Pakistan Geographical Review, Vol.80, No. 2, December. 2025, PP 30-49

INTENSIFYING CHALLENGE OF ELECTROMAGNETIC RADIATION POLLUTION: AN ASSESSMENT OF CAUSES, EFFECTS AND REMEDIAL MEASURES WITH REFERENCE TO PAKISTAN

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ABSTRACT

The most threatening of all kinds of environmental pollution is caused by electromagnetic radiation (EMR). Its dangers are further increased due to the reason that electromagnetic radiation pollution (EMRP) is invisible and widespread. Almost entire global population is persisting under its influence, and many people are unaware of its harmful effects. Incessant and often unobserved exposure to EMR increases worries not only for human health but also for the environment, with growing effects on ecosystems and wildlife. Caused by natural and human sources like electronic implements, broadcasting antennas, and transmission lines, it is threatening to flora, fauna and human health. Its threats to human health consist of potential DNA impairment, augmented cancer danger, and several non-thermal effects such as headache, sleep disorder and decreased concentration. Largely based on secondary data and using descriptive approaches, the study in hand presents an assessment of the major causes and effects of EMRP. Based on the findings, study also attempts to suggest some protective measures against EMPR. The lessons drawn can be useful for further studies on the issue as well as for the planners to create awareness among people.

KEYWORDS: Electromagnetic radiation, Environment, Harmful effects, Human health, Pollution

1. INTRODUCTION

Electromagnetic radiation pollution (EMRP) is one of the most pressing environmental issues of modern age. It is a fast-growing global level environmental concern that exists almost everywhere and has the potential to develop even more critical as the technology advances (Arman, 2022; Metthew et al., 2024). When electromagnetic radiation (EMR) exists in a situation at reckoned harmful levels, it is termed as EMRP. Caused by natural and human sources, dangers of EMRP are further increased because of its omnipresent and invisible nature. The sun, stars, lightning, geomagnetic field, and radioactive materials are the main natural sources of EMR. The sun releases broad-spectrum radiation from visible light to ultraviolet and infrared. Radioactive elements emit Gama-

rays. Besides, lava, auroras and some organisms also emit light and other types of radiation. Thermal (infrared) radiation is produced by all objects with a temperature over absolute zero. However, modern technologies have become a major source of EMRP which is instigated by electromagnetic fields (EMFs) resulting in electromagnetic waves (EMWs), or also called as EMR (Mahmud et al., 2022). This pollution, in many cases, is much risky than EMRP caused by natural sources. Thus, EMRP is mainly caused by human sources which are too many and increasing exponentially over time. About all electromagnetic implements from common electric plug and sockets to parabolic and telecommunication towers have energy losses into the environment which is called as EMRP.

Although, naturally emitted EMR from the earth and other natural sources is useful for various terrestrial systems in several ways, but with the addition of emission from human sources, the total amount of EMR emitted into the environment exceeds several times the safe limits for humans and ecosystem. Electricity transmission lines and electrical appliances are believed to be main sources of EMFs and low frequency and high intensity radiation. However, they are thought to be not much harmful with low adverse effects on humans and other living organisms. But the EMFs related with the widespread and continuous usage of mobile gadgets can increase health risks. Because of the exponentially growing use of electronic appliances, especially of modern cordless communication devices and the infrastructures that support them, EMRP has become a big challenge that the people across the world are facing today. In fact, present era can be better termed as the era of electronics and technology. Advancement in any field of current life is impossible without the use of electronic equipment and modern devices. Such innovations are not only causing scientific advancements and facilitating people's existence but, in a way, have revolutionized every field of human life. No doubt, recent scientific advances have provided us a range of classy electronic devices to make life comfortable and faster. In contemporary world, people depend much on technology, and their lives are intently connected to electronic gadgets. It is, therefore, intrinsically hard now to imagine human life without electronic devices like mobiles, electric lights, computers, laptops, routers, refrigerators, ACs, etc. All these have become companion appliances of our routine daily life. Nevertheless, all these technological advancements and electronic amenities that facilitate the people and make the world work together are not merely blessings for us but also have several underlying adverse impacts on the environment and human health. People customarily look on the benefits of these appliances and very few are cognizant of their hitches. All electronic devices emit radiation, a kind of energy that propagates in the form of waves or particles. For example, cell phones use EMR to pass on data. When this

energy amasses in the environment or stays in human body for a long duration, becomes hazardous.

Due to its pervasive nature, people everywhere are vulnerable to varying levels of EMR, which will continue to grow as technology progresses. Manmade sources including radioactive materials used in nuclear power generation plants, weapons, telecommunication towers (antennas), high-voltage power transmission lines, cell phones, computers, Wi-Fi routers, microwaves, and all other electronic devices release a flood of invisible energy waves into the environment. Be at home, in the bazar, on the road, or at work, EMR is produced all over the places where electricity is used. Although clear-cut data on the health threats of EMRP are not yet available, there are potential effects on people who are exposed to high levels of EMR on daily basis. The hazards are further increased by the continuous exposure of the people who are ignorant of the potential health effects of EMR. More alarming is that traditionally there has been a dearth of devoted studies and proven national criteria for EMRP limits in Pakistan. However, alike to several other countries, recently some worries have been expressed about the effects of EMR on ecosystem and human health leading to debates on the issue in Pakistan as well. As a result, government has realized the need for further research and regulations. Pakistan Telecommunication Authority (PTA) has noticed about the deficiency of required precise standards and prior research on the matter in the country. Concerns have also been raised for improved monitoring and use of modern safety measures by telecommunication operators. Considering these facts, the article in hand attempts to present an assessment of the EMRP, its sources and effects, and mentions protective measures to lessen its hazardous impacts with reference to Pakistan.

