UTILISING VIIRS DNB NIGHTTIME LIGHT DATA TOGETHER WITH LANDSAT DAYTIME DATA TO ASSESS CHANGES IN LIGHT POLLUTION IN ETHEKWINI METROPOLITAN MUNICIPALITY (EMM)

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KEYWORDS: Light pollution, NTL data, Night-time imagery, artificial light, VIIRS DNB, urban area

ABSTRACT:

Night-time light (NTL) data has become widely used in different studies, including urbanization and light pollution subjects. Some sources of NTL data have made the data freely available on online platforms, making it easy to study subjects that relate to the use of artificial light at night. African countries have not published much on the use of NTL data. Still, there has been a development in different countries in the continent, such as economic growth and the provision of new and improved infrastructure. These developments can be considered primary contributors to the increase in light pollution worldwide. This study aimed at using NTL data together with familiar daytime data to assess how light pollution has been changing in eThekwini Metropolitan Municipality and again assess the changes in the sources of light pollution through the assessment of Land-use Land-cover (LULC) change of the study area. NTL images were reclassified into five different classes of light pollution using the reclassification tool in ArcMap 10.7. Supervised classification was performed to assess the changes in LULC. The confusion/error matrix was done to verify the accuracy of these classifications. These showed that light pollution is increasing in eThekwini Metropolitan Municipality, with the increased built-up area also being witnessed. NTL data is becoming useful worldwide, and it is highly recommended for African countries also to do research using this data in their studies

1. INTRODUCTION

Economic development and urbanization are significant contributors to the effect of light pollution rising as an environmental issue. When a country or region grows economically, there will be a rise in light pollution occurring in that area (Jiang, 2017). Light pollution can disturb the observance of the beautiful night sky, obstruct small astronomic objects, and disrupt the regular routines of a human body. Prastyo and Herdiwijaya (2019) did a study in 2019 investigating light pollution in different areas such as Asia, Europe, and North America. Their study's findings concluded that light pollution is a global environmental issue (Prastyo and Herdiwijaya, 2019).

Night-time light (NTL) remote sensing is the best option for studying human activities and their effect on the environment. Using NTL mainly focuses on human activities at night, allowing those activities to be easily alluded to and understood better than they can be done using daytime data. This is because the use of artificial light at night can only be effectively detected at night. This type of light is advantageous in detecting human activities on the ground (Levin, 2019).

Light pollution is becoming a world challenge as it seems to be growing over the years concerning the developments around the world. To study light pollution effectively, we need to use the night-time light data (NTL), which is data that is collected at night-time. This is used because light sources can be effectively detected at night rather than during the day—this is where the remote sensing of night-time light comes in handy (Levin, 2019). According to Elvidge et al. (2013), night-time light data is part of remote sensing data obtained by observing the existence of artificial lights on the earth's surface.

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The NTL data sources are becoming abundant over the years. Different NTL data sources make the NTL data available online. Some online platforms make the data freely available while selling commercially on other platforms. The most common data sources with freely accessible NTL data (non-commercial) are the Defence Meteorological Satellite Program's Operational Line-scan System (DMSP-OLS), the Suomi National Polar Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS). The International Space Station (ISS) also has night-time lights available for free. Still, they are not calibrated, meaning their information may be incorrect and need to be corrected before use. The ISS provides astronaut satellite imageries from different regions worldwide (Zhao, 2019). Night-time light data can only be monitored by a satellite sensor with spectral bands that can collect low light imaging data from different sources on the earth's surface, such as artificial light. Night-time light remote sensing is gaining more recognition as a focal point in many research areas, especially natural and social sciences (Li, 2017).

It is stated in the publication by Elvidge et al. (2013) that VIIRS DNB night light imagery is better than the DMSP-OLS imagery. They said that the VIIRS reduces the pixel footprint (ground instantaneous field of view (GIFOV)), it has a finer spatial resolution of 742m. It also has a finer quantization and in-flight or on-board calibration of data which makes the data from the VIIRS satellite superior to the data from the DMSP satellite. The low-light imaging data is filtered to produce high-quality night-time light data. The low-quality data is excluded from the final product by calibrating the satellite sensor steps. This will give out the radiance product that will have zero or null where there was no lighting detected in the area on the surface.

VIIR has 22 bands, but it uses the Day-Night Band (DNB) for night-time light data collection. The DNB can detect low lights better than the OLS. The DNB detection of clouds and high albedo is collected without the moonlight, whereas in OLS, clouds and high albedo features are not captured when there is little or no moonlight (Elvidge et al., 2013).

