A Quantitative Analysis of Light Pollution in Gurgaon and a Deepened Understanding of its Impacts

Suhani Gupta[1], Sudhi Vashistha[1], Shailja Gauniyal[1], Tanishka Rajesh Arora[1], Idha Nehra[1]

[1] *Amity International School, Sector-46, Gurgaon, Haryana, India*

Abstract

Light pollution is an emerging environmental and health challenge in rapidly urbanizing Indian cities. This study quantifies night-sky brightness across Gurgaon using a low-cost, Arduino-based Sky Quality Meter (SQM) and integrates these measurements with perception surveys from 91 residents. A total of 62 ground-based data points were collected, revealing distinct spatial variations: highly commercial and densely populated zones recorded the brightest skies (16–17 mag/arcsec$^{\mathbf{2}}$), while peripheral and semi-rural areas such as Sultanpur National Park showed comparatively darker skies ($> 20 mag/arcsec^2$). Survey results indicated that most residents underestimate the role of artificial lighting, often attributing poor sky visibility to air pollution, although 62% reported sleep disturbances due to excessive outdoor lighting. Together, these findings highlight a mismatch between public awareness and measurable light pollution levels. The study advocates practical mitigation strategies, including shielded fixtures, adaptive lighting policies, and citizen-led monitoring. By providing localized evidence, this work contributes to the limited body of light pollution research in India and offers a foundation for community-driven initiatives and policy intervention.

Keywords: Light pollution; Sky Quality Meter (SQM); Urban skyglow; Night-sky brightness; Gurgaon

Preprint Statement:
This manuscript is a non-peer reviewed preprint submitted to EarthArXiv. It has also been submitted to *Urban Climate* for peer review.

*Corresponding author: suhanigupta0906@gmailcom.com
Email addresses: suhanigupta0906@gmail.com (Suhani Gupta[1]), sudhivashistha@gmail.com (Sudhi Vashistha[1]), shailjagauniyal@gmail.com (Shailja Gauniyal[1]), tanishkararora@gmail.com (Tanishka Rajesh Arora[1]), idhanehra@gmail.com (Idha Nehra[1])

1. Introduction

Rapid urbanization and industrial development have brought about significant changes to the environment. While some effects like air pollution, water pollution and soil pollution are widely recognized, a more subtle form of environmental degradation, light pollution, has emerged as a growing concern. Light pollution, defined as the excessive or misdirected use of Artificial Light at Night (ALAN), has far-reaching consequences on a global scale.

More than 80% of the world's population lives under skyglow [16]. Rayleigh scattering of excessive light by dust particles in the atmosphere creates a haze in the sky, obstructing our view of the stars above. In the visual sense, light pollution occurs in four forms: glare (caused by the luminance contrast between the light source and darker background), light trespass (when outdoor unwanted light enters into a room and illuminates it), skyglow (luminance of the night sky) and clutter (arrays and groupings of bright light making the surroundings confusing to navigate) [12]. A 2023 study by Kyba et al. analyses global light pollution trends over 2011 and 2022 and reports that the night sky becomes 10% brighter every year [30].

However, the effects and dangers of light pollution extend beyond its visual obstructions. Various studies link light pollution with a multitude of diseases including but not limited to sleep disorders, diabetes, depression, obesity, breast and prostate cancer. A study by Melika et al. (2025) provides insight into how light pollution affects molecules in the body that take part in circadian rhythm processes and affect melatonin production. ALAN, particularly the blue light disrupts these cycles by delivering conflicting signals to the brain [33].

Melatonin, generated by the pineal gland, regulates sleep and the circadian rhythm. It has oncostatic qualities and therefore can prevent cancer growth by estrogen suppression, angiogenesis inhibition, and apoptosis induction. Researchers have postulated that ALAN exposure may pose as a risk factor for breast cancer via its ability to suppress nocturnal melatonin production [41]. A study by Blask et al. (2005) demonstrates that female night shift workers have an increased risk of breast cancer due to exposure to ALAN [3]. A similar study by Papantoniou et al. (2015) links excessive artifical light exposure with prostrate cancer in males [38]. The International Agency for Research on Cancer (IARC), in 2007, has classified shift employment that disrupts circadian rhythms as a possible human carcinogen [42].

ALAN also affects the migratory patterns of animals. A major consequence is its disorienting influence on nocturnal migration. Nocturnally migrating birds are attracted to excessive light during flight. This expands the cost of the migration journey in terms of time and energy expenditures, enhances the risk of mortality through collisions with illumined structures [31, 18, 43]. Sea Turtle hatchlings use visual clues to find the ocean. However, when ALAN is stronger than the natural light, hatchlings become either misoriented, disoriented or both. ALAN along coastlines discourages female turtles from coming ashore to nest, reduces the overall success of nesting, causes nesting sites to become more clustered, and leads to higher rates of egg predation [45, 4, 47].

Aside from its disastrous effects on living species, the lack of knowledge about light pollution is an alarming scenario which must be catered to. The deficit in public knowledge is further compounded by a lack of media attention and educational initiatives dedicated to the topic. While conservation campaigns for other environmental issues are common, those highlighting the dangers of light pollution are less frequent and tend to be localized. Kaushik et al. (2022) developed an online questionnaire to assess the awareness ratio of light pollution among Indians. The sample size of people questioned was 358, and only 49% were aware of the term "light pollution" [27]. This makes it difficult for the public to grasp the scale of the problem and its far-reaching consequences.

As far as the authors' research has taken them, currently laws for light pollution have been in effect in India nor have any official mappings been done to understand light pollution levels.

2. Objectives

This study aims to create a comprehensive map of the light pollution levels in different parts of the city of Gurgaon and correlate results with responses received from a survey that was carried out. This would help establish a relation between measured values of light pollution and its impact on the local environment. Following is a list of objectives the study aims to achieve:

1. To develop a Sky Quality Meter and carry out ground based light pollution measurement of Gurgaon.
2. To use these readings and plot a comprehensive map of light pollution levels in different areas of the city.
3. To carry out a local survey to gauge light pollution awareness levels, current lighting habits and possible light pollution impacts.
4. To analyse readings and survey responses and create connections in light pollution levels and impact.
5. To identify possible solutions to spread awareness and reduce light pollution.