1.1. Study Area

This study deals with the global situation of EMRP in general and with the situation that prevails in Pakistan in particular. Pakistan is the 5th biggest populous country of the world and second biggest in South Asia, containing a population of 241.5 million according to 7th population and housing census conducted in 2023 (Gop, 2023). Currently, its population has reached to 255.2 million showing a growth rate of 1.66% or 4.0 million per year and raising the crude density to 331.08 persons per km^2 (Pakistan Population, 2025). Use of electronic appliances in the country is very common and growing exponentially. Most of its inhabitants, especially those living in cities or working nearby to the EMR sources, are highly vulnerable to radiation effects. Containing a geographic area of 796,095 km^2, Pakistan is located between longitudes 61^{o}E & 76^{o}E, and between latitudes 23.5^{o}N & 37^{o}N. It shares boarders with world's two biggest populace courtiers China on the north and India on the east. Afghanistan is

located on the west and Iran on the Southwest while the Arabian Sea is situated on its south. It has variety of physical features ranging from highest mountains on the north and Indus lowlands and deserts in the middle and southeast and coastal belt on the south. Climate also varies significantly with variations in topography ranging from semi-arid and arid in major parts of the country and humid in small portions on the north and in narrow coastal belt on the south. Temperature varies evidently, showing a falling trend from south to north and average annual precipitation decreases from north to south.

From economic point of view the country is a central hub for investment and trade for many nations as it enjoys a bridge between Central Asia, the Middle East and South Asia. It has a remarkable connectivity potential through its ports and projects like CPEC. Country's policy has been restructured focusing on prioritizing economic growth and integration based on its strategic location, reducing a lone dependence on geopolitical collaboration that traditionally contributed external exchange. Currently, Pakistan is a semi-industrialized and a developing country having a mixed and developing economy, with service sector contributing over 50% of its GDP (GoP, 2025). Role of its cities in spreading EMRP is increasing with the mounting use of electronic goods.

2. MATERIAL AND MEATHODS

Although, there are numerous beneficial uses of EMR, this study deals merely with its adverse effects. In addition to personal societal observations, the data was acquired primarily from secondary sources which consist of a few local and international reports, UN surveys, internet websites, earlier research-works and texts of numerous kinds. Various reports of the Institute of Electrical and Electronics Engineers (IEEE) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) were also followed to obtain concerned information. The taped information was integrated and analyzed applying descriptive approach. The obtained information was incorporated to underscore EMRP causes, effects and protective measures against the issue.

3. MAJOR FINDINGS AND DISCUSSION

3.1. EMR and its Types

EMR is produced when electromagnetic waves (EMWs) travel. The EMWs are generated when electrically charged particles vibrate. The vibrating charged particles in turn, generate electric fields around them which also vibrate. The vibrating electric fields, in succession, produce perpendicularly vibrating magnetic fields. The vibrating electric and magnetic fields acting at right angles combine to produce EMWs which travel vertical to both

fields (Fig. 2). These are thus transverse waves, not deflected by electric or magnetic fields (Bhattacharjee, 2023). But they have ability of interfering or diffraction. These waves are divided into a range of wavelengths and frequencies, termed as electromagnetic spectrum (Table 1 & Fig. 1).

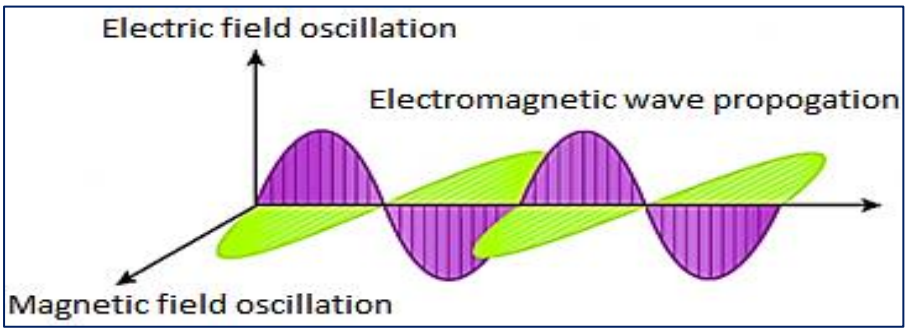

Figure. 1: Creation of EMWs by electric and magnetic field's oscillations

EMWs are clusters of free electrons having very low (3 Hz) to very high (10^{24} HZ) frequency ranges travelling with the velocity of light (Table 1). It means, EMWs are produced from the beam of electrons propagating through electric and magnetic fields functioning vertical to each other. Having enormous mass, these waves can pass through any kind of substances or mediums including solid, liquid, gas and space (Bhattacharjee, 2023). Amassing EMWs from various sources are causing environmental pollution and threatening to human health and other living organisms with slow killing effect. Some amount of EMWs is absorbed by the mediums or bodies through which they propagate, eventually damaging them. Therefore, it is earnestly required to update existing strategies and formulate effective new guidelines and rules for the protection of nature and its dwellers from harmful effects of EMRP.

