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"INCREASING LIGHT: DECLINING INSECTS, IS LIGHT AN EMERGING POLLUTANT OF ECOLOGICAL INTEREST?"

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Abstract
Ecologists have extensively studied the pivotal role of natural light in regulating species interactions. Nevertheless, limited attention has been directed towards the consequences of artificial light in specific artificial light at night (ALAN). Over the past century, the escalation of artificial illumination, attributed to urbanization, has become pronounced, exerting significant impacts on the biology and ecology of various species in their native habitats. Considerable research has been conducted on the repercussions of artificial light at night (ALAN) on animals and humans. However, the influence of ALAN on insect ecology has received minimal to no attention in comparison. Given the crucial ecological significance of insects and the existing scarcity of comprehensive information, it is imperative to undertake further investigations into the ramifications of Artificial Light at Night (ALAN). This paper aims to address this gap by providing an overview of research on insect mortality induced by ALAN. Our research observations reveal that insects are attracted to artificial light sources, engage in erratic flight patterns, experience exhaustion, lose wings, and eventually succumb. We conducted thorough investigations across three sampling sites, spanning three different seasons, with a total observation period of 270 days (30 days per season in each site). Our research findings demonstrate that insects exhibit a higher attraction to light during rainy seasons, followed by winter and summer. This research is essential for a more nuanced understanding and the development of scientifically informed mitigation strategies aimed at the conservation of insect populations and the holistic well-being of natural ecosystems.

Key Words: Ecology, Light pollution, Ecology, Food web, Pollinators, Artificial light at Night, Predators, Entomology

Introduction
Light pollution brings artificial illumination into the night time surroundings, affecting not just urban habitats but also untouched landscapes, disturbing the inherent rhythm of day and night and, consequently, the biological circadian system. This nocturnal artificial light (NAL) or (ALAN) Artificial light at night stands out as a prevalent type of human-made pollution, posing a growing peril to worldwide biodiversity due to its repercussions across various biological scales, from cellular to ecosystem levels (Gaston et al., 2018; Hölker et al., 2010; Koen et al., 2018). Artificial light at night (ALAN) is potential anthropogenic marker of this epoch (Borges RM., 2022), drastically affecting all living entities.

Light pollution arises from heightened illumination emanating from human-crafted objects into the lower atmosphere. Notably, there have been significant strides in evaluating and alleviating the repercussions of light pollution on vertebrates, humans, and natural ecosystems (Rodrigo-Comino J et al.,2023) However, the influence of light pollution on insects, crucial keystone species in ecosystems, remains unexplored or overlooked.

The attraction of insects towards synthetic illumination results in disturbances to their inherent daily solar and lunar illumination patterns, escalating their movement towards these synthetic light origins. Consequently, these insects frequently shed their wings and gradually perish. Certain insects lured by illuminations find themselves ensnared, incapable of returning to their native habitat, generating what can be categorized as "lethal snares" leading to there death.

If the demise of insects that are pollinators has an unfavourable impact on food production, it is crucial to acknowledge that the more extensive reduction in insect populations jeopardizes insect population diversity, subsequently influencing the steadiness of ecosystems and creating an imbalance in predator and prey relationships affecting energy transfer in ecosystem. Insects deliver a multitude of ecological services, the disappearance of which has predominantly eluded thorough examination. Projections indicate that in the upcoming decade, around 0.01 billion species, encompassing 40% of insects, might confront extinction (C.S. Owens, et al., 2020).

Given the significant deficiency in the investigation of insect decline caused by artificial light at night and the significance of these insects and the ecological services they provide, the research endeavours to comprehend the mortality of insects due to artificial light at night.

This investigation highlights the necessity of exploring the consequences of artificial light on insect populations, as it significantly affects both pollinators and the diversity of insects. These potential impacts have far-reaching implications for the stability of ecosystems and global food security.

Materials and Method

Our study encompassed 3 types of locations, including ATM sites (12.998423577356801, 77.57384268193233), commercial place (13.0027050989842, 77.5719477196579), residential house (13.006472736289583, 77.57115657485174) each of these places was surveyed for 90 days for three different seasons that is summer winter and rainy that is a total of 270 days survey. Firstly, light was quantified using a lux meter, a device that measures illuminance in lux units. And survey was conducted daily over a span of 30 days in 3 diffrent seasons to comprehensively understand the extent to which insects were being attracted to artificial light sources, becoming trapped and ultimately loose wings and die.

During the data gathering phase, intentional endeavours were undertaken to sustain heterogeneous sample stations, replicating the inherent variety of human habitats. At the onset of each day, as the sun ascended, we systematically gathered and enumerated the captured insects. Subsequently, these specimens were preserved for further in-depth studies.

