How can Light Pollution over the City of Mumbai be Assessed and Reversed?

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Abstract:

Light pollution, which adversely affects entire ecosystems, is a lesser-known but completely reversible form of pollution. The financial capital of India, Mumbai has been experiencing a steady rise in light pollution levels. This research article aims to answer the question "How can light pollution over the city of Mumbai be assessed and reversed?" It uses satellite data to map radiance levels over four representative locations in Mumbai over the last decade. To put it into a global perspective, the overall radiance level of Mumbai in 2023 is compared with that of nine other megacities. A graphical analysis of both sets of data reveals that radiance levels over Mumbai have increased in the past decade but in comparison with other global megacities such as New York or Shanghai, they are considerably low. Of particular concern, however, is the sharp increase in radiance level over the biodiversity hotspot within the city: Sanjay Gandhi National Park. The paper further explores five case studies of places from around the world that have successfully identified the emergent problem of light pollution, and introduced policies to mitigate it. Several reports indicate that although awareness about light pollution is generally lacking in India, policies introduced under energy-efficiency programmes have indirectly helped reduce radiance levels and new technological innovations now allow a smart lighting environment. The paper concludes that taking inspiration from global case studies, it is not impossible for cities like Mumbai to implement workable alternatives to conventional lighting practices to curb light pollution.

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Introduction:

Light pollution is, "the excessive or inappropriate use of outdoor artificial light" (Cobb, n.d.). The definition may be expanded today to include indoor lighting. Artificial Light at Night (ALAN) has given birth to light pollution and the loss of dark skies is but one of the problems created by light pollution.

Van Gogh painted his famous 'Starry Night' in Saint Rémy, France, in 1889. Now the Milky Way is no longer visible from Saint Rémy. In fact, a third of humankind cannot see the Milky Way now due to light pollution (Ramalagan, 2016).

The night sky over the City of Mumbai, shows only a handful of pale stars and an unnatural skyglow. Newspaper articles about how Mumbai was "upgrading" its streetlights system to LED bulbs and was spending hundreds of millions of rupees to "beautify" lamp-posts with decorative LED lighting make it all the more urgent for us to begin to examine what is the state of light pollution in the city.

Research Methodology and Sources

For a problem as knotty as light pollution, a combination of quantitative and qualitative methodology needs to be complemented by action research method which is collaborative and focussed on problem-solving.

How does one quantify the light pollution over a city?

Measuring radiance levels of street lamps using a spectroradiometer at a few locations within the city and translating that primary data into a numerical statement of the problem is not a workable method. More importantly, streetlights are not the only source of light pollution. The outcome of such a fieldwork and primary data collection would have a limited range of conclusions.

On the other hand, Satellite data readings presenting a reliable overall picture, are readily available online. The NASA light pollution map (Stare, 2024) shows the different levels of radiance over the entire globe as a series of various colours. The lighter colours (green/yellow) indicate regions of low levels of radiance, and darker shades (orange/purple) indicate a greater number of light sources, and hence, radiance. It also shows how the radiance readings over precise locations in the city changed over a large span of time. It also provides average trends on a larger scale, that is, for entire cities and countries, to be able to put the problem of light pollution in Mumbai into a global perspective.

The Suomi National Polar-orbiting Partnership (SNPP) satellite and the Visible Infrared Imaging Radiometer Suite (VIIRS), present a powerful, sophisticated and interactive tool for visualisation of the distribution of artificial light around the globe. The SNPP is an active satellite, launched in 2011 by NASA, as a source for monitoring meteorological conditions on Earth, as a part of a larger aim of monitoring the development of climate change (NASA Science, 2011). The VIIRS, launched in 2012, onto the SNPP holds a Day-Night Band (DNB) sensor, which captures night-time light (LAADS DAAC, n.d.). The readings it captures are useful to analyse the increase in light pollution being observed throughout the globe. The images are filtered to eliminate the impact of clouds, aurora, fire, stray lights, boats, lunar-illumination, and various temporal lights using VCM-VIIRS Cloud Mask, before the process of data averaging, which makes the radiance readings independent of natural sources of light and cloud-disturbance (Bedi, 2022). A researcher did not have this advantage until 2012.

Although the map also contains Bortle scale data, which measures sky brightness on a scale of 1 to 9, it is consciously discounted for this research for being too broad, whereas radiance values from the satellite data are specific and precise.

