Tehran and Tabriz have had a gentle slope of growth over a nine-year period. The results of studies on light pollution also showed an increase in light pollution from 2012 to 2020 in the studied cities.

The following are suggested from the studies and results obtained in this study:

- More uses of night light images in various projects as a useful source in the fields of economy, urban growth, traffic and ...
- Using the urban budget for the growth of all urban areas and not just a specific area
- Using night light images in environmental fields, especially in the field of light pollution (these images have proven their high efficiency in this field).

## Author contributions

**Samaneh Bagheri:** Conceptualization, Methodology, Software, Data curation, Writing-Original draft preparation, Validation, Investigation, Visualization, **Sadra Karimzadeh**: Conceptualization **Bakhtiar Feizizadeh:** Conceptualization.

## Conflicts of interest

The authors declare no conflicts of interest.

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