VIRRS DNB can capture bright scene features with the help of nocturnal airglow from the ionosphere with an extremely low illumination source. VIIRS can detect significantly dimmer lighting on the earth's surface. But it is difficult to extract the dim lighting from the image because of the bright lighting from the bright albedo surface, such as the lakebeds, ice, and snow. More remedies for the challenges with the VIIRS DNB data make it better than the DMSP-OLS data. Both the DMSP-OLS and the Suomi NPP VIIRS DNB are capable of detecting low light imaging data. Still, the difference between the two sensors is that VIIRS DNB data is more improved than the DMSP as it has a better spatial resolution. It is calibrated on board, and its spectral bands are single capable of differentiating between light emissions for thermal sources and electric sources (Elvidge et al., 2013).

The above stated properties of the two NTL data sources has prompted for this study to conduct the research using the VIIRS DNB NTL data for better quality results. Even previous studies supported the use of VIIRS data over the DMSP (Elvidge et al., 2013). The VIIRS NDB NTL imageries used in this study were downloaded from the National Oceanic and Atmospheric Administration (NOAA) website found in the following link http://payneinstitute.mines.edu/eog/. This type of data can be used to study different subjects depending on the of the researcher and the region it is being used on and in this study it was used to study light pollution but it also important to explore some of the studies that can be studied using NTL as done on the next paragraphs.

NTL remote sensing also assists in having more knowledge about energy consumption and greenhouse gas emissions. It is essential because it will assist in the law-making process, such as climate change and carbon reduction laws. In the paper published by Zhao et al. (2019), it was mentioned that Elvidge et al. (2013) and Doll (2008) in the mid-1990s did studies that proved a strong relationship between the data derived from the DMSP-OLS and the electric power consumption and the carbon dioxide emission. Zhao, 2019 also included in their paper a proposition of studies that can be done relating to energy consumption and greenhouse gases using night-time light data. The studies they proposed focused on mapping the spatial distribution of the electric power consumption and the carbon dioxide emissions starting from global to local scales. Another was to explore the spatiotemporal dynamics of the electric power consumption and the greenhouse gas emission using the night-time light data. Amaral (2005, for example, did a study that estimated the electric power consumption in Brazil. Using the modified invariant region (MIR) method, they derived the lit areas at the municipal level by inter-calibrating the global night-time light scenes via the MIR method.

Light pollution is also studied using NTL data. In this case light pollution was the main focus of the study. Looking at the background of light pollution. Artificial lights were introduced for humans to adapt to the night environment and live and work in it. Light pollution has been growing over the years since the industrial revolution came into effect with the industrial civilization. This has made it a problem realized by many researchers and experienced by many people worldwide, meaning it is something researchers need to look at to avoid more of its negative impacts on the people and the environment (Coetzee, 2019). Barentine (2019) said that the remote sensing observations made over time have proven that most of the world's population lives in areas affected by light pollution. Light pollution is caused by the artificial light sources used at night, such as streetlights, fluorescent markers, advertising billboards, commercial lights, decorative lights from yards, and many other sources. It comes in different forms, including sky glow, glare, light trespass, and clutter. Sky glow is the most common type of light pollution.

Katz (2016) did a study to quantify light pollution in Jerusalem where he performed a comparative analysis between the field measurements and the EROS-B imagery. The research measured night-time lights using the Sky Quality Meter (SQM) devices, and the light measurements at night were done from space by the EROS-B imagery. It was discovered from this research that mainly; bright areas are mostly located in areas where there is less vegetation. He proposed a need to understand light pollution at the local level and look into how it changes. Adelabu and Olusola (2021) stated that the application of NTL data in African countries is still lacking. In contrast, other international and developed countries, such as the United States of America, are improving when applying the use of NTL data in their research.

In trying to bridge the gap that the African region is facing when it comes to using NTL data, a study was conducted by Mncube et al. (2021). The study assumes that light pollution is affected by the land use land cover (LULC) changes that the region faces over time, with LULC having to be part of the sources of NTL. The study aimed at using NTL data together with familiar daytime data to assess how light pollution has been changing in eThekwini Metropolitan Municipality and again assess the changes in the sources of light pollution through the assessment of Land-use Land-cover (LULC) change of the study area. The paper's objective is to assess the changes in light pollution and its sources (LULC) in eThekwini Metropolitan Municipality over eight years (2012 to 2018).

2. METHODOLOGY

This paper forms part of a more extensive study, which comprised three objectives: identifying and quantifying light pollution in eThekwini Metropolitan Municipality, identifying the sources of light pollution in eThekwini Metropolitan Municipality, and the last objective being the one mentioned above that this paper reports on.

