Could electromagnetic radiations have any effect on insects and their behaviour?

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Electromagnetic radiations (EMR), are the radiations that travel through space by carrying electromagnetic radiant energy. These radiations vary in strength from low energy to high energy. The energy is spread all around in many forms, such as radio waves, microwaves, X-rays etc. Sunlight is also a form of EM energy, but visible light is only a small portion of the EM spectrum, which contains a broad range of electromagnetic wavelengths.

In classical physics and modern quantum theory, EMR is flow of energy or photon at the universal speed of light via free space or through a material medium in the form of electric and magnetic fields which generally characterized by its intensity and frequency of time variation to the electric and magnetic fields. It has created due to electrically charged particles undergoing periodic change of electric or magnetic field. Due to their different sources of emission and effects on matter, they are called by different names. However, these EM waves carry energy, momentum and angular momentum away from their source particle and can impart those quantities to matter with which they interact.

Likewise, EMR also interacts with arthropods life. It always remains to be a contradictory with insects. Most of the advance technologies like electronic gadgets, mobile phones emit electromagnetic radiations. Their harmful effects have already warned humans of their safety but somehow at present they are still the fastest growing industries. At present, global biodiversity declining very fast rate among which arthropods are major one. The arthropod biodiversity is declining at the rate of 1-2% per annum. Among the arthropods, bees and pollinators are highly affected by EMR (Atwal, 2018) which resulted in tremendous disturbances of food web of both terrestrial and aquatic ecosystems. This has also resulted into a wide gap in food chains for which at now humans do not have any alternative way to fill up those food chain gaps. Such facts undoubtedly emphasize to initiate the strategies to act on reduction of electromagnetic radiations for preservation and maintenance of not only arthropods but for whole biodiversity along with humans for their healthy survival.

EMR and insects:

In mid-20th century, there is been abrupt increase in the emission of EMR (radio waves, microwaves, infrared, visible light, ultraviolet, X-, and gamma radiation) in the environment (Table 1). Now days, android phones have also entered in this category with advance cellular system i.e. 5G. The 5G utilizes frequencies up to 120 GHz (Thielens *et al*., 2018). Their adverse effects have already been seen on vertebrates (Humans, mice, birds) and up to limited extent on arthropods especially bees (Atwal 2018).

Table 1. EMR and their impact on organisms.

Sl. No.	Radiation	Energy type	Frequency	Wavelength	Impact on organisms	Example
1	Extremly low frequency (ELF)	Non - ionizing	$10\text{-}10^{6}$Hz	$10^{7}\text{-}10^{3}$m	Safe and beneficial in appropriate dosage	Power lines, electrical wiring
2	Very low frequency (VLF)	Non – ionizing	$10^{6}\text{-}10^{7}$Hz	$10^{3}\text{-}10^{1}$m	Safe and beneficial in appropriate dosage	Radio navigation
3	low frequency (LF)	Non – ionizing	$10^{7}\text{-}10^{8}$Hz	10^{1}-1m	Safe/ low danger	Radio, TV
4	Radio frequencies	Non – ionizing	$10^{7}\text{-}10^{12}$Hz	$1\text{-}10^{-1}$m	Safe/ low danger	Radio, television, Mobile phones
5	Microwaves	Non – ionizing	$10^{10}\text{-}10^{12}$Hz	$10^{-1}\text{-}10^{-3}$m	Danger	wireless network, routers, satellite and space craft communication
6	Infra-red	Non – ionizing	$10^{14}\text{-}10^{12}$Hz	$10^{-4}\text{-}10^{-5}$m	Danger	Electrical heater, cooker, remote control, thermal imaging cameras
7	Visible	Non – ionizing	$10^{14}\text{-}10^{15}$Hz	10^{-6}m	Safe and beneficial in appropriate dosage	Li-Fi, underwater communication,
8	Ultraviolet	ionizing	$10^{15}\text{-}10^{17}$Hz	$10^{-7}\text{-}10^{-9}$m	Extremely Harmful	Lamps, TVs, tablets, computer etc.
9	X-rays	ionizing	$10^{16}\text{-}10^{20}$Hz	$10^{-8}\text{-}10^{-12}$m	Extremely Harmful	X ray machine, electron microscope, radiography etc.
10	Gamma rays	ionizing	$>10^{19}$Hz	$>10^{-11}$m	Extremely Harmful	Nuclear reactors,

In May 2011, World Health Organization (WHO) mentioned radiation with the frequency range of 30 kHz to 300 GHz in Group 2B and can be a 'possible' human carcinogen, (Baan *et al*., 2011; IRAC, 2013), but somehow, they are being ignored. The maximum studies of EMR have been conducted on two insects i.e. the fruit fly (*Drosophila melanogaster*) and honey bees (*Apis mellifera*). In fruit fly, EMR shows developmental delay and reproductive failure while in honey bees they were found degrading the colony strength and oviposition rate. Due several limitations like methodologies, equipped laboratory, rearing techniques and time limitation etc. researchers are unable to obtain its effects on other insects.

