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Light pollution: A brief overview

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Abstract

In this paper, light pollution was emphasized based on the other research papers from technical to developing term. The review highlighted examples of the propagation of light pollution and its danger to human health, plants and animals, the environment, and its impact on astronomers. Scientists have been studying light pollution, which resulted in a demand for methods to quantify it. These methods can be categorized into four: scales, models, one-dimensional instruments, and satellites. This paper discusses the different ways of measuring light pollution. Light pollution is a global issue that needed to more attention. Steps taken to combat light pollution are the invention of dimmable LEDs, light fixtures, light cutoffs, motion-detected lighting systems, glare-free lighting. Organizations also facilitate programs that aim to spread awareness among people.

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Introduction

The world struggles to resolve the increasing issues of pollution. Many studies are showing that pollution is the number one threat to the destruction of the ecosystem. The scary consequences to human health and the contamination of the environment are part of the alarming effects of pollutions. The beauty of natural environment has been destroyed by air, land, water, noise, thermal and light pollution. Among the types of existing pollutions, light pollution is newfangled.

Light pollution refers to excessive lights from artificial sources (Gallaway *et al.,* 2010). The International Dark-Sky Association defines light pollution as the unwanted effect of artificial lights from its components, namely skyglow, glare, light trespass, and light clutter. It is progressively spread out throughout the globe. Growing urbanization and industrial civilization are the primary sources of light pollution. There are studies (Chepesiuk, 2009; Du, Zhang, & King, 2018) which reveals that animals and various ecosystems are affected by light pollution as it disrupts their activities which hinder their growth and development. Alterations from their natural habitat can cause a significant difference in the ecosystem (Chepesiuk, 2009; Du, Zhang, & King, 2018). Light pollution interferes with the natural light-dark cycle in their habitat thus, resulting to change in species' behavior (Altermatt and Ebert, 2016). It is notable that there are adverse effects on the environment brought by light pollution (Falchi, Cinzano, Elvidge, Keith, & Haim, 2011). Also, astronomy observations have been hampered by light pollution as it deprives the beauty of the night sky (Longcore & Rich, 2004; Liu *et al.*, 2018). There are portions of the Milky Way Galaxy which can be viewed by the naked eye in the night sky through a dim natural light. However, this picturesque is not possible in most places because of the excessive artificial light brought by skyglow, a byproduct of light pollution where the sky is brightened by urban lights (Du, Zhang, & King, 2018).

Many scientists have discovered the impacts of artificial light at night on scientific astronomy, human health, ecological processes, and aesthetic enjoyment of the night sky. The growing awareness about light pollution has led to the recognition of light pollution as a worldwide environmental concern that needs to be resolved for the sake of the greater good (Bennie *et al.*, 2015). As it continuously disrupts the environment, light pollution justifies the need for ongoing studies to understand its hidden consequence and reduce its impact. Several studies already uncovered the significant correlation between perceptive cities and the undeniable increase in light pollution (Ziou & Kerouch, 2018). However, with the intensification of other environmental problems, light pollution gained minimal attention (Stone, 2017). The necessity of attention on the rising problems brought by light pollution leads the paper to give contributions on providing the overview in this issue.

This paper showcases the latest review on light pollution as it is deemed essential to understand the current situation and studies to come up with great solutions. The authors signify its necessity to promote light pollution awareness and conservation suitable for both academic and community standards. This paper aims to show how Light pollution may affect the ecosystem, specifically in the environment, plants and animals, humans, and to the astronomy community. Methods on quantifying light pollution and some of the steps used to prevent it are also discussed in this paper.

Propagation of Light Pollution

The first world atlas of the artificial sky brightness revealed that light pollution of the night sky is not only referred to in developed countries like usually perceived. This issue appears to be a global-scale problem that alarmingly nearly every country in the world (Falchi *et al.*, 2011).

Light pollution is the effect of artificial light development that significantly affects the change in a natural quantity of light at night time (Cinzano and Falchi, 2014). The night sky's luminosity obtained light and dispersing properties of the atmosphere (Horvath, 2014). It is a wide range of expressions describing the uncontrolled use of artificial lights.