Table 1: EMR spectrum

Name of radiation (spectrum)	Wavelength	Frequency
Radio waves	100 mm – 1 m	3 Hz – 300 MHz
Microwaves	1 m – 1 mm	300 MHz – 300 GHz
Infrared radiation	1 mm – 750 nm	300 GHz – 400 THz
Visible light	750 nm – 400 nm	400 THz – 800 THz
Ultraviolet radiation	400 nm – 1 nm	10^{15} Hz – 10^{17} Hz
X-rays	1 nm – 1 pm	10^{17} Hz – 10^{20} Hz
Gamma rays	I pm – 0.0001 pm	10^{20} Hz – 10^{24} Hz

Source: Bhattacharjee, 2023, P. 7.

Furthermore, EMWs or EMR can be gauged based on intensity, and electrical, magnetic and electromagnetic frequency. Major forms of EMR arranged by reducing wavelength and increasing frequency from left to

right are shown in Fig. 2. All these types of EMR vary in wavelength and frequency which define their distinctive characteristics and usages. The customary titles and effects of EMR are mentioned in Table 2.

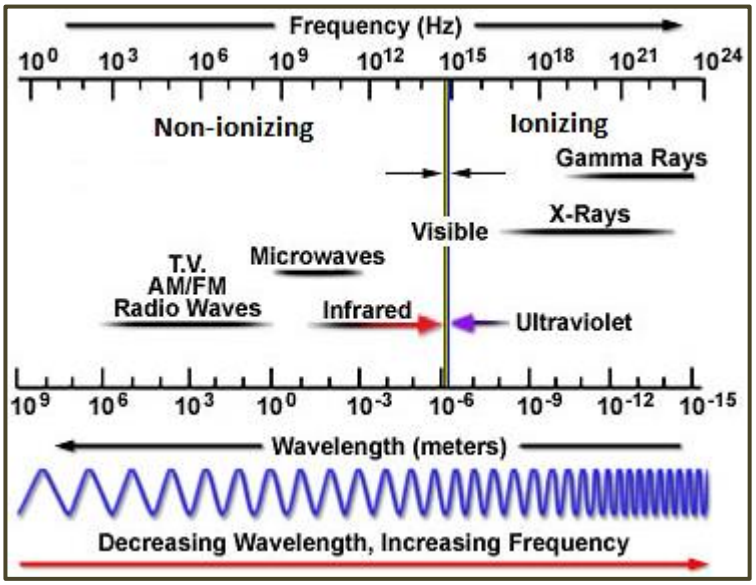

Figure 2: EMR spectrum and major types

Table 2: EMR types based on class, waves, frequency, wavelength, ionizing and non-ionizing properties, and its long-term exposure effects

Name (Class)	Division	Frequency	Wavelength	Energy	Long-term exposure effects
Extremely low frequency (ELF)	Radio Waves (RW)	3 Hz	100 Mm	Non-ionizing (NI)	Less harmful (LH)
Super low frequency (SLF)	RW	30 Hz	10 Mm	NI	LH
Ultra-low frequency (ULF)	RW	300 Hz	1 Mm	NI	LH
Voice frequency (VF)	RW	300 Hz	1 Mm	NI	LH
Very low frequency (VLF)	RW	3 KHz	100 km	NI	LH
Low frequency (LF), radio	RW	30 KHz	10 km	NI	Harmful
Medium frequency (MF)	RW	300 KHz	1 km	NI	Harmful
High frequency (HF)	RW	3 MHz	100 m	NI	Harmful
Very high frequency (VHF)	RW	30 MHz	10 m	NI	Harmful
Ultra-high frequency (UHF)	Microwaves (MW)	300 MHz	1m	NI	Dangerous

Super high frequency (SHF)	MW	3 GHz	1 dm	NI	Dangerous
Extremely high frequency (EHF)	MW	30 GHz	1cm	NI	Dangerous
Far-infrared (FIR)	Infrared (IR)	300 GHz	1 mm	NI	Dangerous
Mid-infrared (MIR)	IR	3 THz	100 ums	NI	Dangerous
Near-infrared (NIR)	IR	30 THz	10 ums	NI	Dangerous
Visible light (NUV) (VL)	Ultraviolet (UV)	300 THz	1 um	NI	Dangerous
Near-ultraviolet (NUV)	UV	3 PHz	100 nm	NI	Hazardous
Extreme ultraviolet (EUV)	UV	30 PHz	1 nm	Ionizing	Lethal
Soft X-Rays (SX)	X-Rays	3 EHz	100 pm	Ionizing	Lethal
Hard X-Rays (HX)	X-Rays	30 EHz	10 pm	Ionizing	Lethal
Gamma Rays (Γ) (GR)	Gamma Rays	300 EHz	1 pm	Ionizing	Lethal

Source: Nigerian Communications Commission (NCC): Deployment of 5th Generation (5G) Mobile Technology in Nigeria, August 2020.

