



# The Evolution of Lighting in South-West India from Night-Time Lights: 2012–2020

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**Abstract** Human-induced alterations of the landscape and the same driven climate changes are seriously making drastic changes in the processes on the Earth's surface, regionally and globally. Visible Infrared Imaging Radiometer Suite (VIIRS) night-time light datasets can precisely detect the intensity and scope of human activities. Accurate and temporal monitoring of urban areas and urban sprawls is highly imperative to the detection and assessment of regional development of a region. This study quantitatively assessed and mapped the light extents and urban region in Kerala, one of the southwest Indian states from 2012 to 2020 with the help of low light imaging day/night band data collected from the VIIRS and utilised VIIRS night time Lights V.2 time series from the monthly averages with filtering to eliminate extraneous features

such as aurora, biomass burning, and background. ISO-CLUSTER based classification and the threshold methods are used for the light extent and urban region extraction respectively. The result indicated that the Kerala State experienced very high urbanization from 2012 to 2019. But in the case of 2020, there was a decrement in the radiance due to the lockdown and night curfews followed by the COVID-19 global pandemic. Normal life including transportation, industries, and business, etc. was affected much before the national lockdown in Kerala. It was proved with the help of time series data generated from mid-2019 to the end of 2020. The time-series data was generated with 580 night light datasets of NASA's Black Marble VNP46A2 from 1st June 2019 to 31st December 2020 on daily basis.

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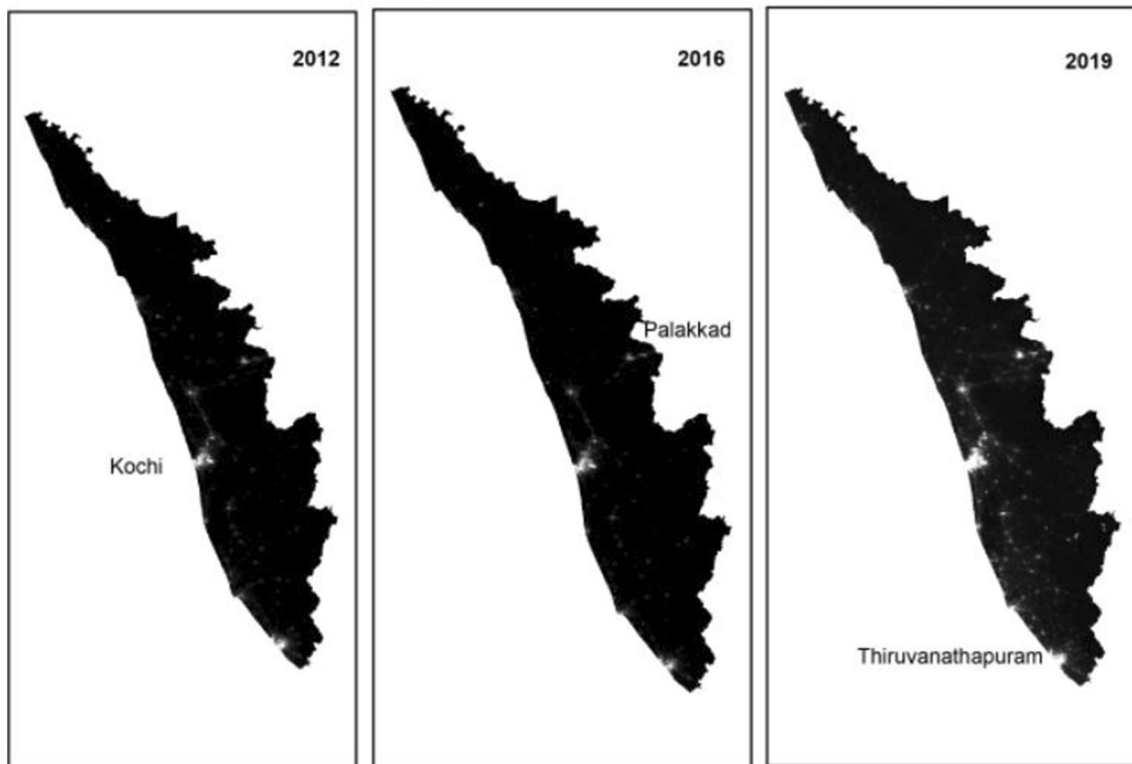
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## Graphical abstract

### The Evolution of lighting in Southwest India from VIIRS Night-time Lights



**Keywords** Night time lights · NASA-black marble · VIIRS-DNB · COVID-19 · Time series · VNP46A2

## 1 Introduction

The anthropogenic interactions of the landscape and man-induced climate changes are seriously upsetting the processes on the Earth's surface, regionally and universally, making a variety of challenges for the officials and technical people to recognize and address the consequences and changes at the global level [1, 2]. The new geographical concepts, tools, datasets and methods are emerging to advance the understanding of areas in natural resource management such as urbanization, environmental changes from a global perspective. The footprint of human beings is a prominent indicator of human influences on both the ecosystems and the environment [3]. Space-based observations proved that it has remarkable capability in monitoring, analysing, estimating, and predicting the temporal changes that are faced by the earth's surface and qualitatively and quantitatively accessing the dynamics of human action and its environmental impacts [4]. At the beginning of the twenty-first century, people realized that satellite

remote sensing technology will remain to have a vital part in earth observation. One of the important hallmarks of the human footprint on the earth's surface, the lighting measured from the earth's surface is most helpful for the identification of the human settlements and the economic dynamics. This will be exploring the potential for continuous observation and monitoring of human activities and identification and understanding of impacts related to the environment compared to the salient advantages over optical, infrared and radar satellite products used for human activity monitoring [5].

Global night-time lights are among the most widely recognized satellite data products, providing a visual expression of humanity's presence across the earth's surface. In addition, the global delineation of light areas and their brightness levels are utilizing by scientists for a wide range of disciplines, from economists and biologists to astronomers [6]. The making of global night-time light requires a large number of night observations especially high-quality observations and electronics for deriving stable measurement of brightness as seen from space.

In general, it takes a full year of night observations to ensure that the product's latitude range reaches the fullest possible extent, with the majority of the Earth's surface

having multiple observations free of extraneous features unrelated to electric lighting. The processing chain features a cascading set of filtering steps [7]. The processing starts with the filter process removing cloudy sunlight and moonlight data to purify a set of candidate pixels for inclusion in the annual data product. The next step is to trim outliers, such as biomass burning and aurora, to obtain a grid where background areas, lacking detectible lighting, can be more readily distinguished from lighting. The background areas are then converted to zeros and lit grid cells are filled with the average radiances. The objective of the filtering is to retain as many of the surface lighting features as possible while completely zeroing out the background and extraneous features. Early urban-related studies are generally based on statistical data collected by individual or government bodies. It was due to the lack of availability of accurate products and timeliness, these data could not provide spatial detection of urbanization promptly.

Various optical remote sensing data widely used for different scales in various research fields are the Landsat series from National Aeronautical and Space Administration (NASA), USA, SPOT from French Space Agency, and high spatial resolution imagery like Quick Bird, Worldview, IKONOS from Digital Globe USA, Planet data and Maxar data from Planet and Maxar Space companies under private ownership. But these optical sensors are less popular in the long-term detection of regions with cadastral level/large scale due to the relatively complicated data processing, high cost, procedure, sophisticated equipment requirements and sometimes the availability of cloud-free images. Compared to those optical data, the night-time light images available from Defence Meteorological Satellite Program's Operational Line Scan System (DMSP/OLS) are more cost-effective and are available over a larger temporal window span [8–10]. So, in the early days, DMSP/OLS seems to be a practical data source for observation of urban regions with large scales and time series.

The Visible Infrared Imaging Radiometer Suite (VIIRS) of day/night band (DNB) offers Night-Time Light (NTL) data, which is very useful to map the accurate boundaries across the world with higher spatial resolution compared to DMSP-OLS. The NTL data from VIIRS is more positively correlated with social interactions, which are giving an overall idea about the origin of why cities exist and boom. The non-face contacts and face-to-face interactions on the road through an information system in the urban region resulted in larger radiance values in the NTL data in the related pixels than in the neighbouring rural regions having dark pixels [11]. More than that the NTL data ensures the extraction of urban areas from both spatial and temporal perspectives [12, 13]. The new generation of NTL data

from the VIIRS sensor is capable to produce more convenient data for the accurate extraction of urban areas [14]. The major advantages of VIIRS data over DMSP-OLS include lower light imaging detection, fine quantization, higher spatial resolution, and in-flight calibration.