Result and Discussion

In the regulation and dynamics of numerous ecosystem services (ES), insects assume a pivotal role (Noriega JA . et al., 2018). Insects constitute the most varied assemblage of multicellular life forms on Earth, contributing to a plethora of ecosystem services. These vital roles include the facilitation of pollination, acting as natural bio-control agents for pest management, participating in the decomposition of organic matter, and aiding in the seamless transference of energy within food chains maintaining food web dynamics. Insects help in seed dispersal,

insects like termites act as ecosystem engineers; insects can be used as potential biological monitors. Expanding beyond their ecological significance, insects have found diverse applications in the human sphere. They provide several useful products to mankind of significant economic importance and also offering nutritional benefits to human diets and health. Moreover, insects have become integral ingredients in the formulation of feeds for aquatic creatures such as fish and turtles, as well as for livestock, showcasing the versatility and interconnectedness of their role in various domains of our existence (Chowdhury GR., et al., 2017). In precise insects play pivotal roles in ecological processes, impacting plant reproduction, nutrient cycling, and serving as vital indicators of environmental health. Recognizing threats and conserving insect populations are imperative for sustaining balanced and resilient ecosystems.

The challenges of habitat degradation and fragmentation loom large for temperate and tropical insects, especially impacting rare, endemic, and specialized species. Agricultural expansion, marked by the extensive application of chemical pesticides (insecticides and herbicides), continues to pose potential threats, contributing to the decline of insect populations. Additionally, climate change, characterized by the heightened frequency of extreme climatic anomalies, may disproportionately affect tropical insects with narrow geographic ranges and low tolerance to shifts in temperature and rainfall. Invasive species and pathogens further imperil insect diversity (Basset Y and Lamarre GP., 2019). Notably, the often-overlooked menace of light pollution remains insufficiently explored, and its impact on insect decline warrants heightened attention, particularly with the escalating trends of urbanization and increased lighting in the near future.

As the global economy undergoes rapid development, the extensive proliferation of outdoor artificial light at night (ALAN) in urban areas has resulted in a growing and pervasive issue of severe light pollution across the globe (Huang C. et al 2023) fig.1. While an increasing number of studies have started addressing the challenges posed by light pollution, there remains a noticeable absence of a comprehensive literature review that systematically examines the research progress, focal areas, and evolving trends in night-time light pollution. Light pollution in India is grown exponentially in the last 2 decades fig.2. (Kumar P. et al., 2019 and Kaushik K. et al., 2022)

Light pollution, a consequence of excessive and misdirected artificial illumination, has emerged as a pivotal factor influencing the intricate dynamics of insect ecosystems. The disruption it imparts upon the natural behaviours and navigational patterns of insects is profound, with consequences reverberating through their diversity and population dynamics. This study embarked on an exhaustive exploration, delving into the nuanced relationship between light pollution and the demise of insect populations, meticulously examining the insect corpses amassed over a 30-day period a total of 270 days across different seasons and diverse locations.

In the throes of the summer season, the entomological survey unravelled compelling insights. In the controlled environment of an Automated Teller Machine (ATM), a staggering 316 insect corpses were meticulously catalogued, yielding a daily average of 10.53. Parallel investigations conducted in residential areas documented 133 insect cadavers, reflective of a daily average of 4.43. Simultaneously, commercial sites bore witness to the retrieval of 349 insect corpses, resulting in a daily average of 11.6. These figures unequivocally underscore the deleterious impact of light pollution on insect populations during the summer months.

Transitioning to the winter season, the scenario painted is equally disconcerting. Within the confines of the ATM setting, 408 insect corpses were methodically catalogued, averaging 13.6 per day. Residential locales exhibited a daily average of 6.36, contributing to a total of 191 insect cadavers. Notably, commercial spaces experienced a more pronounced effect, with a daily average of 14.23, culminating in the accumulation of 427 insect corpses.

These findings starkly accentuate the exacerbation of insect mortality during the winter season, underscoring the insidious impact of artificial light on nocturnal ecosystems.

The rainy season investigation continued its sobering revelations, uncovering a total of 439 insect corpses within the ATM setting, equating to a daily average of 14.63. In residential areas, the daily average stood at 7.5, resulting in the accumulation of 225 insect cadavers. Commercial locations documented a daily average of 14.33, contributing to a total of 430 insect corpses ref fig 3,4,5,5,7&8. These observations coalesce to reinforce a consistent and alarming trend of increased insect mortality associated with light pollution during the winter months ref Table 1 and fig.3-7.

Light pollution profoundly affects insect populations, influencing their behavioural patterns, ecological dynamics, and overall well-being. This ecological issue stems from the disproportionate or misguided artificial illumination resulting from human activities. The impact of light pollution on insects encompasses various aspects of their life cycles. Firstly, it disrupts nocturnal behaviour, affecting activities such as foraging, mating, and navigation, leading to confusion and disorientation. Additionally, insects exhibiting photo taxis are drawn to artificial lights, causing them to deviate from their natural habitats, expending unnecessary energy and increasing vulnerability to risks. Light pollution also interferes with the intricate mating rituals of nocturnal insects, potentially diminishing reproductive success and contributing to long-term population decline. Furthermore, nocturnal pollinators face disruptions, diverting them from natural pollination routes and causing cascading effects on plant reproduction and overall biodiversity. Insects attracted to artificial lights experience elevated mortality risks due to collisions, exhaustion, and increased vulnerability to predators, impacting population dynamics. Light pollution induces alterations in the distribution patterns of insect populations, potentially impacting ecosystem dynamics. Given the pivotal roles insects play in ecosystems, disruptions caused by light pollution have cascading effects, compromising the ecological balance and affecting other species in the food chain.

