Chapter

Artificial Light at Night: A Global Threat to Plant Biological Rhythms and Eco-Physiological Processes

Rekha Sodani, Udit Nandan Mishra, Subhash Chand, Indu, Hirdayesh Anuragi, Kailash Chandra, Jyoti Chauhan, Bandana Bose, Vivek Kumar, Gopal Shankar Singh, Devidutta Lenka and Rajesh Kumar Singhal

Abstract

Light is crucial environmental factor for primary resource and signalling in plants and provide optimum fitness under fluctuating environments from millions of year. However, due to urbanization, and human development activities lot of excess light generated in environment during night time and responsible for anthropogenic generated pollution (ALAN; artificial night light pollution). This pollution has cause for serious problem in plants as it affects their processes and functions which are under the control of light or diurnal cycle. Plant biorhythms mostly diurnal rhythms such as stomatal movements, photosynthetic activity, and many more metabolic processes are under the control of period of light and dark, which are crucially affected by artificial light at night. Similarly, the crucial plant processes such as pollination, flowering, and yield determining processes are controlled by the diurnal cycle and ALAN affects these processes and ultimately hampers the plant fitness and development. To keep in mind the effect of artificial light at night on plant biorhythm and eco-physiological processes, this chapter will focus on the status of global artificial night light pollution and the responsible factors. Further, we will explore the details mechanisms of plant biorhythm and eco-physiological processes under artificial light at night and how this mechanism can be a global threat. Then at the end we will focus on the ANLP reducing strategies such as new light policy, advanced lightening technology such as remote sensing and lightening utilisation optimisation.

Keywords: artificial night light pollution, minimizing strategies, photosynthesis, pollination, plant growth and development, plant movements

1. Introduction

Light is a major abiotic factor acts as energy source and signalling for plants growth and developments. Sun light is the prime source of energy on this planet and regulates number of essential functions in living organisms. Among them, primary producer as plants, blue green algae and photoautotrophs absorb these lights (especially 400-700 nm refereed as photosynthetically active radiation) and convert into energy source (starch, sucrose and other complex organic compound as food reserve) through the mechanism of photosynthesis [1]. Moreover, other living organisms like heterotrophs (primary consumer and secondary consumers) fulfil their energy requirements via feeding the primary producer food reserves. Therefore, light is an essential factor for all living organism to fulfil their energy requirements. Another important function of light is to act as regulator of signalling along with growth and development functions of plant. For example, photomorphogenesis (light regulated morphogenesis), phototropism (light mediated movements), circadian rhythm (light regulated biological rhythms) and many other crucial processes are under control of light [2]. Light characteristics such as intensity, duration, and wavelength affect the living organisms including plant in positive and negative way. Similarly, from millions of years plants are adaptive themselves to the diurnal changes of light–dark timings and many of the research concluded that change in light–dark duration affect plant growth mild to very drastic levels [3]. However, recent advancement in human development such as highway, buildings, LEDs lightening technology, product advertisements and industries progression lead to generation of excess light in the surrounding which causes anthropogenic accelerated light pollutions. Unlike natural ecosystems, where daily activities are scheduled by natural light–dark diurnal cycles [4], cities are heavily lit to enable performance of a wide array of activities after dark [5]. As artificial light at night (ALAN) becomes more reliable, efficient and affordable, living organisms become increasingly exposed to drastic and pervasive effects of "light pollution."

According to Encyclopaedia Britannica, "light pollution" is "unwanted or excessive artificial light" during night hours. The introduction of ALAN into the environment majorly through electric light sources related to domestic purpose, industrial areas, transportation and street lights. The artificial night light altered the natural light cycle through its beneficial along with harmful effects on the plant ecosystem. Its beneficial impacts imply reduced the risk of night-road accident, the crime rate at night (approximately 30%), and increased working hours and scientific research areas such as speed breeding and tissue culture [6]. Therefore, there is a need to balance the positive and negative impacts of ALAN. Biology can be a science of timing/duration, for example all organisms experience the drastic results due to change in natural light cycle variations [6]. They are the utmost important physical factors for time. These include common daily activities (e.g. photosynthetic activity, stomatal movements, enzyme activity, flower opening, sleep movements, fragrance emission, dark recovery and repair). Indeed, the lunar cycle and the yearly/seasonal cycle dominate and regulate the lives of most organisms. Influences on biological life history have repeatedly been found to create events that occur later in life. Climatic changes can cause food and reproductive capacity to become mismatched, which in turn leads to organisms projecting highly developed phenology [7]. Likewise, plant-environment interaction is very important to decide the present and future growth of living organisms including plants. It has been documented that ALAN affects the micro-environment attributes such as light, soil biology, humidity, biotic community and their interactions surrounding the living organisms including plant [8, 9]. Moreover, in few recent studies it was showed that ALAN not only limited to light area but it can affect the living organism beyond this and can drastically affects the ecosystem services and biodiversity [10]. Consequently, pollination, net primary productivity, flowering, ecosystem services and nutrient recycling are the important eco-physiological functions, which are influenced by ALAN. The effect of ALAN in living organisms such as animals and humans are studied very well and several studies, and meta-analyses showed the effects on as behaviour (sleep, food, foraging, and flying), reproduction, vigilance and many other important activities [11, 12]. However, the effect of ALAN are very limited till date, only in last few years scientists are working on the ALAN and plant processes relationships and achieved some milestones. While considering the above facts, this chapter covers the present advances in ALAN research on plants specific to biorhythms and eco-physiological functions. Consequently, this analysis point out on some important strategies which are crucial for minimizing the extent of this pollution in environment.

