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Article

Studying light pollution as an emerging environmental concern in India

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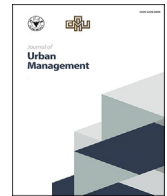
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Research Article

Studying light pollution as an emerging environmental concern in India



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ABSTRACT

The growing global population has increased the demands for urban housing development not only in the cities but in suburbs and rural areas as well. This gradual but speedy urbanization and globalization have introduced a new kind of “night lifestyle” among people, who engage in various entertainment activities late in the evening till early mornings. This influx of urban architecture and changes in lifestyles have resulted in increased use of various kinds of lighting systems in our cities to a point where some cities like Mumbai and New York City are known as “the cities that never sleep.” Although this might be contributing significantly to the economy, they cause greater harm-light pollution, with little to no awareness. This paper, therefore, deals with the various types and causes, and thus the consequences of light pollution, ranging from plants, animals, humans to astronomy. The documentation done so far concerning light pollution has been done by scientists and astronomers from the West. Thus, an attempt has been made to assess the awareness ratio among Indians between the ages of 16–65 through an online questionnaire, analyzing the collected data qualitatively. It was found that majority of the participants were not aware about the term ‘light pollution’ and consequently were not aware about the threat that comes with it. So the objective of this review paper is to bring attention to the severity of the issue of light pollution and make people aware of the consequences it has on our lives. All the effective mitigation policies and regulations from various countries around the world that were theorized to deal with this risk and propagate awareness are included. Our goal is to bring these solutions to practice in the Asian and South Asian countries like India and make the masses informed as light pollution is still a relatively new and alien concept.

1. Introduction

Light pollution refers to excessive, enormous, and unnecessary use of artificial light in the form of outdoor lighting sources that has adverse effects on the environment, lifestyle, wildlife, astronomy, etc. Despite the grave consequences of the unchecked and hazardous use of different forms of artificial lighting sources, whether indoor or outdoor, the general population has little to no awareness about this type of pollution that they are being exposed to daily. Countless research and interventions are confirming the presence and the effects of air, water, soil, and noise pollution, but only a few sources discuss the environmental threat of light pollution. Outdoor lighting poses a profound threat to astronomy (Riegel, 1973). Astronomical light pollution refers to the difficulties in viewing the night sky and observing celestial objects because of artificial illumination during nighttime. This issue has been stressed by many astronomical

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agencies and centers like IDA (International Dark-Sky Association) since the early 20th century (Longcore & Rich, 2004). IDA also gave an official definition which states light pollution as any adverse effect of artificial light that includes skyglow, glare, light trespass, light clutter, decreased visibility at night, and energy waste (Rajkhowa, 2014). Many kinds of research have found out various factors and consequences linked to this pollution, stating that the situation will worsen over time. The worsening effects were studied much later, drawing attention to the fact that light pollution has both direct and indirect negative influences on all living beings—plants, animals, and human beings. In animal, insect, and bird species, light pollution alters many biological processes like migration, breeding, nesting, and hatching. It has increased nocturnal alertness in Peahens during the nights (Yorzinski et al., 2015). Much observable evidence has been put forth by researchers that prove the implications of aquatic habitats as well. The artificial light pollution near the coastal regions affects the coral reefs, and sea turtle hatchlings lead to a considerable decline near the beaches (Behera & Mohanta, 2018; Rosenberg et al., 2019). There also has been a drastic decline in pollination in plant species worldwide due to lighting used at night that has led to negative repercussions in their reproductive system and hence resulting in an ecological imbalance (Knop et al., 2017). Insects are sensitive to increasing artificial light usage during the night. Moths, butterflies, and other insects have also declined over the past years (SolanoLamphar & Kocifaj, 2013). It also affects human physiology and circadian rhythms by causing vision loss, stress on the retina, skin cancer, etc. (Raap et al., 2015). There are various harmful health effects of artificial lights around us (Falchi et al., 2011; Stevens, 2009). Aesthetic amenities also endure this brunt (Morgan-Taylor, 2015; Depledge et al. 2010), and so does the urban ecosystem (Davies et al., 2013; Gaston et al., 2015; Kyba et al., 2011; Longcore & Rich, 2004; Duarte et al., 2019). The spectral compositions of artificial lights are the causes behind all the damaging effects on the various aspects of our life (Aube et al., 2013; Longcore et al., 2018). With increasing urbanization, human beings are spending more of their time indoors or in vehicles, reducing the exposure to the natural daytime lighting that is essential for our biological processes. More exposure to artificial lighting has alarming consequences. It often alters our sleep and wake cycles leading to sleep deprivation (Smolensky et al., 2015). Apart from the health concerns, there also awaits a problem of high energy consumption and wastage with the increased dependence on artificial light sources (Mishra, 2018). Studies on how human manipulations in lighting impact the lives of living creatures like plants have been happening since the 17th and 18th centuries (Hunt, 1854 & 1854; Darwin, 1881). Intermittent light during the night, irrespective of the intensity and duration, has significant physiological effects (Smith, 1982; Meravi & Kumar Prajapati, 2018). Flora is also being affected as the excessive artificial light and the reduced number of dark hours bring about changes in the photosynthesis process that is extensively vital for survival (Pattini et al., 2006). Humans are diurnal animals, but the exponentially increasing use of night light has pushed our daily activities into the night, affecting our biological and physiological processes (Falchi et al., 2011). Smog is also affected by light pollution. According to the study by the American Geophysical Union, light pollution is responsible for destroying nitrate radicals that prevent the atmospheric smog from subsiding which happens at night. The measurement of light pollution in its totality is difficult because the natural atmosphere is not pitch dark (Rajkhowa, 2014).

