



Invisible Waves, Visible Harms: A Comprehensive Review on the Adverse Biological Consequences of Mobile Communication Radiations

Utpalendu Ghosh*

*Department of Zoology, Trivenidevi Bhalotia College, Raniganj, West Bengal- 713347, India.

***Correspondence to:** Dr. Utpalendu Ghosh
, Department of Zoology, Trivenidevi Bhalotia College, Raniganj, West Bengal- 713347, India.

*Email: utpalendu.ghosh9@gmail.com

ABSTRACT

Purpose: The aim of this study is to summarize the peer-reviewed literature as investigated for the last decades on the effects of these radiations on various aspects of human health.

Conclusion: Mobile phones have revolutionized communication, making it instant and accessible worldwide. Today it is pervasive & has become an integral part of our livelihood. Owing to its increased importance, mobile telecommunication infrastructures are parallelly perpetuating at an alarming exponential rate. It has been evident from several studies that for the basic operation of cellular phone a widespread human exposure to radio-frequency energy (RFE) is required, & it works in association with mobile base stations & towers providing network coverages in most areas. This has raised deep concern about the potential effects of electromagnetic radiation (EMR) emitted from such cellular devices & network towers.

Keywords Radio-frequency energy (RFE), Electromagnetic radiation/waves (EMR/W), Electromagnetic Fields (EMFs), Non-ionising radiation, Cell phones/networks, DNA damage, ROS (reactive oxygen species).

INTRODUCTION

Human beings are constantly surrounded by and exposed to both natural background radiation and man-made radiation. This radiation is a natural part of our environment, and life on Earth has evolved to coexist with these levels.

Natural electromagnetic radiations (EMRs) mainly encompass those coming from the sun. EMRs from the Sun reach the Earth in the form of photons spanning an extremely broad range of energies, from high-energy X-rays to ultra-long radio waves. After accounting for atmospheric effects and cloud cover, the solar power density incident on the Earth's surface under clear-sky conditions can reach approximately 1000 W/m² at midday (Coddington et al. 2016), which is nearly 100 times higher than the ICNIRP exposure limit (10 W/m²) for UMTS (universal mobile telecommunications system) radiation (ICNIRP Guidelines. 2020). Despite this high intensity, solar radiation is generally well tolerated by the human body, although excessive exposure can result in sunburn and an increased risk of melanoma. At the same time, it also confers important health benefits, such as the synthesis of vitamin D. The primary reason for this tolerance is that solar photons possess a wide range of frequencies, polarizations, and phases, and they arrive from multiple directions rather than propagating along a single coherent path.

On the other hand, Man-made EMRs are primarily generated by high-voltage power transmission lines and electrical appliances at low frequencies (LF), and by antennas used for wireless communication at radio frequencies (RF). Unlike most natural EMRs, these artificial fields are typically polarized. Polarization may enhance biological activity through several mechanisms. First, polarized EMFs can produce constructive interference, leading to localized amplification of field intensity. Second, they can drive charged and polar molecules—particularly free ions within and around living cells—to oscillate coherently in parallel planes and in phase with the applied field. These forced ionic oscillations generate additive electrostatic forces on the sensors of electro-sensitive ion channels in the cell membrane, potentially causing irregular channel gating and disruption of cellular electrochemical homeostasis. Consequently, field polarization may act as a critical factor that significantly increases the likelihood of biological and potential health effects (Panagopoulos et al. 2015). The present literature mainly focuses on the biological effects of such radio frequency energies generated from wireless communication system, including mobile phones & telephone towers.

Radiofrequency energy (RFE) is a type of non-ionising radiation, which is electromagnetic in nature. Living tissue lying close are susceptible to absorb such waves (Volkow et al. 2011). Such types of exposures are dependent on several factors, namely the type of mobile device used, the technology platform on which the device is working, the distance between the phone/mobile tower and the user, and also the duration of mobile phone use.

Mobile phones are present everywhere, and for many, irreplaceable & unescapable. With the increasing population density, the requirement for cellular connectivity and gigabytes of data for internet access in several devices (ranging from personal computers to smart phones) is sky rising endlessly. Consequently, both the density of installed base stations and their power output is expected to increase globally (Pearce et al. 2020). In due course of time, the exposure limit to these non-ionising radiations is increasing unintendedly leading to human harm.

Several studies conducted in the recent past have evidently suggested the negative impact of EMR exposure from cell phones & their associated networks on human health, which includes: tumour of brain, cancer, reproduction, cognition, behaviour, sleep-wake cycle, immunity and many more. Mobile phone radiation has the capacity to penetrate the human body and disrupt cellular structures, leading to significant biological effects. These effects are particularly pronounced in highly radiosensitive cells, such as those found in the stomach lining, gonads, epithelial tissues, and bone marrow. Radiations can interact directly with DNA or indirectly through the generation of reactive radicals (or ions), which further damage biological molecules. Research has demonstrated that mobile phone radiation can alter the expression of genes involved in stress responses, cell cycle regulation, and other key cellular functions. For example, some studies suggest that radiation exposure affects genes related to apoptosis (programmed cell death) and the production of heat shock proteins (Abtin et al. 2024). Changes in gene expression may lead to altered protein synthesis, thereby impacting processes such as cell signalling, metabolism, and immune function (Mousavy et al. 2009). Moreover, mobile phone radiation has been shown to influence cell viability, proliferation, and apoptosis. It may also disrupt signalling pathways, potentially affecting cell growth, differentiation, and overall human health. Figure 1 illustrates the common biological effects of mobile phone radiation and its association with human diseases.