In EMR spectrum, frequency increases with decreasing wavelength, increasing the energy carried by wave termed as photon energy. When EMR moves, proton and electron in its hauler signal interact as fields in any kind of setting because of its ionizing (gamma rays and x-rays) and non-ionizing (ultraviolet, infrared, microwave, radio frequency and shallow frequency) characteristics (Matthew, 2022). It is essential to differentiate between the effects of ionizing radiation (IR) and non-ionizing radiation (NIR). High doses of former (ultraviolet, x-rays and gamma rays) can be lethal for cells and DNA, and later (radio-waves from mobile phones and microwaves) is relatively much less risky. Today, a kind of electromagnetic wave technology, known as radio frequency (RF), is widely used for communication that has made linkages between areas much easier and facilitated human life. However, accelerated increase in its demand has led to a higher level of involvement with communication implements, something that is certainly dangerous for humans and other living organisms (Mubashir and Majid, 2022). Extended association with RF implements certainly has an impact on human health and environment.

3.2. Causes of EMRP

In the world over and in Pakistan also, wherever electricity is consumed, electric fields are generated that finally cause EMRP. Fig. 4 shows some significant natural and human resources of EMR. The major sources of low frequency EMFs are electrical installations, high voltage transmission lines, and electrical appliances used at homes, offices and other places. High frequency EMFs are produced by radio and TV transmission transmitters,

communication system antennas, radars, air and maritime navigation systems etc. (Arman, 2022). Almost all electronic devices and installations release energy into the environment, which when crossing the safety limits cause EMRP. About all industries cause EMRP, but the top most examples are electrical appliances installation and up-keeping firms, electricity production and supply companies, electrochemical industries, transmission systems, radars, air and naval transportation systems, communication (3G, 4G, 5G) towers, research institutions and universities, welding (electric, arc, spot, and induction welding) companies, health applications (diathermy, electro-surgery, MRI), and non-destructive testing firms.

In Pakistan, EMRP has recently become a serious issue due to the fast spread of telecommunication towers, extensive use of personal electronic gadgets, and widespread use of domestic and industrial electronic appliances. High density of antennas and towers, especially in cities, providing broadcasting and telecommunication services, has become a main concern. Besides, increased use of personal devices and industrial and household implements is also the main cause of public exposure to EMR.

Virtually all of us are cell phone users. By the early 2024, there were about 191.8 million operative mobile links in Pakistan (PACRA, 2024). By the end of FY 2024, the number of mobile phone subscribers increased to 192.53 million. According to the updates of PTA, in February 2025, the number of cellular phone users augmented to over 196 million (PTA, 2025), and Pakistan ranked world's 7th country by number of cell phones in use (Table 3). The minister of state for Information Technology and Telecommunication, on May 18, 2025, pointed out that Pakistan has surpassed 200 million mobile phone users (PPF, 2025). Another alarming concern is that Pakistan ranked 10th in the world by number of hours consumed on cellular (Android & iPhones) phones. In 2023, Pakistanis spent an aggregate of 99 million hours on their cell phones (Siddiqui, 2024). In such type of scenario, one can easily understand the level of people's exposure to EMR.