Artificial lighting used at night has provided us with both visibility and safety. But it has also led to an increased number of human activities that include building newer infrastructure, rapid economy, and industrial growth. But this assumption is misguided as most of these artificial lights do not solve their purpose of visibility or safety. With the technology influx day by day, there have been many energy-efficient inventions like LEDs that are now replacing the traditional lighting sources. But these LED lights are not as sustainable as they promise to be. They have a disadvantage to biodiversity due to the artificial light at night (Schulte-Romer et al., 2019). Identifying the sources can be done with the help of CCD cameras arranged in an ascending movement from the ground level to 10m over the many light sources like advertisement hoardings, decorative lights, aiming at the inferior view (Galatanu, 2014). Thus, increased usage of artificial lights at night has been negatively impacting our health and biodiversity for decades now (Cotarelo-Valledor, 1923; Gallaway et al., 2010). There's no specific categorical division in light pollution like other types of pollution. For instance, the burning of coal releases harmful gasses like carbon dioxide and sodium dioxide that lead to air pollution. But light can turn into a pollutant when there is an imprudent amount of usage and dependence, leading to both direct and indirect effects including glare, fading of stars at night, and changes in the biological processes among both plants and animals. The First Atlas of Artificial Night Sky Brightness shows that 60% of the world's population lives under light-polluted skies, and 21% live in places with constant intervention from light pollution in the

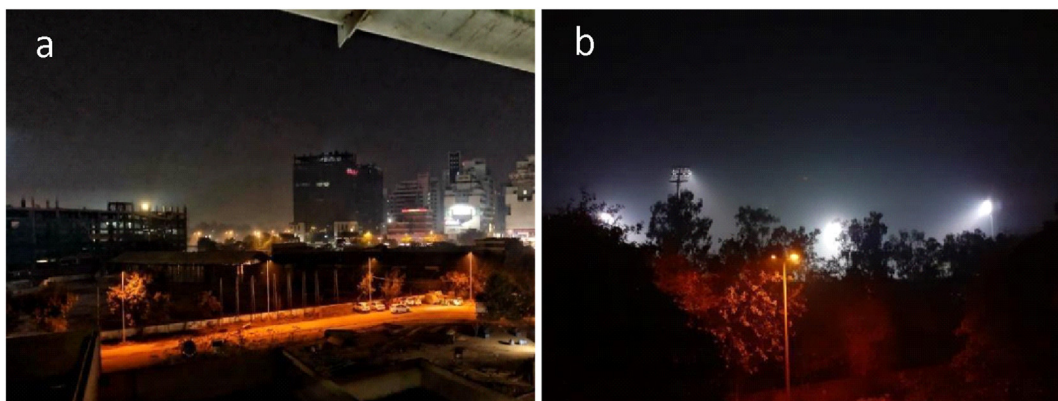


Fig. 1. Light pollution in Delhi, India on (a) January 12, 2020 & (b) February 4, 2020 (Source: Author).

nighttime sky (Falchi, 2011; Cinzano et al., 2001). Through research, it was found out that 63% of the world's population live in light-polluted areas with 99% of them being the American and European populations (Navara & Nelson, 2007).

India's urban population grew slightly faster than its rural population during 2001–11. India's National Commission on Population (NCP) found out that approximately 38.6% of Indians (600 million) are likely to live in urban areas within the next 15 years (by 2036) (Aijaz, 2021). UN (2014) expects four Indian cities, namely Ahmedabad, Bangalore, Chennai, and Hyderabad, with populations ranging from 5 to 10 million, to become megacities in the coming years, bringing the country's total to seven megacities by 2030. A study from January 2019 showed the constant rise in outdoor lighting in the past 20 years and the detrimental effects it has been having in many parts of India. New Delhi, Telangana, Maharashtra, Karnataka, and Uttar Pradesh have reported high levels of light pollution and saw a further increase from 1993 to 2013. West Bengal, Gujarat, and Tamil Nadu saw a rise in pollution despite having low levels initially (Ghosh, 2019). Fig. 1a and b shows the skyglow and light clutter as a consequence of street lights in Delhi India.

The objective of this review paper is to bring attention to the severity of the issue and make people aware of the consequences it has on our lives. An online survey was done in the form of a questionnaire to assess the awareness ratio of Indians between the age of 16–65, and the results showcase the lack of proper information and understanding of the topic amongst people, and that is the concerns dealt with in this review paper.

2. Components of light pollution

Major causes of light pollution are inefficient, unappealing, or unnecessary uses of artificial light. This type of pollution can be broadly divided into various categories that affect us daily. They are discussed below and shown in Fig. 2.

2.1. Light trespass

When the light passes over the predetermined range, it is known as light trespass or spillover. For instance, when undesirable light pervades someone's house or building (Fig. 2). This can be a major daily hassle causing chronic issues of sleep deprivation and insomnia when light enters through a window. Many cities in the U.S have come forth with policies related to street lighting to safeguard rights against light spillover (Mishra, 2018; Rajkhowa, 2014).

2.2. Skyglow

The orange-pink glow that envelopes the night skies of many cities and metropolises is called skyglow or sky glow. Not only do the natural factors cause sky glow, but uneconomical and artificial lighting emit unnecessary glow to the sky and are further scattered through dust particles, gas, and water droplets in the air. During the bad weather where these tiny particles are even more present in the sky, skyglow becomes more prominent, causing additional interference for the astronomers to view the night sky objects. The Mars Hill Observatory in Arizona reported 0.5 magnitudes of the rise in the sky glow from 1976 to 1988 (Garvey, 2005; Rajkhowa, 2014).

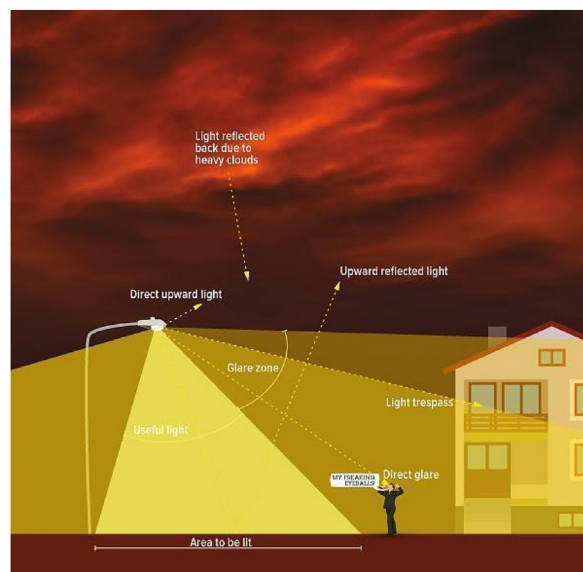


Fig. 2. Various components of light pollution (Source: Anezka Gocova, “The Night Issue”, Alternatives Journal 39:5, 2013. Accessed on May 24, 2020).