The study investigated light pollution and its sources in eThekwini Metropolitan Municipality in KwaZulu-Natal, South Africa.

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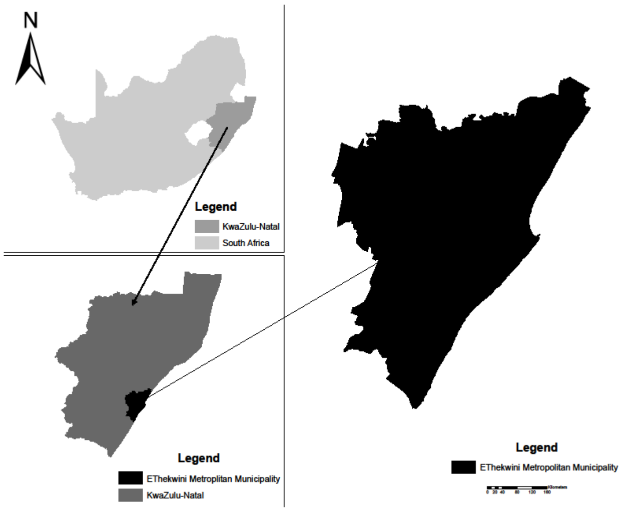

Figure 1 Study area (Mncube et al., 2021)

The study involved the usage of VIIRS DNB NTL data for the reclassification of light pollution into five different classes. The classes of light pollution ranged from very low, low, medium, high to very high light pollution. The data was download for the period of eight years in two-year intervals meaning that the imageries were for the years 2012, 2014, 2016 and 2018. Light pollution was assessed for the four different seasons in each year being summer, autumn, winter and spring. That resulted in each year having four different light pollution maps. These maps were reclassified using the reclassification tool in ArcMap 10.7 with 5 class values adapted from a study done by Prastyo and Herdiwijaya (2019).

To assess the light sources, LULC supervised classification was done using Landsat 7 and Landsat 8 imageries obtained from the USGS Earth Explorer website. These were also downloaded for the same period as the images for NTL, the only difference was that for the Landsat images, only one image was classified for each year. The images were downloaded for the summer time later in the year to allow for coverage of different changes that may have taken place in the year. Supervised classification tool also in ArcMap 10.7 was performed to classify the LULC classes. The classes classified included the commercial areas, recreational areas, built-up areas, vegetation cover, transport facilities and routes. The accuracy of the images was tested using the confusion matrix analysis, which involved assessing the metadata in ArcMap in conjunction with the pivot table in Excel. Needed accuracy percentage for each map needed to be 80% and above (Rwanga, 2017) of which all the maps met his standard and they were accepted to be used further in the analysis of results.

After the accuracy of all the maps was done and accepted, the change detection analysis was done to assess the changes in light pollution and the changes in light pollution sources (LULC change) over the years. Change in light pollution was evaluated by assessing the change in the area of each of the five classes of light pollution. The change in each light pollution class, whether it decreases or increases attributed to changes in light intensity in the area. For the area covered by each light pollution class to be devised, the classified maps were converted to polygons using the ArcMap conversion tools. These were then dissolved to get the shape are according to ArcMap. The created shape area was used to calculate the area in hectares covered by each light pollution class. This was done using the calculate geometry tool found on the attribute table of each feature file in ArcMap. The area was calculated using the compute area tool in ArcMap. The changes were investigated by subtracting the area of a later year from the area of the earlier year. The data obtained in the attribute table while doing these calculations was copied to the Excel worksheet. All the needed calculations were performed in excel, and the graphs were produced. This assisted in showing where and how much did the change occur. The same procedure was followed to assess change in the light pollution sources, which are the LULC classes. The maps from different consecutive years were compared to each other to see where the changes were located and how intense they were.

For the changes in light pollution sources, the changes in LULC classes were assessed using the calculations of the area covered by each LULC class and investigating the changes where each class changed to the next class. The changes in light pollution were assessed by looking at the change in the area covered by a class of light pollution, meaning the change in intensity over different regions of the eThekwini Metropolitan Municipality. Another change was that of the causes of the light pollution, where the LULC change was analysed. The data used in this analysis is the maps produced when the light pollution and the sources were investigated in the previous study. These maps showed the location of each class of pollution from very low to very high, and the others showed the dominant LULCs in the municipality.

Map intersection was done to show the shift in the area of each class of light pollution. The maps produced from the night-time light images were done by comparing the analysed maps to the ground truth points. This process is called the conventional approach to accuracy assessment. This was done by verifying the occurrence of light sources where the light pollution was classified as very high in the maps and checking the dominant land-use or land-cover dominant in the area. The changes in light pollution each year in different seasons were also investigated using the changes in the area of the coverage of the light pollution classes. This was done using the area in hectares calculated for each of the classes of light pollution concerning each season and year.