Insects represent the most varied and widely distributed life forms, present in nearly every corner of the Earth (Stork, 2018). Insects, whether active during the day or night, constitute the most diverse organisms on earth and contribute significantly to maintaining equilibrium in local ecosystems. Light illuminations are among the environmental modifications that directly impact insect conduct, either favourably or unfavourably. Illuminations have a positive impact when it is a natural event, such as sunshine and moonlight. Conversely, ALAN radiance influences the behaviour of insects negatively (Owens et al., 2020). Light pollution is a circumstance where a naturally dim region is illuminated by artificial light at Night (Cinzano et al., 2000; Falchi F et al., 2016). Nonetheless, their behaviours could be impacted by light pollution in specific ALAN, unintentionally disturbing the inherent balance (Juddinas et al., 2023).

Among the sampling sites studied in different seasons maximum insect cadavers were collected during rainy seasons followed by winter and summer. Among the sites studied summer showed 798 insect corpses collected, winter with 1026 and rainy season with 1094 fig 3&4 there is a least difference between winter and rainy. In periods of rainfall, insects dwelling in trees may encounter difficulties in occupying their native wilderness habitats as their ability to take flight becomes hindered (Price, 1997). Likewise, subterranean insects may face obstacles in constructing burrows when their tunnels are flooded by rainwater (Thomas, 2013). During winter, the prevalence of overcast skies can result in subdued illumination, subsequently prompting heightened reliance on artificial lighting during night-time that could draw the insects towards light source.

The impediments faced by arboreal insects during rainy periods, coupled with the diminished visibility brought about by winter's overcast conditions leading to an upsurge in artificial lighting, collectively contribute to a heightened mortality rate among insects. The raw data generated from these occurrences prompts a deeper exploration into the intricate relationship between artificial light exposure and the observed increase in insect mortality. This connection between environmental factors and insect survival underscores the significance of understanding and addressing the impacts of artificial lighting on insect populations.

Artificial illumination has the potential to interfere with crucial aspects of insect behaviour, including mating, nocturnal activities, and foraging patterns, thereby instigating disruptions within ecosystems. Movement and predation, integral ecological processes vital for the proper functioning of ecosystems, are significantly influenced by Artificial Light At Night (ALAN). This phenomenon alters the dynamics between prey and predator, as it lures insects into human habitats, exposing them to unconventional predators (Dyer et al., 2023). The resulting heightened predation, exacerbated by light pollution, extends its impact on insect populations and introduces disturbances within the intricate tapestry of food webs. This intricate interplay underscores the far-reaching consequences of artificial light on the delicate balance of ecological systems.

The extensive ecological ramifications arising from disrupted insect populations encompass habitat fragmentation and a diminished level of genetic diversity, as highlighted by (Pungavi and Nalini 2023). Their prognostication of a substantial 40 percent decline in global insect populations underscores the critical nature of our research, which accentuates the pivotal role that light pollution might play in precipitating this decline. By shedding light on the potential influence of artificial lighting on insect abundance, our findings contribute to a deeper understanding of the multifaceted factors contributing to the observed decline in insect populations worldwide.

In summary, the meticulous collection and scientific analysis of insect corpses across varied settings and seasons unveil a robust correlation between light pollution and the discernible decline in insect populations. The heightened mortality rates, particularly during rainy season, underscore the pressing need for proactive measures to mitigate the adverse impact of light pollution on insect ecosystems. Implementation of rigorous light management strategies and the elevation of public awareness regarding the far-reaching ecological consequences are imperative for the preservation of insect diversity and the overall health of terrestrial ecosystems.