3. Literature Review

3.1. Efforts to Map Light Pollution

In 1986, Garstang constructed a model to calculate the night-sky brightness caused by a city at its center and outside the city, and at arbitrary zenith distances and implemented it in Denver. [17, 8] This was the first attempt to quantify light pollution. Subsequently, in 1998, Falchi and Cinzano used data from the DSMP (Defense Meteorological Satellite Program) satellite data to quantify light pollution in Italy, therefore increasing the area surveyed [15]. In a 2013 study, Cinzano and Falchi mention important indicators to quantify light pollution: [8]

1. Upward light flux.
2. Artificial night sky brightness (both sea level and elevation)
3. Naked eye sky visibility (or limiting magnitude)
4. Loss of star visibility (loss of limiting magnitude)
5. Sky Irradiance
6. Radiation density in the atmosphere

Since then, methodologies to detect light pollution have come a long way. The most frequently used technology to map light pollution over large areas is the VIIRS DNB (Visible and Infrared Imaging Radiation Suite Day Night Band). There have been numerous attempts to map light pollution in different areas around the globe. Two global popular light pollution mapping programs are provided by the citizen science program, Globe at Night and lightpollutionmap.info, which is an interactive website combining data from VIIRS, World Atlas 2015 and SQM data.

Xu et al. (2019) and Ji et al. (2024) used VIIRS data to map light pollution in China [46, 26]. Nisar et al (2022) used VIIRS and SQML data to map light pollution in Lahore [37]. Yerli et al. (2021) took a similar approach to map light pollution in Turkey [48].

In India, Bedi et al. (2021) conducted a study which highlights brightness levels of the 10 most populated cities (Delhi, Kolkata, Mumbai, Bangalore, Chennai, Hyderabad, Ahmadabad, Surat, Pune and Jaipur) using VIIRS data and correlates results with city safety, unemployment, crime rate and street lights data. Bengaluru stands with the maximum light pollution levels, followed by Kolkata, Hyderabad and Delhi [2]. In a subsequent study (2021), the authors conducted a macro-level analysis using VIIRS DNB data and micro-level analysis using ground based surveys to map light pollution levels in Bengaluru [1].

Khanduri et al. (2023) investigated the spatio-temporal trends of ALAN across critical riparian habitats in major indian river basins using VIIRS data and observed light pollution trends in these areas over a period of 8 years (from 2012 to 2020) [28]. Singh et al. (2022) used satellite based Nighttime Light (NTL) data available from 1993-2013 and processed it with linear regression to understand how India's population growth and fast urban and industrial development have changed the country's night-time lighting patterns. The given results show that New Delhi, Telangana, Maharashtra, Karnataka and Uttar Pradesh now have very high level of light pollution, while West Bengal, Gujarat and Tamil Nadu have gone from low to high level [29].

3.2. Light Pollution Mapping Techniques

Various techniques are present to map light pollution, which are divided into 4 broad categories: (i) Satellite Remote Sensing (such as VIIRS-DNB, DMSP-OLS), (ii) In-Situ Photometric Instruments (Sky Quality Meters), (iii) Distributed/citizen science measurements (Globe At Night), (iv) Modelling and Data Fusion. We will primarily be discussing the first two categories.

The DMSP-OLS (Defense Meteorological Satellite Program - Operational Linescan System) provided the first global continuous nighttime light record operated by the NOAA (National Oceanic and Atmospheric Administration). It was used extensively for socioeconomic and ALAN studies during the years between its first release in 1992 and 2011. The DMSP operates satellites in the Sun Synchronous Orbit (SSO). The OLS is an instrument in every satellite which is an oscillating scan radiometer with two spectral bands- the visible band (visible and near-infrared) and the thermal band. Having a swath width of 3000km and covering 14 orbits per day, each OLS instrument generates a complete coverage of nighttime data in a 24-hour period. Data has a spatial resolution of 2.7km. [14].

Over 2 decades, 9 satellites carrying the OLS were launched to collect nighttime images. Although the advantages of these satellites have been recognized, several disadvantages exist as well. These include (i) relatively low spatial resolution, (ii) light saturation in highly populated ubran centers, (iii) absence of onboard calibration, (iv) the blooming effect (overestimation of lit area) due to the coarse spatial resolution of data and reflectance of light from adjacent areas like water bodies and (v) limited accessibility to high-quality daily OLS data. [20]

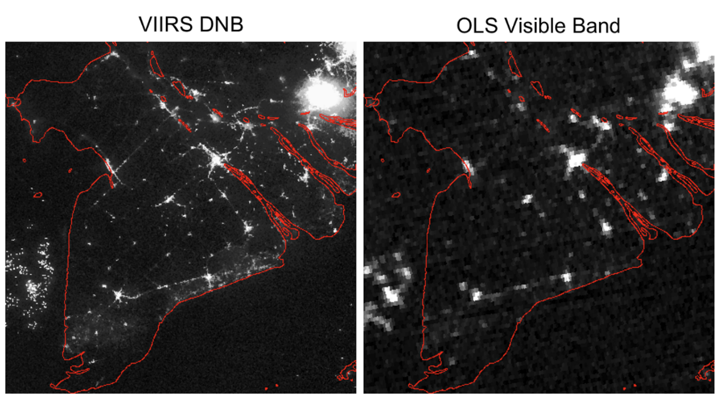

Figure 1: Comparison between resolution of VIIRS-DNB (left) and OLS (right). Both images show the Mekong Delta region of Vietnam on November 23, 2014. We see that the VIIRS data is more sensitive and has finer spatial detail. Credit: Elvidge et al. (2013) [13]

The VIIRS-DNB (Visible Infrared Imaging Radiometer Suite- Day and Night Band) is a sophisticated sensor in satellites Suomi NPP and NOAA-20 orbiting the Earth in the Polar SSO (Sun Synchronous Orbit), and detects visible-to-near-infrared radiance at much finer native spatial resolution (750 m at nadir) than DMSP. It has radiometric calibration, a large dynamic range, and better sensitivity to low-light scenes. The DNB is extremely important. It attempts to maintain a constant resolution over the entire 3,060 km orbital swath. [36]. However, VIIRS DNB is effectively panchromatic (broad-band) and has limited sensitivity to the blue/short-wavelength part of the spectrum — a key drawback now that many urban areas use blue-rich LED lighting. [32, 36]. Figure 1 shows a comparison between resolution of VIIRS-DNB and OLS data.

The Sky Quality Meter (SQM) is a low-cost photometer widely used to measure zenith night-sky brightness (NSB). It reports values in astronomical units of magnitudes per square arcsecond (mag/arcsec^2), where larger numbers indicate darker skies. Typical devices combine a silicon photodiode or light-to-frequency sensor (e.g., TSL237/photodiode) [9]. SQM Models include handheld (SQM-L) and ethernet/networked (SQM-LE) variants. SQMs have a relatively broad spectral response (approx. 390–600 nm, depending on model), and a finite angular acceptance (field-of-view), so their readings are zenith-weighted rather than full-sky integrated [40]. Limitations of SQMs include zenith measurement, sensitivity to nearby lighting, inter-instrument variability, and dependence on atmospheric conditions (clouds, aerosols, airglow).