2.3. Over-illumination

The excessive use of light well beyond that required for a specific activity is referred to as over-illumination. Many places, both indoors and outdoors, have lights on when no people are present. In many cases, this goes beyond the need for security lighting. Examples include office buildings that have lights on all night even though the buildings are virtually empty or even landmarks, historic buildings, and attention-seeking skyscrapers (Rajkhowa, 2014).

2.4. Light clutter

Excessive groupings of lights that are bright and confusing are referred to as light clutter. This is commonly found in overlit cities and areas which are highly populated. The rapid increase of light clutter also causes the other four types of light pollution in the metropolises. Such groupings of lights can cause confusion leading to many accidents. You can observe the clutter in places with improper lighting arrangements, especially roads and streets, and places with overly bright advertisement screens (Garvey, 2005; Mishra, 2018).

2.5. Glare

When eyes are exposed to the bright light, it produces an effect called glare. This happens in the cases of car headlights and streetlights that can be dangerous for pedestrians because when bright lights are flashed directly to the face, it almost blinds one and may lead to vision impairments as well (Fig. 2). It is divided into four categories: first, distracting glare where the lights reflect off the lens or reflecting within the lens, second, discomforting glare where the direct glare even from the natural sources like sunlight can cause eye discomfort because the luminance is greater than that can be adapted by the eye, the third, disabling glare which is much more intense as compared to discomforting glare, seriously interfering and blocking the vision and the last one is blinding glare which is reflected from smooth surfaces and can block and compromising the vision (Rajkhowa, 2014).

3. Causes of light pollution

Natural light consists of the light from natural objects such as the sun and other celestial objects, whereas light pollution is due to lighting through different sources and mediums. Sources of light pollution include skyglow, lighting on the roadways, streets, automobiles, illuminated tall buildings, offshore and undersea vessels (Azman, Dalimin, Mohamed, & Abu Bakar, 2019)

Residential, commercial, industrial outdoor lights, etc. are designed poorly to contribute significantly to light pollution. Most of these lighting sources are used at night that causes light spills in the sky (Fig. 3). Rather than being used in areas that require illumination, they seriously affect the natural light. Light trespass, as mentioned above, is present around us all time but does not consciously release, for instance, the excess artificial light from outside entering our rooms. Ignorance of the effects that excessive light illumination, spillover, and clutter can have on our environment has led to poor planning and placement of streetlights. Often these powerful sources of light are turned on throughout the night. Along with the vehicles that use the road, these street lights emit light to a lot of places where they are not meant to be. It has been noted that roadway lights produce about 35%–50% of light pollution.

Irresponsible usage of light like keeping the lights on for long periods, etc., and not contributing towards minimizing waste of energy is another cause of light pollution. IDA published the estimations about energy consumption and wastage due to light pollution, showing that about 9 million tons of coal and 32 million barrels of oil have been wasted that results in \$1.74 billion wastage of energy resources each year. Large electronic sign boards lit up by powerful lights and places using a lot of light to attract attention like shops, etc. cause light pollution as the lights used by these are not directed to someplace but are scattered in many directions. This leads to increased dispersion of light.

3.1. Excessive use of light

The steadily increasing amount of light from towns and cities has made it exceedingly difficult to observe the sky. In towns and cities, the illumination from various lighting sources gets directed in the sky and scatters in the air leading to a visible glow called skyglow. This also interferes with many astronomical observations as it makes it difficult to view various celestial objects in the night sky. Tall



Fig. 3. Light pollution caused by streetlights (Source: Conxcorp. Accessed on May 22, 2020).

buildings and structures like wind energy generators, towers, or lighthouses cause light trespass.

The cheaper alternatives like LED'S have many hidden fatal effects like over usage without proper shielding or preventions from over-illumination. The overly bright light sources such as tube lights and bulbs project excess light in the surrounding that has a negative impact. Some of the streetlights include those white LEDs that emit shorter waves of blue light leading to skyglow and severely impacting the animals as well.

Production units responsible for gas or oil also have concerning consequences. For instance- NASA space images show how the glow over the Bakke oil fields in North Dakota appears as bright as Chicago and Minneapolis. Apart from night lights, gas flares and machinery also pollute the night skies. Humans could see up to 2500 stars at night through the naked eye. Over the years, rising light pollution has reduced this number to 200 to 300 stars or even less than a dozen in metropolitan cities. The pollution has increased by approximately two percent between 2012 and 2016, as shown in a study conducted in 2017.

Although two percent does not seem much, these percentages compound over time.

Light Pollution, like all other types of pollution, is manmade, and its exponential increase rate has made it even worse in the past few decades. In addition to the reasons mentioned above, overpopulation, poor planning, night-time excess lighting, smog, vehicular lights, etc., also contribute equally to the advancement of this hazard.

4. Effects of light pollution

Regular exposure to excessive illumination from various indoor and outdoor sources has been found to have serious consequences on not only human beings but also on other animals, insects, and plant species by slowly damaging the circadian clock. Various night sky observatories all around the world have also noted changes in the visibility of various celestial bodies in the sky, making it difficult to observe the night sky in many cities and sub-urban places due to artificial light used at night-time. Some of the known impacts of light pollution are discussed below.