All primary data garnered from satellite imaging, is converted into graphical representation in the form of line and bar graphs using Google Sheets to help visualise quantitative analysis and draw convincing evidence-based conclusions about the exact state of light pollution over the city of Mumbai.

Secondary sources are used simultaneously to build a qualitative analysis. In the last decade there has been a sustained interest among researchers and environmental activists towards a better understanding and better handling of the problems around ALAN. A range of secondary sources, such as

A. research papers;

B. reports, guidelines, statistics published on websites of professional, governmental and non-governmental organisations; and

C. newspaper reports and magazine articles

are used to review the literature as broadly as possible. Reputed open-access publishers such as Frontiers, and academic social hubs such as ResearchGate are helpful for a preliminary research project of this scale.

While reviewing literature about the causes and effects of light pollution, technicalities of measuring it, and its solutions, one notices the curious fact that researchers from disciplines as diverse as biology, astronomy, ecology, and engineering have all sought to approach the problem of light pollution in very different ways and amalgamating all discussions into a cohesive narrative is challenging. To appreciate the interdisciplinary nature of the study of light pollution, care is taken to select sources from different fields, looking at the problem through multiple lenses. Although they discuss different aspects, they are similar in their unbiased and objective approach to the problem of light pollution, and are all international, reputable sources.

The interdisciplinarity of the problem poses some unique problems to someone trying to research the area. For example, surprisingly, there is no clear way yet to standardise light pollution measurements across disciplines (Hölker et al., 2021). Dialogue across disciplines is yet to be forged.

The paradigms used by engineers, ecologists and civic authorities are divergent. Engineers, for example, love the impressive energy efficiency of LEDs. It takes an ecologist to draw their attention to how LEDs are increasing light pollution. To that engineers may say that the upward light output ratio (ULOR) of an LED bulb can be set to be only a small percentage of its light output ratio (LOR). Using LEDs does not mean using a single light bulb, however, and so the technological specifications of one light bulb can be grossly misleading. The combined Upward Light Output of millions of LEDs will be off the charts.
While environmentalists see this, AL engineers are not likely to. This creates an information gap between the two parties, and constructive development in AL technology does not take place (Hölker et al., 2021). Similarly civic officials are

accustomed to thinking about safety, visibility for vehicular traffic, law and order and are not likely to worry about migratory birds.

Thus, what is needed is a greater dialogue and exchange across disciplines, professions, organisations and civic bodies to begin to generate awareness and to begin to find solution. It is therefore fitting to draw on case studies of action research carried out in five different cities as a useful point of reference for the study.

A Brief History of ALAN Technology:

The issue of light pollution is linked to the broad historical context of the evolution of artificial lighting technology. A timeline may in fact be drawn along which the rapid spread of light pollution can be traced going hand in hand with technological advancement.

The Development of artificial lighting (AL) technology is a fairly recent phenomenon in human history (Science Museum, 2020). During a span of a little over 200 years, human beings have made lights increasingly safer, more convenient to use and maintain, longer-lasting, cost-effective and energy efficient. With each new step ahead, the luminous efficacy (a measure of how well a light source produces visible light – the ratio of luminous flux to power) of artificial lamps has consistently risen:

Era	Type of AL	Luminous efficacy (lm/W)
Early 19th Century	Open Flame Gas lamp	1
Early 19th Century	Carbon arc lamp	2-7
Late the 19th Century	Incandescent bulbs	5-18
20th Century	Halogen lamps	5-35
20th Century	Fluorescent lamps	40-110
Late 20th Century	LED	60-200

(Energy Star, n.d.; Yeutter, 2020).

Currently we are witnessing the next phase in AL technology: LED (Light Emitting Diode) lights are set to take over the whole AL market and the process of replacing other types of lamps with LEDs has already begun across the globe. In 2012, 49 million LED products were installed in the US. It was estimated to have cut the yearly energy costs by $675 million (U.S. Department of Energy, 2013). Since 2015, the government of India has implemented the Unnat Jyoti by Affordable LEDs for All (UJALA) scheme, which is the world’s largest LED distribution programme. Another example is of the Streetlight National Programme (SLNP), under which over 13 million LED street lamps were installed throughout India as of March 2024 (Ministry of Power, Government of India, n.d.).