3.3. Light Pollution Legislations

Light Pollution has been recognised as a global issue and many international organisations as well as countries have begun to take steps to reduce light pollution levels in their cities. The International Commission on Illumination (CIE- Commission Internationale de l'Éclairage) has published CIE 136–2000 and related reports that frame recommended practice for urban and outdoor lighting design [10]. Professional standards from the Illuminating Engineering Society (IES) in the U.S. similarly shape acceptable luminance, glare control, and fixture shielding in practice [22]. Complementing standards, the International Dark-Sky Association (IDA) and partners created the Model Lighting Ordinance (MLO) and a library of "dark-sky recognized" statutes that many municipalities and states adapt to local law [24]. These documents are commonly cited as the technical/legal basis for local regulations and for designing lighting that minimizes skyglow and ecological impacts.

The European Union has adopted the EU Green Public Procurement criteria for road lighting and traffic signals. It aims to address the environmental issues associated with the design, installation and operation of these systems, keeping in mind energy consumption, durability and light pollution. It proposes lighting criteria based on upward and horizontal light output ratios. Limits on Correlated Colour Temperature (CCT), G-Index for the glare and blue light output have also been set. Furthermore, the main principle is ALARA (as low as reasonably achievable). [11, 1].

France stands out for a national decree (Decree of 27 December 2018, implemented 2019) that places concrete limits on outdoor lighting, requires night-time extinction of certain public/commercial lights, and explicitly aims to protect biodiversity and night-time observation of the sky. The Decree of France accommodates maximum parameters for limiting the night- time brightness as well as standards for luminaries. [35, 1] .

Chile's approach to light pollution control is widely cited as one of the strongest globally, largely because northern Chile hosts world-class observatories like ALMA, VLT, and the upcoming Extremely Large Telescope. The latest update, Supreme Decree No. 43 in 2022 expanded national scope beyond astronomical zones. Limits have been set on maximum CCT allowed ($\leq 2700K$ in all national territories and $\leq 2200K$ in special protected zones). It mandates full cutoff and caps on illuminance/luminance levels depending on land use (urban, rural, industrial). [34]

Some countries regulate light pollution primarily at the municipal level. In China, local governments issue their own technical standards. Shanghai's DB31/T316 standard specifies requirements for decorative and functional lighting in public and semi-public spaces, along with limits on intrusive light entering residences. Beijing's localized standards regulate lighting in residential and commercial areas, pedestrian routes, stairs, underpasses, and public landscapes [19, 1].

India currently has no specific light pollution based regulations. The Bureau of Indian Standards (BIS) has published lighting standards such as IS 10322 (Part 5) for outdoor lighting, IS 13383 (Part 3) for floodlighting, IS 1885 (Part 16, Sec 2) on Lighting Fittings and Lighting for Traffic and Signalling and IS 1944 (Part 6) for lighting of public thoroughfare. These regulations recommend minimum and maximum illuminance for different road types and areas and suggests for fixture design to reduce glare and light spillage. However these regulations do not specify limits on upward light emission or spectral content of lighting, nor are there any explicit requirements for curfews or dimming during low-traffic hours [7, 6]. The Bureau of Indian Standards (BIS) has also developed the National Lighting Code (NLC) SP-72:2010, which sets standards for lighting in public spaces and roadways. It recommends illumination levels ranging between 4 and 20 lux depending on the type and function of the street [5].

3.4. Light Pollution Zones and Metrics

Effective management of light pollution necessitates the classification of geographic areas into designated lighting zones. The first framework was introduced by the CIE, which was a 4-zone system which divided regions based on night brightness of local environment [25]. These zones are:

1. **E1:** Intrinsically dark landscapes (eg: national parks)
2. **E2:** Zones with low district brightness (eg: Roads with only streetlights)
3. **E3:** Zones with middle district brightness (eg: Residential areas)
4. **E4:** Zones with high district brightness (eg: Urban areas with high night-time activity)

Another prominent framework in this domain is the Model Lighting Ordinance (MLO), developed by the Illuminating Engineering Society of North America (IESNA) and the International Dark-Sky Association (IDA). MLO proposes a five-tier lighting zone [23]:

1. **Lighting Zone 0 (LZ0):** Intrinsically dark areas in which no permanent lighting is installed.
2. **Lighting Zone 1-4 (LZ1-4):** Similar to E1-4 of the CIE 4-zone system

The principal distinction between LZ0 and LZ1 lies in the permissibility of lighting infrastructure: LZ0 strictly forbids permanent lighting installations, whereas LZ1 permits limited, carefully regulated illumination designed to minimize ecological and astronomical disturbance.

Along with this, numerous metrics have been proposed to evaluate luminaire performance and their effectiveness in addressing light trespass, skyglow, and glare. IESNA proposed the BUG rating system as a comprehensive framework for evaluating luminaire photometric distribution. This three-component metric addresses: Backlighting (Light emitted behind the luminaire that may cause light trespass onto adjacent properties), Uplight (Light directed upward that contributes to skyglow) and Glare. The BUG system provides numerical ratings for each component [21].

The CIE introduced Upward Light Ratio (ULR) or Upward Light Output (ULO) rating system specifically for exterior fixtures. This metric focuses primarily on limiting skyglow by quantifying the percentage of total luminous flux emitted above horizontal by a luminaire. However, both (Figure 2 and ULR metrics failed to account for reflected upward light components from specific installations. Thus, the CIE recently introduced the Upward Flux Ratio (UFR), which considers direct upward emission from luminaires, luminous flux reflected from intentionally lit surface areas and light scattered from surrounding surfaces illuminated by spilled light.

The Light Pollution Index offers another methodology for combining the effects of direct and reflected upward flux from various lighting applications, including street lighting and facade illumination.

A major limitation is that most of these metrics still do not account for realistic scenarios and therefore are not very accurate [12].

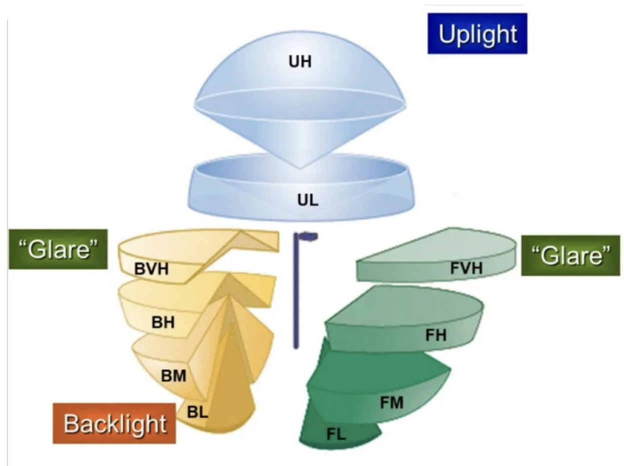

Figure 2: Sections of a bulb contributing to different components of BUG. Credit: https://www.accessfixtures.com/

4. Methodology

4.1. Survey

A survey was conducted to assess the awareness levels of light pollution in Gurgaon. We surveyed 92 people through an online google form, without initially mentioning the purpose of the survey to be an assessment of light pollution. This helped us avoid bias and gain a more authentic response. The questionnaire included questions asking how many stars viewers generally see in the night sky, whether outside light affects their sleep and what they believe is the reason for decreased visibility of the night sky.