2.1 Study Limitations

Conducting this study in the middle of the pandemic has been such an obstacle. We were on lockdown; therefore, we could not access the University campus and the needed resources, which delayed data collection and analysis. Also, data availability was a hindrance because the initial plan was for the study period from 2012 to 2020, but because the data for 2019 and 2020 was not available, it had to end in 2018. Having limited information on the analysis of night-time light data was also a constraint during the study because there was a need to go deeper into understanding the subject under study, but the information on analysis limited me. Another constraint was the Covid-19 pandemic at the beginning of the study. It resulted in many omissions in the data collection. Field data collection could not be done physically, but I was forced to do it remotely, which may have missed some of the prominent and current factors of the study area.

This contribution has been peer-reviewed.
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3. RESULTS

3.1 Results of Change in Light Pollution

Light pollution changes have been analysed from the reclassification done in ArcMap 10.7. These maps can be seen in figure 1 to figure 4 below. These maps show the location of different light pollution classes in eThekwini Municipality, grouped for each season in different years of the study period. The colours range from deep red to yellow with deep red being very high light pollution class and yellow being very low light pollution class.

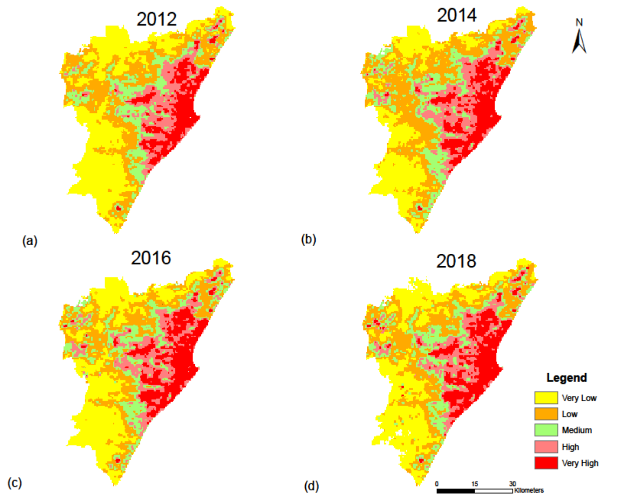

Figure 2. Summer light pollution