2. Artificial light at night (ALAN) current status and anthropogenic sources of ALAN

Human development is continuous and complex process, also crucial for their existence for long term on this planet. This process culminates a number of novel pollutants (also known as anthropogenic pollutants) and creates a problem of other living organisms also environment sustainability. Although, this emerging pollution is global problem but the conditions might be severe when the pollution affects the endangered species in protected areas and natural hotspots [13]. Therefore, researchers tried to quantifying the ALAN worldwide by data generated from remote sensing technology, geographical information system, hyperspectral, visual infrared imaging radiometer, day/night band, and satellites [14–16]. In the year 2001, the first globe atlas of artificial night sky brightness based on US air force satellite data, which reported that the brightness of sky is increasing continuously and in world nearly two-third of world population living in an area where ALAN is higher than threshold limits (when the artificial night light brightness is greater than 10% of natural brightness). Also, many countries such as US had this value much higher and above 99% population facing this problem [17]. Consequently, the new world atlas on artificial night light brightness by using satellite data, day/night band, and Suomi national polar orbiting partnership satellite, which improve the resolution and accuracy reported that in new world 80% of world population facing the problem of excess night light brightness (brightness >14μcd/m^2) [15]. Therefore, ALAN is spreading swiftly and considered as global problem and now every countries trying to study the trend of light brightness in their protected area using advanced technology. For example, India analyse the trend from 1993–2013 using defense meteorological satellite programme, which help in identifying the sensitive sites such as protected areas and setting the new light policies and priorities [18]. Although the ALAN varies in intensity, colour, timing, and wavelengths and also vary with the particular country and location. A list of ten highly polluted night light brightness cities of world and India are showed in **Figure 1(a, b)**. In the represented figures, data on light brightness using light pollution map reveals that the situation of some cities in world such as Doha, Abu Dhabi, and Kuwait are very crucial as they have light brightness >160nW/cm^{2*}Sr., which is 3–4 times higher than highly night light polluted brightness (50nW/cm^{2*}Sr. considered as highly light polluted area).

The natural sky glow during night consists of comes from moon light, integrated starlight's, zodiacal light and airglow. In the recent times due to anthropogenic activities excess light generated in the surrounding that causes disappearance of natural darkness, artificial glow in sky, and loss in visibility of the stars and Milky Way's [19]. There are several anthropogenic factors that are responsible for pollution in night light such as decorative lightening during various festivals, lightening in buildings, malls and in homes, traffic light (consist of four wheeler, two wheeler light), road/highway light (to reduce accidents), advertisement light (to enhance marketing of different products), ship and aeroplane light, and street