4.1. Humans

With the growing population and urbanization, artificial light at night is a necessary demand. Nevertheless, it has been observed over the years that the presence of artificial light at night can have negative consequences on the physiological functions of human beings by affecting their circadian rhythm - which refers to the biological clock in the brain that regulates the sleep-wake patterns not only in humans but in all mammals. Undesirable exposure to light is one of the major factors that can cause circadian disruptions and other physiological abnormalities like metabolic disturbances leading to cardiovascular, kidney disorders, and type II diabetes. Increased exposure to artificial lighting at night can increase cortisol levels and reduce melatonin levels which can lead to both reduced sleep and the presence of depressive symptoms (Kumar, Ashawat, et al., 2019). Koo et al. (2016) conducted a study to find correlations between obesity and outdoor lighting. Although there was no direct causal relationship between the two, there are many studies that show a rise in obesity in the last few years because of artificial light used at night as it reduces nocturnal melatonin production. The human eye is also sensitive to LED lamps affecting visual perception as well (Lamphar et al., 2013). Retinitis pigmentosa (RP) and age-related macular degeneration (AMD) among any retinal diseases can be caused due to constant exposure to artificial lighting as they alter light wavelengths and intensities (Contín et al., 2015).

Romeo et al. (2013) conducted a study where Sprague Albino rats were exposed to artificial light for 20–90 days which resulted in the reduction of TH-positive dopamine neurons, suggesting that light pollution could be a possible cause of Parkinson's disease in human beings but it still needs relevant testing.

4.2. Plants

ALAN affects the natural cycles of plant species, as well as the dark hour, which is necessary for the plants to perform photosynthesis efficiently (Martineau et al., 2012). Meravi and Prajapati conducted a study in the year 2018 where they studied the effects of street lighting on the photosynthesis process of the plants growing near the streetlights. Artificial light sources also harm the nocturnal pollination networks which are a major threat to terrestrial ecosystems. This impacts the reproductive process of the plants (Knop et al., 2017).

4.3. Animals

Interference by artificial lights has extensive effects on fish, amphibians, coral reefs, reptiles, birds, mammals, and all other wildlife species (Bennie et al., 2015). Light pollution interferes with the movement of the migratory bird species, especially nocturnal birds at night as they often get trapped by the illuminated sources in the urban areas and affect their sleep cycles. Birds also collide with the buildings due to reflected light surfaces (Cruz et al., 2018). Among many threatened bird species, Petrels are at high mortality risk because of this type of pollution.

Rodríguez et al. (2017) did an experiment that examined how metal halide (a type of light spectra used in lighting systems) increases the mortality risk as compared to other kinds of light spectra, high-pressure sodium lights and light-emitting diodes. Birds that didn't come in contact with excess lighting were found to have better health conditions than others. In 2015, Barranco and Hughes studied the effects of LED lights and halogens on Amphipods near coastal areas of the Great Barrier Reef. LED lights proved to have more effect, altering the behavior and distribution of the Amphipod which impacts their whole ecosystem. Artificial light sources near beaches have

reduced turtle hatchlings over time, as adult female turtles seek much darker zones to lay their eggs (Behera & Mohanta, 2018). Response to the light sources by the fish varies from species to species but mostly fishes avoid the white light sources which are used by industrial fisheries. Bright light sources can have a severe impact on the behavior of fish species like damaging their eyes which is mostly adapted to the darker environment. (Rajkhowa, 2014). The coral reefs in the shallow water levels are sensitive to light/dark cycles as much of their behavior is influenced by the natural light. So, they are negatively impacted by artificial lighting as well (Rosenberg et al., 2019).

4.4. Astronomy

More than 80% of the population in the world cannot see the clear night sky or even spot the stars because of the rising Artificial Light at Night (ALAN). It impacts the astronomical observatories around the world who are facing difficulties in spotting celestial objects due to sky glow, light scattering, or ground reflections (Riegel, 1973). The sky glow makes it difficult to spot these celestial objects that already appear fainter in the sky. The visibility of galaxies and nebulae is much more affected than the stars (Rajkhowa, 2014).

5. Case studies from the different parts of the world

Over the past few decades, light pollution has become one of the serious environmental issues in many parts of the globe. Countries have been trying to educate themselves about the concepts related to light pollution and increase awareness about it to the masses. Many of these countries have introduced various policies related to this issue but many still stay unaware of this type of pollution.

5.1. United States

The US alone accounts for energy wastage of up to 7 billion dollars every year. It has been reported under the California Energy Commission (2005) that outdoor lighting sources consume 6% of the 4.054 million megawatt-hours (MWh) of electricity produced. A study conducted by Cinzano et al. (2001) showed that artificial lighting at night has polluted 0.6% of the landmass that is more than natural levels (Gallaway et al., 2010).

Awareness about the issue of light pollution was first in the US. There are many founding astronomical observatories and centers in California and Arizona that have observed the sky brightness and its effects on the dark skies over the years (Walker, 1973). International Dark-sky Association (IDA), a non-profit organization, was founded in the USA, aiming at reducing sky glow and brightness by increasing awareness and regulations related to lighting systems (Kyba, 2018). Former US President, Barack Obama for his climate change plans proposed a scheme for more power-efficient lamps and lighting systems. Many studies also showed that many people visiting the National Parks in Western America are willing to pay to preserve the dark skies (Hölker et al., 2010).

5.2. Europe

Bennie et al. (2014) conducted a study to identify the areas with changes in brightness in Europe. Although it has been noted that most of the countries are experiencing a rise in light pollution, there are some regions like Moldova, Ukraine, Hungary, and Slovakia with contractions in overall brightness. Some declines are also observable in economically developed countries like the UK, Norway, Northern Germany, Denmark, and Belgium. There have also been many initiatives like a review of LED street lighting, EU Eco-Design of Energy Using Products Directives, and a Council of Europe Resolution on human rights and the environment (Morgan-Taylor, 2015).

In Finland, the light emissions from various sources have considerably increased since the 1950s (Lyytimäki, 2006). The crucial sources of light pollution are street lighting and vehicles on non-illuminated roads. Traffic is also a contributor to this issue because of light scattering (Lyytimäki et al., 2012).