Approximately 77% of responses showed that people believe the cause of decreasing visibility of stars in the sky is air pollution. There were a notable few responses which mentioned light pollution and others mentioned cloudy skies, fog and haze. While people know about haze and its effects, they fail to realise that this 'haze' is nothing but light pollution. This is an alarming statistic that indicates that the concept of light pollution still evades the majority of the respondents.

Yet, unbeknownst to them, light pollution affects their day to day lives. 62% of the respondents reported that they experience sleep disturbances due to excess outdoor lighting (figure 3).

Gurgaon has been divided into sectors by the administration. We asked the respondents which sector they reside in to correlate further responses and identify a trend.

Figure 3: Respondents were asked if outdoor lighting affects their sleep.

We correlated sector responses with responses to a rating-based question that asked the respondent to rate the brightness of outdoor lights (5 being extremely bright and 1 being minimal brightness). 97% of the respondents residing in sector 28, 56 and 48 reported said increasing night disturbances as a consequence of lighting and rated 5 on the scale. We analysed the city map of Gurugram (provided by the local administration) and identified these 3 regions to be located near hubs of commercial activity (Golf Course Road, MG Road and Sohna Road) as well as residential areas.

Furthermore, we asked the respondents about sky visibility at night and 67% respondents reported being able to view only less than 7 (Figure 4). Ideally, in a dark sky area with minimal artificial light, approximately 4000 should be visible. [44].

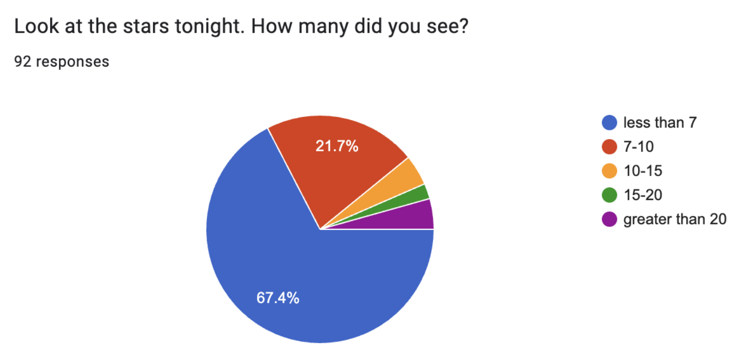

Figure 4: Respondents were asked how many stars on average they see at night.

Lastly, we also inquired about lighting practices of users on an average. Most of the respondents used outdoor lighting for decorations and festival lighting, while some others also had porchlights installed. 44% of the respondents preferred neutral white tones for daily use lighting while 34% and 39% used bluish white lights and yellow lights respectively.

4.2. Study of Demographical Area

Gurugram is situated in the state of Haryana, southwest of Delhi. The total area of the district spans approximately 1258 square (Figure 5 shows the Master Plan of the city).

Gurgaon is divided into the following regions:

1. **High-Density Residential and Commercial Zones:** Includes Central Gurugram (sectors 14–56, MG Road corridor, Cyber City) where you find dense residential neighborhoods interwoven with commercial hubs with extreme street lighting, billboards and heavy nighttime illumination.

2. **Medium Density Residential Zones:** They span across several planned and unplanned neighborhoods, featuring mixed lighting. Mainly LEDs and old yellow streetlights. These are mostly normal housing area, some well planned and some not. Moderate impact on light pollution; While the sky is darker than in central areas, the scattered LED still contributes to the cumulative light pollution across the city.

3. **Industrial Areas:** Include factory clusters and warehouses, particularly around Manesar and the outskirts. These warehouses run 24/7. To keep the area safe and functional at night, industries use very bright light 'floodlights'. When these floodlights shine upwards or sideways instead of 'only' downward, their light spreads into the sky, this creates an intense skyglow.

4. **Peripheral and Rural Areas:** Rural and peri-urban areas include villages and farmland around Sohna, Pataudi and Farrukhnagar, as well as ecologically sensitive zones like Mangar Bani forest, Sultanpur National Park and the Aravalli foothills. These places stay naturally dark at night.

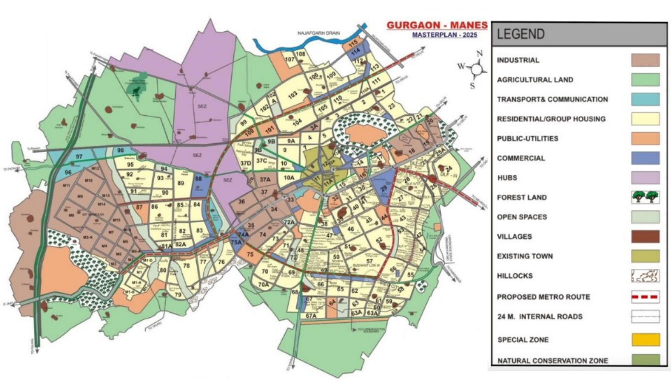

Figure 5: Master plan of Gurgaon. Source: [39]

4.3. Sky Quality Meter

Our study is more localised and therefore relies more on ground based readings. We prefer to collect the data using Sky Quality Meters.

Satellite data records the light directed upwards from the earth's surface and the atmosphere. While it does assist in mapping light pollution over a larger scale, the satellite data often misses localized variations. SQM readings are very precise, they often include Scattered light, Airglow and all the local sources of light, which the satellites tend to miss. SQM readings effectively quantify light pollution by assessing the collective impact of these light sources on the night sky's overall brightness, usually at the zenith. SQMs can deliver continuous, real-time measurements.

The version used in our study is an inexpensive adaptation, costing only around INR 1,000, making it extremely accessible for research and educational purposes, whereas the majority of commercial SQMs are priced around INR 17,000 in price. Previous research has also shown that similar low-cost SQM-based designs and modifications are effective as reasonably priced instruments for light pollution monitoring.

For the SQM, we use an Arduino Uno as our microcontroller, along with a TSL2591 light/lux sensor by Adafruit. This light sensor collects light that passes through the 15 degree FOV lens and measures its intensity. The final value, measured in magnitudes per square arcsecond is calculated and is displayed by the 16x2 LCD with I2C. All these components are placed in a box, making it compact and portable. The Arduino is powered by a 9 volt battery.