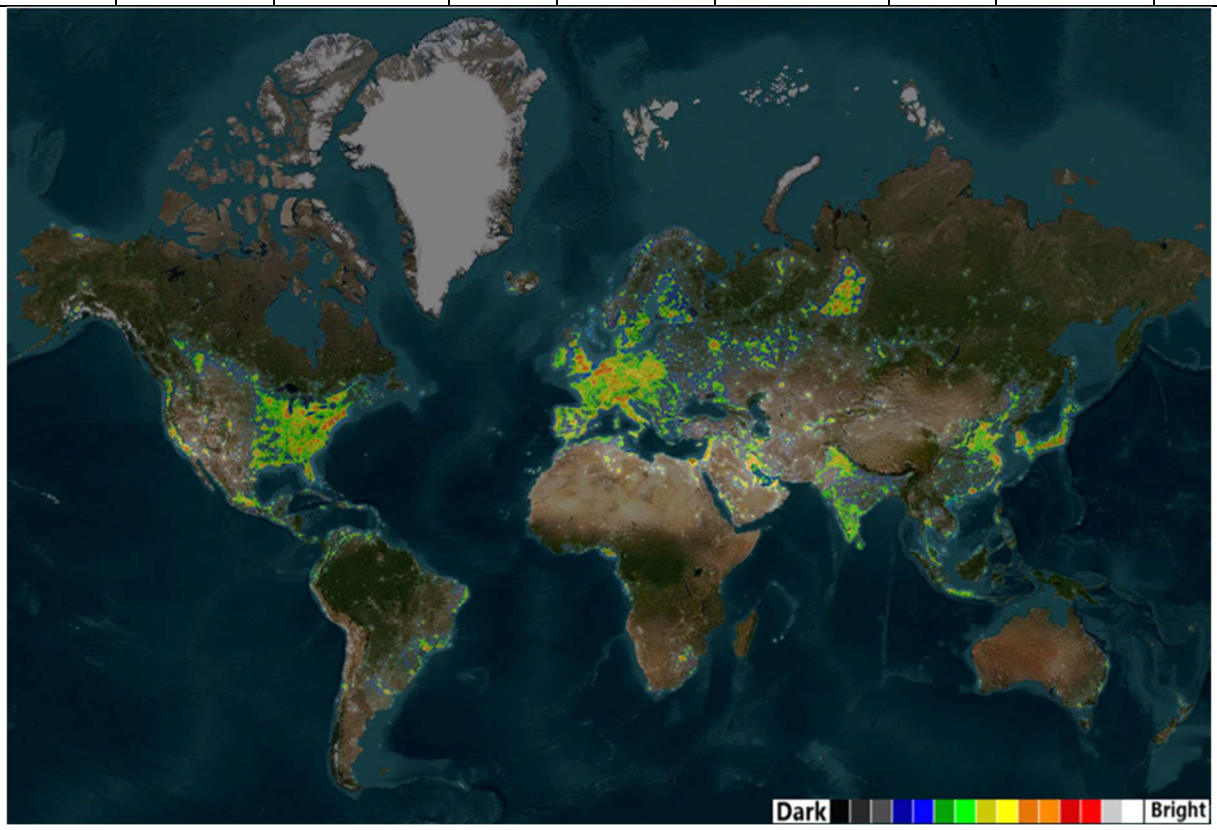
To address these intricate ecological issues, it becomes imperative to implement targeted mitigation strategies against light pollution. Approaches such as employing shielded outdoor lighting, adopting darker sky policies, and fostering awareness regarding the ecological significance of minimizing unnecessary artificial light in nocturnal environments are essential. Conservation efforts oriented toward preserving natural darkness emerge as critical interventions for sustaining the health and diversity of insect populations within ecosystems.Our research findings strongly suggest that artificial light can lead to a decline in insect populations, providing evidence that light pollution is indeed an emerging ecological pollutant of interest.

Tables and Figures

Period of survey	Summer (ATM)	Summer (Residence)	Summer (Commercial Place)	Winter (ATM)	Winter (Residence)	Winter (Commercial Place)	Rainy (ATM)	Rainy (Residence)	Rainy (Commercial Place)
Day 01	10	5	12	24	11	14	11	6	9

Day 02	12	4	15	12	9	13	15	5	19
Day 03	10	3	16	11	7	17	36	8	15
Day 04	9	6	13	12	11	16	17	7	13
Day 05	10	7	16	9	9	19	12	11	25
Day 06	12	6	15	2	6	12	14	14	16
Day 07	6	4	18	41	9	15	16	17	28
Day 08	13	3	13	14	4	13	19	6	11
Day 09	15	0	11	11	7	14	21	8	7
Day 10	4	0	16	12	3	16	16	9	9
Day 11	12	2	12	3	6	18	13	6	5
Day 12	11	3	12	4	9	11	18	17	21
Day 13	10	5	13	11	11	14	19	14	16
Day 14	10	7	14	16	10	13	22	11	17
Day 15	11	3	11	17	0	14	23	3	8
Day 16	13	6	10	12	0	11	12	9	17
Day 17	13	8	13	14	0	18	14	11	13
Day 18	11	9	13	17	6	13	11	9	16
Day 19	16	3	14	18	4	15	9	6	15
Day 20	14	2	13	12	3	11	13	7	19
Day 21	9	11	11	13	2	16	9	7	11
Day 22	6	0	17	14	7	15	4	0	17
Day 23	9	0	9	15	5	19	6	0	23
Day 24	10	3	3	16	6	13	7	3	21
Day 25	9	4	5	12	0	14	12	6	14
Day 26	13	6	4	13	10	10	14	4	17

Day 27	15	4	7	14	9	12	18	7	2
Day 28	6	6	3	13	8	14	11	6	11
Day 29	9	4	6	11	7	16	10	7	1
Day 30	8	9	14	15	12	11	17	1	14
Total	316	133	349	408	191	427	439	225	430



