Using Visible Infrared Imaging Radiometer Suite (VIIRS) Imagery to identify and analyze light pollution

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Abstract. Light pollution is any adverse effect of artificial lighting including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste. Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object. Remote sensing can be used for identification of light pollution. The purpose of this study is to identify and analyze the light pollution by using remote sensing imagery. This study uses VIIRS DNB Free Cloud Composites imagery to identify light pollution in Yogyakarta province and surrounding areas. VIIRS imagery which obtained is processed to get information of light pollution by classifying the information into several classes presented in a map. Selected few sample points as test sites to determine the actual condition. Field work conducted at three location, they are Yogyakarta City, Depok Beach, and Gajah Mungkur reservoir. Night sky condition analysis conducted field tests as well as night time shooting the night sky conditions. Analysis of the night sky conditions are calculated qualitatively using Botlre Dark-Sky Scale with a value range of 1-9. Field test results show that Yogyakarta City has a value of 8, Depok has a value of 3, and Gajah Mungkur Reservoir has a value of 4. The conclusion of study is VIIRS imagery can be used for identification light pollution and calculation analysis of light pollution can use Botlre Dark-Sky Scale.

1. Introduction
This time the use of artificial light is highly increased, thus at night the light intensity of artificial light is also increased. The artificial light is used by settlement, industries, highways, and decorating lights. The excessive intensity of artificial light at night results in an increase of light pollution. Light pollution is as any adverse effect of artificial light including sky glow, glare, light trespass, light clutter, decreased visibility at night, and energy waste. Generally, light pollution thriving along with the change of environment, especially in urban areas. It is also along with the change of land use from farms to settlements or industries that also affect the increase of artificial light usage at night [1].

Light pollution is generally divided into two categories: astronomical and ecological. The astronomical definition of light pollution involves too much light blocking out the starry night sky, which seriously impede the studies of astronomers. Astronomical light pollution was the astronomers who turned their attention to light pollution and harmful effect of limitless lighting for the first time. Disturbing light form luminous sources made it almost impossible to accomplish astronomical research, since they were many fold more intensive than the natural background lighting. Researchers talk about light pollution when the artificial lighting reaches 10% of the natural background lighting. Ecological light pollution usually refers to the effect that too much light has on the environment,
including humans [2]. Overnight darkness probably plays a significant role in the human body. Light pollution also basically determines the decisions, behavior and direction of migration of animals, even if they have to find the place of food sources or the area reproduction. The direction of the sea is defined by the starlight reflecting the surface of water or by the moonlight. Due to the impact of artificial lights the turtles start for the wrong direction not for the water but for the land, which leads to their death [3].

Light pollution is a relatively new phenomenon. The first light bulb was invented only 160 years ago. Since then light emissions have grown steadily, even exponentially in certain areas. Artificial lighting has become integral part of our culture. It conveys a feeling of safety and wealth. Nevertheless, scientist warn of detrimental effects of excessive light emissions. Among the negative effects of light pollution are: 1) disturbance of biological rhythms, 2) psychological effects, and 3) environmental degradation [4,5]. Artificial light causes a lot of trouble for insect, too. Light sources lure night-flying insects from their natural habitats and feeding place. Excessive light emissions do not only have negative effects on the natural environment. They are also enormous water resources. A sustainable use of light and energy pays off for the municipalities and the individual household. Some countries have introduced laws to limit the light pollution [6].

The problem of light pollution needs to be considered in this era. The study of light pollution becomes important for government policy. Remote sensing technologies have been able to map the light pollution. Information of radiation values of artificial light on earth can be obtained from satellite imagers. Visible Infrared Imaging Radiometer Suites (VIIRS) DNB Free Cloud Composites is one of imagery that can be used to obtain information of the amount of light pollution on earth. This study aims to get light pollution information using VIIRS imagery and identifying the night sky condition in study area.