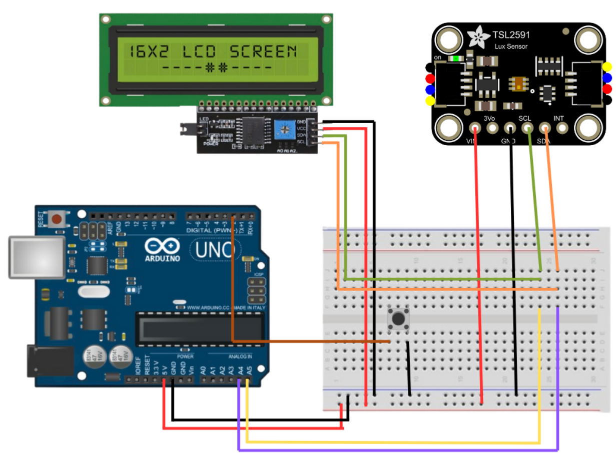

Figure 6: Circuit Diagram of the SKy Quality Meter

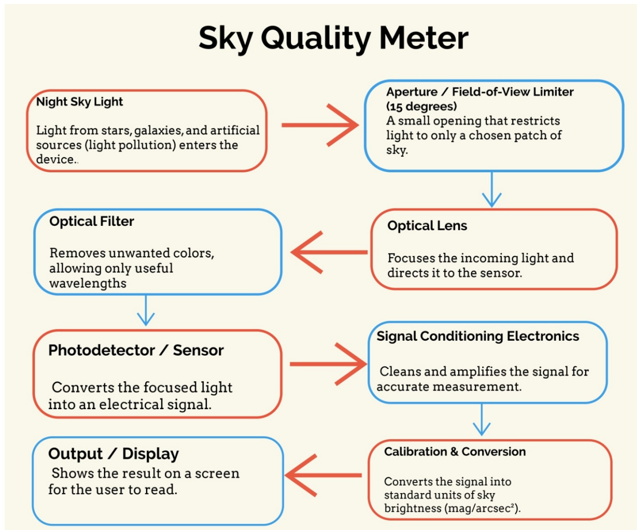

Figure 7: Working of an SQM in measuring sky brightness

The light from external sources enters the lens. The lens ensures that excess ambient light does not interact with the light sensor, only the light coming from and around the Zenith is used (that gives us actual sky brightness and is not affected by nearby lighting). This light falls on the photosensor and converts the focused light into an electrical output. Inside the sensor, the signal is amplified and processed into standard units of sky brightness. Finally, once the pushbutton is pressed, this output is displayed by the LCD. A flow of the SQM working has been given in figure 7.

We take the SQMs to different areas in the city at night and use it in a point in that area which is not extremely close to any bright lights. We point the device to the zenith in the sky (the zenith is the point in the sky or celestial sphere directly above an observer). Pointing at the zenith with a 15 degree FOV lens ensures that the surrounding ambient light does not affect our results and only the scattering in the sky just above us is calculated. We take multiple readings and calculate the mean reading.

We repeat this process in different areas of the city.

We keep in mind the experimental error that may affect our readings. However since our study aims on a more comparative analysis of trends in the city, we allow room for minimal inaccuracy in readings.

5. Results

5.1. SQM Readings

We collected 62 data points. We measured light pollution levels in 62 different areas of Gurgaon. Figure 8 is an overall plot of the data and Figure 9 shows a more zoomed-in view.

It is important to note that even the smallest change in a mag/arcsecond^2 value has a drastic shift in brightness. Therefore, although most of our readings lie in the $17-18$ mag/arcsec^2 range, we are primarily concerned with the decimal values. In general, readings below 18 mag/arcsec^2 represent very bright urban skies with significant light pollution, where only the brightest stars are visible. Values between 18–20 mag/arcsec^2 correspond to suburban conditions, with the Milky Way largely washed out. The range of 20–21.5 mag/arcsec^2 is typical of rural areas where a considerable portion of the night sky is preserved, and the Milky Way is faintly visible under good conditions. Values above 21.5 mag/arcsec^2 are characteristic of truly dark-sky sites with minimal artificial lighting, where the night sky's natural features, including the Milky Way and faint constellations, can be observed in detail.

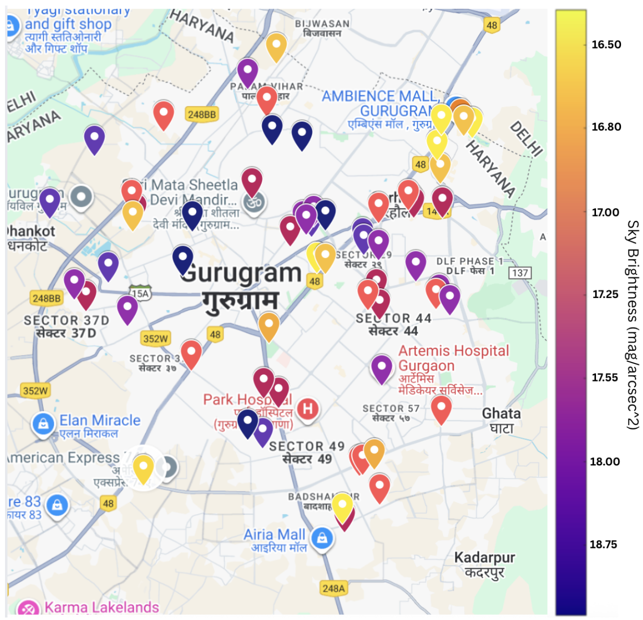

Figure 8: Overall view of light pollution levels in Gurgaon

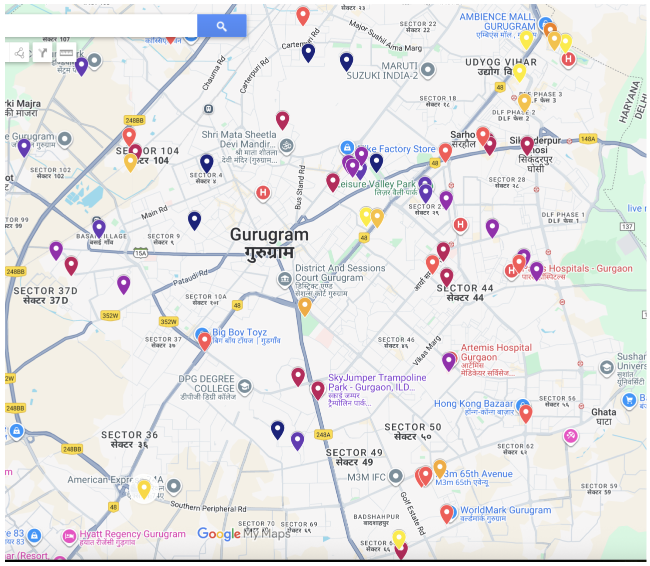

Figure 9: Zoomed-in view of data points

The spatial distribution of light pollution levels shown in Figures **??** and **??** highlights clear differences across urban and suburban areas of Gurgaon. As expected, regions surrounding large commercial complexes and high-traffic roads exhibit significantly brighter skies, with SQM values clustering in the 16–18 mag/arcsec^2 range. By contrast, residential neighborhoods and suburban edges show comparatively darker skies, with values extending into the 18–19 mag/arcsec^2 interval, though still far from pristine conditions.