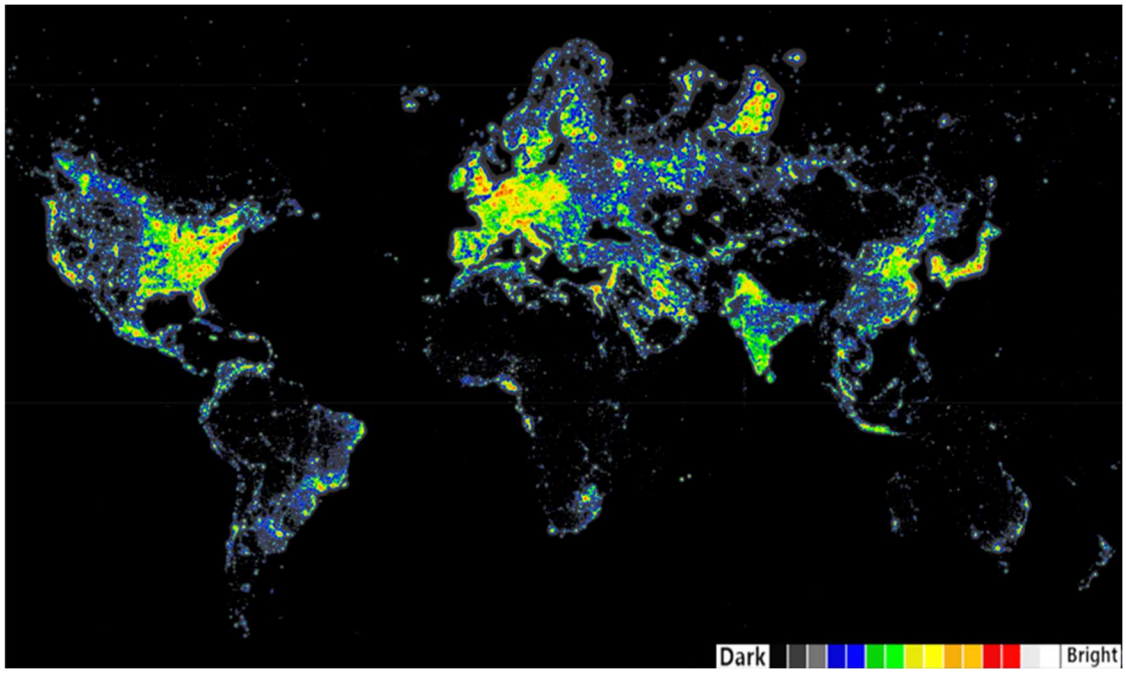


Figure 1.World map showing light pollution across different continents and countries in the globe.