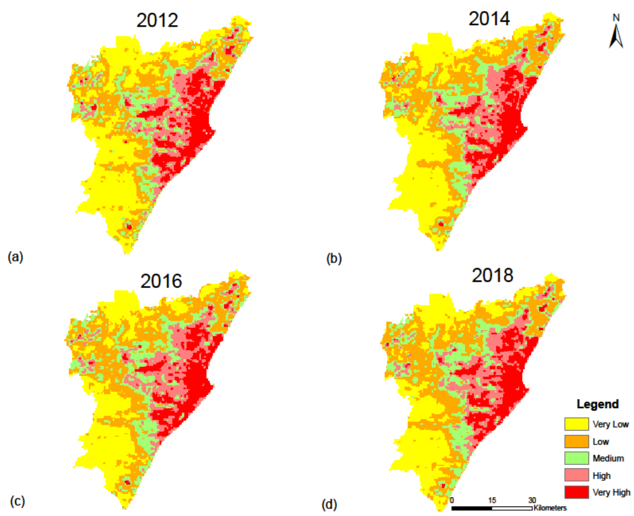

Figure 3. Autumn light pollution

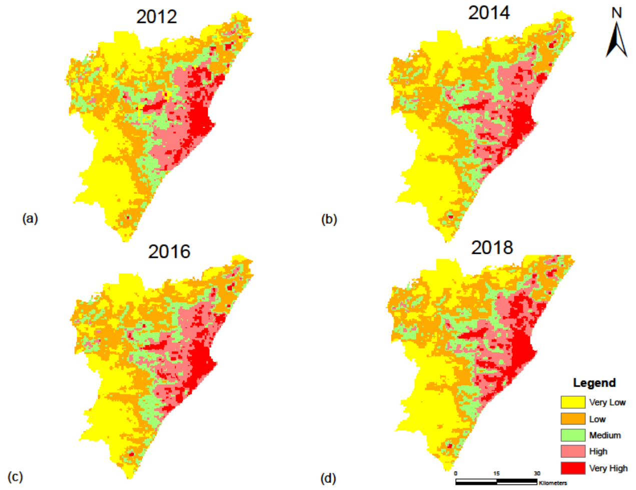

Figure 4. Winter light pollution

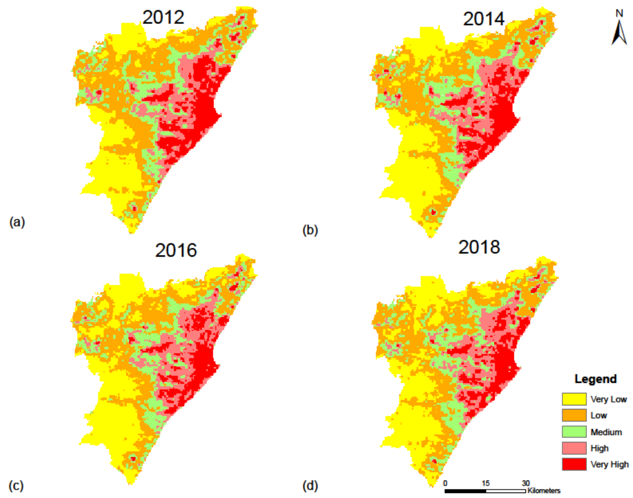

Figure 5. Spring light pollution

Changes from one class to another were investigated, and the results were used to attribute to change in light intensity over the EMM. The results will be presented by using maps and graphs to show where the main changes occurred. The changes were investigated from a year-to-year period rather than from a season-to-season period because that will not allow for effective change in light pollution classes to be seen. Figures 1 to 3 show maps attributing to the changes in light pollution classes. The maps shown below are used to show where the changes in light pollution occurred and also which class of light pollution changed in one year to which class later.

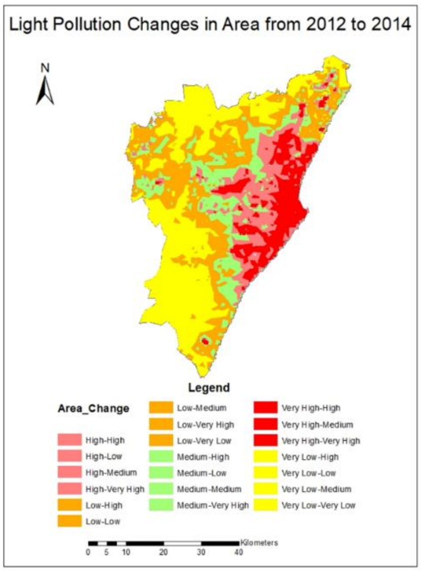

Figure 6. Light pollution changes between 2012 and 2014

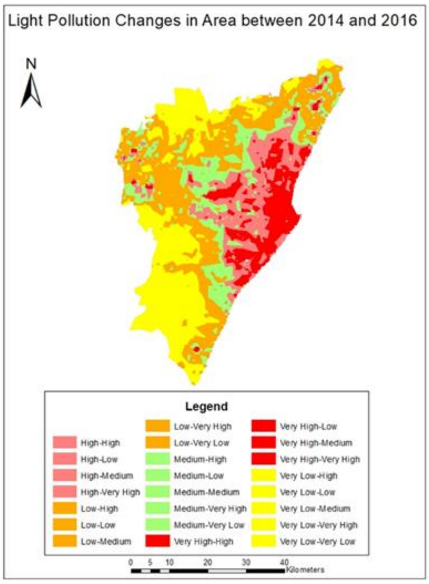

Figure 7. Light pollution changes between 2014 and 2016

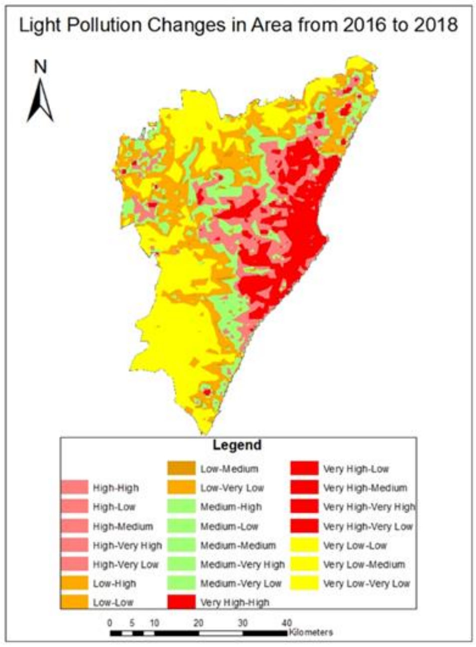

Figure 8. Light pollution changes between 2016 and 2018

The graphs presented below in Figures 4 to 7 highlight the abovementioned results. It shows how many changes have been seen in light pollution over the past eight years. The graphs show the changes in each light pollution class as per season each year. A change from one class to another can be said to show a change in the intensity of the lighting in that area because the more the light is intense, the more there will be light pollution.