This heterogeneity underlines the importance of localized light pollution studies, since broad averages can obscure sharp spatial contrasts that are directly linked to land use. The zoomed-in view further illustrates how even small shifts in distance from high-intensity lighting zones can yield measurable improvements in night-sky brightness. In particular, areas near hospitals and residential clusters appear moderately darker than those surrounding malls and major intersections, suggesting differences in both lighting practices and traffic density.

We present a table separating the measurements of light pollution levels in areas near malls and shopping markets, areas near hospitals, and areas.

Area	SQM (mag/arcsec^2)
Artemis Hospital	17.790
Paras Hospital	17.815
Medanta Medicity	17.724
Park Hospital	17.706
Max Hospital	17.421
Fortis Hospital	17.261

Table 1: Hospitals and Medical Centres

Area	SQM (mag/arcsec^2)
Ambience Mall	16.687
ILD Mall	17.464
Ardee Mall	18.054
M3M 65th Avenue	16.995
MGF Metropolis	17.547
Sahara Mall	17.505
Huda Market (Sec-14)	17.791
Baani Square	17.672
Good Earth City Centre	17.712

Table 2: Commercial Areas

Area	SQM (mag/arcsec^2)
Taj City Centre	17.339
Ramada by Wyndham	17.352
Flow Sports Life	18.125
Sultanpur National Park	20.837
Sikanderpur	17.392
AISG46	17.788
MRIS46	17.726
Tau Devilal Sports Complex	16.935

Table 3: Miscellaneous

Area	SQM (mag/arcsec^2)
Sector-14	17.791
Sector-24	18.025
Sector-52	18.037
Sector-9	18.607
Sector-4	17.956
Sector-17	17.333
Sector- 67	17.661
Central Park Resorts	17.406
DLF Phase I	17.615
DLF Phase II	16.685
DLF Phase III	17.624
M3M Merlin	17.311
Emerald Hills	17.208
Park View City 1	17.573
Parsvanath Greenville	17.421

Table 4: Residential Areas

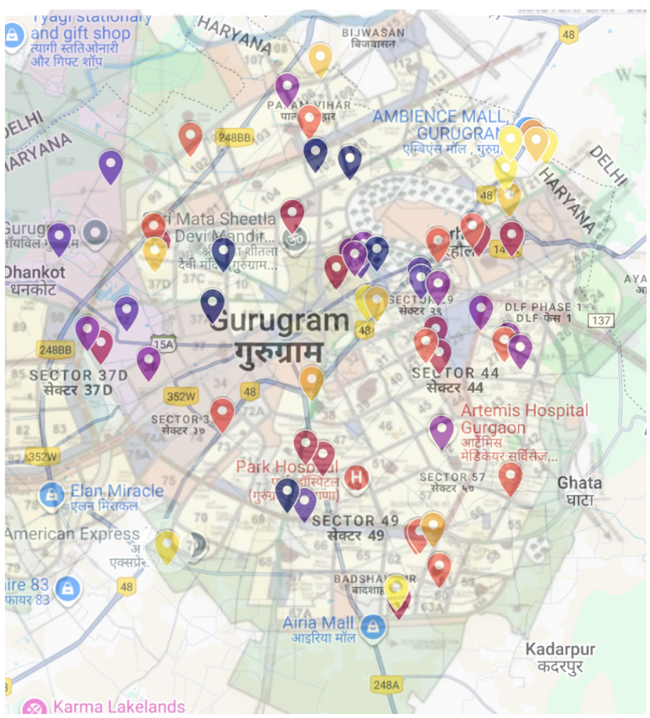

Figure 10: Overlay of readings with master plan map (Light pollution key similar to Figure 8 and Master Plan key similar to Figure 5)

We observe that a lower SQM value (higher brightness) was observed near more commercial areas such as malls and marketplaces. Another interesting thing that we noted was the excessive lighting in and around hospital and medical centres. Although hospital lighting is essential, the excessive amounts of blue-white light might be detrimental to both patient health and health of nearby residents.

Figure 10 shows an overlay of our mapping on the Gurgaon-Manesar 2025 master plan. Areas that the plan refers to as "industrial areas" and "public utilities" (hospital, schools, stadiums, hotels) showed extremely high brightness, followed by "residential areas". Under residential areas, it is important to note that societies and apartment complexes showed higher brightness than neighbourhoods with independent houses.

Areas that are not active in night-time activities such as sports academies (except Tau Devi Lal Stadium- excessive floodlighting is present here), preserved areas such as Sultanpur National Park showed low night time brightness. This confirms our previous prediction of light pollution levels.

5.2. Correlation with survey responses

The survey recorded high mentions of nighttime sleep disturbances due to outdoor lighting in areas such as Sector-28 and Sector-56. Sector-28 is located near the commercial hub of Sector-29, which recorded a night sky brightness of 17.458 mag/arcsec^2. This is a probable cause of extreme light based disturbances. Sector-24 is near Cyberhub and cybercity which is a hub full of offices and restaurants with excessive light pollution levels.

4. fix references (alphabetical order) 5. check if any text to be reduced

6. Discussion

The present study qualitatively explores light pollution in Gurugram by integrating sky brightness measurements using an SQM and citizen survey responses. Although the actual numerical SQM data are yet to be collected, preliminary observations suggest that central urban areas and industrial zones, such as Manesar, are likely to exhibit higher sky brightness. Peripheral and rural areas, including regions near the Aravalli hills, are expected to maintain darker skies due to minimal artificial lighting.

Survey responses indicate that residents in heavily lit areas often underestimate the impact of artificial night sky brightness. This suggests a mismatch between perception and actual sky brightness in urbanized zones, highlighting the importance of combining objective measurements with subjective surveys.

Additionally, the type of lighting, such as white LEDs in urban streets, likely influences skyglow levels and perception. Industrial floodlights, particularly those without proper shielding, are probable contributors to localized bright spots in the sky, which may affect nearby residential areas and ecological systems.

Solutions include:

1. **Improved street lighting practices:** Using shielded fixtures, adaptive lighting and colour temperature management
2. **Industrial Lighting Regulation:** Controlled floodlights, zoning policies on restricting unnecessary night-time illumination in non-operational areas, and periodic audits
3. **Urban Planning Interventions:** Lighting Zoning, Green Buffers to maintain natural patches and tree cover between industrial zones and residential areas (reduces light trespass), sky-friendly architecture that limit facade lighting and illuminated advertisements at night.
4. **Public Awareness and Community Action:** Awareness campaigns and citizen science initiatives.
5. **Policy Recommendations:** Regulatory frameworks by municipalities that limit upward lighting and excessive brightness in commercial and industrial areas.