Some insects have found capable to recognize EMR for example honey bees. They are able to detect magnetic field and EMR of same magnitude for orientation, navigation and foraging (Venbergen *et al.*, 2019). Sometimes for intraspecific and interspecific (plant-pollinator) communication, they also utilize EMR (Clarke *et al.*, 2013; Greggers *et al.*, 2013). But ultimately it could disturb the physiological functions even more in some cases affects its survival. At now, each species on this earth have some relationship with environment for some special functions like pollination, food chain, nutrient cycle etc. but unfortunately, climate change, pollutions including EMR, deforestation, urbanization etc. created an unresolved threat for biodiversity conservators to preserve them in present scenario for future generations.

Effect of EMR on insects:

At present very few researches were conducted on insects to observe the effect of higher radio Frequency and EMR on them (Fig. 1).

According to Thielens *et al.*, (2018) when insects are exposed to EM fields, it is partially absorbed by their body based on their frequency. If frequency is at or above 6 GHz, it will increase the general absorption of RF power. Their simulations with insects, showed a shift of 10% in the incident power density to frequencies above 6 GHz that would lead to an increase in absorbed power between 3–370%. These results were the outcome of their research on four insects i.e. *Tetragonula carbonaria* (Australian Stingless Bee), *Apis mellifera* (Western Honeybee), *Schistocerca gregaria* (Desert Locust) and *Geotrupes stercorarius* (Beetle) with the help of micro-CT imaging to develop realistic model. These shifts ultimately could bring the changes in insect behaviour, physiology, and morphology over time due to increased body temperatures, from dielectric heating. Similarly, in 2020 they conducted an in-situ experiment in Belgium exclusively on economic insect *Apis millifera* and on its different cast i.e. two workers, one drone, one larva and a queen. They exposed the five-bee model to different frequency of EMF i.e. from 0.6 GHz up to 120 GHz. The average absorbed radio-frequency power increases by factors 16 to 121. It concludes that 10% of the incident power density would shift the frequencies up to higher than 3 GHz. It would lead to an increase of this absorption between 390–570%. In the series of experiment, Francis, 2020 showed the impact of EMR released from cell phones and their base stations on organisms. He highlighted the negative effect of these EMR on plants, insects, birds and some other animals. According to him radiations from mobile base stations and from cellular mobile is almost identical i.e. Global System for Mobile communication (GSM) 900 or 1800, except that it is simply more powerful. GSM 900 mobile phones emit radiations with a frequency between 890 and 915 MHz, while base stations emit radiations

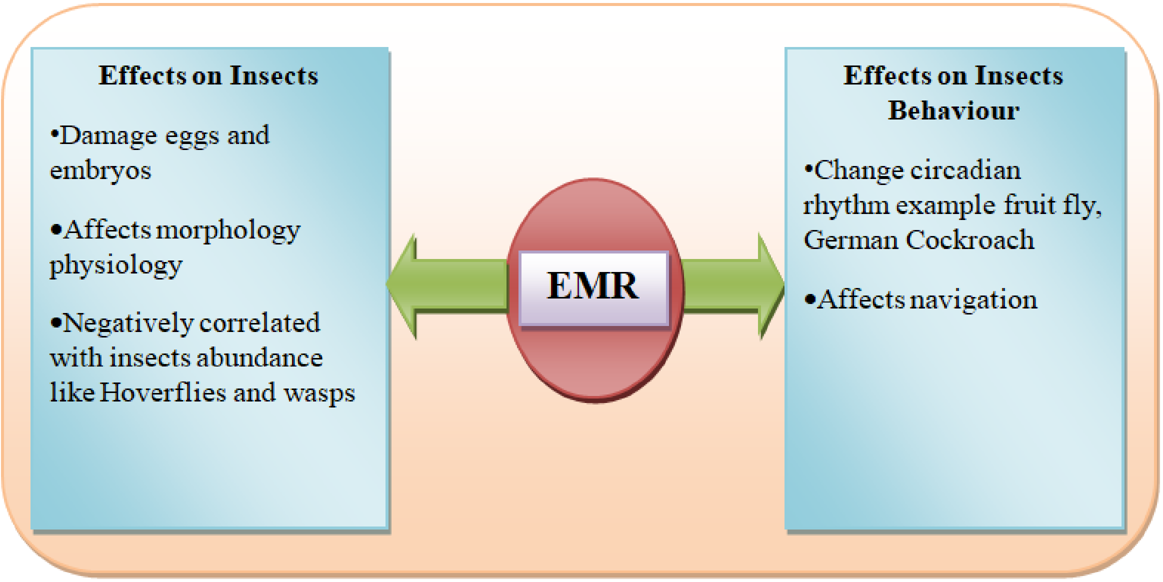

Fig. 1: Effects of EMR on Insects and their behaviour.