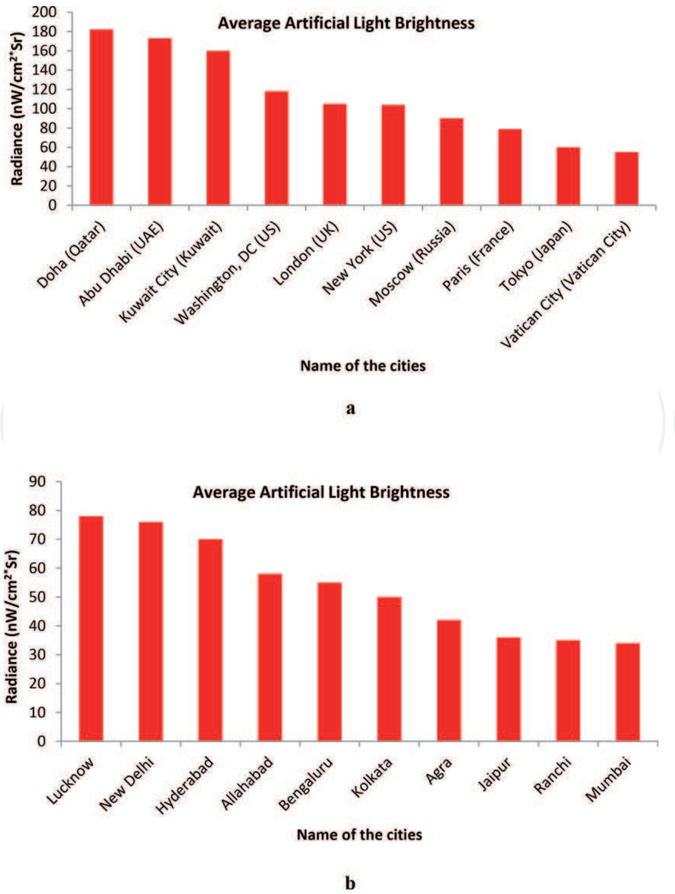

Figure 1.
(a, b) Represent the list of top ten world highly night light brighten cities (mean value of 28.27 km² area at 10 km elevation) of world, (highest value is near to 185 which is very high), and India during the year 2019-2020. Data procured from https://www.lightpollutionmap.info/.

lightening [20]. These artificial lights vary in wavelength, timing (few minutes to whole night), colour (violet to red) and intensity (very low to very high). Also, the origin of this lightening varies such as LEDs light (light emitting diode), halogen light, tungsten bulb, and florescent light (tube lights). Moreover, it varies with the locations such as market area having light for 3 to 4 hours, home lights early evening hours and road light (whole night).

3. Plant biorhythms or circadian rhythms and their response under light and dark cycle

Biorhythms are known as adjustment mechanism in living systems that keep body homeostatis, adaptive processes and dynamic equilibrium. Biological rhythms are endogenous and closely linked with external environmental elements but regulated by endogenously such as genes. Phytochrome and cryptochrome pigment plays a key role in coordination and regulation of plant biorhythms [21, 22]. Phytocrome repons to red and far-red light, while crytochrome responds to ultra violet/blue light. Arabidopsis has five phytochrome *PHYA* to *PHYE* and two crytochrome *CRY1* and *CRY2* [21, 22]. Plant biorhthms are mostly classified as (a) cicadian rhythms; (around or approximately; dies meaning day), (b) circaseptan rhythms; (weekly), (c) circalunar rhythms; (monthly), (d) circannual rhythm; (annual) [21, 23, 24]. In different way, biorhythms classified on the basis of duration for example, (a) short duration; on the order of seconds or minutes for example water and ion exchange across the cell membranes, (b) long duration; varies from days to months for example complex sequence of events and the quantitative changes regulated at cell, tissue and organ level [25–28]. Moreover other classification of biorthyms include (a) ecological rhythms; monthly, seasonal or diurnal (b) Physiological rhythms; based on various organs bioelectric activity [29–30].

Among the all known rhythms, circadian thythms are very well known and documented by many reserchers. Circadian clocks are the biological oscillators that enable the organism to coordinate their physiology and behavior under periodic environmental fluctuations and also evolved in organisms in response to the daily rotation of the earth [23]. Circadian clock can influence diverse plant crucial processes like leaf movement, photosynthesis, stem extension, stomatal opening and hormonal regulations [23]. The circadian clock constitutes of three components: input, central oscillator and output pathways. Each component contains a number of genes i. e., PHYs (PHYTOCHROMEs), CRYs (CRYPTOCHROMEs) and PHOTs (PHOTOTROPINs) are the very well recognized light receptor genes of input pathways and transmit external light stimuli into the central oscillator [31]. Phytochrome interacting factor 3 (*PIF3*), ZEITLUPE (ZTL), PSUEDO-RESPONSE REGULATOR (*PRR*) have important role during light signalling and affects the circadian clock [32]. Free running period (FRP) is the period length of cercadian rhythms measured under constant conditions and varies among tissues, organisms and even cells of the same cell type [32]. In circadian of *Arabidopsis thaliana* oscillator consist of interlocking transcriptional feedback loops and control signicant process such as growth and metabolism. Circadian rhythms defined by three fundamental parameters: Periodicity**;** time to complete one cycle of 24 hours [33], Entrainability**;** circadian rhythms are self-sustaining and endogenously generated, therefore they maintain under constant environmental conditions like constant light or dark and temperature, Temperature compensation; the period remain relatively constant over a range of ambient temperature.