2. Study area and data
2.1 Study area
This study is performed in Daerah Istimewa Yogyakarta (DIY) and Central Java provinces. The area of DIY province is 3,185,80 km2 and astronomically located on 7033’ – 8012’ South Latitude and 110000’ - 110050’ East Longitude. DIY is located in Java Island which is bounded by Indian Ocean on south. Climate circumstances of DIY province are classified as tropical climate with annual rainfall average of 3,000 mm/year and average of 25 - 31°C. Central Java province is astronomically located on 5040’ - 8030’ South Latitude dan 108030’ - 111030’ East Longitude which has tropical climate with temperature average of 24,80 – 31,80 C and rainfall average of 2,618 mm/year. The region which has low rainfall and frequently droughts is located in Blora, Rembang, half of Grobogan and surroundings, and southern Wonogiri [7]. Figure 1 shows the map of study area i.e. DIY and Central Java provinces.

2.2 Remote sensing data
Visible Infrared Imaging Radiometer Suites (VIIRS) DNB Free Cloud Composites imagery is one of remote sensing data that can provide information of light pollution. This imagery is produced by Suomi National Polar Partnership (SNPP) which is collaboration between National Oceanic Atmospheric Administration (NOAA) dan United Nation Aeronautics and Space Administration (NASA). VIIRS imagery has 3000 km wide swath and wavelength spectrum between 0.5 – 0.9 µm. Radiometric resolution of the imagery is up to 14 bits and capable of detecting light limit up to \( \sim 2E \times 10^{-9} \text{watt/cm}^2 \times \text{sr} \). VIIRS has the ground pixel footprint at nadir of 724x724 m (0.55 km²). Some VIIRS data sets are available and can be downloaded from the National Oceanic and Atmospheric Administration. DIY and Central Java are included in the recorded area. The imagery used for this study is the result of recording in September 2015. The chosen imagery on that time is based on assumption that September is driest month in Indonesia that has minimum cloud cover. If the cloud cover is minimum artificial light on earth which cause the light pollution can be recorded optimally.
3. Methodology

3.1 Image Processing
VIIRS DNB Free Cloud Composites imagery which the result of Suomi National Polar Partnership (SNPP) satellite is used to detect faint radiant emissions. The use of VIIRS Imagery that catch the radiance value of earth surface also better to detect dimmer lightning than any imagery, like DMSP. The radiance information is processed to get light pollution information. Baugh (2015) stated that, quantitatively, VIIRS DNB Free Cloud Composites had been calibrated, both radiometric and geometric by NOAA and NASA [8]. So that in image processing cutting/masking has been performed according to study area by using ENVI 5.0. The available data in official website of NOAA has been divided into 6 files of (00N/060W).

3.2 Fieldwork
Extraction of information of light pollution is not just obtained by imagery interpretation but also performed by fieldwork to validate the actual circumstances whether it is appropriate with the imagery or not. The result of performed fieldwork is used to identify and transformed into Bortle Dark-Sky Scale so that the light pollution can be classified. The adapted fieldwork is based on the imagery, that is low and high radiance value. Fieldwork was also performed by observing astronomic objects. Sky photography was also conducted at 00.00-03.00 p.m.-the most effective time for astronomical observation-. The camera which used was Canon EOS 600D with f-stop of f/3.5; exposure time 30 sec; ISO speed ISO-1600; Focal length of 10 mm; and partial metering mode. The checklist which was used contained information of coordinates, area description, land cover description, circumstances description, astronomic objects that can be identified, and location sketch were used for area analysis.
3.3 Bortle Dark-Sky Scale interpretation

The Bortle Dark-Sky Scale is a nine-level numerical scale that measures the night sky’s brightness of a particular location. It quantifies the astronomical observability of celestial objects and the interference caused by light pollution. John E. Bortle created the scale and published it in the February 2001 edition of sky & telescope magazine to help amateur astronomers evaluate the darkness of an observing site, and secondarily, to compare the darkness of observing sites. The scale range from Class 1, the darkest skies available on Earth, through Class 9, inner-city skies. It gives several criteria for each level beyond naked-eye limiting magnitude (NELM). The accuracy and utility of the scale have been questioned in recent research. Naked eye in astronomy is the visibility of astronomical objects is strongly affected by light pollution. Limiting magnitude is the faintest apparent magnitude of a celestial body that is detectable or detected by a given instrument. In some cases, limiting magnitude refers to the utter threshold of detection [9].