In the account of this are sky glow, light trespass, and glare (Gallaway *et al.,* 2010). The sky glow is known to be the light that comes from the ground that fills the sky with various light colors. At the same time, glare denotes the light that conceals its issue instead of illuminating its subject because of imperfectly directed light. Associated with this is 'light trespass' or 'light nuisance.' As a result, the light dimmed the issue rather than illuminate (Dunnett, 2015).

Light pollution's primary origin is said to emerge from the lighting of streets and highways and its rapid increase due to urbanization (Fletcher and Crampton, 1973). The necessity of building infrastructures to support population growth is a signal for artificial light's continuous production (Luarte *et al.,* 2016). Production of outdoor lighting is a symbol of a more civilized society inclined to a safer environment at night, but this also symbolizes the disruptions of the natural night glow (Pun *et al.,* 2014). Road lamps that keep road floods with light, vehicles that move along a non-illuminated area, traffic signs, and safety warning lights became a great contributor as well (Lyytimaki and Tapio, 2012). As a way of living in modern society, most people are more likely to stay inside infrastructures, producing a disturbing level of illumination compared to the natural light that the environment makes (Bará and Escofet, 2017). The improper and overwhelming use of lighting is simply producing light pollution (Elsahragtya and Kimb, 2015).

Light pollution spreads in the atmosphere like what happens to other pollutants. It changes the observer background of the night sky condition (Falchi and Cinzano, 2011). The carbon released into the atmosphere as a result of electrical generation represents another negative externality of artificial lighting (Kuechly *et al.,* 2012).

Light pollution doesn't only exist in highly developed countries; some factors may affect the propagation of light pollution. It involves the Gross Domestic Product of a city revealed by some of the research. An earlier study by Elvidge *et al.* (1997) concluded that the area lit is highly correlated to gross domestic product and electric power consumption. This paper focused on the correlation between luminosity and gross domestic product and found a strong correlation between the two. Some studies used nighttime light to predict income per capita at the sub-national level to indicate light pollution. Population density is used as an indicator to identify the distribution of artificial light in the night sky. The area's population is directly proportional to the amount of light pollution produced (Cinzano *et al.,* 2001). According to Gallaway *et al. (2010*), the population remains an essential explanation for the existence of light pollution. Both developed and populated areas encounter the problem of light pollution leading to losing the dark sky. The increase in the human population equates to the increase in light pollution.

Another factor affecting the propagation of light pollution is land use planning and zoning. A study by Wu and Wong (2012) identified the leading causes of light pollution on a regional scale: land use. Land use planning and zoning is a process that defines goals and objectives to achieve a community's vision. Commercial districts produce the lightest pollution, followed by residential areas, then recreational areas. In Metro Manila, 44.8% of its land is for residential use, the commercial space is 12.2%, and the recreational areas are 28.4% (Asian Development Bank, 2016). Therefore, most of the light pollution in Metro Manila came from residential areas. In urban areas, streetlights, digital billboards, floodlighting, bright skyscraper-illumination, vehicle lights, construction site lightings, etc., are the common source of light pollution (Heilig, 2010). These light sources are usually active and used during the night, thus contributing significantly to light pollution. It is possible to eliminate light pollution without removing the capacity to provide safety functions of light at night (Pun *et al.* 2012).

Light Pollution and its Effects

Light pollution affects everyone and everything in its way, just like how other types of pollution works. Just like every other pollution that exists in this world,

light pollution deteriorates and destroys our environment. Though it is not noticeable, light pollution kills us, too. An adverse effect of light pollution from different artificial light forms given less attention and unnoticeably affects wildlife and another ecosystem (Hu *et al.,* 2018). Most life forms, including humans, have this innate body clock that helps in metabolic processes and growth. Also, a significant number in the proportion of global biodiversity is said to be nocturnal (Perkin *et al.,* 2010). Artificial lights cause the attraction and repulsion of each entity, leading to the growth of predation, unsuitable migration, and competition for resources. Which dramatically affects the balanced relationship (Horvath *et al.,* 2009) and drastic maladaptation that may trigger the sudden decrease of population among organisms (Horvath *et al.,* 2010). Whereas for humans, too much exposure to artificial light at night gives a high risk of having cancer (Reiter *et al.,* 2011). Either day or night condition, there are physiological and behavioral activities on the process for each organism. The change in the ratio of light and absence of light has consequences (Gaston *et al.,* 2013).