The circadian rhythm is closely associated to the light–dark cycle. Circadian rhythms remain consistent in response to no time cues but can be entrained by ambient conditions. But it's been clear that different stimuli have varying effects on our circadian rhythms. Many environmental parameters provide stimulus to the clock, where the best characterized and most potent entraining stimulus is light in plants [34, 35]. Further, it is shows that shoot tip sends an unknown signal to the roots so root maintain circadian rhythm. While the lack of shoot apex signals loss of rhythmicity in the decapitated root, which can be overcome by direct exposure of root to LD cycles (light: dark) even as low intensities. It is clear that roots are entrained by light in preference to shoot apex derived signals [36]. In the context of photoperiodism, the circadian rhythm is combined with light signaling. The photoperiod sensor permits plants to respond to the annual cycle of day length, by the production of flowers, tubers and frost tolerant buds in appropriate seasons [37]. Accurate entrainment is important for photoperiodism, certainly general physiology shows that the crucial difference between light dominant plants (most of the flowering in long days) and dark dominant plants (most flowering in short days) is in the entrainment of their photoperiodic rhythm [38]. In light signaling pathways both phytochrome (phy) and cryptochrome (cry) regulate clock components to attain entrainment in plants [39]. The phytochrome responds to a red light and the cryptochrome absorbs in the UV-A/blue wavelength. Recognition of variations in day length confers plants seasonal flowering. This mechanism includes a time-keeping mechanism that integrates intimation of light environment to estimate the duration of day or night. Time-keeping activity is the outcome of the circadian clock. In Arabidopsis, an increase in flowering under long days (LD) happens through transcriptional induction of florigen gene FLOWERING LOCUS T (FT) specifically under LD conditions. The FT promoter binds with CONSTANS (CO) transcription factor which directly confer its LD-specific induction [40].

CONSTANS characterizes as a photoperiodic timer gene with its transcript level being managed by the circadian clock. CO proteins accumulate in response to exposure to light [41].

4. Impact of the artificial light at night time on circadian rhythms

As sessile plant receive light as signal and resource. Diurnal cycle of dark and light period is vital for regulating numerous processes in plants such as daily events of enzymes activity, gas exchange, photoperiodic movements, metabolism, stomatal movements, flowering opening, dark repair recovery and photosynthesis. The impact of artificial lighting on the body clock and its circadian rhythms is an important research topic. Night shifts introduction has changed the natural 24-hour cycle. There are multiple different categories of artificial lighting that are being utilized. It is various forms, from brief pulse to long lasting night glow, from narrow emission spectra to broad emission spectra, from low emission intensity to high intensity emission, and from local emission focus to glowing of sky. Effect of ALAN on some plant circadian process are disused thoroughly and represented in **Figure 2**.

4.1 Enzyme activity or metabolism

It is very well documented that enzymes are essential for optimum growth and development of plant. Also, they help in regulating all the physiological, biochemical processes in plants. Important physiological and biochemical processes of plant include such as seed germination, photosynthesis, respiration, and translocation. In this regards an experiment conducted in rice using the different light intensity (from low to high) during night hours and observed that ALAN drastically reduce the germination capacity by reducing the activity of α-amylase enzyme [42]. Moreover, a recent study conducted perennial ryegrass using the different duration

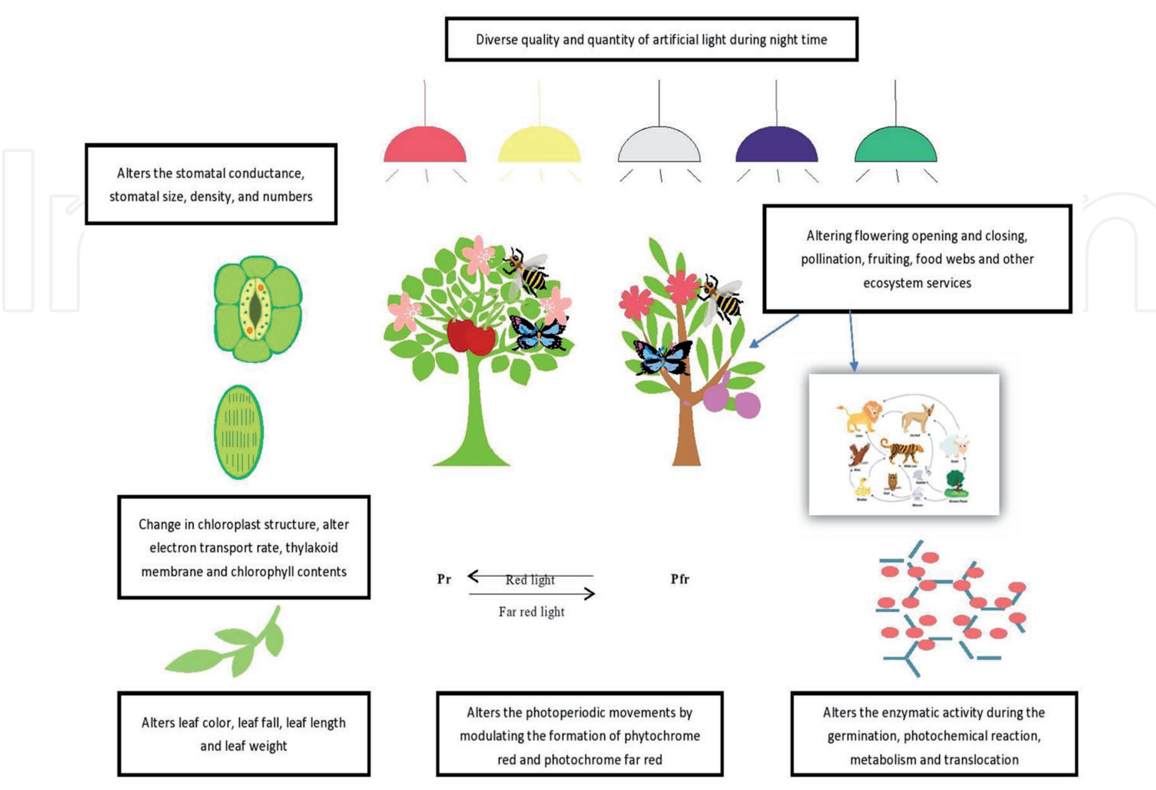

Figure 2.
Represents the impact of artificial light at night on plant circadian and eco-physiological processes.