Light pollution in the UK has increased considerably since the mid to late 1980s. The first-ever coordinated intervention to tackle light pollution was the Campaign for Dark Skies that had two principles of examining threats and the spread of light pollution. Although known for their spaces at night, rural areas also are noted to be affected by nighttime light pollution. In action, the campaign has ensured controlled and efficient measures in the UK by being up to date with the technological advancements in the lighting systems (Dunnett, 2014).

5.3. Asia

In 2000, Korea began with light pollution awareness and the first management plan was executed in 2009. Cha et al. (2014) did a review on the 'Light Pollution Prevention Act' implemented by the then Korean government to manage light pollution. A committee was also established to execute the plans within the act every five years. This committee evaluated and set some zones for light pollution management targeting four types of light sources - lighting used for advertising, decorative purposes, signboards, and streetlights. It was also made sure that the disobeyers paid a fine of 1000 USD to the local district office. The paper suggests that this act can help prevent the harmful effects of light pollution on animals and humans.

Ho and Lin (2014) conducted a study that analyzed the light pollution caused by advertising signs due to light trespass in Taiwan. It also examined many control policies regarding illumination, covered area, density, and the position of a vast number of signboards installed.

The issue of light pollution is not recorded well in China, with a lack of control policies and appropriate regulation. Growing

urbanization has led to more energy consumption and increased usage of lights at night in many cities that are also known as 'sleepless cities' (Jiang et al., 2017).

The Hong Kong international airport and the Kowloon Peninsula are highly illuminated areas in Hong Kong that point out that night luminance is linked with the population (Fig. 4). There are some cases where citizens have filed complaints through the internet, but there are no laws or policies to prevent light pollution yet (Wu & Wong, 2012).

Ghosh (2019) noted in her article, a 60-page document was presented by an IT professional Nilesh Desai to the environment ministry pointing to the areas with the highest light pollution in Mumbai and urging them to take necessary steps regarding the same. Further, he has also submitted maps of India and Mumbai indicating the extent of light pollution. He also commented on the lack of awareness and guidelines regarding this new age pollution.

Growing population, urbanization, industrialization, frequent poisonous emissions of solid particles and dust in the air are some causes of rising light pollution. Center for Land and Water Resource Management G.B. Pant National Institute of Himalayan Environment and Sustainable Development in Uttarakhand, Faculty of Natural Sciences of Jamia Millia Islamia, and National Center for Earth Science Studies in Kerala conducted a case study to review the causes and effects of light pollution in a developing country like India (Kumar, Ashawat, et al., 2019). The intensities of light pollution were observed from limited chosen but diverse areas of land at a regional level. Areas present in Karnataka, Telangana, Uttar Pradesh, Maharashtra, and New Delhi revealed high intensities of light pollution that were investigated through spatial analysis. The states of Tamil Nadu, West Bengal, and Gujarat also showed a noticeable change in the intensities from low to high levels of light pollution. The study produced the results that can aid in increasing awareness and assist the actions related to environmental protection in various parts of the country.

An analysis was done on those states that reported the problems of light pollution, and the states with high levels of light pollution were grouped into five categories:

- High light pollution
- Moderate light pollution
- Lower rates of light pollution;
- The increasing trend of light pollution in cities like Maharashtra, Haryana, Bangalore, Telangana, and South Delhi

High rates of light pollution were to be observed in the capitals of most states in the country (Fig. 5). The reason for this can be the change in the brightness levels of the night sky that is a consequence of increased urban growth with developments in different spheres like agriculture, industries, economy, and infrastructure. Overall, light pollution is more prevalent in industrialized places than in rural areas where traditional lighting systems were utilized that did not impair the night. Overall, light pollution is observed as being more present in developed areas as compared to rural areas that used traditional methods of lighting that didn't harm the night sky like artificial light from the urbanized areas does.

6. A questionnaire survey conducted in India

A sample from the Indian population, with 358 participants from age 15–65 years was taken and a survey was conducted asking them a variety of questions ranging from their knowledge about light pollution, how they think others perceive it and what impact it can have on our lives to assess their understanding and level of information. The sample population included both males and females from varied age groups and was conveniently sampled. This survey aimed at finding out how much people are aware of this potentially devastating threat and their take on the same.

The participants ranged between 15 and 65 years to get a preliminary idea about how the information graph has been over generations and unfortunately it has not been significantly positive. It was seen that knowledge about light pollution is scarcely available for the common folk, irrespective of age groups.

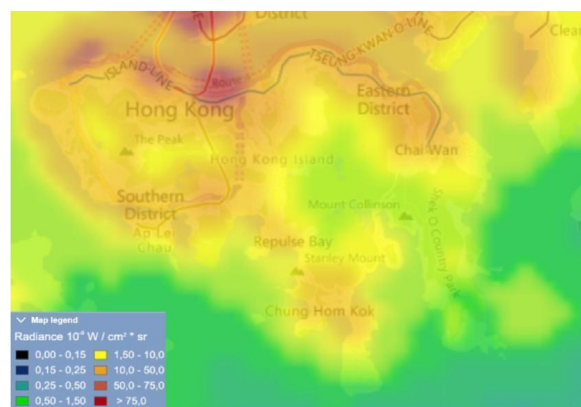


Fig. 4. Night-time lighting in Hong Kong in 2012 (Source: lightpollutionmap.info).