Future prospects of this study include collecting data from different sources (such as satellite data) and correlating both data. Future work could involve long-term monitoring to study night-to-night, seasonal, or festival-related variations in sky brightness, which would reveal dynamic patterns of urban light pollution. Surveys could explore how light pollution affects sleep patterns, health and local wildlife. The study could test the effectiveness of light reduction strategies, such as shielding streetlights, dimming LEDs

7. Conclusion

This study highlights the extent of light pollution in Gurgaon by quantifying night sky brightness across a variety of urban, suburban, and semi-rural locations. The results consistently show a strong spatial gradient: highly commercial and densely populated zones, such as Ambience Mall, Cybercity, and Udyog Vihar, exhibit very low SQM values (16–17 mag/arcsec^2), corresponding to extremely bright skies. In contrast, peripheral areas such as Sultanpur Park and Basai Village record higher values (>18 mag/arcsec^2), reflecting relatively darker skies though still affected by light domes from the city.

Overall, the analysis confirms that Gurgaon's skies are substantially degraded by artificial illumination, with most populated sectors falling well below the thresholds associated with natural night environments. The data also suggest that even moderate reductions in urban lighting could meaningfully improve sky quality, particularly in transitional zones between commercial centers and residential neighborhoods. Future work could build upon these findings by incorporating temporal variations (seasonal or nightly measurements), expanding geographic coverage, and directly correlating satellite-derived radiance values with ground-based SQM data. Such efforts would not only provide a more comprehensive understanding of Gurgaon's light pollution but also strengthen the case for targeted mitigation strategies in urban planning and public policy.

Acknowledgment

We extend our sincere gratitude to our Respected Principal ma'am, Dr. Arti Chopra for providing us with the valuable opportunity to undertake this study. This experience has greatly enhanced our critical thinking skills, and taught us work ethic. We are grateful to Ms. Manu Sharma, Ms. Shilpi Sharma, and Ms. Manisha Sharma for guiding us through this project. We appreciate the online data sets available and past studies done in this field. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Suhani Gupta: Conceptualization, Methodology, Investigation, Software, Writing, Visualization. **Shailja Gauniyal:** Data curation, Investigation. **Sudhi Vashistha:** Validation, Formal analysis, Visualization. **Idha Nehra:** Validation, Writing – review and editing. **Tanishka Rajesh Arora:** Resources, Project administration.

References

[1] Tanya Kaur Bedi, Kshama Puntambekar, and Sonal Singh. Assessment of light pollution in indian scenario: A case of bangalore. *Journal of The Institution of Engineers (India): Series A*, 102(3):657–672, 2021.

[2] Tanya Kaur Bedi, Kshama Puntambekar, and Sonal Singh. Light pollution in india: appraisal of artificial night sky brightness of cities. *Environment, Development and Sustainability*, 23(12):18582–18597, 2021.

[3] David E Blask, George C Brainard, Robert T Dauchy, John P Hanifin, Leslie K Davidson, Jean A Krause, Leonard A Sauer, Moises A Rivera-Bermudez, Margarita L Dubocovich, Samar A Jasser, et al. Melatonin-depleted blood from premenopausal women exposed to light at night stimulates growth of human breast cancer xenografts in nude rats. *Cancer research*, 65(23):11174–11184, 2005.

[4] Michael Brei, Agustín Pérez-Barahona, and Eric Strobl. Environmental pollution and biodiversity: Light pollution and sea turtles in the caribbean. *Journal of Environmental Economics and Management*, 77:95–116, 2016.

[5] Bureau of Indian Standards. National Lighting Code (NLC) SP-72:2010. Technical report, Bureau of Indian Standards, New Delhi, India, 2010. Code of practice for outdoor public lighting and roads.

[6] Bureau of Indian Standards. Search results for Lighting Standards, Accessed 2025.

[7] Bureau of Indian Standards. IS 10322: Code of Practice for Indoor and Outdoor Lighting, Latest edition.

[8] P Cinzano and F Falchi. Quantifying light pollution. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 139:13–20, 2014.

[9] Pierantonio Cinzano. Night sky photometry with sky quality meter. *ISTIL Int. Rep*, 9(1), 2005.

[10] Commission Internationale de l'Éclairage. CIE 136-2000: Guide to the Lighting of Urban Areas. Technical report, International Commission on Illumination (CIE), Vienna, Austria, 2000. Technical Report.

[11] Shane Donatello, Rocío Rodríguez, Miguel Gama Caldas Quintero, Oliver Wolf JRC, Paul Van Tichelen, Veronique Van, and Theo Geerken VITO Hoof. Revision of the eu green public procurement criteria for road lighting and traffic signals. *Publications Office of the European Union: Luxembourg*, 127, 2019.

[12] Jiangtao Du, Xin Zhang, and Derek King. An investigation into the risk of night light pollution in a glazed office building: The effect of shading solutions. *Building and Environment*, 145:243–259, 2018.

[13] Christopher D Elvidge, Kimberly E Baugh, Mikhail Zhizhin, and Feng-Chi Hsu. Why viirs data are superior to dmsp for mapping nighttime lights. *Proceedings of the Asia-Pacific Advanced Network*, 35(0):62, 2013.

[14] Christopher D Elvidge, Edward H Erwin, Kimberly E Baugh, Daniel Ziskin, Benjamin T Tuttle, Tilottama Ghosh, and Paul C Sutton. Overview of dmsp nightime lights and future possibilities. In *2009 Joint Urban Remote Sensing Event*, pages 1–5. IEEE, 2009.

[15] Fabio Falchi and Pierantonio Cinzano. Maps of artificial sky brightness and upward emission in italy from dmsp satellite measurements. *arXiv preprint astro-ph/9811234*, 1998.

[16] Fabio Falchi, Pierantonio Cinzano, Dan Duriscoe, Christopher C. M. Kyba, Christopher D. Elvidge, Kimberly Baugh, Boris A. Portnov, Nataliya A. Rybnikova, and Riccardo Furgoni. The new world atlas of artificial night sky brightness. *Science Advances*, 2(6):e1600377, 2016.

[17] RH Garstang. Model for artificial night-sky illumination. *Publications of the Astronomical Society of the Pacific*, 98(601):364, 1986.

[18] SA Gauthreaux, Carroll G Belser, C Rich, and T Longcore. *Effects of artificial night lighting on migrating birds*, volume 2006. Island Press Washington, DC, USA, 2006.

[19] Wu Guanglei, Jack Ngarambe, and Gon Kim. A comparative study on current outdoor lighting policies in china and korea: A step toward a sustainable nighttime environment. *Sustainability*, 11:3989, 07 2019.

[20] Qingxu Huang, Xi Yang, Bin Gao, Yang Yang, and Yuanyuan Zhao. Application of dmsp/ols nighttime light images: A meta-analysis and a systematic literature review. *Remote Sensing*, 6(8):6844–6866, 2014.