Class 1: Excellent dark-sky site. The zodiacal light-gegenschein and zodiacal band (S&T: October 200, page 116) are all visible – the zodiacal light to a striking degree, and the zodiacal band spanning the entire sky. Even with direct vision, the galaxy M33 is an obvious naked-eye object. The Scorpius and Sagittarius region of the Milky Way cast obvious diffuse shadows on the ground. To the unaided eye the limiting magnitude is 7.6 to 8.0 (with effort); the presence of Jupiter or Venus i the sky seem to degrade dark adaptation. Airglow (a very faint, naturally occurring glow most evident within about 15 of the horizon) is readily apparent. With 32-centimeter (12.5 – inch) scope, stars to magnitude 17.5 can be detected with effort, while a 50-cm (20-inch) instrument used with moderate magnification will reach 19th magnitude. If you are observing on a grass-covered field bordered by trees, your telescope, companions, and vehicle are almost totally invisible. This is an observer’s Nirvana.

Class 2: Typical truly dark sky. Airglow may be weakly apparent along the horizon. M33 is rather easily seen with direct vision. The summer Milky Way is highly structured to the unaided eye, and its brightest parts look like veined marble when viewed with ordinary binoculars. The zodiacal light is still bright enough to cast weak shadows just before dawn and refer dusk, and its color can be seen as distinctly yellowish when compared with the blue-white of the Milky Way. Any clouds in the sky are visible only as dark holes or voids on the starry background. You can see your telescope and surroundings only vaguely, except where the project against the sky. Many of the Messier globular clusters are distinct naked-eye objects. The limiting naked-eye magnitude is as faints as 7.1 to 7.5 while a 32-cm telescope reaches to magnitude 16 or 17.

Class 3: Rural sky. Some indication of light pollution is evident along the horizon. Clouds may appear faintly illuminated in the brightest parts of the sky near the horizon but are dark overhead. The Milky Way still appears complex, and globular clusters such as M4, M5, M15, and M22 are all distinct naked-eye objects. M33 is easy to see with averted vision. The zodiacal light is striking in spring and autumn (when is extends 60 above the horizon after dusk and before dawn) and its color is at least weakly indicated. Your telescope is vaguely apparent at a distance of 20 or 30 feet. The naked-eye limiting magnitude is 6.6 to 7.0 and a 32-cm reflector will reach to 16th magnitude.

Class 4: Rural/suburban transition. Fairly obvious light-pollution domes are apparent over population centers in several directions. The zodiacal light is clearly evident but doesn’t even extend halfway to the zenith at the beginning or end of twilight. The Milky Way well above the horizon is still impressive but lacks all but the most obvious structure. M33 is a difficult averted-vision object and is detectable only when at an altitude higher than 50. Clouds in the direction of light-pollution sources are illuminated but only slightly so, and are still dark overhead. You can make out your telescope rather clearly at a distance. The maximum naked-eye limiting magnitude is 6.1 to 6.5, and a 32-cm reflector used with moderate magnification will reveal stars of magnitude 15.5.

Class 5: Suburban sky. Only hints of the zodiacal light are seen on the best spring and autumn nights. The Milky Way is very weak or invisible near the horizon and looks rather washed out overhead. Light sources are evident in most if not all directions. Over most or all of the sky, clouds are quite noticeably brighter than the sky itself. The naked-eye limit is around 5.6 to 6.0, and a 32-cm reflector will reach about magnitude 14.5 to 15.
Class 6: Bright Suburban sky. No trace of the zodiacal light can be seen, even on the best nights. Any indications of the Milky Way are apparent only towards the zenith. The sky with 35 of the horizon glows grayish white. Clouds anywhere in the sky appear fairly bright. You have no trouble seeing eyepieces and telescope accessories on an observing table. M33 is impossible to see without binoculars, and M31 is only modestly apparent to the unaided eye. The naked-eye limit is about 5.5, and a 32-cm telescope used at moderate powers will show stars at magnitude 14.0 to 14.5.