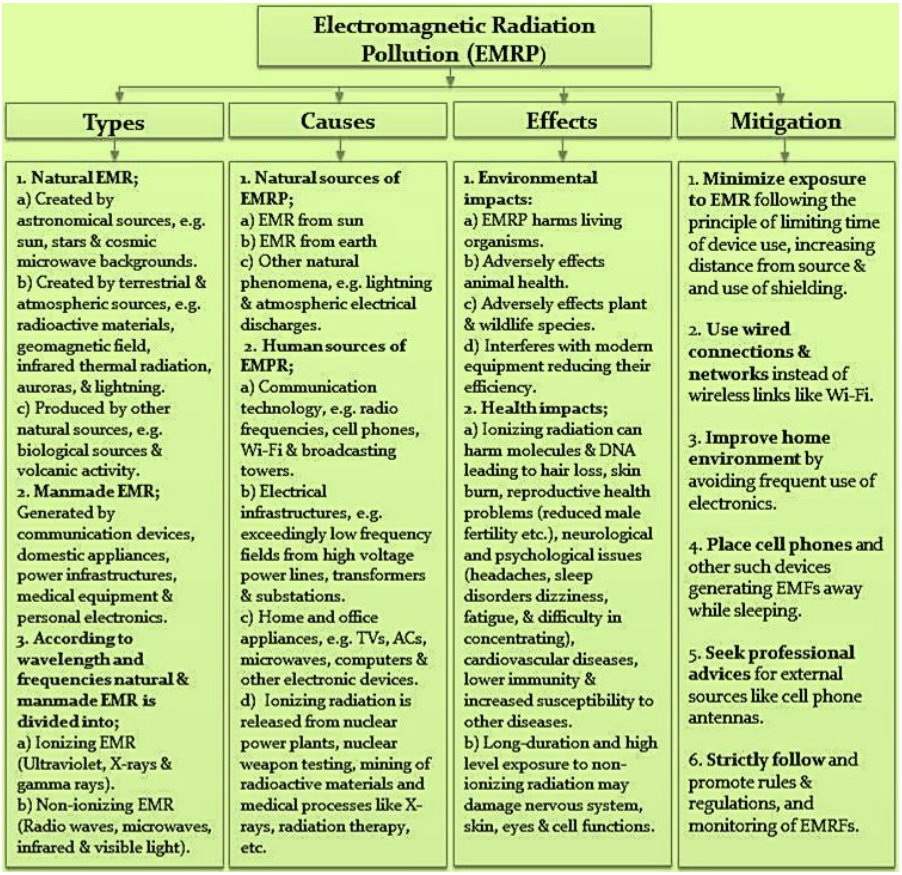

Figure 3: Major types, causes, effects and mitigation against EMRP

Table 3: World's top ten countries by No. of cell phones in use

Rank	Countries/World	No. of cell phones	Inhabitants	Phones/100 people
1	China	1,610,360,000	1,420,050,000	113.38
2	India	1,515,971,713	1,375,245,994	110.18
3	Indonesia	385,573,398	237,556,363	162.28
4	United States	380,577,528	327,874,628	116.27
5	Brazil	284,200,000	201,032,714	141.3
6	Russia	256,116,000	142,905,200	155.5
7	Pakistan	196,017,287	241,422,083	80.1
8	Nigeria	190,475,494	190,551,754	99.5
9	Bangladesh	180,780,000	162,951,560	111.11
10	Japan	146,649,600	127,300,000	115.2
	World	7,950,000,000+	7,621,018,958	104.32

Source:
https://en.wikipedia.org/wiki/List_of_countries_by_number_of_mobile_numbers_in_use (Accessed on 31-10-2025)

Furthermore, exponential augmentation in demand for electronic technology has led to higher levels of rendezvous with electronic appliances, especially with communication gadgets, which are undeniably damaging to humans and other living organisms. Presently, we are living in an enormous omnipresent burst of EMR from various sources (Shaikh and Majid, 2022). In Pakistan, use of domestic electronic goods is also on the rise. In 2024, the household appliances were estimated at PKR-328.6 billion (PKCRA, 2025). Among the most common appliances are TVs, ACs, fans, refrigerators, washing machines, deep freezers, microwave ovens and water dispensers (Fig. 5). When such electronic goods reach to their end-of-life, share a major fraction of the e-waste which is divided into ten different categories and becoming another amassing problem (Iqbal et al., 2015). Although, the sources of EMR are known, there is no any specific data or precise public study for ranking and mapping the areas of Pakistan by their exact level of proneness to EMR. Fig. 1 provides a rough idea of the areas more prone to EMR. While dealing individual areas, it is essential to differentiate amongst EMR produced by natural and manmade sources. For instance, some northern areas of Pakistan indicate greater levels of natural gamma radiation from stream sediments. However, to understand the intensity of issue to some extent, density of EMR sources can be used. The areas of Pakistan highly prone to non-ionizing EMR are those with a high concentration of cell phone towers, major urban centers and their peripheries, and places adjacent to high voltage electricity transmission lines. PTA recognizes the problem of EMR emitted from antennas and is liable for permitting the services. As a solution, PTA has emphasized on infrastructure sharing to limit the number of towers in urban centers.

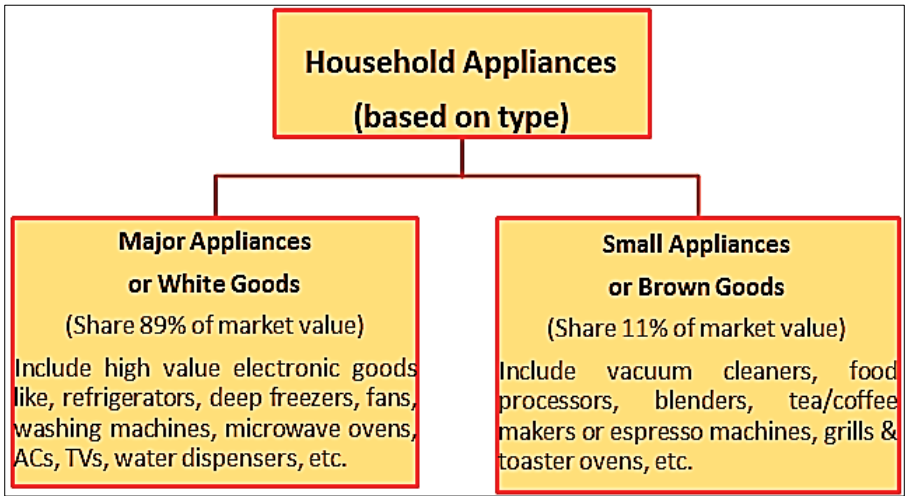

Figure 4: Types of household appliances used in Pakistan

3.3. Concerns and effects of EMRP

Although, its precise impacts remain vague, and its consequences are hard to find out with complete precision (Ishai et al., 2024), EMRP has influences on environment, plants, animals, humans and almost all living organisms (Fig. 4). With the advancement and unprecedented companionship and interference of electronic technology in our daily life, concentration of EMWs in the environment is rising by leaps and bounds (Bhattacharjee, 2023). Besides harming mediums, materials and bodies to which they strike, EMWs also play a significant part in global warming through their thermal effect. As a result of EMFs generated due to modern gadget technologies used across the globe, EMR is all over. Therefore, controlling EMRP effects is a global issue, and the unanimous action of world community is important in this regard.