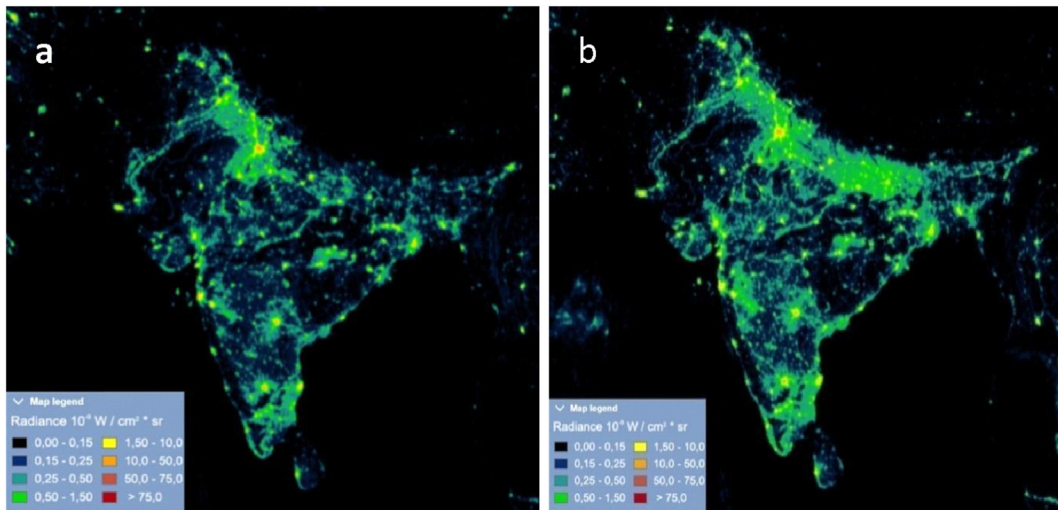


Fig. 5. Light pollution map of India in (a) 2013 and (b) 2019. Delhi, Uttar Pradesh, Bihar, Maharashtra, Telangana, Karnataka, Tamil Nadu and West Bengal have recorded high rates of light pollution (Source: lightpollutionmap.info).

Convenience sampling was employed as the sampling technique. Respondents who are “convenient” to the researcher are used in convenience sampling. There is no set procedure for obtaining these respondents; they could be found by simply asking people on the street, in a public facility, or at work, or simply online. So, in a nutshell, this is a sampling approach used by qualitative researchers to choose individuals who are easy to reach and convenient for them. Snowball sampling was also employed. Snowball sampling is a sort of convenience sample in general use. Snowball sampling is a method of recruiting in which volunteers are requested to aid researchers find more prospective participants. We contacted participants from our contacts and also asked them to share the survey with other potential participants.

The number of participants is 358 since we aimed to incorporate a mixed method of analysis - 1) qualitative to analyze people's opinion and knowledge of light pollution and related facets and 2) quantitative to assess the responses through measurable likert scales. The survey questions were designed after extensive on-ground surveys where we informally asked the general public about their take on light pollution and on what aspects do we need to focus on.

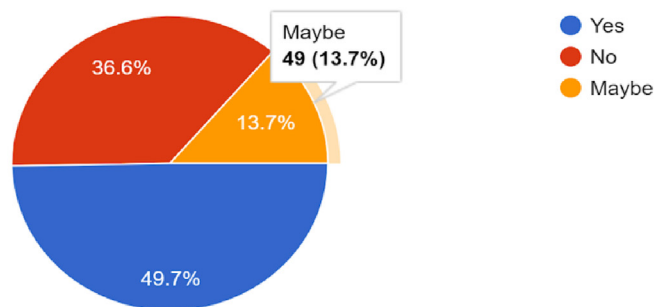
The participants were asked various questions about what they think light pollution is, how big of a threat it seems according to them, when was the first time they were made aware of it and how much public awareness do they think exists.

They were asked to elaborate on what they know about light pollution.

Some of those responses were.

Have you heard the term light pollution?

358 responses



a: Awareness about the term Light pollution

Fig. 6a. Awareness about the term Light pollution.

- “Violation of UV and other harmful rays in the sunlight”
- “Pollution which is not very harmful”
- “Maybe something related to environment”

When they were asked where and when they heard about the threat, most of the responses mentioned hearing about it ‘once’ in a TV show or lecture or movie, but never in its totality or in a systematic, informed way.

On a scale of 1–5 from least to most, we asked them to mark how often they hear about it and 57% of people said not at all. When asked if they think excessive artificial lighting has, knowingly or unknowingly, impacted them in any way, 76% of people responded yes, 20.4% responded no and the remaining were not sure. All the responses are shown in the figure from 6a to 6e.

There were certain limitations observed in the conducted survey as well. Social desirability bias can be present as we can see 91% of respondents agreeing to have heard about light pollution. It is highly likely that some respondents might have searched about light pollution before filling the form or said so because they believed it is meant to test their knowledge leading to indirect loss of accurate information because of this online mode of conduction.

Keeping aside the errors because of social desirability, extreme case/middle response bias alongside other biases that the responses in the survey might have undergone, inclusive of all age groups and genders, clearly show how people are majorly unaware of this environmental hazard and how they agree that it is underrepresented. The people, who responded as it not being a threat, when questioned, were found to be either unaware or misinformed about the environmental and living hazards it posed thus, proving the baseline argument that light pollution awareness is lacking in our society and education systems. It is also seen that the people who knew what it was heard about once in a science lecture or a news telecast and still weren't completely informed let alone made to take steps in preventing it.

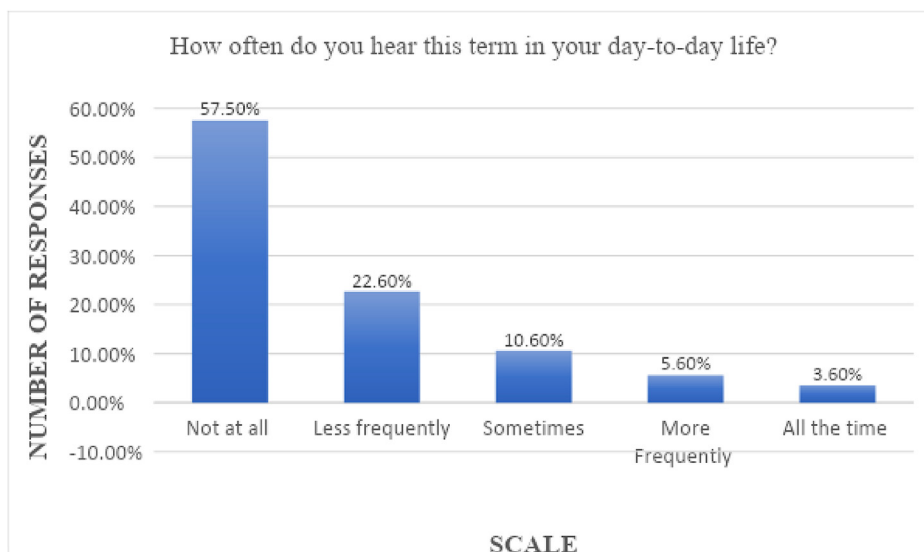
The survey had a section with basic information about what light pollution is to enable access to this information through the survey itself. In the feedback column, people were appreciative of the fact that this survey was informative and how this issue needs to be brought to light and addressed on a public platform. This basic survey helped bring the issues we have formally reviewed in the paper into the forefront, giving it a grounded base.