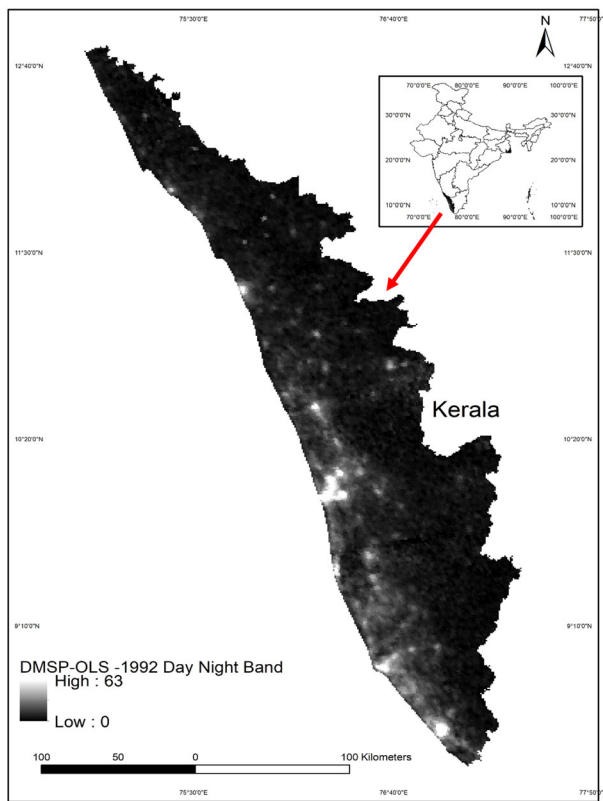
The feature extraction from the NTL using the thresholding technique is very popular due to its reasonable accuracy and simplicity [15]. In one of the studies, [16] assessed the threshold for a local window based on the background information, and [17] proposed a multi-threshold method. These studies applied different thresholds for areas with different income levels after a comparison analysis between the NTL and population distributions. [18] and [19] used optimal dynamic thresholds to map the urban extents of each urban cluster thresholding from Landsat TM and MODIS data. This technique was modified and extended to urban extent mapping at the global level.

Given the above discussion, this study is an initial and first attempt to generate and map the time series of light and urban extents over Kerala State from 2012 to 2020 from VIIRS-Day Night bands and with the supporting data sets of MODIS land cover products and NASA's Black Marble VNP46A2 datasets.

## 2 Methodology

### 2.1 Description of the study area

Kerala is one of the southernmost Indian States popularly known as “God's Own Country” lying between  $8^{\circ}17'30''$ – $12^{\circ}47'0.40''$  N and  $74^{\circ}27'47''$ – $77^{\circ}37'12''$  E. It is packed in between the Arabian Sea in the west and the Western Ghats in the east. The state contains high ranges, midlands, and coastal plains. The climate is mainly tropical wet and maritime tropical. Summer usually runs from March until May; the monsoon begins in the first week of June and ends in September [20]. As per the 2011 population census the State had 33.4 million people and the population density is 859 persons per  $\text{km}^2$  and the state consists of 14 districts (Fig. 1). The major cities in the State are Thiruvananthapuram, Ernakulum, Kozhikode, Trissur and Palakkad. Kochi is the only metro city in the State. The capital city Thiruvananthapuram located in the southernmost part of the state. Compared to all other Indian states, Kerala has many unique indicators in development. The urbanisation trend in Kerala is not concentrated in any particular cities or towns. Unlike other Indian states, Kerala doesn't have a distinctive demarcation between rural and urban, this is one of the unique features noticeable in the state. Based on the census data surveyed by the Census of India, a giant jump was observed in the case of the urban population. Based on



**Fig. 1** Study area

the survey the urban proportion increased to 90% from the 2001 to 2011 census in the Kerala state [21].

## 2.2 Urban region extraction and identification

The essential information utilized for this research incorporates the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on-board the Suomi National Polar Partnership (SNPP) satellite launched in October 2011 which was designed to acquire high-quality radiometric datasets. VIIRS is a 22-band visible/infrared sensor having 3000 km swath width against the earlier U. S. Air Force Defence Meteorological Satellite Program (DMSP) and a higher spatial resolution of 15 arc-second (500 m) compared to the Operational Line scan System (OLS) in the DMSP, VIIRS observes Night Time Lights of the earth every 24 h [22]. The day/night Band (DNB) with a spectral range of 0.5–0.9  $\mu\text{m}$  was used for the night observations [23]. VIIRS/DNB came with numerous improvements over its ancestor DMSP-OLS, especially a higher spatial resolution, a full in-flight calibration, a lower detection limit, a finer radiometric quantization and a wider dynamic range compared to DMSP-OLS. The present study investigates the time series of the years 2012, 2016, 2019 and 2020. The process of assembling annual global night-time light products begins with the establishment of a reference grid.

The processing considers all the nightly VIIRS-SNPP-DNB data collected during a year, working in monthly increments. The monthly DNB cloud-free composites are generated by averaging the radiances from orbital segments that are free of sunlight, moonlight, and cloudy data based on the VIIRS cloud mask. The V.1 monthly products are produced with and without stray light corrected data. The versions excluding stray light corrected data are indicated with a “vcm” in the file name. Those with stray light corrected data included are indicated by a “vcmsl” in the file name. Making annual VNL from the monthlies is filtering out biomass burning and other outliers, thus isolating the background. In the original method based on the nightly DNB data, histogram-based outlier removal was used to generate an annual average radiance grid free of biomass burning and other ephemeral events [24].

The present study utilised Annual VNL V2 data products derived from the VIIRS DNB band. These are the modified datasets of its early version VNL V1. This version datasets are already processed with initial filtering to remove sunlight, moonlight, background noises, and cloudy pixels leading to rough data composites containing lights such as fires, and aurora, the specialty of these datasets is made monthly increments and combined to form a rough annual dataset. These products use the twelve-month median radiance to discard high and low radiance outliers, filtering out most fires and isolating the background. In V1 datasets, background areas are zeroed using a data range estimated from  $3 \times 3$  grid cells, and the threshold for the background data range indexed to cloud cover levels. But in the new method adopted in V2 intensive attention is given to setting a single data range threshold for distinguishing the grid cells from the background for each 15 arc-second grid cell. The multi-layer approach was used to detect lighting present in each 15 arc-second grid cell with a single data range threshold across all the years in the series.

The light extent of the study area of each year was extracted using the ISOCLUSTER based digital classification method. The nearest neighbour was used as the resampling technique in the datasets both spatially and temporally. Around 100 sampling points were taken for validation across the study area using a random basis. The accuracy assessment was carried out and the kappa coefficient was calculated using ERDAS Imagine software suite. The projected subset data of the various years was used to find out the urban extraction with the help of the threshold method. The present study defined and extracted the urban regions under the characteristics of light variation from SNPP-VIIRS-NTL images. Based on the distance from pixels and radiance values, the images were mainly separated into 3 major parts, particularly, potential urban centres/Central Business District (CBD), potential urban

transition regions and potential non-urban (rural/semi-rural) regions. In rural and urban center regions, pixels are always with low or high radiance values respectively and are stable relatively, while the pixel values in transition regions are always located between rural regions and urban centers. Transition regions cover a wide range of radiance values and also experience tremendous changes [25, 26] (Fig. 2). The region with radiance values less than  $30\text{nW/cm}^2/\text{sr}$  considered as non-urban areas, the radiance lying between 30 and  $60\text{nW/cm}^2/\text{sr}$  considered as transition raster and the radiance values greater than  $60\text{nW/cm}^2/\text{sr}$  treated as the urban regions. For filtering purposes, the Sobel edge operator was used and it utilizes a spatial gradient measurement in 2D on the images and it is considered to be the best edge detection filter in many research fields [27] (Fig. 3). This filter consists of two moving-window kernels ( $3 \times 3$ ) of different directions. The gradient results measure how rapid pixel values are changing with distance in two perpendicular directions and also the difference with other surrounding pixels [28, 29]. Moreover, it can be combined to calculate the gradient (G) at each pixel and even the direction of the gradient [30]. Based on these filtering techniques the gradients of each pixel within transition regions were assessed.