Class 7: Sub-urban/urban transition. The entire sky background has a vague, grayish white hue. Strong light sources are evident in all directions. The Milky Way is totally invisible or nearly so. M44 or M31 may be glimpsed with the unaided eye but are very indistinct. Clouds are brilliantly lit. Even in moderate-size telescopes, the brightest Messier objects are pale ghost of their true selves. The naked-eye limiting magnitude is 5.0 if you really try, and a 32-cm reflector will barely reach 14th magnitude.

Class 8: City sky. The sky glows whitish gray or orangish, and you can read newspaper headlines without difficulty. M31 and M44 may be barely glimpsed by an experienced observer on good nights, and only the bright Messier objects are detectable with a modest-size telescope. Some of the stars making up the familiar constellation patterns are difficult to see or are absent entirely. The naked eye can pick out stars down to magnitude 4.5 at best, if you know just where to look, and the stellar limit for a 32-cm reflector is little better than magnitude 13.

Class 9: Inner-city sky. The entire sky is brightly lit, even at the zenith. Many stars making up familiar constellation figures are invisible, and dim constellations such as Cancer and Pisces are not seen at all. Aside from perhaps the Pleiades, Messier objects are visible to the unaided eye. The only celestial objects that really provide pleasing telescopic views are the Moon, the planets, and a few of the brightest star clusters (if you can find them). The naked-eye limiting magnitude is 4.0 or less.

4. Results and discussions

4.1 VIIRS DNB Free Cloud Composites imagery information

The result of information extraction of VIIRS DNB Free Cloud Composite consists of two main information, which are cloud cover and light pollution (recorded artificial usage on earth). The exposure on earth at night were recorded by the satellite sensor can be directly identified using VIIRS DNB Free Cloud Composite imagery. The radiance value of the imagery is correlated with the amount of recorded lights from earth surface, the higher radiance value, the brighter the pixel hue, and vice versa. The high brightness of the pixel value represents the earth surface condition which is brighter due to amount of artificial lights. In contrast, the regions which look darker are light pollution minimum. The distribution of location with quite plenty use of lights is shown in Figure 2. The area which have bright hue indicates an excessive use of lights on Northern coastal of study area i.e Northern coastal of Java and on the Southern, Yogyakarta and Surakarta. On the other hand, most of study area has minimum lighting condition. This surely can affect the light pollution level that occurs on earth surface.

The cloud cover information which obtained from extraction of DNB Free Cloud Composite shows the amount of clear sky of an area which is not covered by clouds. Figure 3 represents clouds cover information. The lowest radiance value of the imagery of 0 while the highest value of 17. The high pixel value shows that the area is rarely covered by clouds and vice versa. The area which often covered by clouds in the imagery is visualized with darker hue, compared with the area which rarely covered by clouds. Spatial distribution of region which rarely covered by clouds is on Northern of study area, which are Wonogiri, Blora, Gunungkidul, Rembang, and Grobogan regions. This recorded clouds coverage information is very useful as one of factors of light pollution level.
Figure 2. Light radiance information of VIIRS DNB Free Cloud Composites Imagery.

Figure 3. Information of cloud coverage of VIIRS DNB Free Cloud Composites.
4.2 Fieldwork
The night sky condition of Gajah Mungkur reservoir is showed in Figure 4. The radiance value of the area is in range of 0.207987 to 0.69997 x10^{-9} watt/cm^2*sr and in range of 11 to 13 for cloud coverage information. Figure 4 shows the night sky condition at Gajah Mungkur reservoir. Fieldwork result shows that night sky condition at Gajah Mungkur reservoir is free from disruption of artificial lights, or in other word is light pollution minimum. For astronomical observation, the Gajah Mungkur reservoir is observable without optical aids such as Telescope. Many of astronomic objects such as planet (Mars), space dust, Milky Way, and other objects can be observed clearly, including constellations. The result of Bortle Dark-Sky Scale interpretation shows that the area is classified as Class 4, which is Rural/Suburban transition. This is marked by galaxy of Milky Way which could be seen clearly under horizon. Generally, other astronomic objects also can be identified. The result of performed fieldwork gives information that light pollution of Gajah Mungkur reservoir and surroundings came from local activities such as fishermen, industries, and etc.