3.4. Ecological impacts of EMRP

When manmade EMR reaches to the levels that harm the natural ecosystems is termed as ecological EMRP. The ecological impacts of EMR are wide-ranging as it can impair functioning of ecosystems substantially. Several research revealed damaging effects of EMR on flora and fauna, with a drop in the number of insects being specifically shocking because it may cause cascading effects (Levitt et al., 2021c; Balmori, 2021; Mahmud et al., 2022; Nozadze, 2025). Higher levels of EMR can cause altered and stressed growth in plants, decline in radial growth of forests especially of pine trees, damage to floral life and impairment of food chain balance. This may lead to the extinction of some species, and reduction in biodiversity. Some studies indicate reduced growth and stressed responses of plants. Stress related modifications shown by plants in their physiology include alterations in enzyme activity and hormone levels. In some cases EMR can reduce seed-borne pathogens without causing any damage to seeds (Levitt et al., 2021a; Levitt et al., 2021b; Levitt et al., 2021c).

Further EMR associated effects on wildlife include reduction in the density of mammals, bird species and other organisms including storks, bats, sparrows and bees (Shukla, 2025). The main reason behind the decline in bird's density is adverse impacts of EMR on their magnetic based homing mechanisms. Studies conducted on wildlife revealed that EMR has caused intellectual, heart and reproductive problems in animals which are alarming for ecosystem (Levitt et al., 2021b). Those animals which are already vulnerable due to poorer defense mechanisms are specifically sensitive to EMR exposure. This is why EMR impair navigation behavior of birds and bees, and reproduction process of birds, insects and a number of animals. Some studies have reported weakened navigation in birds, bats and bees, decline in reproductive success of birds, insects and some animals, physiological strained reactions, and disorders in insect's behavior such as reduction in lifecycle and colony strength of honeybees (Mahmud

et al., 2022). Navigation and migration abilities of the species which depend on magnetic fields for their orientation, like bats and migratory birds, are adversely affected by higher levels of EMR. Delicate and sensitive organisms in the environment like honeybees and fruit flies are seriously affected (Mahmud et al., 2022). In honeybees, effects ranging from decreased egg laying to colony collapse in certain cases, reduced foraging, dropped honey output, and physiological alterations like reduced lipid levels have been specifically recorded (Migdal et al., 2022). Besides, signs of physiological stress, like alterations in hormone levels and enzyme activity, have been reported in some species. EMR may also cause behavioral alterations, such as decreased scavenging activity in bats and changed swimming speed in fish. Such kind of changes can upset natural ecosystems by influencing pollination, seed dispersion and predator-prey affairs. Disturbance in food supply may result due to EMR effects on insect populations. Organisms like bats, some birds, and others that depend upon insects and pests for food may reduce with the reduction in these creatures. Reduction in pollinators can impair the reproduction of flowering florae, eventually distressing the whole ecosystem.

In sum, a momentous research review of more than 1,200 studies by US scholars, concerning the impact of NIR on flora and fauna, has shown the harmful impacts at even very small intensities including the effects on orientation and migration, nests and den construction, mating, reproduction, and survival (Levitt et al., 2021a; Levitt et al., 2021b; Levitt et al., 2021c). On the other hand, opinions also exist that some impacts on ecosystem may reverse when the exposure to EMR stops (Matthew, 2024). However, the extent of restorability is determined by the type, strength, and time of exposure, as well as the biological system impaired and gravity of the preliminary loss.

3.5. Health impacts of EMRP

Today, we are surviving under the burst of EMR which exist everywhere but with higher intensity in the cities and near the emission sources. Human body is naturally capable of handling EMR to a certain limit, but there is no universal single value for how much it can bear. Safety limits depend largely on the form and intensity of radiation. Health effects of radiation vary greatly for different parts of electromagnetic spectrum. However, radiation exposure over 500 millirems per day is normally considered damaging for human body. EMR can threaten human health if its normal levels are surpassed. In modern age, when use of electronic appliances has become inevitable, the emission of EMR in the surrounding environment is crossing the safe limits. Living in association with a flood of electronic appliances that function due to the power of electromagnetic waves, sometimes health can be compromised. These artificial sources of