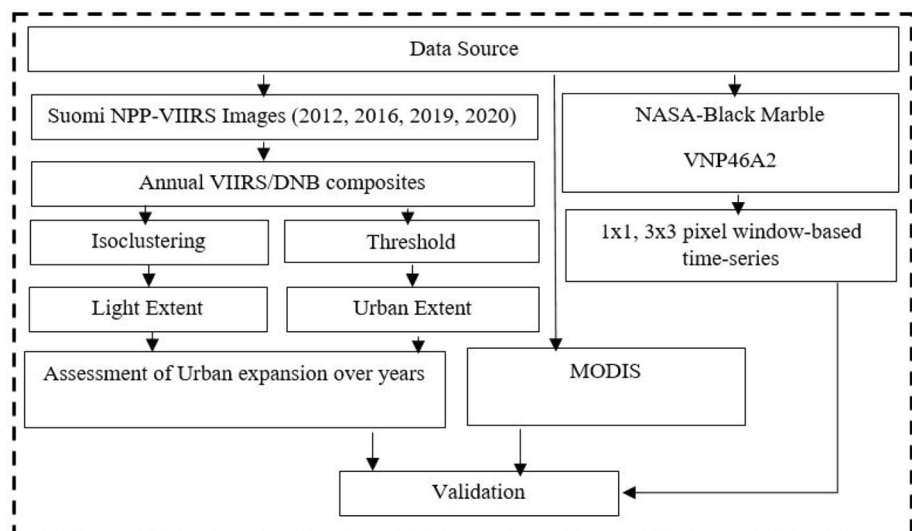
### 2.3 Validation of urban extent

The MODIS/Terra + Aqua Land Cover Type Yearly L3 Global 500 m SIN Grid V006 data set was collected from the NASA Earth Data portal was used for the validation (Fig. 3). The comparison was made with medium resolution annual time-series data with 500-m resolution data of 2012, 2016, 2019 and 2020, which were used for the validation with the urban extent extracted from VIIRS-DNB data.

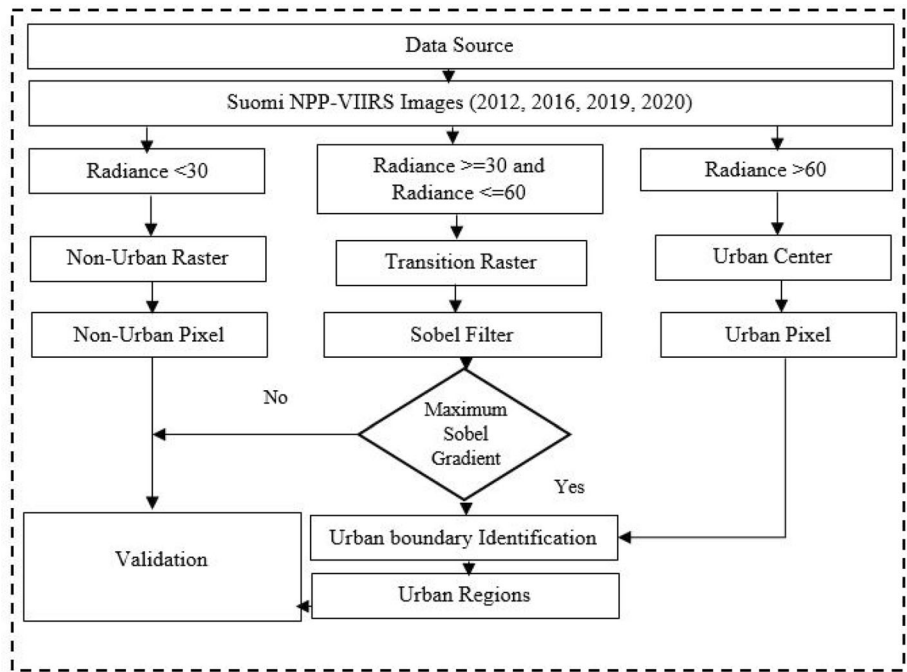
### 2.4 Validation of radiance reduction during lockdown

The lockdown followed by the global COVID pandemic in the year 2020 shows a noticeable decrement in the lights it affects the radiance from features. For the validation purpose, the times series plot was generated during the period from 1st June 2019 to 31st December 2020 from NASA's Black Marble VNP46A2 Gap Filled DNB BRDF Corrected NTL dataset. The VNP46 product suite comes with cloud-free imageries on daily basis in a 500-m spatial resolution. After the acquisition within three to five hours, the processed cloud-free data is available. Basic atmospheric corrections, seasonal corrections, and bidirectional reflectance distribution function (BRDF) corrections were applied to the image for long-term and near real-time monitoring applications [31]. This data contains six layers of information on bidirectional reflectance distribution function (BRDF)-corrected NTL (500 m), snow flag, latest high-quality retrieval (number of days), lunar irradiance, mandatory quality flag, and cloud mask flag [32, 33]. The standard Black Marble product suite (i.e., Level 3 daily and multi-date formats) is available from NASA's Atmosphere Archive and Distribution System—Distributed Active Archive Centre (LAADS DAAC) Data Centre in the HDF5 format. A total number of 580 datasets were used for generating time series of the study area for the 2019 and 2020 years. With the help of python scripting  $1 \times 1$  and  $3 \times 3$  pixels, window-based time series were generated.

**Fig. 2** Overall workflow



**Fig. 3** Urban extraction using thresholding



**3 Results and discussion**

The analysis using the above methodological approach resulted in deriving the following information products for the State of Kerala.

**3.1 Night time lights derived from the monthly average**

The images taken for the study were on in the years of 2012, 2016 and 2019 as the pre-lockdown and 2020 was during the lockdown period due to the global COVID pandemic. After analysing the images, it was clear that after lockdown there was a reduction in the light extent in the state. The maximum radiance recorded in the years 2012, 2016, 2019 was 53.3, 67.905 and 232.005 nW/cm<sup>2</sup>/sr respectively (Table 1), but in the year 2020, it was decreased to 61.315. That means around 170.69 nW/cm<sup>2</sup>/sr reduction in the radiance. It was mainly due to the lockdown. From March second week onwards Kerala State went to lockdown. All the socio-economic and business activities were shut off. But overall, in the seven years of

2012 to 2019, there was an increment of 178.705 nW/cm<sup>2</sup>/sr.