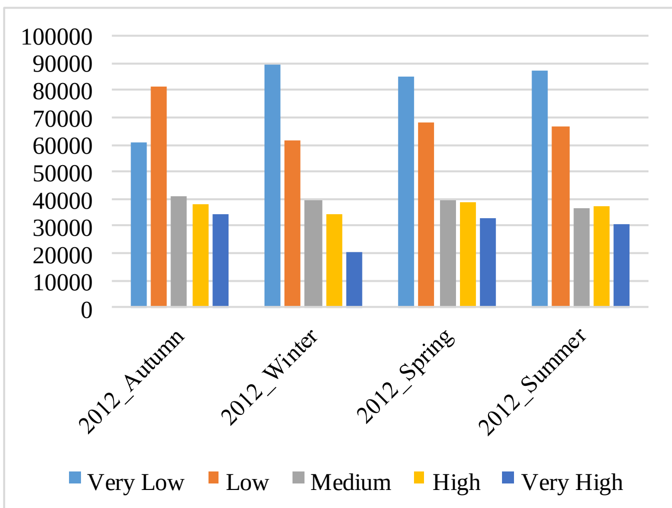

Figure 9. Light pollution changes in 2012

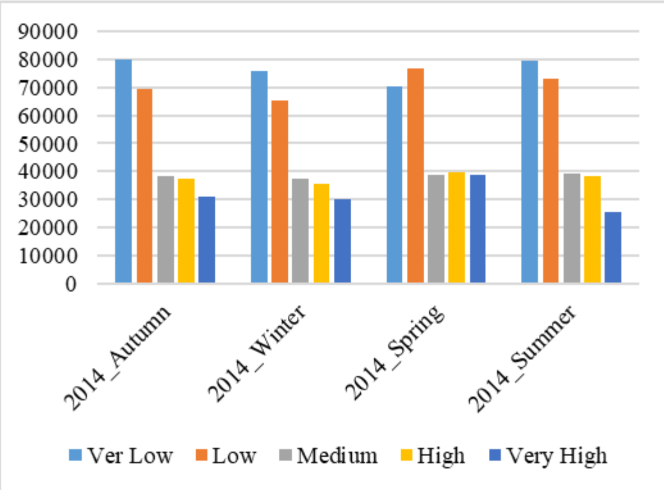

Figure 10. **Light pollution changes in 2014**

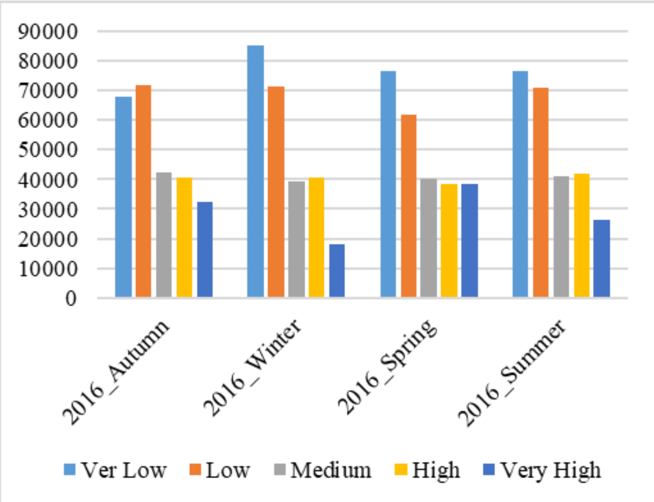

Figure 11. **Light pollution changes in 2016**

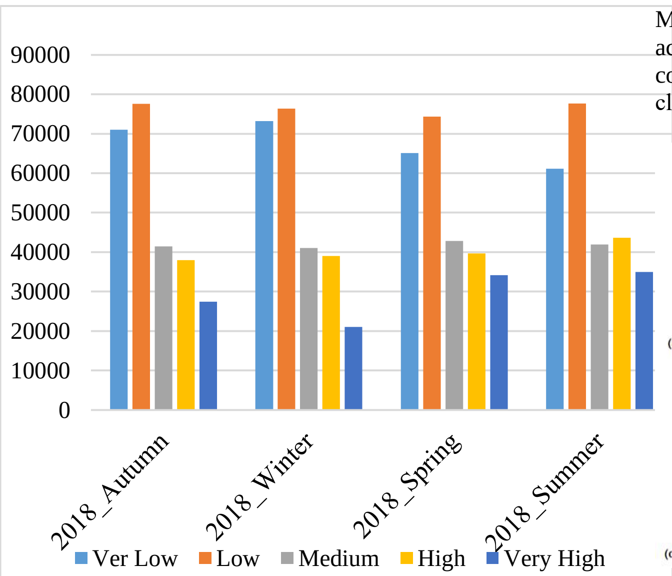

Figure 12. Light pollution changes in 2018

The classes used to investigate the change in light pollution the most were the high and very high classes of light pollution. In Figure 8, there was a fair increase in the high class and an increase in the very high class. This then led to the conclusion that light pollution in EMM is increasing. From the other figures shown, which are maps of change and the bar graphs, it can also be seen that the light pollution is increasing as the area that the very high light pollution class takes up can be seen to be increasing over the years, especially between 2016 and 2018. The area increasing is located mainly around the city centre and residential areas of the municipality.

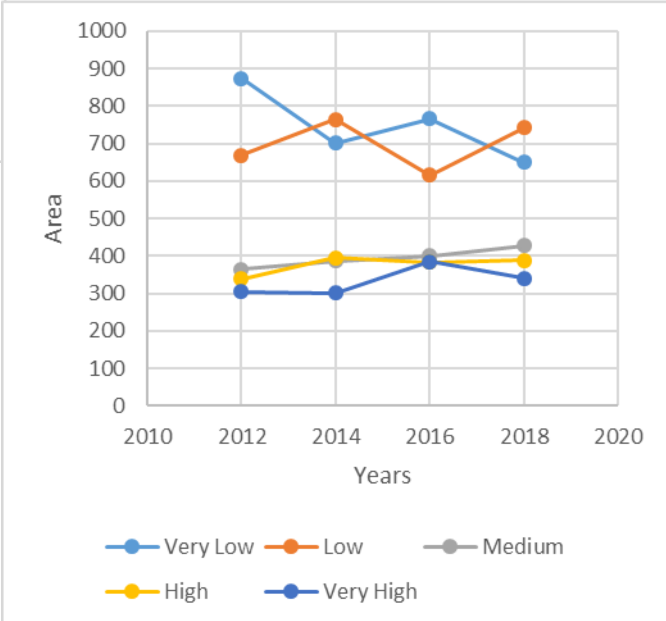

Figure 13. **Light pollution changes from 2012 to 2018**

