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Environmental Assessment of Light Pollution in Varanasi District, Uttar Pradesh, Using Night-Time Satellite Data

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Abstract: ***Light pollution has emerged as an important environmental issue associated with rapid urbanization and increasing use of artificial lighting. The present study assesses the spatial pattern and intensity of light pollution in Varanasi District, Uttar Pradesh, using VIIRS Day/Night Band nighttime satellite data. A GIS-based approach was applied to analyze the distribution of nighttime illumination across urban, peri-urban, and rural areas of the district. The results reveal a strong concentration of high light intensity in urban zones, particularly around Varanasi city, while rural areas exhibit comparatively low levels of nighttime brightness. The findings indicate a close relationship between urban expansion, population concentration, and increasing artificial illumination. The study highlights the usefulness of nighttime satellite data for monitoring light pollution at the district level and emphasizes the need for sustainable and planned lighting practices to reduce its environmental impacts.***

Key words: Light pollution, Nighttime satellite data, VIIRS Day/Night Band, Urbanization, GIS-based.

Introduction- Light pollution has become an emerging environmental concern in recent years as a result of accelerated urban growth and the increasing dependence on artificial lighting systems (Kyba et al., 2017). Excessive illumination during night hours disrupts the natural light–dark cycle, which plays a crucial role in maintaining ecological balance (Falchi et al., 2016). Such disturbances influence environmental quality and affect both natural ecosystems and human well-being (Falchi et al., 2016). Although air, water, and noise pollution have been widely examined in environmental studies, light pollution has not received equal scholarly attention, particularly in rapidly developing regions.

From an environmental perspective, uncontrolled night-time lighting exerts multiple negative impacts on living organisms and natural processes (Falchi et al., 2016). Continuous exposure to artificial light interferes with human circadian rhythms, leading to sleep disorders and related health issues (Kyba et al., 2017). Similarly, wildlife species experience disruptions in feeding behavior, reproduction, and migration patterns due to altered nocturnal environments (Falchi et al., 2016). Additionally, excessive lighting increases energy consumption and contributes indirectly to greenhouse gas emissions, thereby linking light pollution with broader environmental and climate-related concerns (Kyba et al., 2017).

In the Indian context, the intensity of artificial night lighting has increased significantly due to urban expansion, improved infrastructure, religious activities, and the widespread adoption of energy-efficient LED technologies. Despite this growing trend, environmental research in India has predominantly concentrated on conventional pollution forms, leaving light pollution comparatively understudied. Existing studies are largely confined to metropolitan cities, while medium-sized cities and culturally important urban regions remain insufficiently explored . This situation indicates a clear research gap and emphasizes the need for localized environmental assessments using recent and reliable data sources (Elvidge et al., 2017).

Varanasi District, known for its cultural heritage and continuous human settlement, has undergone substantial changes in land use, population density, and night-time economic activities in recent decades (Census of India, 2011). The expansion of illuminated roads, commercial zones, residential areas, and religious sites has considerably transformed the district's nocturnal environment (Kyba et al., 2017). Against this background, the present study undertakes an environmental assessment of light pollution in Varanasi District using night-time satellite data. The study aims to examine the spatial and temporal distribution of artificial night lighting and to generate scientific insights that may support environmentally sustainable urban planning and policy formulation.

Objectives- The main objective of this study is to analyze light pollution in Varanasi District, Uttar Pradesh, using nighttime satellite data. The specific objectives are:

1. To analyze the spatial distribution and intensity of artificial light in Varanasi District using satellite-based nighttime imagery.
2. To identify areas with high levels of light pollution, especially in urban and rapidly developing z ones.
3. To examine the relationship between urban expansion and increasing nighttime illumination.
4. To highlight the environmental implications of light pollution and suggest measures for its control.

Study Area- Varanasi District is located in the eastern part of Uttar Pradesh, India. It lies between approximately 25°10′ N to 25°35′ N latitude and 82°30′ E to 83°10′ E longitude (Survey of India, 2011). The

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district forms part of the Middle Ganga Plain and is characterized by a flat alluvial landscape. The River Ganga flows through the district and plays an important role in its physical, cultural, and economic life.