7. Mitigation and implications

Many major cities like Delhi, Mumbai, and Beijing, New York, etc. have and still play a vital role in contributing to light pollution alongside much other pollution and still gets little or no attention from environmentalists and researchers. Increased attention and awareness are needed from everyone, scientists, and common masses both, to preserve natural darkness and its catastrophe impacts. With the advancement in technology, awareness, and resources of the ecological impacts, some adaptive measures can be devised to resolve the impacts.

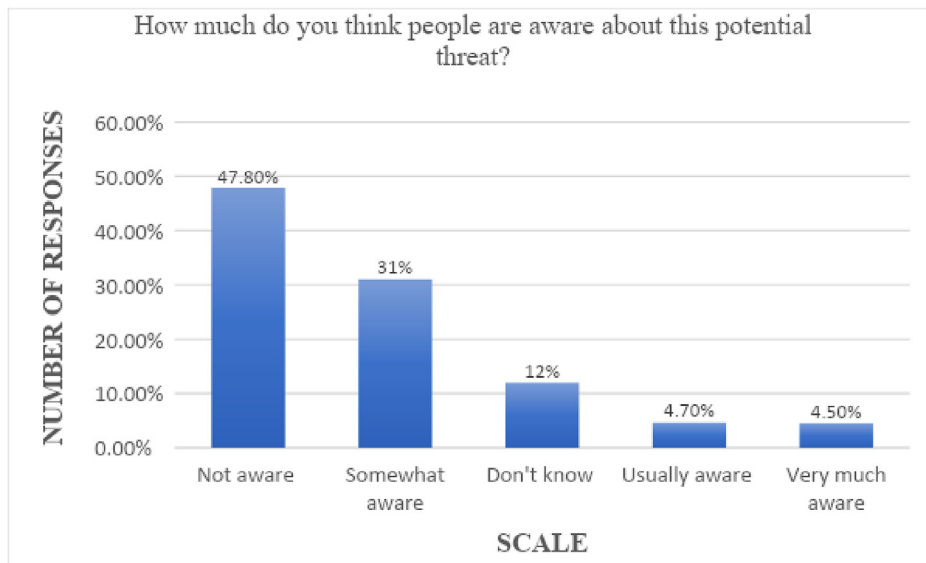
7.1. The need for increased awareness

When the upcoming generations are deprived of real-time exposure and knowledge about the natural environment, they tend to



b: Responses about the hearing of the term “Light Pollution” in our daily life

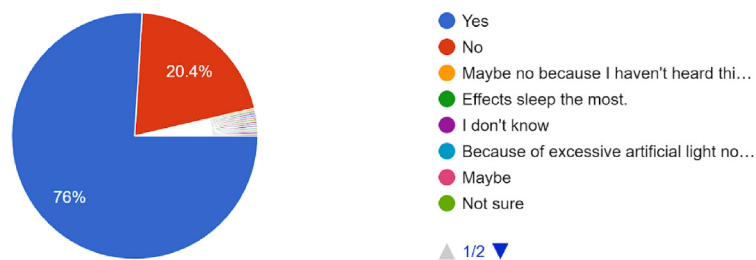
Fig. 6b. Responses about the hearing of the term “Light Pollution” in our daily life.



c: Responses about awareness about threat of the Light pollution

Fig. 6c. Responses about awareness about threat of the Light pollution.

Do you think excessive artificial lighting has, knowingly or unknowingly, impacted you in any way?
358 responses



d: Responses about perception of daily impact of Light pollution

Fig. 6d. Responses about perception of daily impact of Light pollution.

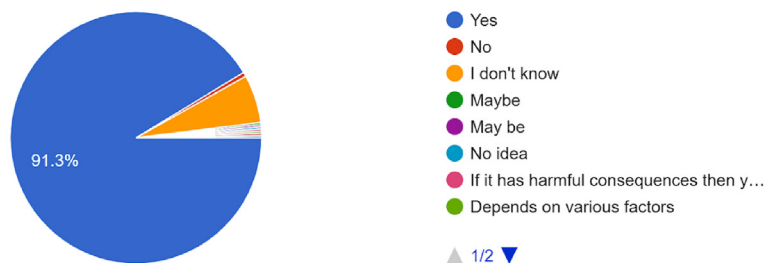
ignore contributing to its preservation. Moreover, the current lifestyle needs and availability of nighttime lighting have made people used to the illuminated night environment and the lack of awareness, taking services for granted, and not realizing the value of the natural resources is what leads to shifting baseline syndrome (Lyytimäki, 2013). This calls for the first and foremost mitigation strategy of increasing the awareness rate of this serious issue on a large scale including both individual and community levels. Lyytimäki et al. (2012) stated that measures aimed at enhancing factual information about light pollution can effectively address recognised unawareness and false awareness. In the event of purposeful ignorance, ethical reasoning or emotive advocacy may be necessary to effectively challenge the overconfidence in present knowledge's sufficiency. The scenario of hidden awareness necessitates the mobilization of critical activist voices on the subject.

7.2. Technical improvements

Other things include cutting down the use of decorative and overly bright lights and the use of unnecessary lighting during the daytime. Installing fixtures and minimizing excess light release from households and industries into the outer environment needs dropping as well (Falchi et al., 2011). Alternatives to artificial lights and automated light management and minimization projects need to be brought up and funded. Falchi et al. (2011) suggested moving freight from rails or ships instead of roads and using energy-saving

Do you think it's important to make people aware about it?