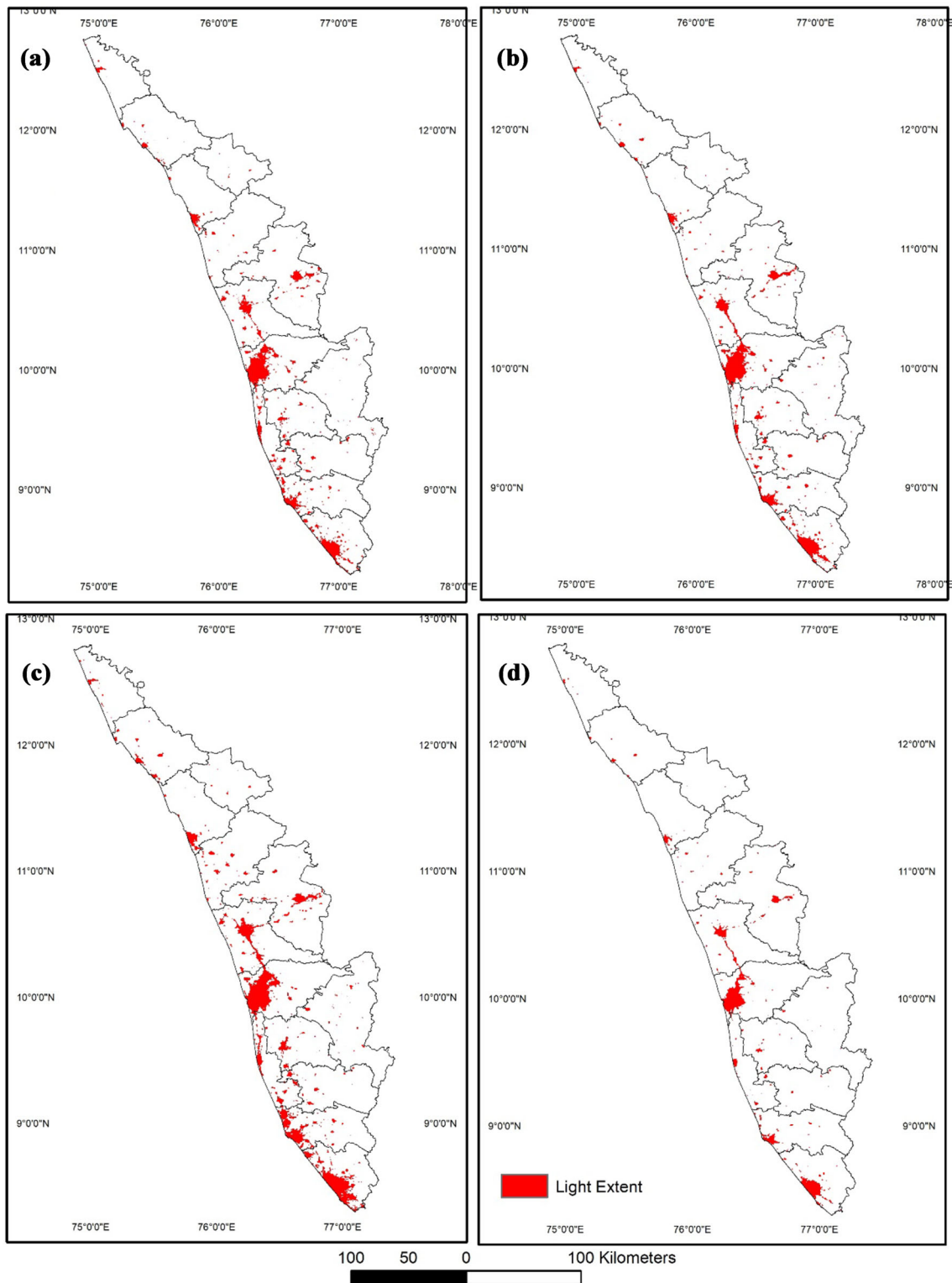
**3.2 Light extent derived from night time bands**

Figure 4 shows the temporal mapping of the light extent of the Kerala state. From this map, it is been clear that the extent of light was increasing from 2012 onwards. Especially the metro city in the central part and the capital city in the southern part of the state were widely urbanized from 2012 to 2019. In the year 2020, it was showing a decreasing trend due to lockdown.

The light extent extracted from the temporal imageries shows that there is an overall increment in the last seven years. In 2012 the light extent was 5.5% of the total state. But it was increased to 9.6% in 2019 subsequently decreased to 7.9%. In 2012 the light extent was calculated spread around 2128.7 sq.km area of the Kerala State. In 2019, the spreading area was increased to 3728.7 sq.km of the state. The spreading of the night-time lighting activity is a clear indicator of urbanisation and socio-economic activities going on in these areas (Table 1, Fig. 7).

**Table 1** Estimation of light extent of various years from ISOCLUSTER analysis

SI. No	Year	Light extent (sq.km)	Area (%)	Radiance (nW/cm <sup>2</sup> /sr)	
				Minimum	Maximum
1	2012	2128.750	5.478	– 0.185	53.300
2	2016	2162.750	5.565	– 0.113	67.905
3	2019	3728.750	9.595	0.041	232.005
4	2020	3063.000	7.882	0.120	61.315



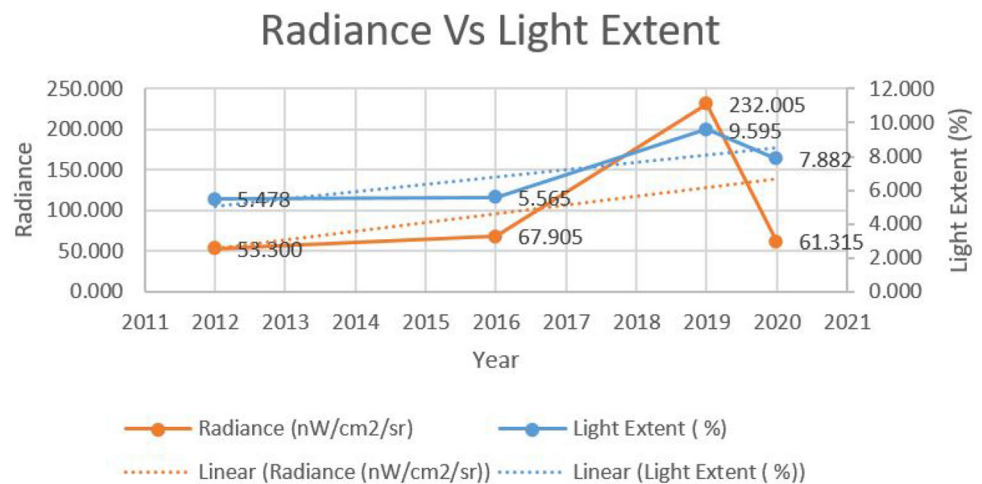
**Fig. 4** Light extent extracted from Night Time bands in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020

Figure 5 shows a positive trend in night time light. Especially in radiance and area percent from 2012 to 2019. In the year 2020, the radiance value was decreased to 61.315 nW/cm<sup>2</sup>/sr. It was due to the major light sources

being halted during the night curfews and lockdown in the state with regards to the COVID-19 global pandemic.

The accuracy was determined from around 100 sampling points across the states through a random selection.

**Fig. 5** Radiance variation over years



The overall accuracy of the ISOCLUSTER classification shows a satisfying output. In 2012 it was 90% and subsequently 92% in 2016, 93% in 2019 and finally 91% in 2020. The estimated Kappa coefficient was 0.89 in 2012 and 0.9 in 2020 (Table 2).

### 3.3 Urban extent derived from night time lights

Based on the threshold technique the study area was classified into 3 categories named urban, non-urban, and transition raster. It is clear that the urban extents were increased from 2012 to 2019. Kochi, the metro city in the state was undergone noticeable urbanization for the past seven years. Similarly, the capital city Thiruvananthapuram, oldest trading port Kollam, cultural capital Thrissur, rice bowl of the state Palakkad, coastal city and spice trade center Kozhikode were shown a fast-growing trend towards urbanization. Due to the lockdown in the year 2020, there was a serious decrement in radiance due to the absence of light sources so that the estimation of urban areas from the light extent shows significant changes in the mapping from the past years (Fig. 6).

The extraction of large urban regions and the fast-growing cities in the states are mapped in a temporal manner. Major cities like Thiruvananthapuram, Kollam, Kochi, Thrissur, Palakkad, and Kozhikode were clearly

shown on the map (Figs. 9, 10). The present resolution of VIIRS-DNB is capable to map large cities or areas having a minimum of 0.25 sq.km. So, many of the emerging urban areas are unable to be extracted from the imagery.

### 3.4 Major cities in Kerala state at night-time lights

The temporal changes in urban expansion of the major cities in the Kerala state are shown in the below figures.

Almost all cities were expanded in 2019 compared to 2012. Kochi Corporation and Thiruvananthapuram Corporation areas showed a significant and noticeable expansion. Similarly, Kozhikode and Palakkad were shown the same trend. The lockdown affected all the cities in the year 2020 (Figs. 7, 8).