The range of light pollution affecting the natural processes in an organism depends on various factors such as the wavelengths of the light emitted concerning the visual receptors, the intensity of light that reaches the organism, and the directionality of light (Gaston *et al.,* 2012).

Environment

About 30% of all outdoor nighttime lighting ends up in the sky. It is equivalent to 17.4 billion kilowatt-hours of electricity (Gallaway *et al.,* 2010). In the city, artificial lights increased sky brightness levels up to six times higher than those recorded in rural locations (Davies *et al*., 2013).

Light pollution is prevalent in metropolitan areas (Lockwood *et al.,* 1990). Urban sky glow scatters in the atmosphere bringing about a brightening of the natural sky beyond background levels produced by urban development. It leads to additional artificial lights around the city like inroads, malls, theatres, and even homes (Navara & Nelson, 2007). Most commercial districts are the ones that are perceived to have the most severe light pollution. Digital billboards are the primary source of light pollution in cities; some were in full power even when the business was not open (Karol *et al*., 2010).

Plants and Animals

Light pollution can change plants' metabolism so that if they are not in a dark place for some time, they never can have flowers and colors (Bashiri *et al.,* 2014). Artificially lit towers steer migrating birds off course and present collision risks. Even brief exposure to bright light can cause some nocturnal frogs to freeze for hours. Artificial light at night can potentially damage some of the world's nocturnal plants and animals, functionally critical marine ecosystems. It can be considered a threat to the world's biological system (Davies *et al.,* 2013).

Humans

Exposure to artificial light at night has shown a connection to obesity, depression, sleeping disorders, cancer, and other illnesses. The 24-hour day/night cycle, also known as the circadian clock, affects physiologic processes, including brain wave patterns, hormone production, cell regulation, and other biologic activities. Studies show that the circadian cycle controls from ten to fifteen percent of our genes. If a disturbance occurs, it can lead to health problems (Chepesiuk, 2009). It is linked to several medical disorders in humans, including depression, insomnia, cardiovascular disease, and cancer, says Paolo Sassone-Corsi, chairman of the Pharmacology Department at the University of California (Chepesiuk, 2009). Alteration of the circadian clock may cause performance, alertness, sleep, and metabolic disorders. Exposure to light at night suppresses the production of the pineal hormone melatonin. Melatonin is an oncostatin or anti-carcinogenic agent; lower blood levels may encourage the growth of some cancers (Falchi *et al.,* 2011). Exposure to light at night (LAN) decreases pineal melatonin (MLT) production and secretion and are not only a source for the phase

shift in daily rhythms (Falchi *et al.,* 2011). While the melatonin rhythm persists in constant darkness, it does not continue in continuous light (McIntyre *et al.,* 1989). Low illuminance evoked little change in plasma melatonin concentrations. Whereas bright room light and higher illuminances completely suppressed plasma melatonin (Zeitzer *et al.,* 2000).

Melatonin is oncostatic/ anticarcinogenic. Melatonin acts as a protective oncostatin agent that suppresses humanmcF-7 breast cancer cell growth xenografts (Pauley, 2004). Irregular working hours, including working at night, have severe psychological and physiological effects. In a study by Hansen (2001), they found out an increase in risk for primary breast cancer among women with predominantly night work. Furthermore, the relative risk tended to increase with the increasing duration of night work.

Light pollution menace for astronomy

As light pollution increases, the willingness and interest in protecting the night sky have increased as well (Kocifaj, 2007). Urbanization invades areas near observatories that threaten the dim skies (Fletcher and Crampton, 1973). Light pollution hinders the nighttime view of astronomical objects (Brons *et al.,* 2008). Besides, astronomy is affected by light pollution, specifically by sky glow. Amateur and professional astronomy is affected by sky glow, hindering activities such as stargazing and the like. One-fifth of the world's population has no access to the Milky Way view (Lyytimäki, 2013). Astronomical devices collect multiple records of light pollution instead of collecting scientific data. Light pollution has the effect of washing away astronomical data (Dupuy and Knox, 2014). Artificial lights can turn astronomical observations hard at numerous locations (Kocifaj, 2014). The knowledge of artificial light and its negative consequences are essential not just for astronomers but also for engineers (Kocifaj, 2007).