Administratively, Varanasi District consists of eight development blocks and includes both highly urbanized areas and surrounding rural settlements (Census of India, 2011). Varanasi city, one of the oldest continuously inhabited cities in the world, is the major urban center of the district. Due to rapid urban growth, expanding infrastructure, religious tourism, and increasing use of artificial lighting, the district has experienced a significant rise in nighttime illumination.

According to the Census of India (2011), Varanasi District has a high population density, with a large concentration of population in urban and peri-urban areas. Commercial activities, transportation networks, religious institutions, and residential expansion contribute to extensive use of outdoor lighting. These factors make the district particularly suitable for the assessment of light pollution using nighttime satellite data.

The combination of cultural significance, urban expansion, and mixed land-use patterns makes Varanasi District an appropriate study area to examine the spatial distribution and environmental implications of light pollution.

Data Sources- This study utilizes satellite-derived nighttime light data along with supporting secondary datasets to examine light pollution in Varanasi District, Uttar Pradesh. The primary dataset employed is the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB), which provides measurements of artificial night-time radiance and spatial distribution of illumination (Elvidge et al., 2017).

Monthly cloud-free composite VIIRS DNB data were accessed through open-access repositories maintained by the Earth Observation Group under the National Oceanic and Atmospheric Administration (Elvidge et al., 2017). These datasets are widely recognized for their enhanced radiometric sensitivity and improved spatial resolution compared to earlier nighttime light products (Li et al., 2020).

Administrative boundary data for Varanasi District were obtained from official government sources (Survey of India, 2011). Additionally, demographic and urban information was collected from census publications to support the interpretation of spatial light intensity patterns (Census of India, 2011).

Methodology- The present study adopts a remote sensing and Geographic Information System (GIS)-based approach to assess light pollution in Varanasi District, Uttar Pradesh. The methodological framework involves the acquisition, pre-processing, classification, and spatial analysis of satellite-derived nighttime light data to examine the distribution and intensity of artificial illumination.

Monthly cloud-free composite data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) were utilized for the selected study period. The VIIRS DNB dataset, developed and maintained by the National Oceanic and Atmospheric Administration, offers enhanced radiometric sensitivity and reduced saturation compared to earlier nighttime light datasets, making it particularly suitable for urban and environmental assessments (Elvidge et al., 2017).

The acquired satellite data were pre-processed to reduce background noise and eliminate non-anthropogenic light sources following standard nighttime light data correction procedures (Elvidge et al., 2017; Li et al., 2020). The imagery was subsequently clipped using the administrative boundary of Varanasi District to extract district-level radiance values for detailed spatial examination.

To evaluate spatial variability, radiance values were classified into low, medium, and high illumination categories using commonly applied geospatial classification techniques (Li et al., 2020). This classification facilitated the identification of zones exhibiting concentrated artificial lighting, particularly in urban and peri-urban regions.

GIS-based spatial analysis was conducted to map and visualize the patterns of nighttime illumination. The interpreted results were examined in relation to demographic distribution and land-use characteristics using official data from the Census of India (2011). This integrated geospatial approach enabled a systematic environmental assessment of light pollution and its spatial characteristics within the study area.

Results and Analysis- The analysis of VIIRS Day/Night Band (DNB) satellite data reveals clear spatial variations in nighttime light intensity across Varanasi District. The results show that artificial illumination is unevenly distributed, with higher light intensity concentrated in urban and peri-urban areas, while rural regions exhibit comparatively low levels of nighttime brightness.

Spatial Pattern of Light Pollution: The highest light intensity is observed in and around Varanasi city, where dense population, commercial activities, transportation networks, religious sites, and tourism-

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related infrastructure are concentrated. Major roads, ghats along the River Ganga, and commercial centers display strong illumination, indicating significant levels of light pollution. Peri-urban areas surrounding the city show moderate light intensity, reflecting ongoing urban expansion and infrastructure development.

In contrast, rural parts of the district exhibit low light intensity, mainly due to limited urban infrastructure and lower population density. These areas contribute minimally to overall light pollution but highlight the growing contrast between urban and rural environments within the district.