As the LED revolution rolls on, we must draw attention to the fact that behind its seemingly unbeatable advantages lies a huge disadvantage: light pollution.

The Negative Impact of Light Pollution:

ALAN has three broad repercussions for all species on the planet.

A) Living organisms heavily depend on the circadian rhythm (latin: circa=around; diēm= day) to regulate their biological processes. Artificial light disrupts the circadian rhythm and has "negative and deadly effects on many creatures, including amphibians, birds, mammals, insects and plants" (IDA, 2014). In humans, this disruption causes serious health risks, including the risk of cancer. Nighttime exposure to artificial light suppresses the production of the hormone melatonin, which has antioxidant properties, induces sleep, boosts the immune system, lowers cholesterol, and helps the functioning of the thyroid, pancreas, ovaries, testes and adrenal glands. Exposure to blue light at night is particularly harmful. "Unfortunately, most LEDs used for outdoor lighting — as well as computer screens, TVs, and other electronic displays — create abundant blue light" (IDA, 2014).

B) Artificial light grossly affects wildlife, and hence ecosystems as a whole. It interferes with the habits of nocturnal animals. Migrating birds rely on moonlight to find their way through darkness. The unnecessary light from buildings often causes them to wander off course, and several birds die from colliding with them. Not only birds, but also creatures living in the sea are affected by this form of pollution. Baby sea turtles, for example, rely on the bright horizon over the ocean to find their way to the sea once they hatch. Artificial light draws them away from their actual home, and millions of hatchlings die as a result (Cobb, n.d.; IDA, 2014). In this way entire ecosystems are affected: if several animals die due to light pollution, other animals that feed on this first species of animals also starve and die, thus causing a domino effect on the food web.

C) Light pollution is a hindrance to astronomers and cosmologists. Kelsey Johnson, professor at the University of Virginia and the president of the Astronomical Society of the Pacific, expresses in her 2019 talk, “As an astronomer, I fight with this [light pollution] every day to do my job. Looking at the rate of increase of light pollution, it will soon not be worth installing telescopes on the Earth.” An article from IDA puts it beautifully: “Without the natural night sky, we could not have navigated the globe, walked on the moon, learned of our expanding universe, and discovered that humans are made of stardust.” (International Dark-Sky Association, 2014)

The first step towards reversing light pollution is to analyse the situation on the ground correctly.

Case study of Mumbai

The radiance levels over various regions of the city of Mumbai across a period of ten years are mapped below. The regions of Borivali, Trombay, and the airport which appear as prominent purple regions on the map, are deliberately selected, as they represent regions of high human activity. Both suburbs have developed rapidly in the past few decades; Trombay is also home to the Bhabha Atomic Research Centre (BARC).

The Sanjay Gandhi National Park (SGNP) has also been consciously chosen as a baseline because it has the lowest levels of radiance in Mumbai. SGNP is a unique National Park because it is situated in the midst of a city. With an area of 104 sq. km., about 20% of Mumbai’s total area, it is a part of the globally significant Western

Ghats Biodiversity Hotspot. It has 274 species of birds, 35 species of mammals, 78 species of reptiles and amphibians, 150 species of butterflies and over 1300 species of plants (Sanjay Gandhi National Park (SGNP), 2014). Human activity there is limited.

	Radiances in Certain Locations in Mumbai (n W/cm^{-2}sr)			
Year	Sanjay Gandhi National Park (SGNP)	Borivali	Airport	Trombay
2014	2.10	32.3	91.4	148
2015	2.20	34.6	90.3	136
2016	1.80	37.4	86.9	146
2017	2.10	43.6	83.1	143
2018	2.40	43.4	90.8	151
2019	2.30	50.5	95.5	189
2020	2.10	45.8	84.6	174
2021	2.60	43.6	72.1	167
2022	3.20	52.4	86.8	168
2023	3.40	58.3	105.1	160

Table 1

*All values are given to 3 significant figures
The readings in Table 1 are from the VIIRS DNB (Román, et al., 2018). They are taken at a zoom level of 10. The mouse pointer of the computer was aimed at approximately the centre of the region under consideration.

