IMPACTS OF NON-IONIZING ELECTROMAGNETIC RADIATION ON THE ENVIRONMENT: A COMPREHENSIVE REVIEW ON HUMANS, PLANT AND LIVING ORGANISMS

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Abstract

Background: Non-ionizing radiation (NIR) is electromagnetic radiation that does not possess enough energy to remove tightly bound electrons from atoms, unlike ionizing radiation. With the increasing use of technologies such as radiofrequency radiation (RFR) and extremely low-frequency electromagnetic fields (ELF-EMF) in various applications, concerns have been raised regarding their potential environmental effects. This review aims to provide a comprehensive assessment of the environmental impacts of NIR, focusing on humans, Organisms and Plants.

Aim and Objective: The study aims to provide a comprehensive understanding of the potential impacts of non-ionizing radiation on the environment and ecosystems. The objective of this comprehensive review is to critically examine and summarize the existing scientific literature on the environmental effects of non-ionizing radiation, encompassing a wide range of frequencies and sources.

Methods: A systematic literature search was conducted to identify relevant studies on the environmental effects of NIR. The databases searched included PubMed, Research gate, Web of Science, Academia, Scopus, goggle scholar and other online journal websites. Keywords included non-ionizing radiation, environmental effects, electromagnetic fields, radiofrequency, microwaves, and various environmental components. Studies published in English and conducted on various environmental organisms, Plants and human were included. The selected studies were critically reviewed, and data were synthesized to assess the overall impact of NIR on the environment.

Results: The reviewed literature revealed that non-ionizing radiation emitted from various anthropogenic sources, such as radiofrequency devices, wireless communication technologies, power lines, and radar systems, has the potential to affect the plants, humans and living organisms. In plants, exposure to RFR and ELF-EMF can affect seed germination, growth, and development, alter the physiological and biochemical processes, and impact reproductive success. Similarly, in animals and Humans, NIR exposure can lead to changes in behavior, reproduction, development, and physiological parameters. Additionally, there were indications of potential disruptions in ecological interactions and community dynamics in certain ecosystems exposed to non-ionizing radiation. The effects vary depending on the intensity, duration, and frequency of exposure, as well as the sensitivity of the species.

Conclusion: The available evidence suggests that non-ionizing radiation, particularly RFR and ELF-EMF, can have significant effects on the environment. However, the overall impact varies across species and depends on several factors. Further research is needed to better understand the mechanisms underlying these effects, evaluate the long-term consequences, and develop appropriate mitigation strategies to minimize potential risks. Given the ubiquity of NIR-emitting

technologies, it is essential to consider the potential environmental effects while ensuring technological advancements are accompanied by responsible environmental stewardship.

Keywords: non-ionizing radiation, environmental effects, radiofrequency radiation, electromagnetic fields, plants, ecological impacts

1.0 Introduction

The impact of non-ionizing electromagnetic radiation (EMR) on people, animals, and plants has increased as a result of the advancement of international communication systems. Numerous studies on the impacts of high-frequency electromagnetic fields produced by Wi-Fi and mobile phone devices have been conducted in recent years, but the findings are still inconclusive. Due to the significant influence of psychological factors and the genetic variety of human populations, this is especially true of research involving humans (Lopatina et al., 2019). The experiments on plants and animals as a whole produced more conclusive findings and showed that EMR within the frequency and intensity ranges often employed in mobile communication devices had a generally detrimental effect (Lopatina et al., 2019).

Given how frequently electronic devices like microwaves, televisions, and mobile phones are used, there is growing worry about the potential health implications of prolonged exposure to the electromagnetic fields (EMF) that these devices create **(Huang et al., 2022).** Some people have reported experiencing symptoms such as headaches, fatigue, increased stress, sleep disorders, skin-related sensations (such as burning, prickling, and itching), rashes, muscle pains and aches, and other health issues as a result of being exposed to the EMF produced by mobile phones and their base stations **(Seitz et al., 2005**). The phrase "idiopathic environmental intolerance attributable to electromagnetic fields" (IEI-EMF), which describes symptoms people experience after being exposed to EMFs, was created by the World Health Organization (WHO) **(Hillert, 2004**).With increasing frequency in a child's daily life, electromagnetic fields (EMFs), such as extremely low-frequency (ELF) or power frequency fields, and radiofrequency radiation (RFR), emit biologically relevant signals at very low intensity levels (Lenhart, 2015).