Common Methods Used in Measuring Light Pollution

Discoveries about the negative effects of light pollution encouraged more scientists to research the matter. Because of this, there is a demand for ways to quantify light pollution (Cinzano and Falchi, 2014). There are various methods in measuring light pollution: scales, devices, models, and satellites. Scales use direct observation, one-dimensional instruments gather data from only one point in the sky, models apply assumptions to formulate theories, and satellites contain sensors that detect light from earth.

Scales

The Bortle Scale

The Bortle Scale works by observing the night sky with the naked eye. While it offers a way to measure light pollution without the use of fancy devices, it only provides general information and has a high percentage error. Observations are classified into one of nine classes, all of which depend on the visibility of the Milky Way, stars, and other components of the sky (Posudin, 2014). Class 1 and 2 are truly dark sites where the Milky Way appears structured and complex and stars can be seen clearly. Class 3 and 4 are rural skies transitioning to suburban skies, where the Milky Way is still visible but with faint details. Classes 5, 6, and 7 are suburban skies transitioning to urban skies, where the Milky Way looks translucent and clouds are distinct. Class 8 and 9 are urban skies, where the Milky Way is invisible and the only visible objects are the Moon, Pleiades - one of the brightest star clusters - and planets of the solar system (Nurbandi *et al.,* 2016).

One-dimensional Instruments

Luminance Meter

A luminance meter, as the name implies, measures luminance in lumens. It has a 6% accuracy rate and a 10% error. It is portable and easy to use but its accuracy and sensitivity drop in areas with poor lighting (Hänel *et al.,* 2018).

Sky Quality Meter (SQM)

A Sky Quality Meter measures the luminance of the night sky in magnitudes per square arc second and on a negative logarithmic scale. It is accurate, cheap, and easy to use (Ges *et al.,* 2018). However, artificial light and particles in the sky such as clouds also influence its reading, so it is not just natural light that is included.

Optical Spectrometer

A spectrometer uses wavelengths as a basis for measuring radiance. When its spectral sensitivity matches that of a human, the measurement is called luminance instead (Hänel *et al.,* 2018). Using a prism or diffraction grating, light is dispersed into different wavelengths where it will then be measured and examined (Posudin, 2014).

Formulas and Models

Walker's Model (1973)

$I=CPd^{-2.5}$

In Walker's model, the population P, a given number of lumens per person C, and distance are taken into consideration to calculate the illumination of the sky (Hector, Ramon, & Manuel, 2010). He thought that the population is directly proportional to the intensity of artificial brightness. The resulting brightness is measured in mag/sec2 (Garstang, 1991). On the downside, it does not factor in things like the amount and intensity of light sources in its calculation.

Treanor's Model

$$P = \frac{L(r)}{L(N)} = \left(\frac{A}{r} + \frac{B}{r^2}\right) x\, e^{-k/r}$$

Where, *L(r)*=sky brightness, *L(N)*=natural sky brightness, *P*=population, *r*=distance, *A*=1.8x10-5, *B*=13.6x10-5, and *k*=0.026 (Hector *et al.,* 2010).

Treanor modified Walker's model to factor in the scattering of light and some atmospheric conditions (Hector *et al.,* 2010).

Berry's Model (1976)

$$B(D) = a\sqrt{P}\left(\frac{U}{D^2+h^2} + \frac{V}{\sqrt{D^2+h^2}}\right) e^{-k\sqrt{D^2+h^2}}$$

Where, *B* is the sky brightness, *P* is the population, *D* is the distance, *h* is the height of scattering layer, a is the luminosity constant, *U*, *V* are experimental constants, and k is the absorption coefficient (Netzel and Netzel, 2018; Hector *et al.,* 2010). Berry's model is based on Treanor's model. Berry revised it to calculate how much glare has polluted the sky (Hector *et al.,* 2010).