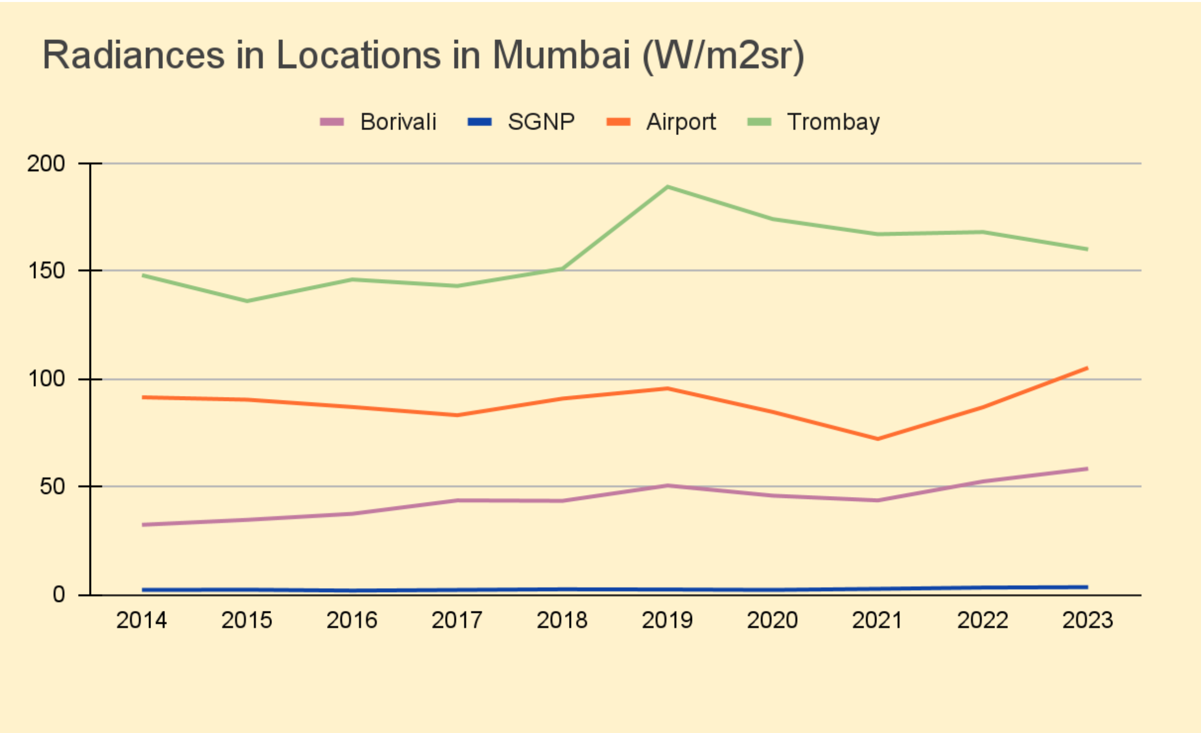

Fig.1

SNPP-VIIRS Data

The graph of SGNP is a fairly straight line running close to the x-axis. Although it tends upward only very slightly in the last two years, it is important to note that the percentage increase in the radiance is 61.9%. In contrast, the Tadoba National Park in Chandrapur district in East Maharashtra and Pench National Park in Madhya Pradesh (which received the Dark Sky Park Certification in January 2024) both have radiance levels of zero throughout the decade. The degradation of the night sky over SGNP is, thus, alarming because light pollution in this area will directly harm the precious ecosystem here.

The three upper lines in the graph show an increasing trend in radiance in the ten years. The reasons could be one or more of the following: increased population, increased human activity, increased sources of light and change in AL technology.

At a zoom level of 7.5, average readings can also be taken for the approximate centre of Mumbai as a whole. The readings increase from 30.2 in 2014 to 46.6 in 2023. This increase shows that the rising trend is uniform across the city and not limited to the areas discussed above.

Mumbai has had to recently sacrifice a region of its Aarey Forest, a part of the SGNP, to accommodate the building of a metro car shed and that is only going to see the radiance levels rise further. Two environmental activists petitioned the High Court to instruct the government to shift the construction project to another location, “to prevent harm to the environment.” (Naik, 2018). Even after several years of legal battle, they could not succeed in getting this relief. The government successfully argued that shifting the car-shed site elsewhere will not be cost-effective. This shows that there are multiple stakeholders who have to negotiate the processes of development and conservation. Even though statistically only 0.33% of the 1800 acres of Aarey land (Swarajya, 2024) was allocated to this construction, it still constitutes the erosion of an extremely precious natural reserve.