between 935 and 960 MHz. Overall, stronger the field, greater is the undesirable impact of the electromagnetic field on life. It could disrupt birds' and bugs' orientation and movement, and affect plant metabolic health, bug life warns. The microwaves (300 MHz to 300 GHz) emitted by cell phone towers and handsets has been found to be responsible for damaging eggs and embryos of sparrows.

In field realistic settings, to observe EMR impact on insect's abundance, Lazaro *et al.*, 2016conducted a small experiment across two Aegean islands. High frequencies (800–2600 MHz) were distributed there. His findings showed that EMR can affect the insect abundance especially wild pollinator. Their analysis revealed a complex correlation between the variable anthropogenic electric field (range 0.01–0.67 $V \cdot m^{-1}$) and insect abundance, but these were contingent on the insect taxon and sometimes varied with geographical (island) location. Greater exposure to EMR was related negatively to hoverflies and wasps abundance, positively to underground nesting wild bees and bee flies and uncorrelated to butterflies abundance. EMR did not show any effect on species richness of wild bees and hoverflies.

Effect of EMR on insect behavior:

Insect behaviour is the outcome of various actions in response to a stimulus or to its environment. It covers a wide range of activities like movement, feeding, learning, reproduction etc. but EMR may hamper them. It could easily understand from the findings of following researchers. Early research by Koschnitzke *et al.*, (1983) on insects (Chironomidae) against different frequencies (64.1–69.1, 67.2, 68.2 GHz) shows that millimeter waves of a power density less than 6 m W /cm 2 exert a non-thermal influence on the chromosomes of our eucaryotic system. All frequencies, which using power densities <6 mW/cm2, were found in responsible to cause a reduction in the size of a particular area of the insect chromosome. Another research was conducted by Fedele *et al.*, (2014) on circadian clock of *Drosophila melanogaster* to observe the effect of electromagnetic field on cryptochrome (CRY) photoreceptor. Basically, these cryptochrome are utilized by *Drosophila melanogaster* to navigate natural EMF during migration when activated by light. From his study they conclude thathCRY2 is blue light-responsive. Deletion of the CRY C-terminus i.e. blue-light sensitive photoreceptor cryptochrome markedly attenuates the EMF-induced period, whereas the N-terminus underlies the hyperactivity. Ultimately, hCRY2, transformants can detect the EMFs.

Likewise, in the way Bartos *et al*., (2019) finds their results on German cockroach (*Blatella germanica*) by utilizing remarkably weak intensities of man-made radiofrequency (RF) i.e of in nanotesla range. They found that weak broadband RF fields can affect the circadian rhythm of the German cockroach (*Blatella germanica*). Their data shows that the circadian rhythm of the insect species *B. germanica* is sensitive to both static MF and RF fields in a light-dependent manner. Some other also noted their impact on physiology. Weak broadband RF noise impacts the insect clock system which is comparatively more sensitive to RF than to static MFs.

At now there are very little evidence of exposure to EMR that leading to any damage or harmful effect on individual's development, reproduction of few insect species like flying insects (Wan *et al*., 2014; Wyszkowska *et al*., 2016). At present most, convincing finding of EMR are with birds and mammals, (Engels *et al*., 2014; Malkemper *et al*., 2018). Overall, the magnetic sense of invertebrates appears to be affected by EMR in the MHz-range although the extent to which arthropods especially insects are dependent on their magnetic sense for successful navigation remains unknown.

Conclusion:

In vertebrates, present scenario reveals that Aves (birds) and mammals are highly affected with EMR (Engels *et al*., 2014). It may be due to the close association of birds with mammals in classification. But one cannot neglect their side effects on invertebrates' organisms like insects. Where these EMR may hamper their abundance, physiology functioning, behavioural aspect and ultimately their survival. But due to unavailability of methodologies, proper techniques, and several limitations by environmental agency one has failed to calculate out those impacts. So, further research on this area must bring some unbelievable results which can surely bring some changes in science of insects. Till date, studies are very less on EMR impact on insects to reach at any conclusion but their possible outcomes may help to understand the side effects of these EMR on these small creatures.

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