Nearly everyone in today's environment is subject to two different forms of EMFs: (a) ELF EMF from electrical and electronic appliances and power lines, and (b) RFR from wireless devices including cell phones and cordless phones, cellular antennae and towers, and broadcast transmission towers. ELF or RFR are used in this context to refer to the specific type of exposure, while the word EMF is used to refer to all EMF in general (Samaila et al., 2023b). This review article offers fresh information on potential health effects, including epigenetics as a potential contributor to neuro-developmental and neurobehavioral issues that are now frequently observed in children's growth, including abnormal states and functional alterations resembling autism and attention deficit hyperactivity disorder (ADHD), which can be brought on by exposure to EMF and RFR. The term "epigenetic" refers to heritable changes in gene expression that do not include changes to the underlying DNA sequence in response to environmental changes. Epigenetics has developed to offer a more precise and stable control of gene expression and genomic regulation. Today, epigenetic refers to any information that can be passed down during cell division that is not inherited through the DNA sequence. It offers ways for the environment and the genome to interact in addition to controlling how genes are expressed. The use of wireless technologies, such as mobile phones and Wi-Fi emissions at levels to which the fetus and young children may be

exposed, has led to the synthesis of several new lines of scientific evidence that show how EMF and RFR present in wireless technologies can cause epigenetic changes that can adversely affect childhood development **(Samaila et al., 2019**). Unfavorable effects on children's health and development, as well as their rising dependency on mobile devices, the incorporation of wireless educational technologies into curricula, and indications that these tools may actually work against rather than in favour of academic success.

Since the mid-twentieth century, several researchers have investigated the effects of electromagnetic radiation on plants, both in the laboratory and in nature (field observations). Both kinds of study have frequently found pernicious effects. Around the world, phone masts have been deployed in the last two decades everywhere. Preliminary published studies have indicated deleterious effects of radiofrequency radiation on trees (Waldmann-Selsam et al., 2016). In a review of the effects of environmental microwaves on plants, it was indicated that effects depend on the plant family and the growth stage, as well as the exposure duration, frequency, and power density. Since 2005, on the occasion of medical examinations of sick residents living near mobile phone base stations, changes in nearby trees (crown, leaves, trunk, branches, growth…) were observed at the same time as clinical symptoms in humans occurred. Since 2006 tree damages in the radiation field of mobile phone base stations were documented. Additionally, unilateral crown damage, beginning on the side facing an antenna, pointed to a possible link between RF-EMF (Radiofrequency Electromagnetic Fields) and tree damage (Waldmann-Selsam et al., 2016).

2.0 Material and Method

2.1 Literature Search

A systematic and comprehensive literature search was conducted to identify relevant studies on the impacts of non-ionizing electromagnetic radiation on the environment. Electronic databases such as PubMed, Web of Science, and Scopus were searched using keywords including "non-ionizing radiation," "electromagnetic radiation," "environment," "ecosystem," "human," and "tree plant." The search was limited to articles published in English from the earliest available date up to the present. Studies were included if they examined the impacts of non-ionizing electromagnetic radiation on the environment, including effects on human, Animals, and ecosystems. Both experimental and observational studies were considered. Papers that were published in a language other than English were excluded. Relevant data from the selected articles were extracted and summarized. The data included the study design, exposure parameters (frequency, sources, and duration), the environmental component studied (Plant, Living organism, or ecosystems), and the reported effects of electromagnetic radiation (Samaila et al., 2023a).

3.0 Result and Discussion

Non-ionizing electromagnetic radiation has been found to have various impacts on humans, plants, and living organisms. Exposure to non-ionizing radiation from sources such as cellular base stations, Wi-Fi, electric wires, and microwave ovens has been linked to health problems in humans. Studies have shown that exposure to non-ionizing radiation can have harmful effects on female fertility, including damage to oocytes, ovarian follicles, and reproductive hormones. Additionally, non-ionizing radiation can disrupt the normal functioning of the body and its systems, including the sexual, nervous, endocrine, and immune systems as shown in table 1.