### 3.5 Fast growing district in Kerala—Kollam—at night-time lights

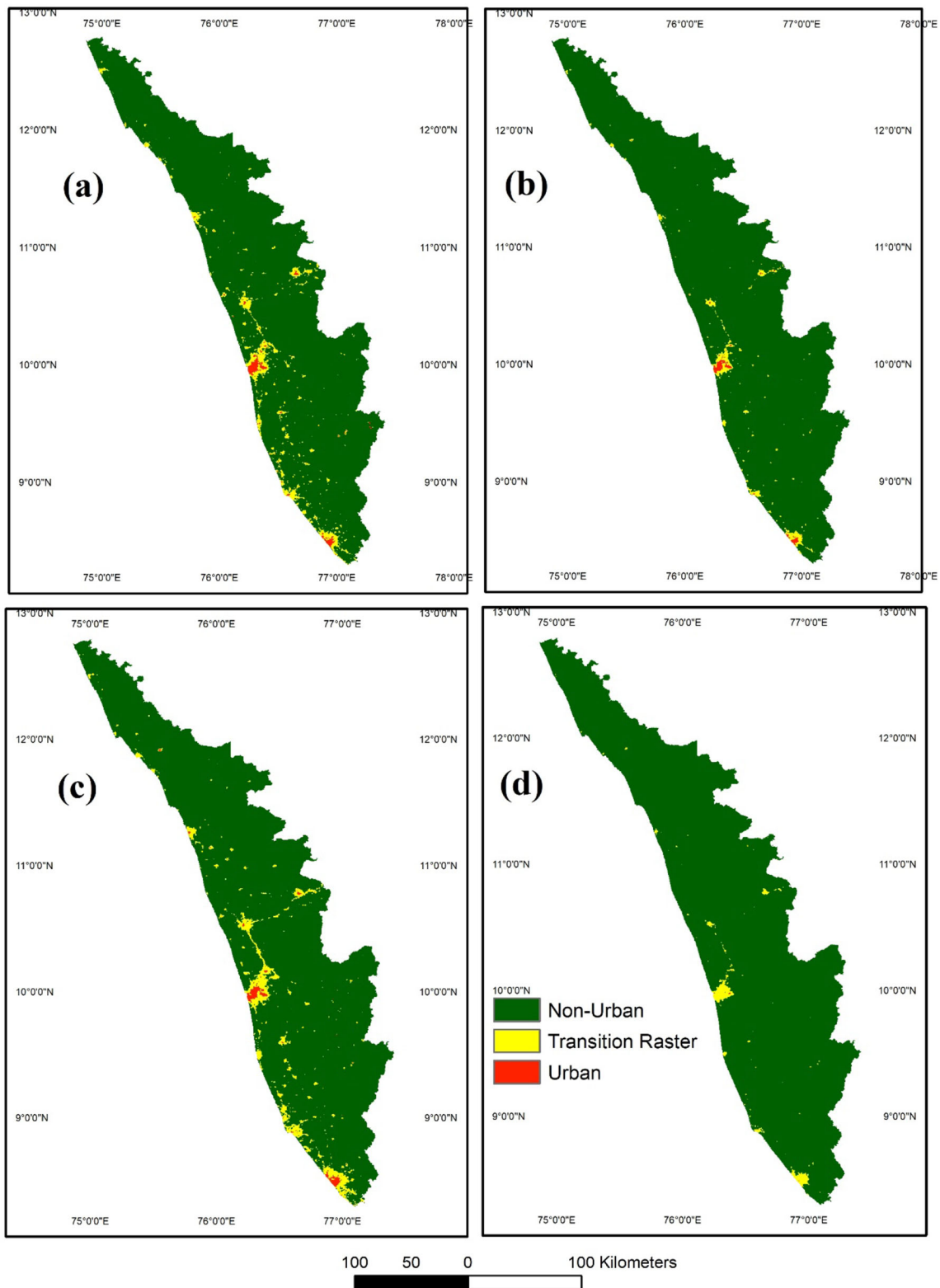
Kollam one of the fast-growing districts in the Kerala state considered as a case study here. It lies between the latitudes 8°45' to 9°10' N and longitudes 76°25'E to 77°15'E. As per the 2011 census, around 2.6 million was the population here and consists of 2487 sq.km area. It is a port city in South India and diverse with rolling plains, jewelled lakes, rivers, mountains, sea, urban features, and also the dense forest. Human actions and social interactions in urban areas result in larger radiance values in NTL data in related pixels than in the neighbouring non-urban extents [34]. The spatial distribution of the urban region clearly shows drastic urbanization that happened in the district from the 2012 to 2019 period (Fig. 9).

Punalur, Kottarakkara, and Karunagappally are the major sub-urban spots in the district. Among these three municipalities, Karunagappally Municipality shows drastic changes in urbanisation. The Karunagappally municipality

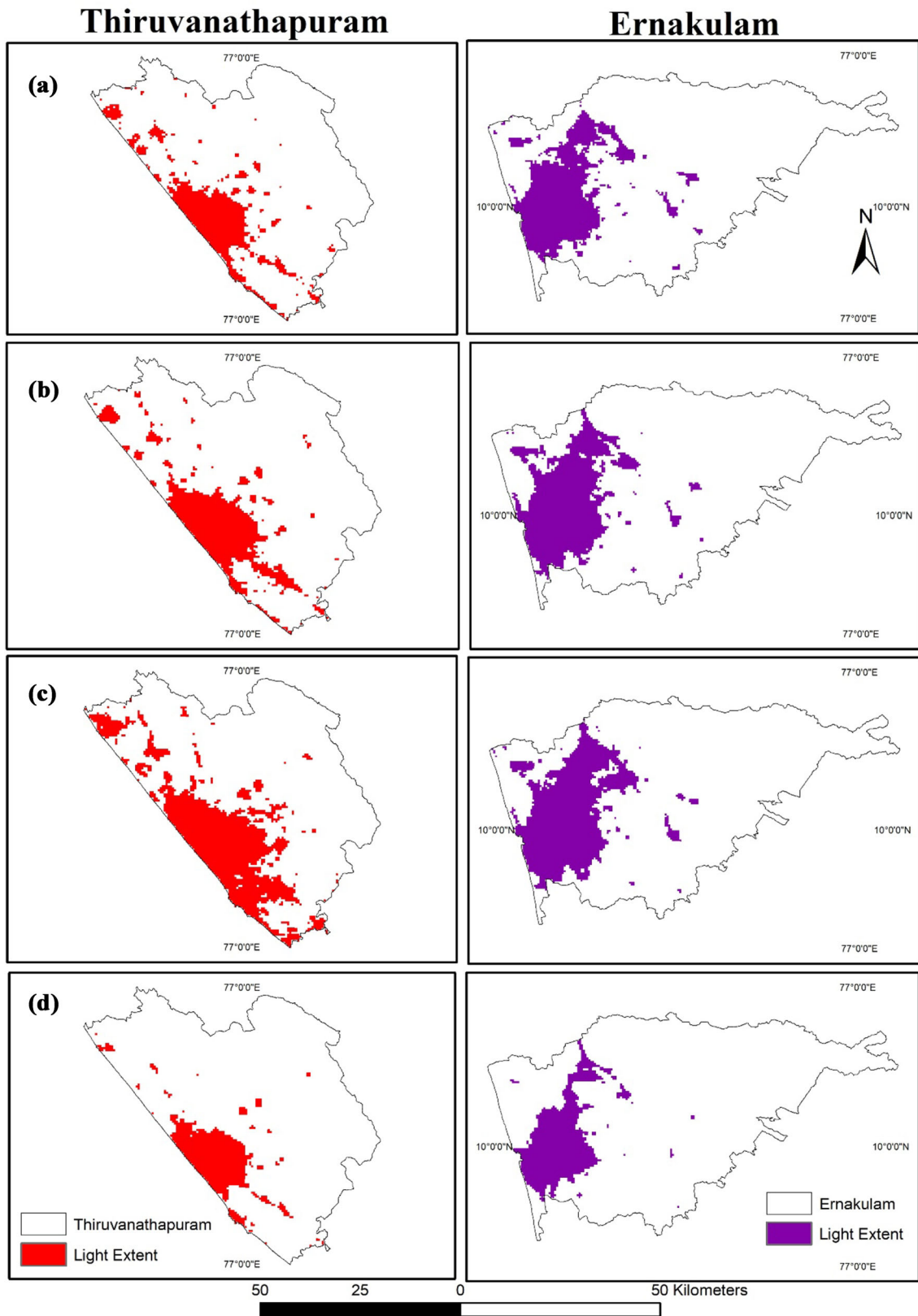
**Table 2** Accuracy assessment of ISOCLUSTER analysis

Year	Overall accuracy (%)	Kappa co-efficient
2012	90	0.89
2016	92	0.91
2019	93	0.92
2020	91	0.90