358 responses



e: Responses related to the importance of awareness about this kind of pollution

Fig. 6e. Responses related to the importance of awareness about this kind of pollution.

sources like infrared detectors for streetlights, car lamps, etc. Proper measures can be taken at different levels and stages to systematically deal with light pollution and its consequences. Both physical and perceptual problems can be managed by coming up with targeted solutions according to the intensity and growth of the pollution.

Cinzano (2002) proposed that we renounce the installation of any new lighting system on a hypothetical scale of declining efficacy. This would not completely eradicate light pollution, but it would bring its rapid annual growth rate to a minimum. Although this method does not cause darkness and is seen favorably by some, it may collide with the growth requirements of sophisticated industrial countries. Another alternative, which has been offered by a number of groups, is to allow for more nighttime illumination while simultaneously putting a cap on the annual growth rates of outside light flux placed in each municipality and the annual growth rates of electric power consumption for external lighting.

7.3. Changes in the policies

Ho and Lin (2014) analyzed the regulatory policies for light pollution from advertising signs in Taiwan. The question that came up post this was whether the luminance limits set by the CIE (the International Commission on Illumination) are proving effective in regulating the trespassing of light or not. This trespassing from the advertisement signs was carefully studied and analyzed with the assistance of field measurements and software simulations. The results from this Taiwanese study showed that despite the luminance of the hoarding being lower than the advised limit of CIE, light trespass prevailed and is a major factor posing serious concerns because it affects a large area, there are installation faults, and the density is too high. Policies for the control of similar environmental impacts in urban settings have been advised as a framework to build on. The measures they suggest for avoiding light trespass is that the advertising signs cause vertical illumination that should be decreased and lowered beyond CIE recommendations and suggestions should also be made about the coverage area of such signs.

The 5th division (exterior lighting and other applications) of CIE includes TC 5–12 (Obtrusive light), which was established with the mission to investigate the effects of obtrusive light from exterior lighting on residents and traffic, and to prepare a technical report that includes measures to describe the effects of light trespass, measurement methods, and acceptable levels. Sports illumination, flood-lighting, and lighting for outdoor work areas have all been the subject of reports (Hermann, 2001) In May 2021, the CIE TC 2–95 - New TC on the Measurement of Obstructive Light and Sky Glow was established. The goal of the TC is to provide guidelines and examples for metrics, measurement methods, and corresponding instrument specifications for the measurement of obtrusive light and sky glow, as well as the estimation of measurement uncertainty contributions for the measurement, which is required to validate assessment criteria for its environmental effects (CIE, 2021).

7.4. Minimizing the ecological impact

The numerous ecological consequences of light pollution in the nighttime darkness are extremely alarming. Motile animals have trouble finding dark shelters for themselves and a reduction in light trespass could enable them in finding the shelter they need. Five major management alternatives were offered by Gaston et al. (2015) which were - (i) Prevention of artificial lighting (ii) Putting a check and thus limiting the usage of lighting; (iii) Trespassing of light should be minimized; (iv) Altering the intensity of lights being used, and (v) Changing the spectral composition of lighting (for instance, using sodium lights). Another useful way to minimize the ecological impact is to maintain and naturally modify the lowly illuminated areas. This could interfere with social as well as economic objectives but at the same time, these decreases in lighting will prove helpful in the conservation of energy and reduction in harmful carbon

emissions. It could, however, continue impacting the nocturnal and crepuscular animals because of our clashing nighttime activities.

Rodríguez et al. (2017) talked about the reduction in mortality of seabirds due to the presence of over-lighting and recommended adopting high-pressure sodium lights instead. These alternatives alongside other strategies can prove effective in the minimization of the negative effects.

Bringing all the necessary information one needs to begin understanding the concept is deeply what this research paper aims to do. This paper identifies how one cannot propose mitigation strategies without workable alternatives. Thus the need and publicizing of such alternatives is extremely important. Routine changes and fast-paced lifestyles have been possible due to the current night light facilities, which we can't change or stop but can aim at restricting them or minimizing them to the essentials. This paper offers various strategies from different parts of the world that other nations can take inspiration from and devise customized strategies for what suits them best. India still falls behind in terms of indigenous research on the subject, and even though there have been some invaluable contributions, further studies are required by Indian scientists and astronomers to understand the extent of light pollution in India from a scientific lens.

8. Conclusions

Light pollution or over brightening of the sky has severe negative effects and is responsible for adverse consequences on human health and immune system, causes sleep deprivation, behavioral changes in organisms, and risking the quality and significance of the night time environment. These negative impacts are visible not only to space explorers but also in our day-to-day lifestyle and environment, leading to degradation of the same. The above findings are studied throughout the world by various researchers. In India we have very few information on this emerging threat. The purpose of highlighting this is to bring awareness to the relatively lesser-known 'pollutants' which are causing equivalent damage as compared to the others. In this study the result of questionnaire survey showed that 57% of the participants unaware about this light pollution term. But when asked about the impact on them of excessive artificial lighting, 76% of the participants responded yes. The comparison between Light pollution map of India of 2013 and 2019 showed Delhi, Uttar Pradesh, Bihar, Maharashtra, Telangana, Karnataka, Tamil Nadu and West Bengal have recorded high rates of light pollution. Problems of glare or clutter or light trespass might not seem that big at first glance, but the latent effects are enormously detrimental. The use of excessive decorative lights or harmful lights is a few causes that can be easily reduced as they have efficient alternatives present that will help minimize the damage. Not using unnecessary lighting, switching off lights when not required, using fixtures, minimizing illumination using day, spreading awareness, etc. are root ways to move ahead and start with. This is something that can be prevented and controlled. But failure in planning accurate management schemes will lead to our physical and mental deterioration and that of the environment as well.

We hope that our work will encourage Indian scholars from various disciplines to undertake more structural light pollution research in our country. Furthermore, we believe that our work would stimulate policymakers to draft policies to address the lack of awareness and reduce the pollution's impact by adopting more sustainable night time lighting.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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