Table 1: Overview of some literature findings

Source	Sample	Wavelength/ Diameter	Frequency/ Mag&El field	Period	Result	Conclusion	References
Wi-Fi router	Honeybee	12.5cm (wave length)	2.4 GHz	7-30day (2-24hrs)	After a 24-hour exposure to a WiFi router, there are noticeable inhibitory effects on sensory olfactory excitability and short-term memory impairment.	NIR decreased honeybee foraging and pollination activity.	Lopatina et al., 2019
3D Merritt four-coil systems	91 birds	2 m (diameter of the coils)	2kHz-9 MHz	2012-2014	Findings show that migratory birds' magnetic compasses were unaffected by intense, narrow-band electromagnetic radiation.	Birds' magnetic compass is completely disrupted under weak narrow-band electromagnetic fields.	Susanne et al., 2016
Solenoid	Honeybees	350 mm (diameter)	50Hz (1- 1.7 mT)	10m-3hours	Behavioral differences were observed across all groups exposed to the magnetic field.	Changes in behavior are a sign that the electromagnetic field has disturbed the honeybee.	Migdał et al., 2022
Helmholtz coils	Edible Crabs	-	250- 1000 µT	24hours	Exposure to 500 µT and 1000 µT were found to disrupt the L-Lactate and D-Glucose circadian rhythm and alter THC	EMF strengths of 250 µT were found to have limited physiological and behavioral impacts	Scott et al., 2021
Mobile phone	Albino mice	-	-	12h dark/light	Ovary and Uterus damage were observed in albino mice	Infertility induction	Aburawi et al., 2021
laptop computers	Human	-	1.15 µT	7hrs/day/ week	Dose dependent decrease in sperm count and motility	Infertility induction	Mortazavi et al. 2010
Power lines	Human	11kV	-	2-3 weeks	**Dermatological effects**: redness, tingling, and burning sensations, **Vegetative effect:** fatigue, tiredness, concentration difficulties, dizziness, nausea, heart palpitation, and digestive disturbances	-	Quamruzzaman et al., 2014 Samaila et al., 2023b
Mobile phone	Human	2.104GHz	-	18hrs/day for 28 days	Alterations in spermatogenesis with significant decrease in sperm cell, spermatogonia and leydig cells which effect the fertility	Spermatogonia and leydig cells were observed which lead to infertility	Oh et al. 2018

3.1 Effect of Non-ionizing Electromagnetic Radiation from mobile phone base stations on the Tree Plants

The inevitable utilization of cellular mobile communication is continuously polluting the environment by hazardous electromagnetic (EM) waves in apical intent. EM waves have been proven as a potent mutagen for animal tissues. Current literature lacks in demonstration of ferocious biochemical effects of electromagnetic waves on plants and therefore it encourages analysis of the biological consequences of electromagnetic radiation exposure on plants. In India and other Asian

countries, Ayurveda is a practiced on a large scale as an ancient system of medicine and health care (Upadhyaya et al., 2022). In the last two decades, the deployment of phone masts around the world has taken place and, for many years, there has been a discussion in the scientific community about the possible environmental impact from mobile phone base stations. Trees have several advantages over animals as experimental subjects and the aim of this study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure. To achieve this, a detailed long-term field monitoring study was performed in the cities of Bamberg and Hallstadt (Germany). During monitoring, observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. In 2015 measurements of RF-EMF (Radiofrequency Electromagnetic Fields) were carried out. A polygon spanning both cities was chosen as the study site, where 144 measurements of the radiofrequency of electromagnetic fields were taken at a height of 1.5 m in streets and parks at different locations. By interpolation of the 144 measurement points, the researchers were able to compile an electromagnetic map of the power flux density in Bamberg and Hallstand. The selected 60 damaged trees, in addition to 30 randomly selected trees and 30 trees in low radiation areas (n = 120) in this polygon. The measurements of all trees revealed significant differences between the damaged side facing a phone mast and the opposite side, as well as differences between the exposed side of damaged trees and all other groups of trees in both sides. Thus, the side differences in measured values of power flux density corresponded to side differences in damage. The 30 selected trees in low radiation areas (no visual contact to any phone mast and power flux density under 50μW/m^2) showed no damage. Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts is harmful for trees. These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time.