Garstang's Model (1984)

I=aPUD(DS)(EF)

Where, *I* is the sky brightness, *P* is the population, *DS* tells how much aerosol is scattered, *EF* is the extinction factor, a is the luminosity constant, *U* is an experimental constant, and *D* = distance (Hector *et al.*, 2010). Garstang's formula includes aerosols, which are suspended particles in the air. The formula also follows Lambert's emission law, which states that a surface viewed from any angle appears to have the same brightness. However, the influence of clouds is not considered in the formula (Hector *et al.,* 2010).

Maps and Satellites

DMSP-OLS

The Defense Meteorological Satellite Program-Operational Linescan System or DMSP-OLS is a satellite with a Visible and Near-Infrared (VNIR) band that allows it to catch electromagnetic radiation from the earth. Its nighttime data has been used to observe phenomena in nature and it has also been used as a database by other studies. However, it lacks calibration, has a low resolution, and is limited in a lot of aspects (Huang *et al.,* 2014). It sometimes results in a distorted image because of the blooming effect, where pixels overflow to another site if there is too much charge in it[pixel].

NPP-VIIRS

Visible Infrared Imaging Radiometer Suite (VIIRS), along with the Suomi National Polar-Orbiting Partnership (NPP), is a radiometer and gathers geological, hydrospheric, and atmospheric data. It quantifies light pollution in radiation values obtained from detecting omissions of light and collecting low-light imagery, which is processed by NPP (Nurbandi *et al.,* 2016). The difference between DMSP-OLS and NPP-VIIRS is that VIIRS can filter out natural light and other extraneous effects, leaving only artificial light to be quantified (Hu *et al.,* 2018).

Prevention and Reduction Method

The introduction of electric lighting has helped improve our lives since we are diurnal which means that we need daylight to do our activities.

The presence of light makes us feel more secure and gives us more time for work and ourselves, but those benefits cost us a lot. It brought a big problem along with it. Light pollution is the alteration in natural light levels due to excessive and unnecessary artificial light. The introduction of electric lighting has helped improves our lives. It made us feel more secure and have more time for work and personal tasks, but light pollution. The creation of solar calendars and star maps, heliocentric and geocentric theories, early observations of astronomical phenomena, discoveries of celestial bodies are essential events in astronomy. They are created even without the help of a telescope. They have done this with the help of the clear night sky. But because of light pollution, which came during the 1930s, the "clear night sky" disappeared (Jiang *et al.,* 2017). The project aims to reduce light pollution by informing people about and preventing it from getting worse, stating the current actions taken against light pollution. The project also aims to reduce the amount of energy wasted per year due to improper lighting. Light pollution is not as recognized as a threat, unlike air pollution. It is linked to various negative ecological and physiological impacts. We need to act against this threat before it gets too much of a problem to handle.

Light Emitting Diodes (LEDs)

The invention of LED Bulbs replaces the used incandescent and fluorescent light. It is more energy-efficient than the previously-stated light sources. LEDs are directional, which means they can be pointed in the direction where it is needed. Incandescent and fluorescent light, on the other hand, shines a light in all directions. Hence, more energy is wasted. But with the introduction of more energy-efficient options for lighting, the problem of light consumption just got worse (Han *et al.,* 2014). Lit outdoor areas grew at a rate of 2.2% per year. Radiance grew at a rate of 1.8% per year. The lit regions' brightness increased by 2.2% per year from 2012 to 2016 (Kyba *et al.,* 2017). LEDs have also replaced HPS in street lighting. The problem is, LEDs emit light with too much intensity, which results in glare. This can be solved using dimmable LEDs (United States Patents of Ang and Beaver, 2008; Rodinger, Chu, and Yan, 2015). Lys *et al.,* (2008) developed a dimmable light, whereas A.C. power source is being used for the power source while A.C. dimmer circuits are used to control the lights' intensity.

Aside from intensity, color temperature and temporal characteristics can also be adjusted. On the other hand, Sun *et al.,* (2012) have used a quantum dimmer to make the intensity of the LED bulb adjustable.