Relationship between Urbanization and Nighttime Illumination: The results indicate a strong relationship between urban growth and increasing nighttime light intensity. Areas experiencing rapid urbanization show noticeable increases in artificial lighting. Expansion of residential areas, road networks, and commercial establishments has led to a steady rise in nighttime brightness, suggesting that urban development is a major driver of light pollution in the district.

Environmental Implications: The observed increase in artificial lighting has several environmental implications, including disturbance to natural darkness, potential impacts on human health, and effects on local ecosystems. Excessive and unplanned lighting contributes to energy wastage and alters the natural night environment, especially in densely populated urban zones.

Overall, the satellite-based analysis demonstrates that light pollution in Varanasi District is primarily an urban-driven phenomenon, with its intensity closely linked to population concentration and infrastructural development.

Table 1: Classification of Nighttime Light Intensity in Varanasi District

Light Intensity Category	DN Value Range*	Dominant Area Type	Major Characteristics
Low Light Intensity	Very Low DN values	Rural areas	Sparse settlements, limited infrastructure, low artificial lighting
Moderate Light Intensity	Medium DN values	Peri-urban areas	Expanding residential zones, developing road networks
High Light Intensity	High DN values	Urban core (Varanasi city)	Dense population, commercial activities, religious and tourism centers

*DN= Digital Number derived from VIIRS DNB Data

Discussion- The findings of this study indicate that light pollution in Varanasi District is strongly influenced by urbanization and intensified human activities. The concentration of high nighttime light intensity within the urban core of Varanasi aligns with earlier research demonstrating a positive relationship between artificial illumination, population density, commercial concentration, and infrastructure development (Elvidge et al., 2017; Li et al., 2020). Such patterns are commonly observed in rapidly expanding urban regions where economic activity extends into nighttime hours.

The spatial configuration identified in this study is consistent with global assessments of nighttime brightness derived from VIIRS DNB data, which show that urban agglomerations exhibit significantly higher radiance values compared to surrounding rural landscapes (Falchi et al., 2016). Similar trends have also been reported in Indian urban environments, where satellite-based nighttime light analysis has been used to monitor urban expansion and infrastructure growth (Kumar et al., 2018). In the context of Varanasi, religious tourism, continuous commercial operations, and dense transportation networks contribute substantially to elevated levels of artificial lighting, reinforcing its status as a major illuminated urban center in eastern Uttar Pradesh.

The observed contrast between urban and rural zones highlights an uneven spatial distribution of light pollution, with rural regions maintaining comparatively darker nightscapes. This growing urban–rural disparity may have environmental implications, including disruption of natural darkness, increased energy demand, and potential ecological disturbances, as discussed in broader light pollution research (Falchi et al., 2016).

Overall, the results underscore the importance of sustainable urban lighting strategies. Adoption of energy-efficient technologies, regulation of excessive illumination, and increased public awareness regarding environmental impacts can contribute to mitigating light pollution without compromising urban safety and economic vitality. Integrating scientific assessment with urban planning policies is therefore essential for environmentally responsible development

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Conclusion- The present study provides a satellite-based geospatial -assessment of light pollution in Varanasi District, Uttar Pradesh, using monthly composite data from the VIIRS Day/Night Band (DNB). The analysis demonstrates that nighttime illumination is spatially uneven, with high light intensity concentrated in urban and peri-urban areas, particularly around Varanasi city, whereas rural regions remain comparatively less illuminated.

The findings establish a clear association between urban expansion, population concentration, and increasing artificial lighting. Rapid infrastructural growth, commercial activities, transportation networks, and religious tourism have substantially contributed to elevated nighttime brightness in the district. These patterns indicate that light pollution is becoming an important environmental challenge in rapidly developing urban regions.

The study further demonstrates the effectiveness of satellite-derived nighttime light data for district-level environmental monitoring. Such geospatial analysis can assist planners and policymakers in identifying zones of excessive illumination and formulating strategies for improved lighting regulation. The promotion of energy-efficient and well-regulated lighting systems can reduce environmental impacts while ensuring urban safety and functionality.

Overall, the research underscores the importance of integrating sustainable lighting strategies into urban planning frameworks to balance developmental needs with environmental protection in Varanasi District. Future research may incorporate temporal trend analysis and ecological impact assessment to further strengthen understanding of light pollution dynamics in the region.

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