Light pollution is still a comparatively unknown environmental issue in Mumbai. In 2022 the city Municipal Corporation spent a whopping 17 billion Rupees on decorative LED fixtures to beautify the city roads (Baliga & Bate, 2023). A recent Public Interest Litigation heard by the Bombay High Court led to the Court directive to the city municipality to take down all decorative lighting wrapped around trees

(Shrivastava, 2024). This goes to show that there is an emerging awareness about the existence of light pollution, and activists are trying to engage with the city planning and city administrative authorities over the issue.

It needs to be mentioned that important factors that affect light pollution levels over an area are outside the scope of the present paper. These factors include population density, biodiversity indices, crime indices and presence of significant industrial centres. The sudden spike in 2019 in the radiance level over Trombay and a sharp fall in 2021 in the radiance level over the Airport, for example, will have to be investigated in depth. Considering these factors will generate a fuller picture of the causes and solutions to light pollution in specific areas.

Light pollution over Mumbai in a Global Perspective

To put the radiance levels in Mumbai into perspective, it can be useful to compare the 2023 values of a few national and international cities.

National cities	Radiance in Cities in 2023 (nW/cm-2sr)	International cities	Radiance in Cities in 2023 (nW/cm-2sr)
Mumbai	46.6	Shanghai	77.2
Delhi	126	Tokyo	64.3
Bangalore	49.1	New York	253
Chennai	23.5	London	166
Kolkata	75.8	Amsterdam	73.0

Table 2

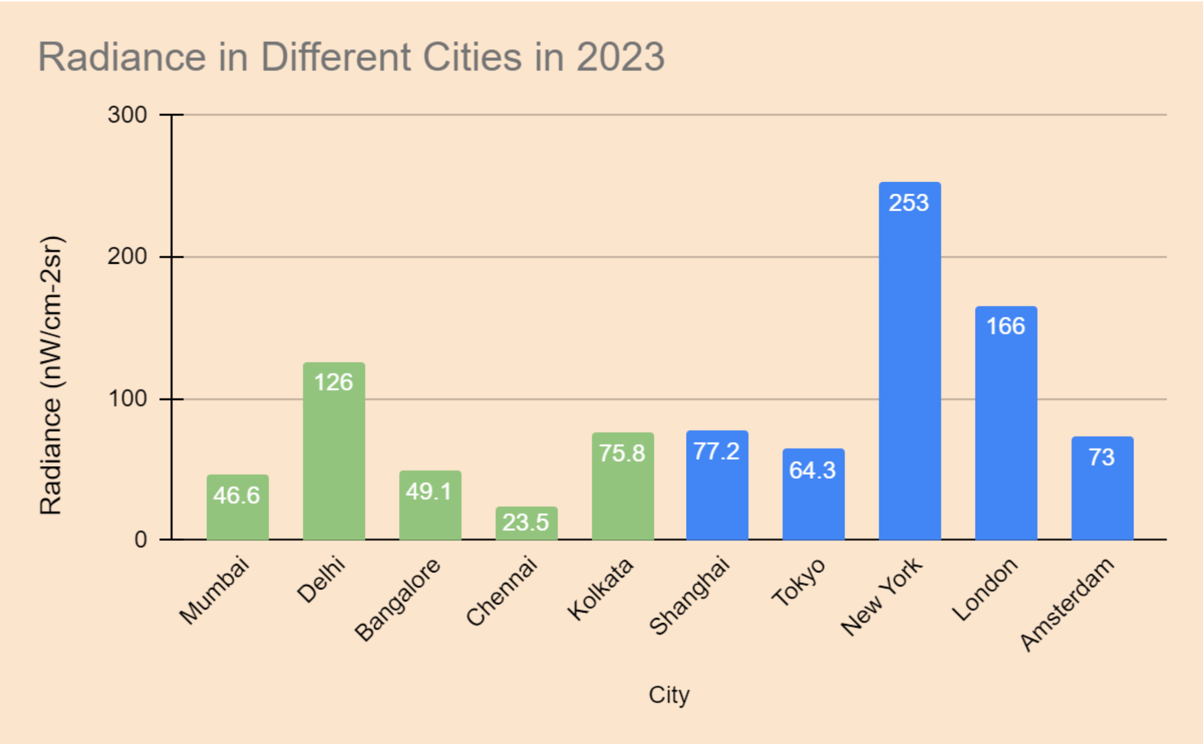

Figure 2

*The cities in India have been coloured green. International cities have been coloured blue.