Color Temperature

Based on a study, LED-equipped traps capture 48% more insects compared to traps equipped with HPS. Results have shown that LEDs harm insects because it gives off a large amount of blue light, which belongs to the UV-Blue-Green trichromatography of insects (Briscoe and Chitkka, 2001; Hori *et al.,* 2014). This can be resolved by adjusting the color temperature of lights according to the FSA standards (3000Kor lower). There are also LED light fixtures that can change color temperature and are also dimmable (Baddela, Serra & Gielniewski, 2014).

Light Cut-offs

Light cut-offs resolve the issue of light trespass by directing light from the streetlights to the desired direction. It works by preventing or lessening the light from reaching areas beyond its coverage area (McCanless, 2013; Ceglia, 1963).

Light cut-offs can be classified into three types: complete cut-off, cut-off, and semi-cute off. Full cut-offs restrict the luminous intensity (measured in candelas) for angles equal to or above 90 degrees to zero. Cut off determines to 2.5% of the luminous flux. Semi cut-offs restrict to 5% of the luminous flux. Complete cut-offs and cut-offs also limit light to 10% of the luminous flux for angles of 80 degrees up to 90 degrees. On the other hand, based on the Lighting Research Center, semi-cut offs are only restricted to 20%.

Motion Detector

Motion detectors can be used in lighting systems so that light will only be used when it is necessary.

Reduction in light emissions helps in reducing the amount of light pollution. (Eskonen *et al.,* 2016).

Glare-Free Lighting

Glare-free lighting can be achieved by using a light polarizer on ceiling fixtures. Polarizers work by titling incoming light from vertical angles of 25-45 degrees. (Kruger, 1967; Ceglia, 1966).

Programs, Standards, and Policies

There is a fair amount of organizations that aim to promote awareness by facilitating programs. Examples are IYL2015 and Globe At Night. Some vendors sell inventions that lessen the impact and fight light pollution (e.g., Starry Night Lights, The Original GlareBuster, Green Earth Lighting, Holophane.com). Some organizations have set lighting standards, such as LEED (Leadership in Energy and Environmental Design). IESNA (Illuminating Engineering Society of North America), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), International Dark-Sky Association (IDA).

There are also policies and laws implemented to fight light pollution (Cha, Lee, Lee, Jung, Lee, Han & Gu, 2014). In the U.S. alone, 18 states (Oregon, Wyoming, Colorado, Arizona, New Mexico, Texas, Arkansas, Minnesota, Florida, Virginia, Delaware, District of Columbia, Maryland, Connecticut, New Hampshire, Maine, New York, Rhode Island, Hawaii, and Puerto Rico) implement policies to minimize the effects of light pollution shown in National Conference of State Legislatures in 2016. The Model Lighting Ordinance (MLO) created by IDA and IESNA serves as a template for municipalities' lighting ordinances. MLO also aims to get rid of fixtures that are not well-shielded. There are also national policies that are implemented by some countries, such as South Korea and France.

Conclusions

In conclusion, light pollution should be recognized as a global threat. As given the sources of light pollution, there are possible ways to reduce it. Light pollution is attached to the growing human population, economy, urbanization, and technology development. Strict implementation of the guidelines to decrease the unwanted or wastage use of light is significant. It is also vital to strengthen the worldwide awareness of the adverse impacts of artificial light on the ecological processes, environment, human health, and the scientific community. The support from industry and the community to the world advocacies on addressing light pollution issues is well needed.

Recommendations

To prevent the increasing propagation of light pollution, one must implement rules that people should follow. There are practical ways to limit the effects of light pollution. Our main contribution to lessening light pollution is to shut off lights when not used as a simple citizen. As for the brave and hardworking people who have no choice but to work at night, it is recommended to reduce the blue portion of the artificial lighting. Through this, shift workers are protected against disorders such as cancer and cardiovascular diseases and reduce sleep disturbances and their consequences among the general population. Awareness and discipline would help limit light pollution's inevitable effects on the environment and ecosystem, stellar visibility, and human health.

It is also helpful as the World Policy release the proper use of lights, road light design, the advisable color intensity of light at home and offices, and installing lights or any devices that produce artificial light like LED billboards.

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