EMR are much influential than natural sources and exposure to them for longer periods can cause serious health concerns. Several studies corroborate that EMR is potentially hazardous for humans because it might interfere with usual electrical functions of the body (Bakare et al., 2024). It is therefore, essential to evaluate properties of EMFs from time to time, in order to know the trends of EMR and to update knowledge of required safety measures. Rising dependence on technology means rising intensity of EMR in the environment and increasing threats to human health including carcinogenesis like leukemia and pathologies of nervous system (Eskandani and Zibaii, 2023). Some studies assert that EMR emitted by cell phones and other electronic goods can pose both thermal and non-thermal impacts and deteriorate human health (Nozadze, 2025). Current studies indicate that EMR can increase the threats of hormonal alterations, blood clotting complications, oncological issues, and various other pathologies. Therefore, the concerns arise that how people can safeguard themselves from damaging effects of EMR released from these appliances and other sources. Some of the health impacts of different radiation waves are briefly shown in Table 4. The most vulnerable population comprises children, persons with feeble health, and pregnant females. Haplessly, there are many indirect means through which EMRP distresses quality of human life. Although, there is a continuous debate and ongoing research on the issue, indications of DNA damage and cancer risk are there. Luckily, human body cells are very efficient in mending the loss. But, if the loss is not restored perfectly, the cell may decease and ultimately turn into cancerous (EPA, 2025). IR has enough energy to disrupt atoms of living cells and thus impair their hereditary substance (DNA). It can cause mutations in human body by ionizing atoms, leading to serious health concerns. Exposure to extreme levels of EMR can cause complications like skin burns, severe radiation syndrome, and long-term health issues like cardiovascular diseases and cancer. Some studies argue that vulnerability to high levels of high frequency (ionizing) EMR can burn skin, harm human cells and damage DNA. While vulnerability to low levels of EMR confronted in the environment does not cause instant health impacts but is a small contributor to overall threat of cancer and other health concerns.

Table 4: Health effects of exposure to various spectrums of EMR

Sr. No.	Name of radiation spectrum/waves	Health effects of exposure to EMR
1.	Radio waves (RW)	Thermal effects (heating, skin burns and damage to body tissues), tumor development, neurological and reproductive concerns.
2.	Microwaves (MW)	Thermal effects (skin burns and cataracts), protein damage in neurons, reduce short-term memory performance, effect immune cells.

3.	Infrared radiation (IR)	Acute effects like thermal burns, chronic effects like premature skin aging, wrinkles formation, damage to eyes & skin, increase in skin cancer risk.
4.	Visible light (VL)	VL has both beneficial and harmful effects like skin damage, sleep disruption, eye problems, photo-aging, skin hyperpigmentation, DNA damage.
5.	Ultraviolet radiation (UVR)	Short-term effects like sunburn & allergic reactions, and long-term effects like early skin aging, skin cancer, and eye damages such as cataracts, immune system suppression, etc.
6.	X-rays	Short-term effects like skin damage, hair loss, allergic reactions, nausea, vomiting & damage to fetus development in pregnancy, and long-term effects like cancer, cataracts etc.
7.	Gamma rays	Immediate and short-term effects of high doses like radiation sickness (nausea, vomiting, diarrhea, fainting, dizziness, confusion, hair loss, skin & mouth sores, internal damage including bone marrow), and tissue damage (harm to cells & DNA leading to burns, blood cells count decrease, internal organ impairment). Long-term effects include increased cancer threat, cardiovascular problems, cataracts, nervous system damage etc.

Although low frequency (non-ionizing) EMR is less threatening to human health, but long-time vulnerability to it could be damaging to nervous system and brain intellectual functioning (Eskandani and Zibaii, 2023). In Pakistan, excessive use of mobile phones, Bluetooth devices, earbuds, and hands-free specifically among the youth is causing hearing losses. All such gadgets emit EMR that damages hearing. The ear (particularly the inner ear) is the direct receiver of the EMR that makes it the most susceptible organ. The subtle hair cells in the inner ear are damaged easily and cannot regenerate. Such losses are often permanent with little or no chance of recovery in later stages (DAWN, 2025). Further concerns are linked to physiological systems leading to sleep and mood disorders, fatigue, anxiety, nausea, dizziness, headaches, depression, memory losses, and reduced fertility. EMR has several other harmful effects also on humans and other living organisms when they are constantly exposed. Sensitive and exposed parts of human body are badly affected. Particularly, skin is highly susceptible to EMR. It is also much risky for children and may hinder their body development.

3.5. Safety measures against EMRP

Apprehensions over EMRP are rising on top of the other types of contamination already existing in the environment. EMFs are produced

all over when the carrier signals are transmitted and it is impractical to stop them because of their essentiality for electromagnetic spectrum setups. Even though, EMFs are invisible and virtually everywhere and EMRP is an issue of ubiquitous nature which cannot be avoided, some steps of protective measures can be taken to reduce their adverse effects both in terms of day-to-day life and business milieu (Metthew et al., 2024). Various local and global organizations like IEEE and ICNIRP have framed some guiding principles setting exposure limits for occupational and residential EMFs (IEEE, 2002; IEEE, 2006; IEEE, 2019; ICNIRP, 2020). These limits are usually based on specific absorption rate (SAR) for RF fields, with a lower SAR (0.08 W/kg) for common public and a higher SAR (0.4 W/kg) for work-related situations (ICNIRP, 2020). For other frequencies, guiding principle focus on limits for magnetic flux density and power density to control problems like tissue heating and RF burns. The standards set for EMR exposure are based on scientific research (Foster, et al., 2025).