3.2 Radio waves impacts on antimicrobial potential of medicinal plants

The high frequency electromagnetic (EM) waves have been proven as potent environmental polluters. The radio towers are considerably increasing to cater to the growing telecommunication requirements. The presented research focuses on the investigation of EM waves on antimicrobial potential of pharmaceutically important medicinal plants viz. Tulsi (*Ocimum sanctum* L.) and Brahmi (*Bacopa monnieri*). The similar work has not been reported till date at the best of our knowledge. The medicinal plants were exposed to EM waves of 900 MHz possessing a 1.9 mG magnetic field. Our former investigation on plant physiology gave deteriorative effects on selected plants physiology in terms of growth, chlorophyll content, protein and carbohydrate content. In the presented article, the antimicrobial activity of two plants was inspected through various bacterial and fungal species. In case of *B. monnieri*, investigations revealed raise in Zone of Inhibition (ZOI) for both the bacterial and fungal strains in the range of 50%, whereas for *O. sanctum* increase of 63.26% and 59.42% ZOI for bacterial and fungal strains were noted respectively upon 24 h of exposure. Minimum Inhibitory Concentration (MIC) also decreased for 24 and 48 h of exposure. The transient raise in antimicrobial activity indicated the induction of plant defense system which can be considered as positive influence of short term radiation on medicinal properties of plants. Both plants exhibited the highest antimicrobial potential for *E. coli* and *P. chrysogenum* showing a prominent decline after 72 h of exposure. A substantial decline in antimicrobial in MIC of *B. monnieri* reported was 211% against *E. coli* and 166% against *P. chrysogenum* upon 144 h of exposure compared to control plants. The antimicrobial potential of *O. sanctum* was also decreased upon radiation, which is having a 392% reduction against *E. coli* and

a 225% reduction against *P. chrysogenum* upon 144 h of exposure. The noteworthy deteriorative effects of radio waves on antimicrobial potential have been observed for both the medicinal plants (Upadhyaya et al., 2022)

3.3 Mechanism of action of NIR on Plant

The plant leaves, branches, stems, and roots behave as imperfect dielectric materials. The wave, comprising of changing electric field and magnetic field, in these plant components, follows the dielectrics wave propagation. The ion oscillations or dipole relaxation within the plant dielectric material may give rise to modifications in biochemical structural behavior. The complex permittivity and permeability in dielectric material shall induce wave losses; this, in turn, may be converted into a significant increase in the temperature of the material under test. In other words, the dielectric loss tangent of plant components may be considered a significant phenomenon for possible biological changes in plant tissues. Apparently, following the Poynting Wave Power theorem, the higher intensity of Electric and magnetic fields shall induce high instantaneous power density in the plant tissues (Upadhyaya et al., 2022).

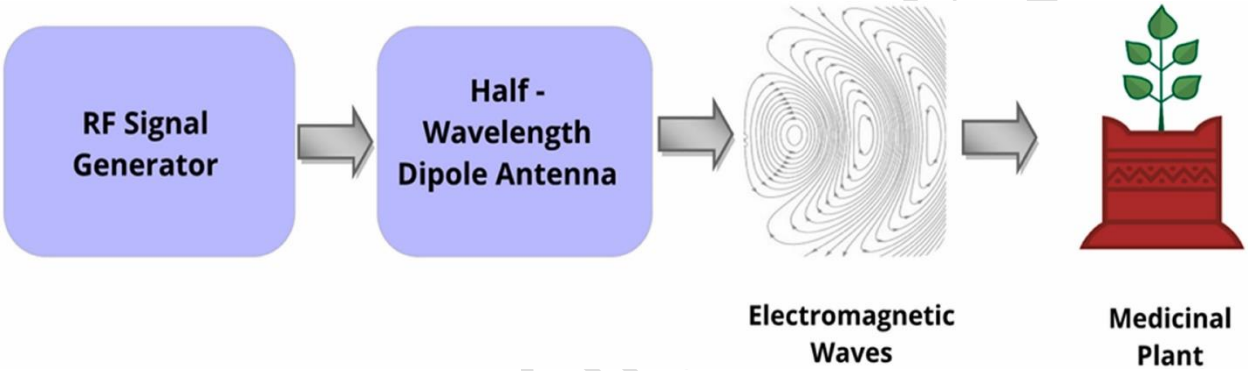

Figure 1: Mechanism of action of microwave on medicinal Plant (Upadhyaya et al., 2022)