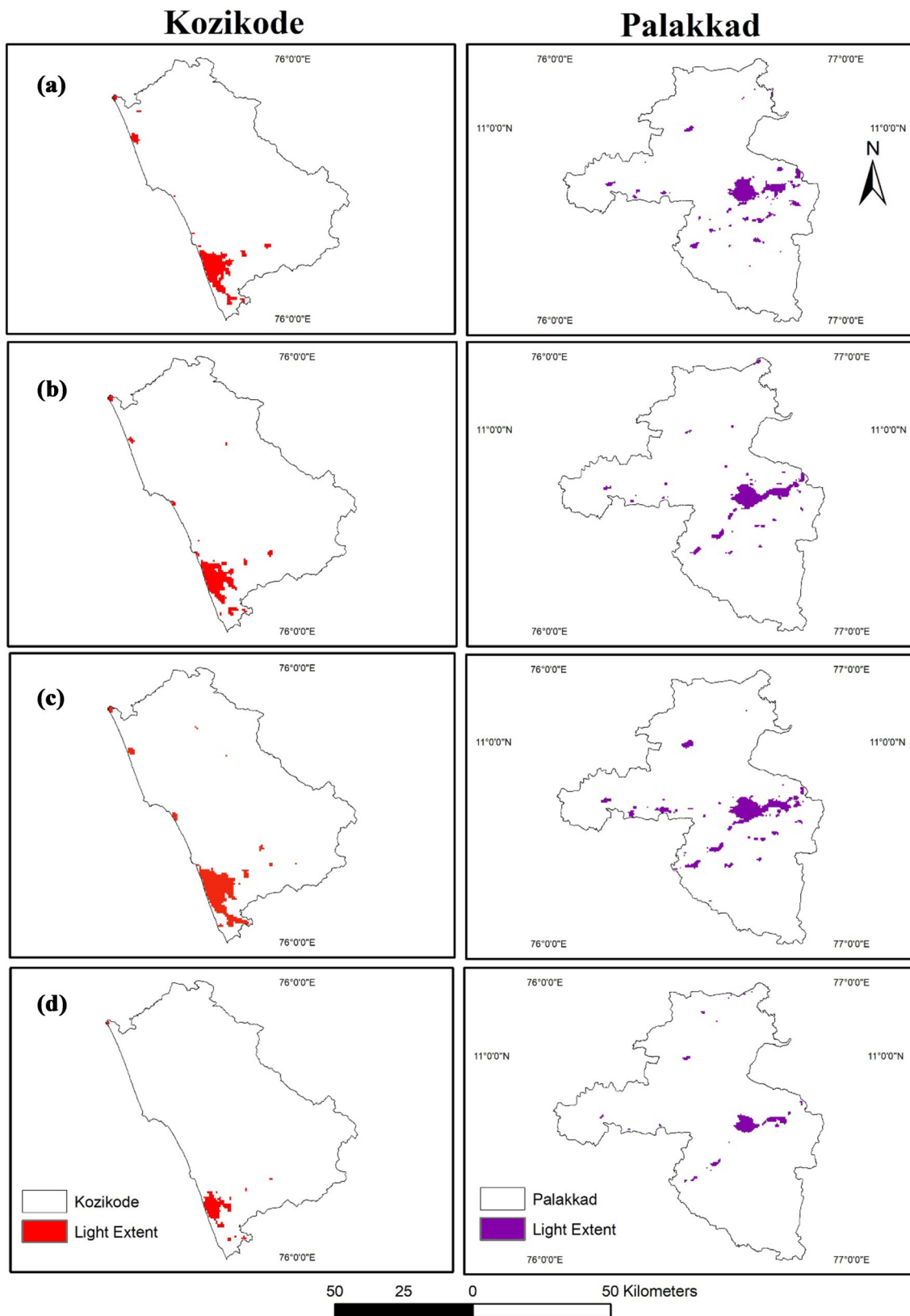




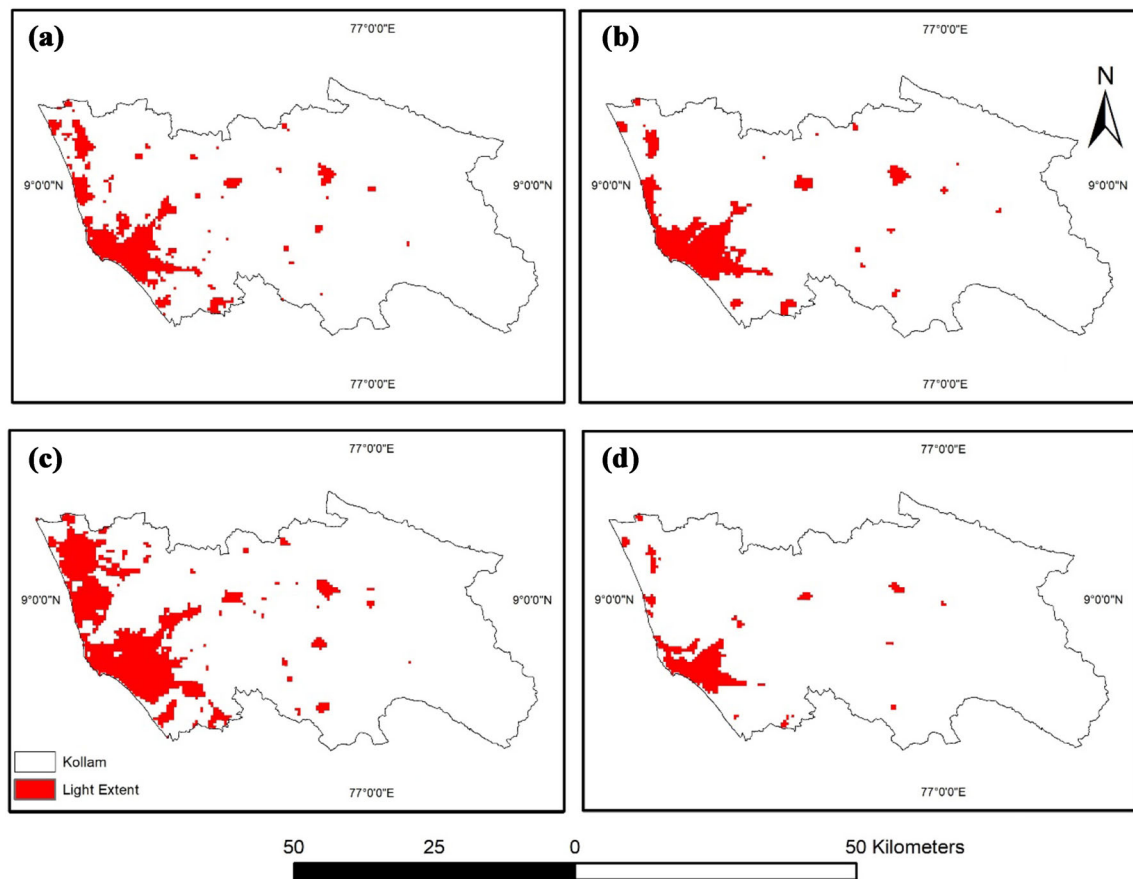
**Fig. 6** Urban and non-urban extraction using thresholding in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020



**Fig. 7** Light extent of major cities in Kerala State (Thiruvananthapuram & Ernakulam) from Night-Time Lights in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020



**Fig. 8** Light extent of major cities in Kerala State (Kozikode & Palakkad) from Night-Time Lights in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020



**Fig. 9** Urban sprawl mapping using light extent from NTL in Kollam District in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020

consists of a 17.64 sq.km area. So, very few pixels in the VIIRS-DNB are covered within the municipality.