Moreover, environmental laws (e.g. Pakistan Environmental Protection Act 1997) are in place to control pollution of any sort, and the process of environmental impact assessment (EIA) is performed in accordance with them. Any activity with likely precarious effects is subject to an evaluation process known as environmental audit. Under this process, precise data about the activities that have potential to create different environmental concerns is gathered and analyzed. Then, factual solutions are proposed in terms of compliance with the responsibilities enforced by law. Following protective measures against EMR can be useful.

I. In the first place, it is crucial to limit the emission of EMR into the environment from human sources and minimize exposure to radiation. For this objective, it is important to respect and strictly obey the governing rules made by the concerned authorities for safety and to carry out incessant monitoring.

II. The key safety measure is to minimize exposure to EMR by limiting device use time, increasing distance from source, and using updated shielding methods (Fig. 6). Radiation dose from the source can be reduced by limiting exposure time. Its effectiveness declines significantly by enlarging distance from the source just like the reduction in heat from a fire while moving away from its place of origin. Similarly proper shielding of recommended materials between the source and organism considerably reduces the radiation dose.

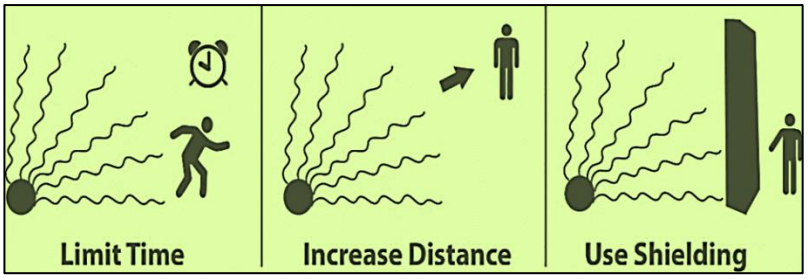

Figure 5: Safety measures against exposure to EMR

III. Radiation effects can be reduced by using wired networks instead of non-wired links like WI-FI, where possible as advised by experts. Where the use of Wi-Fi is unavoidable, disconnecting its router when not in use is a beneficial measure against EMR. Thus, limiting the use of wireless technology is central to minimizing exposure to EMR.

IV. Radiation effects of personal and household gadgets can be minimized following the suggested preventive measures. For example, the safest manner of using cell phone is to use speaker-phone mode or Bluetooth which significantly reduces the EMR emission. Use of cell phones in closed metal spaces like elevators, cars, trains and airplanes is not recommended where it consumes more energy and emits more radiation. Besides, it is safer to avoid keeping cell phones nearby particularly during sleep, and holding them near sensitive parts like heart, brain and genitals etc.

V. It is safer to use light emitting diodes (LEDs) or glowing bulbs instead of compact fluorescent lamps (CFLs) and liquid crystal display (LCD) TVs instead of plasma TVs because they relatively emit much low level of radiation.

VI. Radiation effects can also be lessened by unplugging electrical devices in the houses when they are not in use. Any device plugged into an outlet generates a strong EMF and when unplugged, emits much lower radiation. For example, it is better to use laptops and other such devices on battery mode and then place them away when recharging. Further, it is safer to maintain suitable distance from computer, microwave oven and other such appliances when they are active, and sleep away from electrical outlets.

4. CONCLUSION

EMRP is a serious and mounting environmental concern with potentially dangerous effects on wildlife and human health. It is an omnipresent and unseen enemy intensifying rapidly with the advancement of wireless technology and exponential spread of electronic devices. At present radiation has become a part of our life. No matter where the people are,

they are exposed to varying degrees of EMR, and the levels will keep on rising as technology expands. So, this kind of pollution is in no way an issue that can be ignored. To combat this issue, it is imperative to comprehend the concept of EMRP as much as possible and to take necessary measures. Although, its damaging effects are not yet fully known, this study revealed that long-term exposure to high levels of EMFs can be extremely threatening to humans and other living organisms. Presently, more attention is focusing on to the long-term health impacts of exposure to EMFs. In this regard, strict implementation of governing rules to limit the emission of EMR from all manmade sources, minimizing exposure, and strictly following the safety measures recommended by experts are crucial needs of the time. There are some easy and simple solutions also that can be practiced by any person, such as, use of wired connections instead of wireless networks, and to understand and follow the radiation safety principles of time, distance and shielding.

All in all, the sources of EMR are present in every nook and cranny leading to permanent exposure. The intensifying situation of EMRP requires more than exigent consideration and needs to be addressed more expertly. The key ingredients to environmental and human security are awareness, seriousness and careful attitude about the usage of modern technologies and scientific developments for the benefits of humankind. Increased awareness, monitoring and regulation, individual precautions, and further dedicated research on the issue to devise apt standards and policies, are dire needs of the time. Even though international organizations have formulated certain standards for safety against the dangers of EMR, complete security for living creatures has yet to be attained. In this respect, further research is crucial and concerned departments are required to work efficiently. If we fail to overcome EMRP and its harmful effects timely, there will be probably no pollution free and safer place on the earth to survive.

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