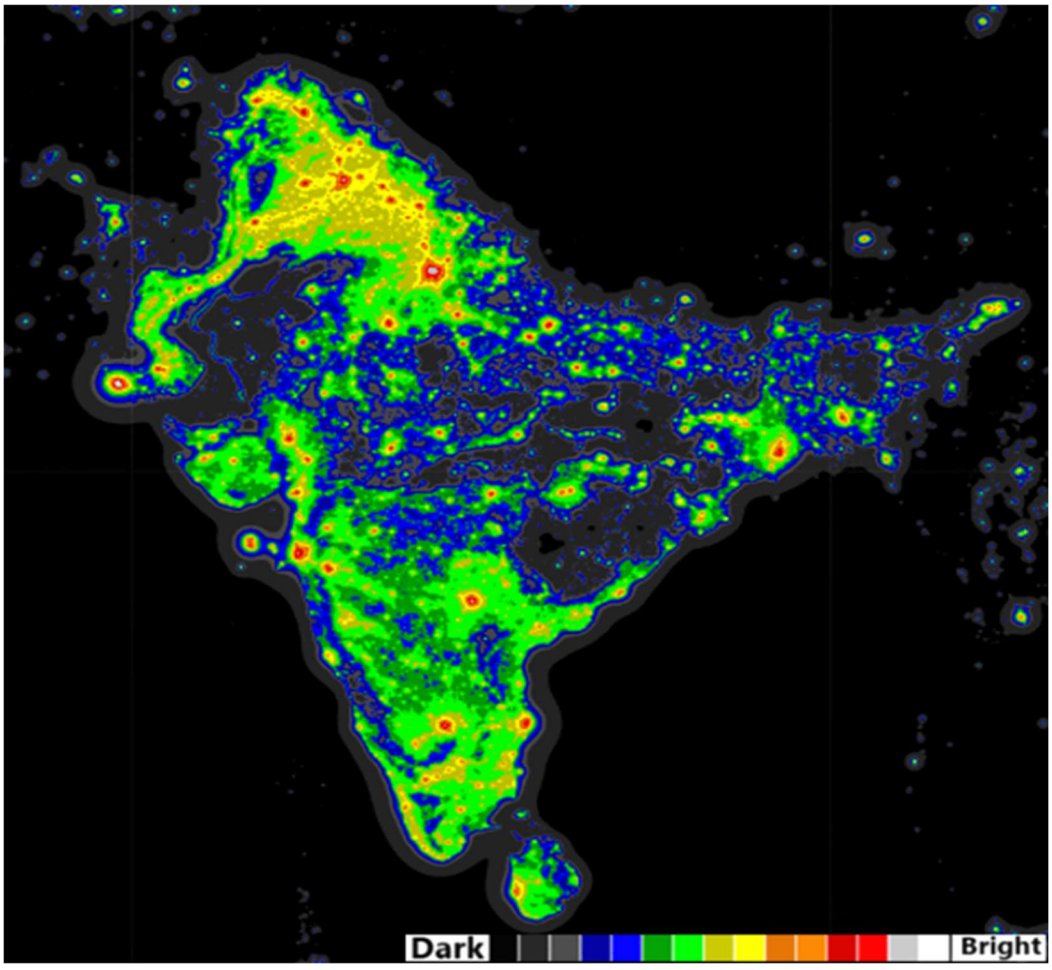


Figure 2.Light pollution map of India and other neighbouring countries

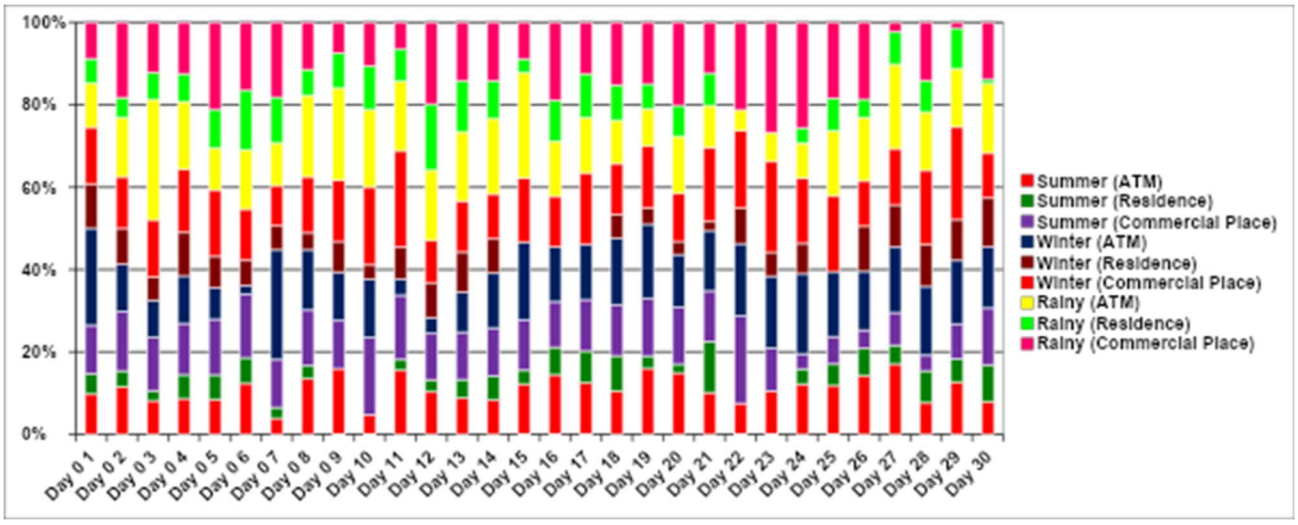


Figure 3.Graph showing collection of insect corpse in 3 different seasons in 3 different sampling sites