3.2 Results of Changes in Light Pollution Sources

The changes in light pollution sources were investigated using the changes in LULC of the eThekwini Metropolitan Municipality over the past eight years. The LULC classes have activities in them that need lighting at night; hence they can contribute to light pollution. Figure 13 shows the LULC classes' maps.

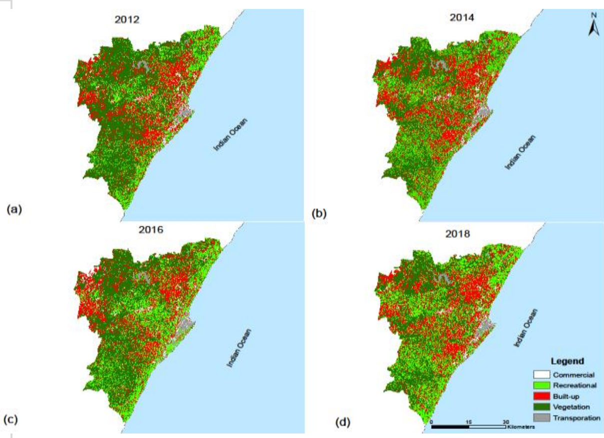

Figure 14. 2012, 2014, 2016, 2018 LULC classes

The changes in these LULC will be shown using the table (Table 1) and a graph (Figure 14) showing the fluctuations in the area covered by each LULC class.

From the graph presented in Figure 14, there was a growth in the built-up area, and the vegetation and recreational classes are decreasing. There was also a slight increase in the commercial class that is also being seen from the graph. This can also be attributed to the percentages of the coverage of each of the classes that are presented in Table 1. The growth and decrease of the aforementioned LULC classes are also seen in the percentages of the different years that were investigated.