The microwaves are absorbed by the cells and tissues of plants. Primarily, electromagnetic waves or energy absorption by tissue is specified through means of Specific Absorption Rate (SAR). The Specific Absorption Rate is the increment in stored energy (dE) in dielectric material with respect to the rate of change of time, being absorbed in accordance with increment in differential mass (dM) contained in the differential volume (dV).

$$SAR = \left(\frac{d}{dt}\right)\left(\frac{dE}{dM}\right) \quad [1]$$

The dielectric material density can be given as:

$$\rho = \frac{dM}{dV} \quad [2]$$

$$SAR = \left(\frac{d}{dt}\right)\left[\frac{dE}{\rho(dV)}\right] \quad [3]$$

The equation of Specific Absorption Rate of varying electromagnetic fields as per the Poynting vector theorem

$$SAR = \left(\frac{\sigma}{2\rho}\right)|E|^2 = \left(\frac{\omega\varepsilon_0\varepsilon''}{2\rho}\right)|E|^2 \quad [4]$$

Where **E =** Peak value of internal electric field, σ = Tissue conductivity, ρ = Material resistivity, ε_0 = Free space permittivity and ε'' = imaginary component of permittivity which is related to the dielectric

losses of the material. The gloomy properties of electromagnetic waves of shorter wavelength upon vegetation have identified by various researchers and are denoted in table 2.

Table 2: Plant species, frequency and the effects

S/N	Plant Species	**Frequency**	Effects
1	Withania somnifera	900 MHz/GSM	Reduction in antioxidant activity
2	Solanum lycopersicon	900MHz/GSM	1/3 decline in ATP concentration
3	Lens culinaris	1800 MHz	Root growth decline
4	Vigna radiate	900MHz/GSM	Rhizogenesis deterioration
5	Zea mays	1800MHz/CDMA	Root Growth reduction
6	Glycine max	900MHz/GSM	Inhibition of epicotyl growth
7	Rosa hybrid	900MHz/GSM	Delayed growth of secondary branch axes

Source: (Upadhyaya et al., 2022)

3.4 Impact of Non-ionizing radiation on Living Organisms

The economically significant decapod edible crab (Cancer pagurus, Linnaeus, 1748) was subjected to varying strength Electromagnetic Field (EMF) exposure (250 T, 500 T, and 1000 T) in Scott et al.'s (2021) study. In addition to behavioral and reaction data (desire for shelter and time spent resting/roaming), stress-related measures (L-Lactate, D-Glucose, and Total Haemocyte Count (THC)) were examined throughout 24-hour intervals. 250 T EMF strengths were shown to have minimal effects on physiology and behavior. It was discovered that exposure to 500 and 1000 T altered THC and interfered with the circadian rhythms of L-Lactate and D-Glucose. Crabs clearly preferred the 500-T and 1000-T EMF-exposed shelters, significantly reducing their time spent roving. Consequently, EMF emitted from MREDs will likely affect crabs in a strength-dependent manner thus highlighting the need for reliable in-situ measurements. This information is essential for policy making, environmental assessments, and in understanding the impacts of increased anthropogenic EMF on marine organisms. Migdał et al. (2022) studied the behavior of one day old bee by exposing it to 50 Hz magnetic field of induction at 1 mT and 1.7 mT for 10 min, 1 h, and 3 h under laboratory conditions. Different behavioral patterns were evident in all groups exposed to the magnetic field. They also displayed a behavior that was absent from the control: loss of balance. There were variations in both the ratio of behaviors and the number of bouts; exposed bees changed behavior more frequently. Differences show how the honeybee organism is responding to the magnetic field, according to their occurrence. A troubling indicator of the honeybee being disturbed by the electromagnetic field is loss of balance, and behavioral alterations support this theory. In a related study, Lopatina et al. (2019) investigated the impact of non-ionizing electromagnetic radiation (EMR) from a Wi-Fi router on sensory olfactory excitability, food motivation, the ability to form a conditioned reflex (PER), and its retention in short-term and long-term memory in the honeybee. The bees were placed in a Faraday cage for varying times (up to 24 h), with the Wi-Fi