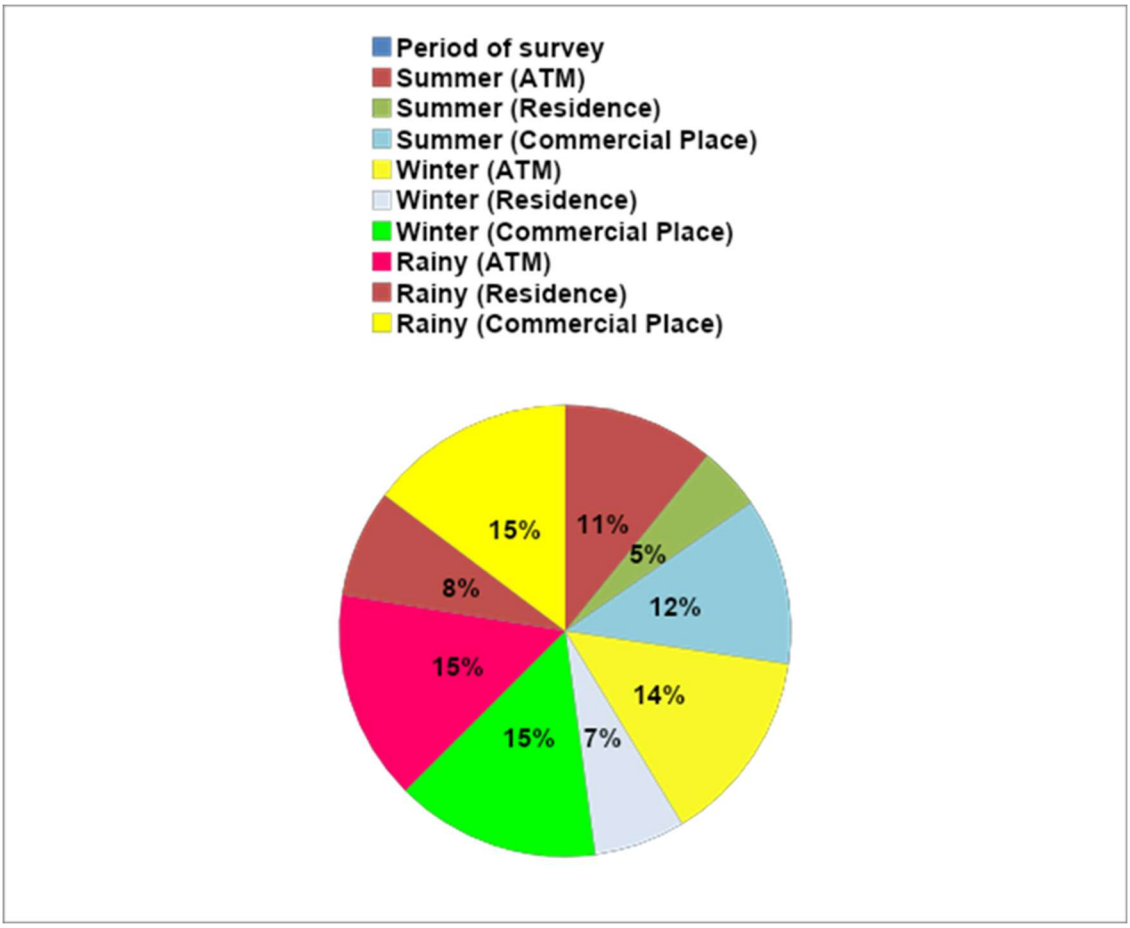


Figure 4. Graph showing percentage of insects collected in different sampling sites in different seasons

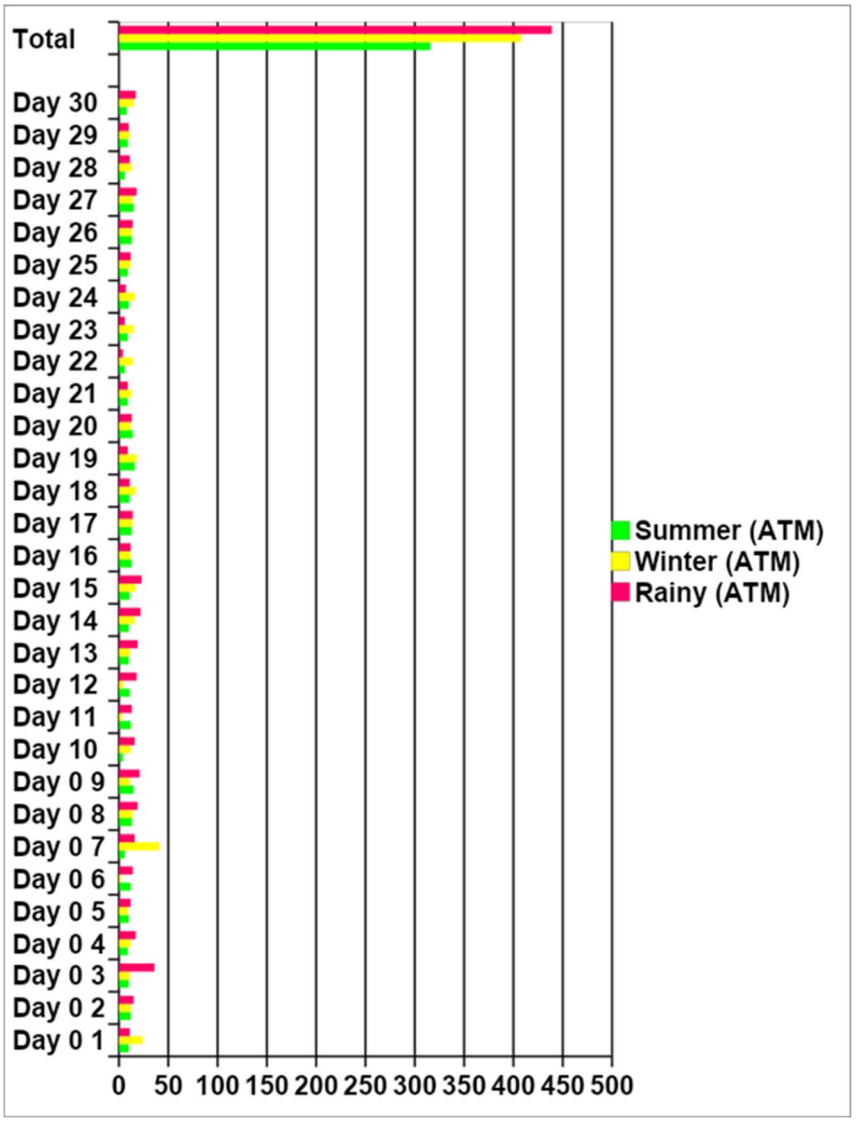


Figure 5. Graph depicts insect corpse collected from ATM sampling site in 3 different seasons