of light as light/dark hr. (24/0, 22/2, 20/4, 18/6, 16/8, and 14/10) and they had found that seed germination percentage (67 to 33%), soluble carbohydrates (27.48 to 9.16 mg/g fresh weight) and soluble protein (13.85 to 10.59 mg/g fresh weight) are lowest in 24/0 conditions as compared to 16/0 light/dark conditions, which showed the drastic effect on the future growth of plant [43]. In this array, a study conducted in yellow poplar using different light intensity from low 1 to high 50 μmol m^{-2} s^{-1} showed that in ALAN leading to reduction in starch turnover (74.7 to 11.4%) via affecting the starch synthesis activity and lower rate of respiration [44, 45]. Therefore, from these studies, it can be concluded that ALAN affect the metabolism of plant at early and late growth stages.

4.2 Stomatal movement and biomass

The stomata are very important for gas exchange and water transpiration in plants. It is also well documented that stomatal movement is circadian rhythm which is also influenced by the intensity and quality of light. In this regard, an experiment conducted using different photon flux density (1, 3, and 50 μmol m^{-2} s^{-1}) and different light sources low pressure sodium lamp, high pressure sodium lamp and LEDs and they found shorter, narrower stomatal aperture, change in osmotic pressure and reduced stomatal size with increased stomatal density and the higher intensity more drastically affect the stomatal attributes in comparison with lower intensity of ALAN. Further, it is also found that the stomatal conductance is reduced under ALAN condition and affects the biomass accumulation and gas exchange [44, 45]. ALAN reduces the both above and below ground fresh and dry weight. Such as in the presence of 50 μmol m^{-2} s^{-1} in ryegrass during night time reduces the below ground fresh and dry weight by 48 and 46% respectively. Similarly, the reduction in above ground fresh and dry weight are 27 and 46% respectively. Therefore, it is expected that in future the result of ALAN might be more drastic and influence stomatal behaviours in plants.

4.3 Photosynthesis

Photosynthesis is the most crucial physiological process in autotrophs and essential for sustaining life on this planet. Earlier, it is documented that the sunlight is the prime source of energy for photosynthesis processes but in recent years many studies conducted using ALAN and found that it hampers the photosynthetic processes. In this aspect a recent experiment conducted using the street light having ALAN intensity near to 340-360lux and exhibited that plant under street light have lower photosynthetic quantum yield (Fv/Fm), non-photochemical quenching (NPQ) values, which ultimately affects the photosynthetic rate drastically [46]. Similarly, a study conducted in yellow poplar using different light intensity and quality during night hours reveals that total chlorophyll content reduced up to 35%, water use efficiency 23%, and photosynthetic rate 42 to 45% [45]. Another study reported in yellow poplar showed that the ALAN affect the ultrastructure of chloroplast by multiplying number of thylakoid membrane stack, reducing thylakoid stacking, and increasing number and size of plasoglobuli [44]. These modifications in chloroplast ultrastructure lead to early senescence, chloric and abnormal leaves. Consequently, ALAN in ryegrass influences the Chl a, chl b and total chlorophyll content, Fv/Fm ration, and electron transport chain. Further, they also ended up that the ALAN act as stressor and influence the photosynthetic efficiency of plants [43]. Therefore, it can be concluded that ALAN act as a stressor for photosynthetic phenomena and expected that in future it may be a global problem of road side trees.