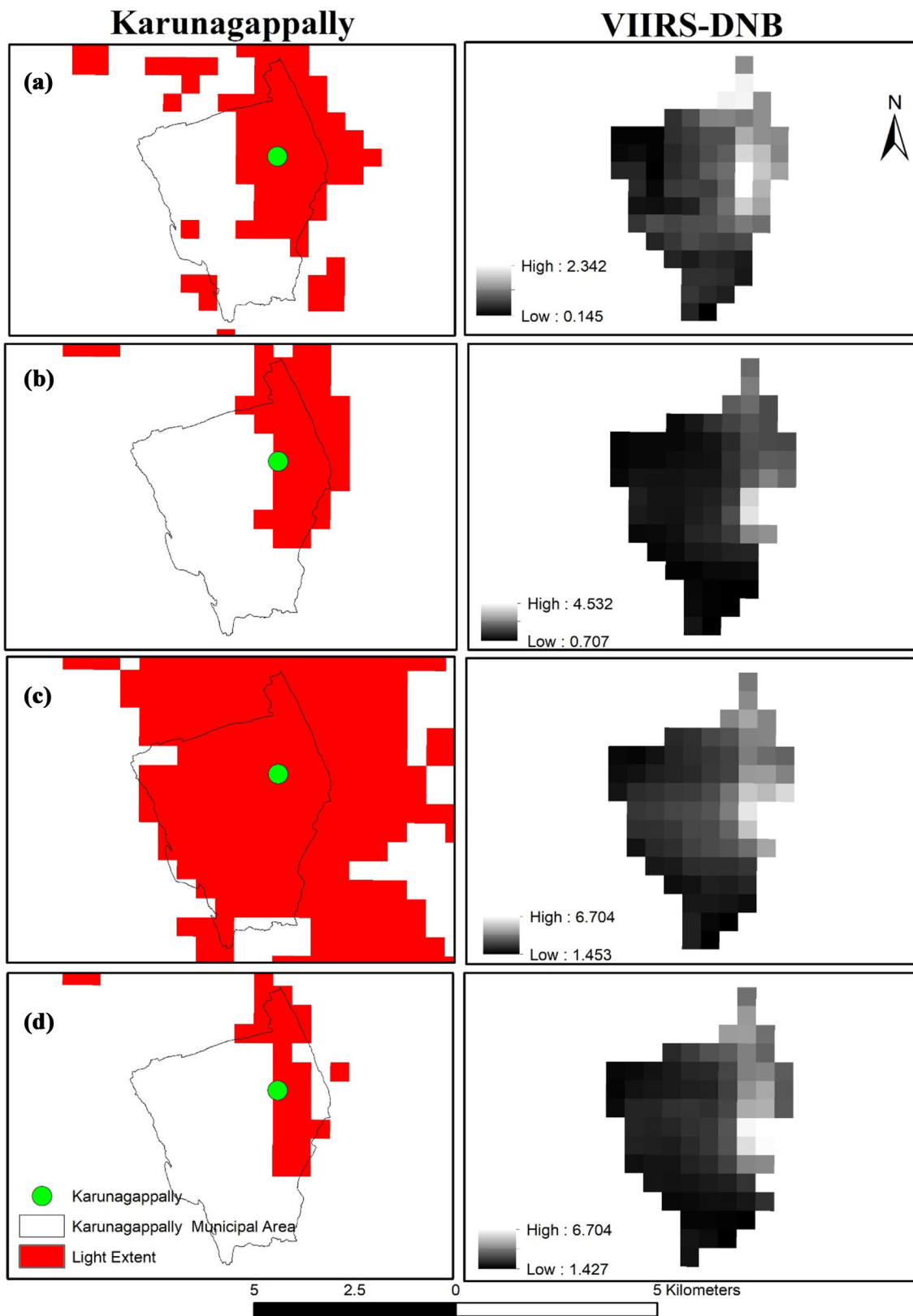
### 3.6 Expansion of municipal areas—case study of Karunagappally

The Karunagappally municipality is located in Karunagappally taluk of Kollam district in Kerala, South West India is considered for the study. It is situated 27 km north of Kollam City and 60 km south of Alappuzha City. Geographically this municipality area lies between  $76^{\circ}30'E$   $9^{\circ}1'N$  and  $76^{\circ}33'E$   $9^{\circ}5'N$  (Fig. 1). The municipality is bounded by Kulashkarapuram Grama Panchayat in the North, Panmana Grama Panchayat in the South, Thodiyoor Grama Panchayat in the East, and Alappad Grama Panchayat in the west. Ochira, Chavara, and Thodiyoor are the nearest towns. The southern boundary of the municipality touches the Pallikal River and the western side is covered by the Travancore–Shornanur (TS) canal (Water Transportation System). The canal and river system is a part of the urban center, Karunagappally. These areas were undergoing rapid urban growth due to the increased number of economic activities and developments over the

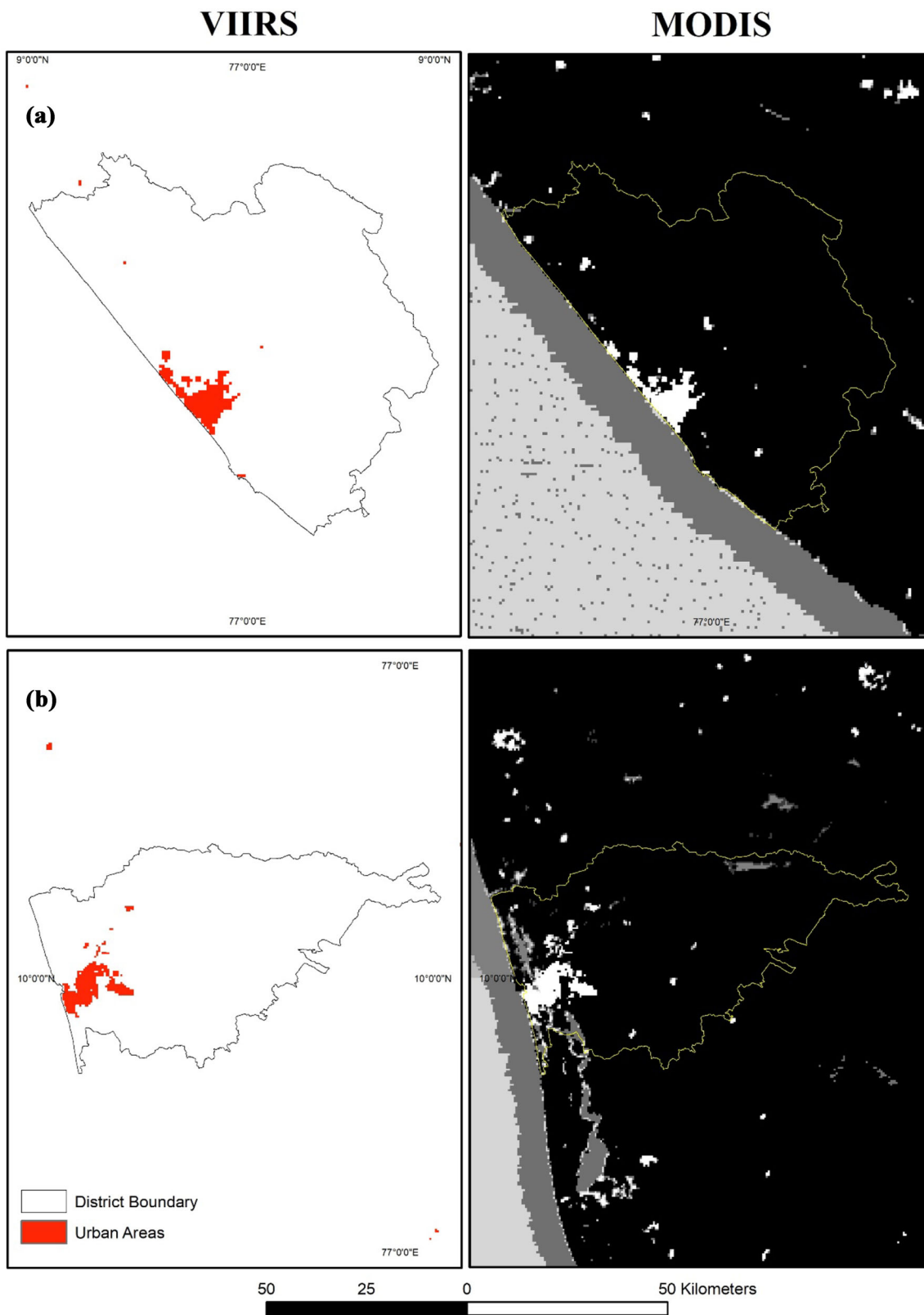
years. On a detailed Scopus survey, it was noticed that no studies related to the impact of urbanization in the Karunagappally region have not yet been published. Figure 10 shows in 2012 the municipal boundary was covered with very few pixels. But in the year 2019, the majority of the municipal area was covered with urban pixels.