It can be observed that on a national and international scale, Mumbai's radiance level ranks second lowest among these values (46.6). The highest is that of New York (253).

Action Research: Five Case Studies from around the World

Comparative data to place the findings related to the city in a global context may be effectively complemented by outlining significant experiments elsewhere in the world to reverse light pollution. It is highly educative to examine what measures have been adopted by communities elsewhere in the world to limit light pollution or to eradicate it completely. A few case studies highlighting those measures are listed below.

There are international organisations like the Illuminating Engineering Society (IES), a peer-based non-profit of lighting professionals, founded in 1906 and the International Dark Sky Association (IDA), a non-profit founded in 1988, and that have contributed actively to spread awareness about light pollution. In a collaboration, these two organisations have published the Five Principles for Responsible Outdoor Lighting (Dark-Sky International, 2023):

1. Switch lights off when not needed,
2. Target light to only where it is needed,
3. Light brightness should be kept to as small a value as possible,
4. Light usage should be controlled using motion sensors which dim or switch the lights off when they are not needed,
5. Use warmer shades of light when possible.

Simple as they seem, these principles, formulated in 2020 and adopted by several communities across the world since, have helped control light pollution in a big way.

Nieu

Niue, located in the South Pacific Ocean became the first country to be recognised as a Dark-Sky sanctuary, by the IDA in 2020(Dark-Sky International, 2023). This means radiance levels of zero. Its small population of less than 2000 is one of the reasons it has been able to achieve zero radiance levels. The island's achievement was largely brought about by some astronomers teaming up with the government of Niue. Here, the astronomers and the government worked with the citizens to replace brighter, short-wavelength LEDs with dimmer, long-wavelength LEDs (from the blue end of the visible light spectrum to the red end), implementing the 5th Principle above as the main method of controlling light pollution.

Flagstaff, a city in Arizona with a population of 65,000, recognised the problem of loss of dark sky way back in 1958. They passed a dark-sky ordinance, becoming the first city in the United States to do so. It is also the world's first international dark-sky city, as recognised by the IDA. Today, more than six decades later, satellite images show that the effort has been sustained. The city has consciously chosen to adopt sodium lamps, which emit yellow hues of light, rather than upgrading to LEDs. Commercial searchlights have been banned, and public outdoor lighting has been shielded. Flagstaff's example is encouraging other cities to adopt better lighting practices. Phoenix and Los Angeles, and Montreal in Canada, have all designed plans to replace their LEDs with those of warmer shades (Peterson, 2017).

Pittsburgh

Diane Turnshek, a scholar at Carnegie Mellon University, has been a changemaker in spreading awareness about light pollution and the importance of dark skies. With her on the team, the City Council of Pittsburgh passed a dark-sky ordinance for the city in 2021 with plans to replace the 35,000 blue-white LED streetlights in the city with LEDs of yellow-hues. The lighting will also use technology such as motion/occupancy sensors, and will be shielded (Payne, 2021).

The German city of **Berlin,** known for low light pollution levels, is one of the very few cities in the world that still widely uses gas lighting. Although it is known for having the largest number of gas lamps in the world, a shortage of gas supply from Russia due to the Ukraine invasion is prompting Germany to replace most, if not all, of the gas lamps with LEDs (Escritt, 2022). However, they are fitting these LEDs to look identical to the gas lamps by choosing LEDs that are yellow in shade (Rennie & White, 2023).

As a test project in **Bad Hersfeld**, Germany, the city has adopted what is called 'Personalised Lighting'. This was launched after the mayor started receiving more complex requests for streetlight management, asking to address light pollution among other concerns. Citizens can control the streetlamps outside their homes using an app, which also has controls in place to prevent unsafe or inefficient practices. This test project showed almost an 80% drop in energy consumption (Wray, 2022).

The Policy Scenario in India

India is aggressively adopting LEDs on a massive scale as a part of their energy conservation programme. However, careful thought is yet to be given to how this energy efficiency translates in terms of light pollution.