4.4 Photoperiodic movements

The impact of relative length of flowering during day and night is refereed as photoperiodism. On the basis of day and night length plants are categorised into long day plant (required longer day length than critical period), short day plant (required shorter than crucial photoperiod) and day neutral plant (do not affect by day length). Therefore, flowering mechanism is very sensitive to critical day length. In the recent years it is found that ALAN severely affects the flowering mechanism in plants. For example, under ALAN and average spring temperature conditions at timing of budburst in deciduous tree species recorded and observed the budburst occurrence about 7.5 days earlier as compared to the normal UK conditions [47]. A long term experiment conducted to observe the impact of ALAN on wild species in natural and semi-natural grassland and authors found that the lightening affects the trajectory of vegetation cover, leading to change in plant biomass and the composition of dominant wild species. Further, they also suggested that the ALAN significantly alters the flowering phenology by shortening or lengthening of flowering period varies from 4 day earlier to 12 day late compared to control conditions [48]. Nevertheless, authors observed the non-significant relationship of ALAN with vegetation composition and flower density in grassland vegetation species. Further, they observed early flowering (about 4 days) in *Agrostis tenuis* and delayed flowering (about 7 days) in *Anthoxanthum odoratum* [49]. Thus, flowering behaviour of the plant species varies with ALAN (timing, duration, intensity, and spectrum etc.). Similarly, a study conducted on foredune vegetation such as *Traganum moquinii* receiving various light intensities during the year and author suggested that vegetation which face direct light or close to light source affected more and their flower and seed production is reduced drastically compared to species which located far from light source [50]. Also the flowering period can vary (reduced or increased) under ALAN, depend upon the type of plant species with their genetic constituents. For example, an experiment conducted using 1000-4000 lx light using LEDs and found that trees flowering are more susceptible than shrub species and plant species are more susceptible than evergreen species [51]. Therefore, it might be possible that in future the photoperiodism phenomenon affected more and can be responsible for evolutionary changes. The responses of plant circadian and ecological processes are represented in **Figure 2**.

5. Impact of ALAN on eco-physiological processes

As earlier mentioned ALAN is a global problem and it act as a stressor for living organisms including plant. Also, some recent studies exhibited that the impact of ALAN can be amplified with unfavourable conditions as pollution. Moreover, the living organisms or plants connected with environmental phenomenon and adaptive themselves. Many plant processes are associated to environment such as transpiration which depends upon the atmosphere humidity. Some of eco-physiological processes influenced by ALAN condition are followed and represented in **Figure 2**.

5.1 Plant growth and development

It is very well documented that the growth and development of plant is highly influenced by the environmental conditions. Also, a positive plant-environment interaction is necessary to grow plant under different environmental circumstances. The night hour lightening has great impact on the plant phenology, physiology, growth and development, reproduction and behaviours [52]. The light pollution is an emerging global phenomenon and accelerated by rapid urbanization, which affects both plant and animal fitness in both developed and developing countries, however the impact are very serious in urban areas. Contrary, it is observed that delayed autumn phenophases in the crown part of two tree species (*Acer pseudoplatanus* L. and *Rhus typhina* L.) positioned next to light source by 13 to 22 days and also deferred duration by 6–9 days. They also observed delayed leaf colouring duration by 6 to 9 days and leaf fall by 6 to 7 days due to ALAN [53]. A recent study conducted using ALAN in perennial wildflower regarding to observe the effect on growth and developments and they concluded that ALAN modulates the growth by interaction with abiotic factors such as soil moisture and affect plant density [8]. Likewise, recent study on the ecophysiological responses of ALAN in plants concluded that this had potential to alter the number of aspects such as germination, photosynthesis, biomass and yield [54]. In these consequences a recent study conducted using the different light intensities during night in rice and authors found out that the harmful impacts of light during night increased with light intensities and drastically reduces the seed germination (−14%), seedling vigour (16.83 to 12.51), root length (8.63 to 7.03) and early growth attributes such as seedling length (17.72 to 13.72 cm), mean time of germination (1.21 to 1.28), coefficient velocity of germination (82.61 to 78.07), germination index (526 to 465), germination rate index (87.83 to 78.50%/day) and mean germination rate (0.83 to 0.78) under artificial light conditions as compared to control, which directly associated the future growth of plant [42]. Moreover, in ryegrass reported that different intensity of light affects the leaf length (20.82 to 16.19 cm), leaf weight (1.02 to 0.58 g/10plants) and physiological parameters, which ultimately affects the growth in negative ways [43]. Therefore, it is expected that ALAN significantly hampers the growth and development of plant.

5.2 Pollination

Globally, pollinators are indispensable source of pollination in both agriculturally important crops and wild plants [55]. Anthropogenic activities such as intensive agriculture, use of extensive pesticides, habitat change, invasive alien species and climate change has substantially reduced population of pollinators [56]. Moreover, ALAN has emerged a new threat to plant reproductive success by disturbing plant-pollinator ecosystem balance. For example, authors witnessed the reduction of nocturnal pollinators visit by 62% in ALAN areas compared to the dark areas and yield was reduced by 13% [57]. They also observed visit of diurnal pollinators at night with nocturnal pollinators under ALAN. The pollinator-population dynamics and plant-pollinator communities are being adversely affected by artificial night lightening. Furthermore, ecological functionality and stability has been challenged by artificial night lightening throughout the world. Also the pollution effect of ALAN by nocturnal moths (Lepidoptera) and concluded that pollination is an ecosystem driven process that can be disturbed by increase of light pollution [58]. Similarly, recent study observed the negative relationship between direct ALAN and reproductive out in *Epilobium angustifolium*, plant species. This result can be due to disturb of pollination services in plants at nigh time by direct light illumination and cannot be compensated by day time pollinators [59]. Antagonistically, it is reported that there is no direct effect of light pollution on the reproductive output of *Silene latifolia* and possible only if diurnal pollinators compensate the decrease in pollination at night and another reason can be development of mechanism in pollinators which can manage the adverse effect of light pollution [59]. Thus, effect and extent of ALAN varies with plant species, and the behaviour of pollinators. Further, it can affect plant and animal biodiversity, species interaction particularly plant and pollinators, ecosystem balance and functioning.