[21] Illuminating Engineering Society. TM-15-11 BUG Ratings Addendum. Technical report, Illuminating Engineering Society, New York, NY, USA, 2017. Technical memorandum providing addendum to the BUG rating system.

[22] Illuminating Engineering Society. The Lighting Handbook: 10th Edition Reference & Application, 2020. Reference manual for lighting design.

[23] International Dark-Sky Association. Lighting Zones. `https://darksky.org/resources/guides-and-how-tos/lighting-zones/`, n.d.

[24] International Dark-Sky Association and Illuminating Engineering Society. Model Lighting Ordinance (MLO) with User's Guide. Technical report, 2011. Model ordinance for outdoor lighting regulation.

[25] Commission internationale de l'éclairage. Guide on the limitation of the effects of obtrusive light from outdoor lighting installations: Technical report: Cie 150: 2003. CIE, 2003.

[26] Meng Ji, Yongming Xu, Yifei Yan, and Shanyou Zhu. Evaluation of the light pollution in the nature reserves of china based on npp/viirs nighttime light data. *International Journal of Digital Earth*, 17(1):2347442, 2024.

[27] Komal Kaushik, Soumya Nair, and Arif Ahamad. Studying light pollution as an emerging environmental concern in india. *Journal of Urban Management*, 11(3):392–405, 2022.

[28] Megha Khanduri, Ruchika Sah, Aishwarya Ramachandran, Syed Ainul Hussain, Ruchi Badola, Ulrika Candolin, and Franz Hölker. Spatial-temporal expansion and determinants of light pollution in india's riparian habitats. *Environmental Impact Assessment Review*, 98:106952, 2023.

[29] Pavan Kumar, Sufia Rehman, Haroon Sajjad, Bismay Ranjan Tripathy, Meenu Rani, and Sourabh Singh. Analyzing trend in artificial light pollution pattern in india using ntl sensor's data. *Urban Climate*, 27:272–283, 2019.

[30] Christopher C. M. Kyba, Yiğit Öner Altıntaş, Constance E. Walker, and Mark Newhouse. Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022. *Science*, 379(6629):265–268, 2023.

[31] Frank A La Sorte, Kyle G Horton, Alison Johnston, Daniel Fink, and Tom Auer. Seasonal associations with light pollution trends for nocturnally migrating bird populations. *Ecosphere*, 13(3):e3994, 2022.

[32] Shihyan Lee, Kwofu Chiang, Xiaoxiong Xiong, Chengbo Sun, and Samuel Anderson. The s-npp viirs day-night band on-orbit calibration/characterization and current state of sdr products. *Remote Sensing*, 6(12):12427–12446, 2014.

[33] Marcellino Melika, John MT Nguyen, William Koh, Emma Marshall, Danielle Prilepskiy, and Rushil Kukreja. Light pollution as an emerging public health threat: Understanding health implications and mitigation strategies. *Available at SSRN 5001161*, 2024.

[34] Ministerio del Medio Ambiente de Chile. Decreto Supremo N° 43 de 2022: Norma de Emisión para la Regulación de la Contaminación Lumínica, 2022. National light pollution regulation replacing earlier 2013 decree, applicable across Chile with special provisions for astronomical zones.

[35] Ministère de la Transition Écologique et Solidaire. Arrêté du 27 décembre 2018 relatif à la prévention, à la réduction et à la limitation des nuisances lumineuses, 2018. French national decree on light pollution control.

[36] NASA LAADS DAAC. VNP02DNB – VIIRS/NPP Day/Night Band 6-Minute L1B Swath 750 m. `https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/VNP02DNB`, 2022. Accessed: 2025-08-11.

[37] Hajra Nisar, Faiza Sarwar, Safdar Ali Shirazi, Dania Amjad, and Rana Waqar Aslam. Assessment and monitoring of viirs-dnb and sqml-l light pollution in lahore-pakistan. *International Journal of Innovations in Science and Technology*, 3(4):94–109, 2022.

[38] Kyriaki Papantoniou, Gemma Castaño-Vinyals, Ana Espinosa, Nuria Aragonés, Beatriz Pérez-Gómez, Javier Burgos, Inés Gómez-Acebo, Javier Llorca, Rosana Peiró, Jose Juan Jimenez-Moleón, et al. Night shift work, chronotype and prostate cancer risk in the mcc-s pain case-control study. *International journal of cancer*, 137(5):1147–1157, 2015.

[39] Winworld Realty. Explore the sector wise map of gurgaon, 2023. Accessed: 2025-08-21.

[40] A Sánchez de Miguel, M Aubé, Jaime Zamorano, M Kocifaj, J Roby, and C Tapia. Sky quality meter measurements in a colour-changing world. *Monthly Notices of the Royal Astronomical Society*, 467(3):2966–2979, 2017.

[41] Richard G Stevens. Electric power use and breast cancer: a hyptothesis. *Am. J. Epidemiol.;(United States)*, 125(4), 1987.

[42] Kurt Straif, Robert Baan, Yann Grosse, Béatrice Secretan, Fatiha El Ghissassi, Véronique Bouvard, Andrea Altieri, Lamia Benbrahim-Tallaa, and Vincent Cogliano. Carcinogenicity of shift-work, painting, and fire-fighting. *The lancet oncology*, 8(12):1065–1066, 2007.

[43] Benjamin M Van Doren, Kyle G Horton, Adriaan M Dokter, Holger Klinck, Susan B Elbin, and Andrew Farnsworth. High-intensity urban light installation dramatically alters nocturnal bird migration. *Proceedings of the National Academy of Sciences*, 114(42):11175–11180, 2017.

[44] Marc Wenger, François Ochsenbein, Daniel Egret, Pascal Dubois, François Bonnarel, Suzanne Borde, Françoise Genova, Gérard Jasniewicz, Suzanne Laloe, Soizick Lesteven, and Richard Monier. The simbad astronomical database, 2000.

[45] Blair E Witherington and R Erik Martin. Understanding, assessing, and resolving light-pollution problems on sea turtle nesting beaches. 2000.

[46] Pengfei Xu, Quan Wang, Jia Jin, and Pingbin Jin. An increase in nighttime light detected for protected areas in mainland china based on viirs dnb data. *Ecological Indicators*, 107:105615, 2019.

[47] Chih-Hao Yen, Yin-Ting Chan, Yao-Chi Peng, Kuo-Hui Chang, and I-Jiunn Cheng. The effect of light pollution on the sea finding behavior of green turtle hatchlings on lanyu island, taiwan. *Zoological Studies*, 62:e47, 2023.

[48] SK Yerli, NAZIM Aksaker, M Bayazit, Z Kurt, ALİŞAN Aktay, and MA Erdoğan. The temporal analysis of light pollution in turkey using viirs data. *Astrophysics and Space Science*, 366(4):34, 2021.