Figure 4. Night sky condition in Gajah Mungkur reservoir.

Figure 5 shows the night sky condition at Depok Beach. The night sky condition in Depok Beach and surroundings is very low of light pollution. Compared with night sky at Gajah Mungkur reservoir, this area is much better because the appearance of astronomic objects is very clear. Based on the imagery, the radiance value of the location of 0.406948 x10^{-9} watt/cm^2*sr to 0.554071 x10^{-9} watt/cm^2*sr and for cloud coverage information is up to 13, which means that there were 13 times of clear sky in a month (September). The result of Bortle Dark-Sky Scale interpretation for this location shows that is classified as Class 3 or Rural Sky. Rural sky condition is indicated by very minimum of light pollution. Many of astronomic objects can be identified easily, including planets (Mars and Saturn) and constellations such as Scorpion, Indian, Peacock, Altar, Sea Goat, and etc. Figure 6 shows some of astronomic objects that can be identified.
Figure 5. Night sky condition in Depok Beach.

Figure 6. Identification of astronomic object at Night Sky in Depok Beach (Constellations of India, Peacock, Altar, and Seagot; Pluto, Saturnus, Mars, Rigel Kentarus, and Hadar).
Yogyakarta City is one of the location for performing fieldwork that has high lighting condition. Figure 7 shows the night sky condition at Yogyakarta, which has high illuminations of reflectance from earth surface. In the VIIRS imagery, this location has quite high radiance value of 23.814596 watt/cm²*sr to 44.069031 watt/cm²*sr and cloud coverage information of 9 to 13. Based on Bortle Dark-Sky Scale, this location is classified as Class 8, which is City Sky. The sky even looks orange that indicates the amount of artificial lights usage, or in other word, this location had been disrupted by light pollution. It is very difficult to identify astronomic objects here, compared with the other location (Gajah Mungkur reservoir and Depok Beach). The high light pollution level is a result of artificial lights usage, which most of them is caused by settlements. There are some reasons why the location had a high light pollution level: high settlements density that result a high electricity consumption, the use of decorating lights and infrastructure, and traffic activities.

![Figure 7. Condition night sky in Yogyakarta City.](image)

5. Conclusions

VIIRS DNB Free Cloud Composites Imagery can be used for identification and analysis of light pollution. The imagery contains information of light pollution (recorded artificial lights usage on earth) and cloud coverage. Bortle Dark-Sky Scale is one of several methods that can be used to determine the level of light pollution by considering the radiance value of earth surface. Based on the VIIRS imagery, the radiance value of Gajah Mungkur reservoir is in range of 0.207987 to 0.69997 x10⁻⁹ watt/cm²*sr, which is classified as Rural/suburban transition (Class 4) in Bortle Dark-Sky Scale. The radiance value in Depok Beach of 0.406948 to 0.554071 x 10⁻⁹ watt/cm² *s, which is classified as Rural (Class 3), and the radiance value of Yogyakarta City is up to 23.814596 watt/cm²*sr to 44.069031 watt/cm²*sr, which is classified as City Sky (Class 8).

For future research, it is better to use more sample sites so the distribution of night sky condition can be identified accurately. It is also crucial to conduct measurement of night sky by using Sky Quality Meter to get the information of light pollution level quantitatively. Temporarily, this research can be used for identifying night sky dynamics in study region.
Acknowledgements

This research is funded by the Ministry of Research, Technology, and Higher Education of Indonesia through Program Kreativitas Mahasiswa 2015/2016. VIIRS DNB Free Cloud Composites imageries are obtained for free from official website of NOAA. We would like to express our greatest gratitude to Muhammad Kamal, Ph.D. who has been willing to be mentor of this research. And also to all member of research who have been involved and friends who have supported this research.

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