3.5 Genetic effects and EMF effects on insects

The research on the genetic effects of non-ionizing electromagnetic field (EMF), mainly on radiofrequency radiation (RFR) and static and extremely low frequency EMF (ELF-EMF). The majority of the studies are on genotoxicity (e.g., DNA damage, chromatin conformation changes, etc.) and gene expression. Genetic effects of EMF depend on various factors, including field

parameters and characteristics (frequency, intensity, wave-shape), cell type, and exposure duration. The types of gene expression affected (e.g., genes involved in cell cycle arrest, apoptosis and stress responses, heat-shock proteins) are consistent with the findings that EMF causes genetic damages. Many studies reported effects in cells and animals after exposure to EMF at intensities similar to those in the public and occupational environments. The mechanisms by which effects are induced by EMF are basically unknown. Involvement of free radicals is a likely possibility. EMF also interacts synergistically with different entities on genetic functions. Interactions, particularly with chemotherapeutic compounds, raise the possibility of using EMF as an adjuvant for cancer treatment to increase the efficacy and decrease side effects of traditional chemotherapeutic drugs. Other data, such as adaptive effects and mitotic spindle aberrations after EMF exposure, further support the notion that EMF causes genetic effects in living organisms (Lai, 2021).

Contrary to popular belief, non-ionizing radiation can directly harm DNA. Genotoxic effects have been found in land-based, aerial, aquatic, and plant species at very low intensity RFR exposures substantially below ICNIRP/IEEE/FCC guidelines. At least 48 articles show that DNA deteriorates when exposed to RFR at 0.4 W/kg. Genotoxic effects are also present in animal and plant species that have been found to be particularly sensitive to both natural and man-made EMF. Since their numbers are dwindling globally, insects are a particular concern (Levitt et al., 2022). At the Larmor frequency, or 1.2 MHz range, insects exhibited the most significant effects. Two further processes linked to the Larmor frequency are radical pair resonance and superoxide production. This implies that RFR effects rely on frequency. 5G and broadband both cover this area. Further research revealed that exposure to extremely low frequency EMF impaired honey bees' (Anthophila's) sense of direction (Levitt et al., 2022). According to the type of bug and length of exposure, researchers first identified progressive responses of insects to RFR (at high intensities) in 1987. These responses included initial attempts to flee, followed by motor disturbances and coordination problems, including stiffening, immobility, rigidity, and eventually death. In contrast to other tropical flies, D. melanogaster could withstand the same field intensity for more than 30 minutes. Alterations in metabolic concentration and the impacts of embryogenesis, which led to accelerated gastrulation and larval growth, were also noted (Levitt et al., 2022). Embryogenesis is the period of time needed for a butterfly to complete metamorphosis. Among the RFR effects seen in bees are significant inhibitory effects on sensory olfactory excitability and short-term memory impairment after a 24-hour exposure to WiFi routers; induced worker piping, the sound that causes colonies to swarm or acts as a warning or distress signal; decreased motor activity and changes in biomolecules in the body; reduction of worker bees and reduced egg laying by queens exposed to cell phone radiation; and induced worker piping (Levitt et al., 2022). Two of the RFR effects observed in bees include significant inhibitory effects on sensory olfactory excitability and short-term memory impairment.

4.0 Conclusion

The research that is now available indicates that non-ionizing radiation, especially RFR and ELF-EMF, can have a substantial impact on the environment. The total effect, however, differs between species and is influenced by a number of variables. More investigation is required to comprehend the mechanisms underlying these impacts, assess the long-term repercussions, and create effective risk mitigation techniques. Given the widespread use of NIR-emitting technology, it is crucial to take into account any potential environmental repercussions and make sure that environmental stewardship goes hand in hand with technical progress. Further research is needed to better

understand the impacts of non-ionizing electromagnetic radiation on the environment and to assess the risks and benefits associated with different levels of exposure.

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