It may be worth noting that there are certain policy measures that seem to tangentially help with the problem of light pollution. India has signed the Paris agreement on Climate Change in 2015, and has committed to reducing its carbon footprint. As part of this agenda, the Government of India laid out the 2017 Energy Conservation Building Code (ECBC). While the main objective of the document is to regulate the energy usage of commercial buildings (Bureau of Energy Efficiency, Government of India, n.d.), the sixth section of the document focuses entirely on Lighting and Controls. There is an exhaustive list of the lighting power allowance, sorted by type of building, and by function of a particular space. The lighting power allowance values are given as LPDs (Lighting Power Densities, in W/m^2). This is the power of light incident on each square metre of an area. Regulating the maximum values ensures that light energy is not wasted. The ECBC document also presents a detailed requirement for all spaces to control their lighting, either by using manual controls or lights with motion/ occupancy sensors that automatically dim when there is no activity in the space.

India, thus, is on a sound environmental track and with the right consultations and collaborations it is not very difficult to prioritise the agenda of reversing light pollution.

Some Important Breakthroughs in AL Technology

Since industries have come too far to give up artificial light at night, we need to develop lighting technologies that increase our functionality without compromising our health. Research happening at the interface of biosciences and engineering is doing just that, and we can see the emergence of technologies such as Dynamic Daylight Harvesting and Human Centric Lighting (Leap Info Systems, n.d.). These systems are designed to optimise human productivity both in the workplace and at home by regulating circadian rhythms despite exposure to artificial lighting.

Human Centric Lighting changes indoor lighting throughout the day, to mimic the changing wavelengths of sunlight. This ensures the workforce is most active at the times their bodies are designed to be most active (about 10 am to 2pm). At these times, the LED lighting is of short wavelengths (blue end of the visible spectrum). Before 10 am, the lights gradually change colour from amber to blue, and after 2pm, from blue to amber, simulating the changing colours of the sun.

Dynamic Daylight Harvesting uses data from sensors to change the intensities of LEDs, to light only those areas which do not receive adequate sunlight. This uses the Principle of Responsible Outdoor lighting which states that lights should only be used when they are needed and only as bright as needed. Both, Human Centric Lighting and Dynamic Daylight Harvesting, minimise energy consumption and maximise productivity. They are often used together as they form a symbiotic relationship between the artificial and the natural systems.

To sum up, consciously incorporating responsible lighting practices, adopting advanced technological solutions, and regulating lighting norms through legislation will go a long way in reversing light pollution.

Conclusion

It can be concluded that by using highly sophisticated satellite data, it is possible to arrive at a reasonably good, holistic assessment of light pollution over Mumbai and to map trends over a span of a decade. The satellite data also allows a comparison of the current scenario with that of other cities. While light pollution levels in Mumbai may not seem so alarming when compared to those of other megacities, development-related projects in the city, such as the metro car-shed construction, are rapidly increasing Mumbai's light pollution levels. High population density and high round-the-clock human activity in this financial capital of India has predictably led to steadily increasing radiance levels over the last decade. What is most shocking is perhaps a whopping 61% rise in light pollution over SGNP over the last decade. There seems to be little awareness in this city about the urgency of preventing light pollution, even in a location which features on the list of eco-sensitive regions of the world. Considering that it is uniquely placed within an urban centre and also is part of one of the world's 36 biodiversity hotspots, SGNP deserves an urgent action research project devoted to designing an actionable programme to save SGNP from light pollution.

Development and Energy conservation are the two goals that drive government agenda but reversing light pollution does not feature clearly on their agenda yet. Certain nation-wide energy conservation measures, such as the ECBC, indirectly help reduce radiance levels, but a more conscious and concerted approach to address light pollution is needed.

The alternatives to lighting policies and practices explored by communities at Nieu, Flagstaff, Pittsburgh, Berlin and Bad Hersfeld discussed above, demonstrate that by adopting necessary technological and policy changes, it is definitely possible to reverse light pollution. Mumbai needs to emulate cities like these from around the world. Over and above the directives laid out by ECBC, all architectural design needs to consciously adopt Dynamic Daylight Harvesting, Human Centric Lighting, and the Five Principles of Responsible Lighting when planning artificial lighting systems for any outdoor or indoor construction.

In a nutshell, reversing light pollution over Mumbai is not impossible. Environmental activists, influential non-profits like IDA and IES, engineers, city-planners, policy-makers, city municipality, private enterprises and ordinary citizens of Mumbai need to come together and collectively respond to the crying need to protect the night-time environment in the city.

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