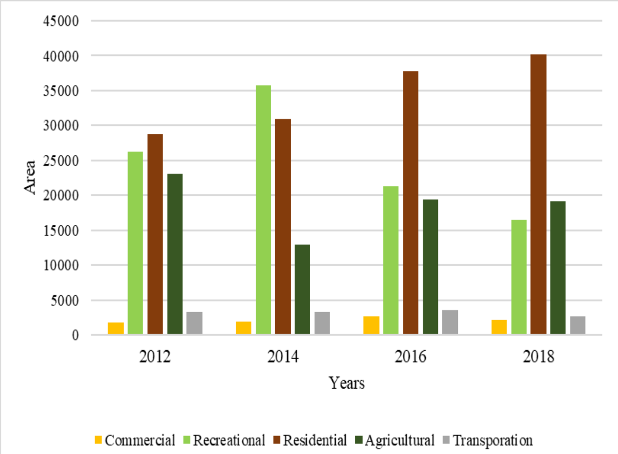

Figure 15. LULC changes over the past 8 years

	2012	2014	2016	2018
Commercial	24%	25%	30%	30%
Recreational	2%	3%	3%	4%
Built-up	31%	36%	50%	45%
Vegetation	37%	32%	23%	16%
Transportation	5%	4%	4%	6%

Table 1. LULC area coverage in percentage

4. DISCUSSION

Looking at the usage of NTL data in South Africa and Africa at large still remains in lack ad unfamiliar. It is a topic that you will not find in conferences, publications and research world as the day time data is being used (Coetzee, 2019). Light pollution also forms part of the so not familiar research subject in South Africa., this study was a way to bridge the gap and try to contribute to the few already done studies using NTL studies and with the publications to be made create awareness about light and its changes.

The classes used to classify the light pollution occurrence in EMM were very low, low, medium, high, and very high. With high and very high light pollution classes located in different areas of the municipality, mainly where the built-up and commercial areas are located, and low and very low classes of light pollution found correlating to vegetation cover. This then attributed to the question of why the classes are located the way they were in the maps of light pollution classes. This was because main activities that use lighting at night are located in these areas. We mainly use streetlights near our homes, the household lighting that may spill outside after the dark, the commercial lights used in shopping malls, advertisement places, parking lots in shopping malls, and other areas (Luginbuhl, 2009).

Light pollution can change due to different factors, such as the changes in the area's economic sector, which might lead to changes in the infrastructure available in that area. Growth in light pollution can be attributed to more areas gaining access to lighting infrastructure, making areas that only had natural light before to now have artificial light. The increase in artificial light can cause an increase in light pollution. In urban areas, light pollution is significantly affected by urban development. This was also seen in the EMM as light pollution has been increasing over the years. This was due to new economic innovations that have been introduced in the area. The period 2012 to 2018 saw not-so-significant growth for the eThekwini Metropolitan Municipality, but there were some developments to improve its economy, such as the improvement of the tourism sector, which brought had a major impact on the municipality's economy before the Covid-19 pandemic broke out. Other sectors that grew were the industrial sectors, most especially the manufacturing and transport sectors (Chipeya, 2020).

The economic index of the area also contributes to some of the factors of light pollution. The economic index is a way of checking the economic growth or decline of the area using different factors such as the Gross Domestic Product (GDP), money supply, Consumer Price Index (CPI), Producer Price Index (PPI), and the employment status. The growth in these can mean more economic and human activities that may need artificial light at night, hence the occurrence of light pollution. Also, growth in the area's economy means an area can afford better lighting infrastructure. That new lighting infrastructure can negatively affect the environment because of the way they emit their light (Rwanga, 2017).

Another factor that can affect light pollution is the changes in seasons. In South Africa, we have periods of load shedding, especially in winter. During load shedding, there is a switching off of electricity supply in different areas to monitor and conserve the energy supply that the country has. During this period, many places are subjected to the darkness that they are not used to and making them aware of what the original night skies are supposed to be. This can be seen in the results presented that show the decline in light pollution every year in winter. The decrease is seen in the high and very high classes of light pollution decreasing. Many Southern African countries are subjected to uneven energy supply, which is one of the reasons for load shedding in our country.

EThekwini Metropolitan Municipality has seen lots of development over the eight-years study period that was investigated, and this includes better facilities in the city, better infrastructure in the residential areas, and the recreational activities available in the municipality were also improved. This was evident when the LULC changes were assessed. The built-up and commercial areas were witnessed to grow and increase in area coverage over the years. This can be used as an explanation for the increasing high, and very high light pollution classes whilst the low and very low classes were decreasing.

5. CONCLUSION

Light pollution is a growing concern for the world, especially in urban areas and big cities. The use of night-time light data can be helpful going forward to look more into the future of light pollution in our region, South African cities, and improve the body of knowledge in remote sensing of night-time light data. Light pollution can, over time, either increase or decrease. In the case of eThekwini Metropolitan Municipality, it has been increasing, which can be due to different factors such as the effect of load shedding and uneven energy supply. Very high light pollution region is seen to be increasing over the area of the municipality, especially around the city centre and the residential and other built-up areas. The vegetation-covered areas have been declining in the municipality, which can be due to the expansion or the growth of the urban/built-up areas.

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