5.3 ALAN as stressor

As sessile in nature plant faces a number of stressor throughout their life cycle such as abiotic stress (drought, heat, flood, cold, salinity, elevated CO_2, and heavy metals), pollutions (air pollution, soil pollution), biotic stresses (insect, and pathogen), and most of times these stress are in combined from and cause for detrimental loss in their optimum growth and developments. All of these are act as stressor for plant and affect plant by changing the physiological, biochemical and molecular processes [60]. Likewise, this light also an important environmental factor and low and high light both act as stressor [42, 61]. Recent studies shows that ALAN also act as stressor and found out that it increases the lipid peroxidation, and reduces total antioxidant capacity in autotrophic red sea corals [62]. Further, an experiment in perennial ryegrass showed that ALAN increases the malondialdehyde (MDA) content and reduce leaf heat stability [43]. Similarly, it is observed that yellow poplar plant accumulate hydrogen peroxide, superoxide radicles and reduced abscisic content under ALAN conditions [44, 45]. Therefore, from these studies it may be concluded that ALAN act as a stressor and responsible for oxidative stress.

5.4 Ecosystem services under ALAN

Abiotic and biotic component of ecosystem coordinate to each other which provide important ecosystem services to humans. Also, the stability of ecosystems is key for sustaining of life on this planet. However, in the recent past due to uncontrolled anthropogenic activities ecosystem and biodiversity services of ecosystems are losing continuously. Among the anthropogenic activities, ALAN is one of the swiftly expanding activity, which is now become a global problem for ecosystem and biodiversity services [10, 63]. It is suggested that ALAN affect the organisms flux across the ecosystems and key driver of ecosystem community structure and can modify the ecosystem functioning beyond the affected area [64]. Moreover, the effects of ALAN are not limited to plants but also it affects the aquatic, forest, desert, terrestrial, mountain and agriculture ecosystem from lower to higher levels [10, 59]. Further it has been found the ALAN had drastic impact of ecosystem services such as foraging, vision, reproduction, signalling and behaviour. Therefore, it can be concluded that ALAN had serious impact on ecosystem services of stable ecosystems.

6. Minimizing strategy of ALAN

6.1 Street light pollution

Street lights should be replaced with energy-efficient LEDs and proper shielding of light in streets and by managing their angels. Street lights should be installed where needed Indian standards [65] has classified the roads according to the traffic density. By considering the road category according to traffic density engineers can design the street light plan and provide the installation specifications. To a report from [66], the Bruhat Bengaluru Mahanagara Palike (BBMP) projected a plan to replace the existing 4.8 lakh city street lights with high energy-efficient LED lights. A number studies conducted to showing their impact on plants ecosystems and hot spots and most of cases it affect in negative way.

Although, some of researcher are concerned and documented about the impact of ALAN but there is no progress in changing the street lights. However, in recent time some countries follow the new light policies, where they replaced the old lights with more efficient lights and change the angle and height of light source to reduce the tree passes.

6.2 Buildings lights

This can be minimize using smart building architecture to decrease the use of excessive outdoor and indoor lights. The utilisation of LEDs, compact fluorescents (CFS) and warm coloured bulbs should be used to minimise energy use and by this way somehow we can protect our environment. The dimmers, motion-sensors and timers contribute a lot to energy saving. Turning-off the unnecessary indoor along with outdoor lights in houses and offices. Avoid Blue light during night time. International Dark Sky-Association (IDA) recommends use only warm lights for outdoor that includes low-pressure sodium (LPS), high-pressured Sodium (HPS) and low-colour LEDs. By using warm or filtered LEDs (CCT < 3,000 K; S/P ratio < 1.2) can reduce the blue light emission [67].