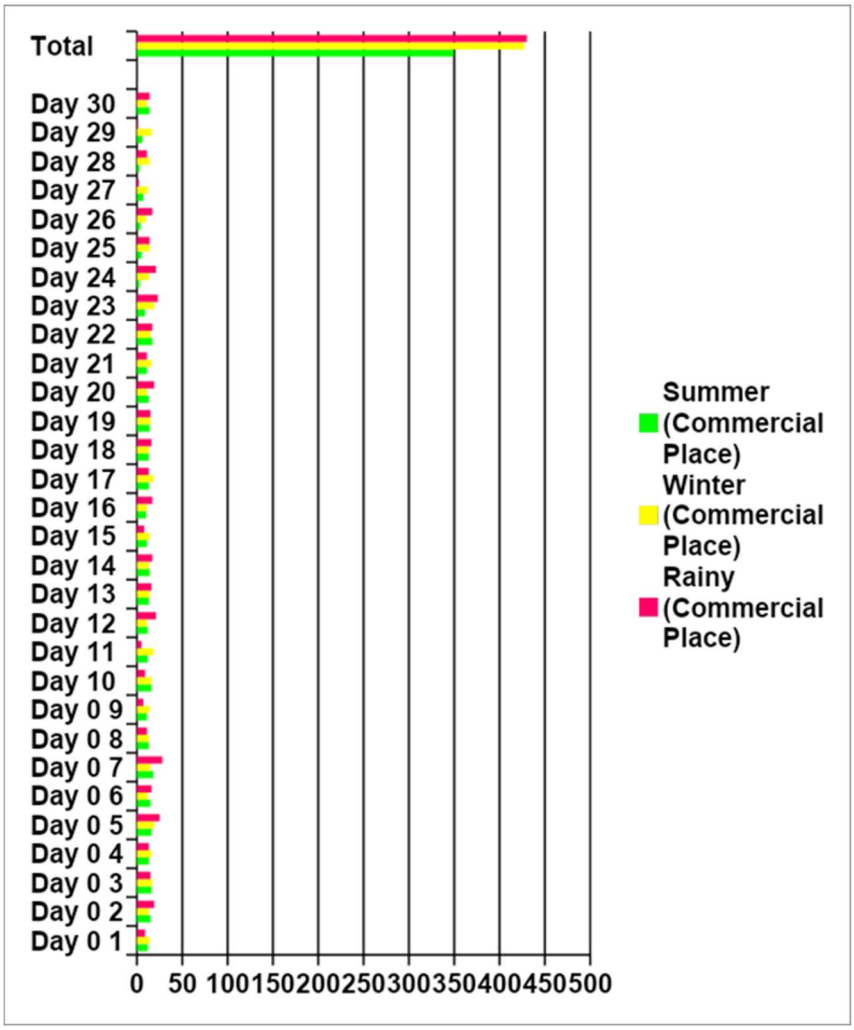


Figure 6. Graph depicts insect corpse collected from Commercial sampling site in 3 different seasons

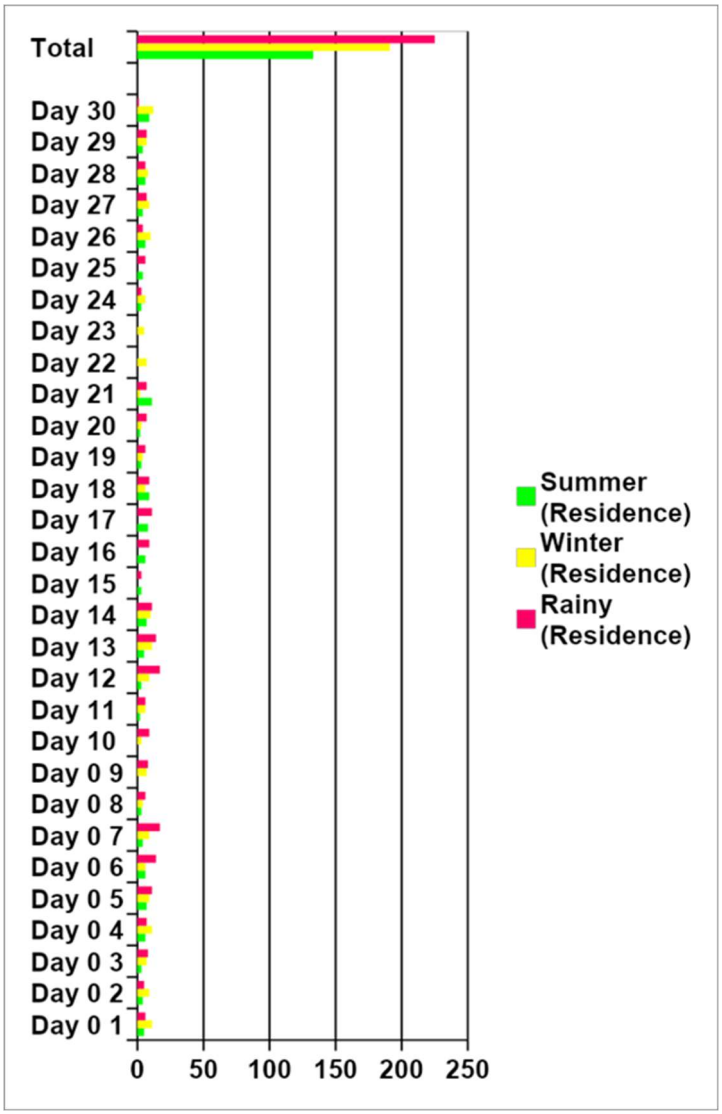


Figure 7. Graph depicts insect corpse collected from residence in 3 different seasons

Figure 7. Diagram A. Shows insects attracted to light in commercial place. B. Residence; C.ATM

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