### 3.7 Validation

The validation of urban region extracted from VIIRS-DNB was compared with MODIS land cover product. Both are 500 m pixel resolution. The capital city and metro city in the state were used for validation. Kochi, the metro city located in the central part of the state. But Thiruvananthapuram is the capital city located in the southern part of the state. In 2012 Thiruvananthapuram was taken for validation. In 2019 the comparison was conducted at Kochi. The result is shown in Fig. 11, from this figure it is clear that the extracted urban region almost matched with respective years of the MODIS land cover product.



**Fig. 10** Expansion of Municipal Areas using light extent—Eg. Karunagappally Municipality in the years **a** 2012, **b** 2016, **c** 2019 and **d** 2020



**Fig. 11** Validation of VIIRS and MODIS data in the years **a** 2012 (Thiruvananthapuram) and **b** 2019 Kochi

### 3.8 Effects of lockdown

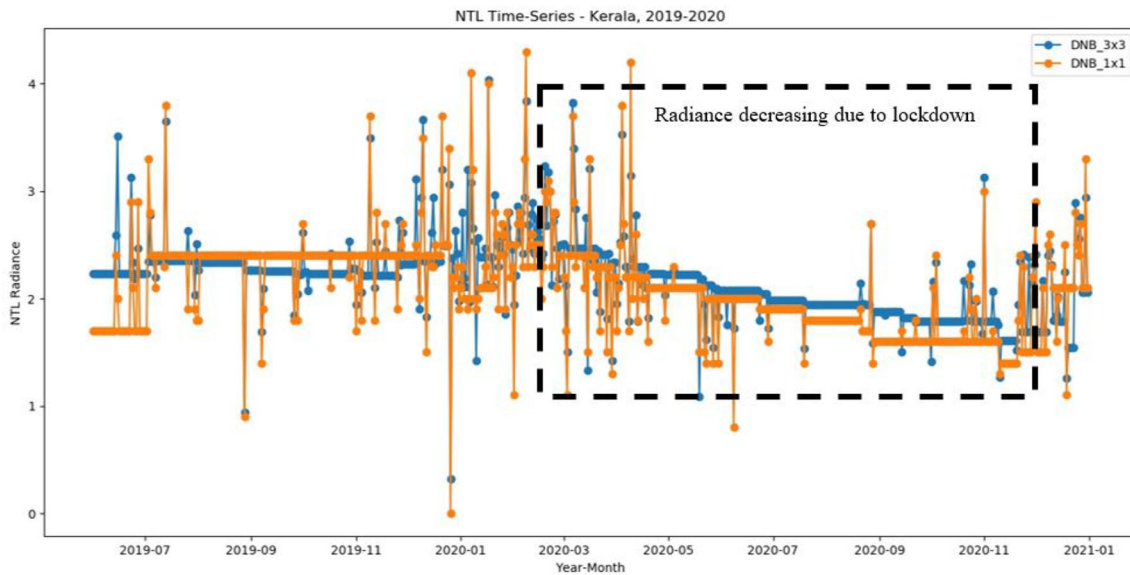
The incidence of the COVID-19 virus is reported in Wuhan, China in December 2019. COVID-19 has infested over 5.5 million people across the world and approximately 3, 50,000 deaths were reported from different parts of the world. The World Health Organization (WHO) declared coronavirus a pandemic due to the extensive scale of the outbreak and also observed this as one of the worst global crises since World War II [35]. The US, Brazil, Russia, Spain, and India are the five most affected counties in the world regarding the number of confirmed cases and are affecting territories and about 210 countries across the globe. The virus spread quickly from one person to another through direct contact, coughs, respiratory droplets sneezes, and even talks. It also gets spread by touching a surface or object that the infected patient touches. Meanwhile, no medicine has been discovered to prevent the spread of the deadly disease. As a part of the control of the spread of COVID -19, the WHO and governmental bodies across the world demanded people for practicing social distancing, avoid community gatherings, functions, transportation, and practice complete lockdown. Almost all countries urged people to stay at their homes, almost all industries, educational institutions, businesses, offices were shut down, both international and national travels were suspended and people started working from home [36–40]. The whole world stands still around the globe since March 2020. Due to the complete shutdown in connection with the infestation of the deadly coronavirus around the globe, industrial activities are curtailed throughout the world. As the industrial emissions and other anthropogenic activities are limited the pollution load was decreased. Most of the studies related to the pollution load and emissions after the lockdown period shows depreciation in the deleterious emissions and improvement in the environmental quality in different parts of the world [41, 42]. The first confirmed cases of Coronavirus in India reported were reported from three students from Kerala traveling from the Wuhan province of China. It was on the 30th of January 2020. The Government of Kerala declared a 'state calamity warning' immediately after the detection of positive cases in the state. Almost 3000 contacts of the affected individuals were undergone for a complete quarantine, out of which 45 were placed in hospital quarantine. On 2020 March 21st the state undergoes a lockdown together with the other states of India after the Prime Minister declared the emergency on the night of 20th March 2020. Usual life including transportation, industries, and business, etc. was affected much before the national lockdown in Kerala. The state is well connected with the public transportation system especially diesel-powered vehicles that have closed completely. So that one of the sources of urban lighting was

completely halted especially the metros and the major cities of the state.

The time-series graph was generated from 580 Black Marble-VNP46A2 daily datasets from 1st June 2019 to 31st December 2020 and this proved that the radiance values decreased from 21st March 2020 onwards. It was due to the lockdown started in the Kerala state. In February 2020 the maximum radiance was more than  $4.5\text{ nW/cm}^2/\text{sr}$ . During the lockdown period, it dropped down around  $0.5\text{ nW/cm}^2/\text{sr}$  (Fig. 12). During this time all the socio-economic activities were shut off all over India and almost all sources of lights were halted especially in the urban areas. The time series generated in  $3 \times 3$  pixels window-based is smoother compared to a single ( $1 \times 1$ ) pixel-based time series generated from the daily composites (Fig. 12). This study demonstrated the far-reaching effects and implications of the COVID-19 lockdown on Night Time Lights (NTL), even on less urbanized and less industrialized regions.

## 4 Conclusions

Kerala is one of the major Indian states experiencing rapid urbanization from the last decade. This is due to the anthropogenically induced land cover/land use changes mainly owing to the conversion of natural landscapes into built terrains. This conversion responsible for increasing the consumption of mortar and cement has modified the thermal characteristics of the urban area which is connected with near-ground anthropogenic, resulting in the increment in fast urbanisation and increment in night-time lights compared to the surrounding semi-urban areas. The present study was carried out with the primary objective of finding the urban extents of Kerala, a rapidly growing state in southwest India with the help of night-time lights. The behaviour of the urban systems can be easily detected by the extraction of the Night-Time Lights data. From this investigation, it is observed that the degree of urbanization and level is relatively high in the state from the past decades. The majority of the land consists of high-end buildings, commercial, non-commercial and corporate establishments. From this study, it is observed that during 2012–2019, major cities in the Kerala state have been tending to large light extents. Especially in the metro and the capital cities. It shows a noticeable increment of socio-economic activities happening in the night times in the urban regions. Through this dataset, it could identify the urban sprawl in the large cities in the state. The urban sprawl of the study area mainly concentrates on the outskirts of the NH-66 passing through it. The urban sprawl pattern adds a slight change in the characteristics of the study area and its landscape. The values of radiance and



**Fig. 12** Time series generation from Black Marble—day night bands

light extent show a positive trend in the study area from 2012 to 2019 subsequently show a decreasing trend in the year 2020 due to the lockdown followed by the Global COVID pandemic. Based on the investigation of this study, high-resolution night-time data is helpful for the study and enhances the accuracy of future research work especially in the domain of spatial population, urban sprawl, etc. The major limitations of this study are that the lack of higher spatial and radiometric resolutions, the sensors could not detect the small urban expansions and light sources. Typically, the VIIRS-DNB operates in the range of 0.5–0.9  $\mu\text{m}$  range so that the detection of light produced by the initial part of the Light Emitting Diode (LED) spectrum is not recognized by the present VIIRS-DNB sensor array. Normally the LED operates in ultraviolet, visible, and infrared regions of the electromagnetic spectrum. The operating wavelength range of commercially available LEDs with a single-element output power of at least 5 mW is 275 nm (0.275 Micrometer) to 950 nm (0.95 Micrometer).

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#### Declaration

**Conflict of Interest** The authors declare that they have no conflict of interest.

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