6.3 Government policies for ALAN

Artificial light pollution is now emerging pollution and governments has also considered it and have provided certain guidelines to decrease the energy wastage, damage to agro-ecological and wildlife ecosystem. During the 13th meeting of the Conference of the Parties, Gandhinagar, India Agenda No. 26.4 "the guidelines for light pollution for wildlife including marine turtle, seabirds and migratory shorebirds" under the Convention on the migratory species (prepared by the Government of Australia) [68]. By seeing the threat of sky glow and emerging challenges of increasing artificial light pollution to the marine species government has taken a proactive approach to develop artificial light in night pollution guidelines. These kinds of initiatives need to be taken by every country to combat artificial night light pollution. Artificial light at night became an unavoidable technology from the societies however this indispensable tool has harmful side effect in term of light pollution [69]. One can understand that artificial light at night is necessary to highlight the scenic beauties of the cities and to provide safety on roads however where artificial light at night is easily available at very low cost there it is over utilized which leads to discomfort in society with a view to disturbing the natural habitats, underline the beauty of skyline etc. Therefore now we can understand that ALAN has two phases of its representation. The detrimental effect can be seen through alteration in the sky glow which is an important constituent of biosphere [70]. According to one study, around one fifth of the global population affected by artificial sky brightness [17]. Challenge that we have is how we can use the ALAN in such a way that maximize the social benefits and reduce the impact of its pollution.

In this regards several articles are available at public domain [71–79]. They have summarized the solution like protecting species rich areas in their natural habitat, policy making on threshold and upper limit of light emission, environmental specific custom based light brightness which is adapted to vicinity of that area, time control of light emission, diurnal adapted colour spectrum and reducing the trespass of lightening. Apart from this, it is suggested that the five ways to minimize the harmful effect of ALAN *viz.* improving light fixtures to direct the light where it needed, switch the light off whenever it is not needed, dim the light and choose the appropriate Illuminants, colour spectra and filters, shade the light to protect the neighbor and learn from nature to maintain its sustainability [69]. Further, suggested to use the decreased height of light poles and increased spacing between light poles to reduce the pollution from ALAN [80]. It is also strongly recommended that environmental impact need to be considered in addition to energy consumption [81]. Moreover, considering the nature and landscape protection, protection of breeding sites and resting places of highly sensitive biological organism, assessing or measurement technology of ALAN pollution must improve to reduce the impact [82]. In addition to above explained policies author suggest that existing lighting plans must be evaluated and can be improved, reducing the decorative lightening, using of covered bulbs that face downwards, use of automatic system to turn off street light at certain times, outdoor lights with glare should be replaced with low glare, use of IDA approved light fixtures and use of motion sensors on important outdoor lights to reduce the impact of pollution caused by ALAN. Although, there are no specific light policy for reducing impact of street light on plant and living organisms but it may expected that in near future countries will adopt some new light policies. However, some of points can be considered under future light policies to reduce the impact of ALAN on plants, which are followed.

- Reduce the height of light source to reduce tress passes
- Change the angle and position of light source
- Light source could be away from trees
- Growing light insensitive tress and crops o road side areas such as day neutral species
- Avoid short day plants near to highways
- Promote self-pollinated species as compared to cross pollinated
- Avoid cross-pollinated species especially which nocturnal pollinated

This approach can be milestone to reduce the impact of ALAN on plants.

7. Conclusion

Human population is continuously expanding and degradation of natural resources is also increasing with human development activities. ALAN has important role during the human development process as it increases the working hours, work efficiency, reduce crime and accidents but due to excess use and accumulation in environment cause a problem of artificial night light pollution. ALAN pollution is anthropogenic and increasing swiftly and has global impact. In the presented chapter we tried to explore the impact of ALAN on plant biological rhythms and ecophysiological processes. Therefore, this study comprises of the recent status of ALAN in world and their sources. In this we concluded that many countries are facing the problem of ALAN and continue expanding their area. Further, we discussed about the plant biorhythms and their regulation by diurnal cycles and concluded that the plant biorhythms are highly sensitive too change in light/dark periods. Thereafter, we provide the some details regarding the plant circadian rhythm, which are affected by ALAN and concluded that ALAN had negatively associated with them. Later on, we detail the some ecophysiological functions under ALAN and concluded that ALAN had drastic effects on plant processes and in future it can be a global problem. In the last we discussed the some strategies and approaches to minimize the effect of ALAN. Therefore, in this chapter we tried to comprise all the recent information, which help scientist to explore more about in this area of research.

Author details

Rekha Sodani[1], Udit Nandan Mishra[2], Subhash Chand[3], Indu[3], Hirdayesh Anuragi[4], Kailash Chandra[5], Jyoti Chauhan[6], Bandana Bose[6], Vivek Kumar[6], Gopal Shankar Singh[7], Devidutta Lenka[8] and Rajesh Kumar Singhal[3]*

1 College of Agriculture, Nagur, Agriculture University, Jodhpur, Rajasthan, India

2 M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Gajpati, Odisha, India

3 ICAR-Indian Grassland and Fodder Research Institute, Jhansi, U.P., India

4 ICAR-Central Agroforestry Research Institute, Jhansi, U.P., India

5 Sri Karan Narendra Agriculture University, Jobner, India

6 Institute of Agriculture Sciences, Banaras Hindu University, U.P., India

7 Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, U.P., India

8 Orissa University of Agriculture and Technology, Bhubaneswar, Odisha, India

*Address all correspondence to: rajasinghal151@gmail.com

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