To address these problems many research projects are ongoing, although they warrant conclusive findings. Debate on human safety in this context still exist. Mobile & telecommunication industries are yet to understand the situation and upheld the absence of concrete scientific evidences that reflects the true scenario.

This article summarizes and critically reviews major studies reporting adverse effects of cell phone and wireless network radiation on human health. Studies are categorized according to reported outcomes, including those describing neglected effect are also discussed. In addition, the prescribed limit for such radiations relevant to human safety are mentioned.

NEGATIVE EFFECTS OF CELLULAR PHONE/NETWORK:

Effect on brain:

In an early study conducted by Salford L. G. et al (1994) on the biological effects of electromagnetic fields (EMF) on the blood-brain barrier (BBB) in sensitive and specific male and female Fischer 344 rat models shows that exposure to various EMF-components of proton magnetic resonance imaging (MRI) induces leakage of Evans Blue labelled proteins, that normally does not pass the BBB of rats (Salford et al. 1994). But whether such opening of the blood-brain barrier can lead to any health hazard demands further investigation.

Hardell L. et. al. (2006) revealed the pooled analysis of two case-control studies on malignant brain tumours diagnosed during 1997-2003 for individuals aged 20-80 years (Hardell and Carlberg 2009; Hardell and Carlberg 2019). It was found that for both — cellular and cordless phones — the risk increases, being high in the group with > 10 years latency period (Figure 2). Another study reported that the risk of a tumour is raised on the same side of the head where phone is used for 10 years or longer (Schoemaker et al. 2005). This also include Maria F. et al. (2024), whose cohort study suggests that long-term mobile phone use may cause brain tumours (Feychting et al. 2024).

Another interview-based, multicentre case-control study conducted by Cardis et al. (2010) examined individuals diagnosed with glioma and meningioma from 13 countries. Although an increased risk of glioma was suggested at the highest exposure levels, potential biases and uncertainties limit causal interpretation. The possible effects of long-term, heavy mobile phone use therefore warrant further investigation (INTERPHONE Study Group, 2010). Similarly, Paul J.V. et al. (2021) predicted an increase in incidence of glioma in Canada in relation to cell phone use (Villeneuve et al. 2021). Volkow N. D. et. al. (2011) has reported that the level of glucose metabolism of the brain region closest to the mobile phone antenna (orbitofrontal cortex and temporal pole) was significantly higher, when 47 healthy participants were subjected to 50 minutes exposure. Although such finding is of unknown clinical significance (Volkow et al. 2011).

Effect on DNA damage & its repair:

A study by Muscat J. E. et. al. (2000) on men and women aged 18 to 80 years with brain cancer, suggest that cell phone has the capability to damage DNA and/or chromosomes (Muscat et al. 2000), when compared with healthy individuals. Such findings were further supported by Hardell L. et. al. (2006) (Hardell and Carlberg 2009) and Lightfoot T. E. (2005) (Lightfoot et al. 2005) (Figure 3).

In another study by Gulati S. et. al. (2020) on human lymphocytes has reported that exposure to frequency channel signals from universal mobile telecommunications system (UMTS) has significant genotoxic effects, such as DNA damage & ROS (reactive oxygen species) generation. Such effects are maximum at 1977.0 MHz frequency range (Gulati et al. 2020). Similar results showing a positive correlation between mobile phone associated EMFs (of ~ 1950 MHz) and DNA damage was evidenced later by Misik M. et. al. (2023). It also revealed the dependency of such damages on: age, body mass & exposure to occupationally relevant chemicals (Mišik et al. 2023).

In a separate experimental study, Durdík et al. (2019) investigated the effects of mobile phone-associated pulsed microwave exposure on umbilical cord blood cells, including CD34⁺ hematopoietic stem/progenitor cells. The study reported a transient increase in reactive oxygen species (ROS) generation, without evidence of sustained DNA damage or altered apoptosis. The investigation assessed multiple biomarkers of cellular damage, including DNA strand breaks, ROS levels, mutations in preleukemic fusion genes, apoptotic features etc (Durdik et al. 2019). A recent animal study by Mevissen et al. (2025) reported a link between RF radiation exposure and the development of two tumor types — brain gliomas and cardiac malignant schwannomas — and noted the same as those identified with limited evidence in humans by the IARC Working Group (Mevissen et al. 2025). Khalil AM et. al. (2020) has explored relationship between the use of mobile phone and DNA damage in oral mucosal cells. They have revealed that apoptotic cells (characterized by damaged DNA) were

highest in individuals having medium to long hours (30-60 min/day) of phone usage (Khalil et al. 2020). Besides, investigations have also demonstrated increased DNA damage in glioblastoma cell line U87 in response to RF field exposure only specific under serum-free conditions, where induction of nucleotide excision repair (NER) appears to be involved (A-Serori et al. 2018). But whether NER activation have any causal positive/negative effects when combined with mobile phone specific radiation and/or chemicals is yet to be verified (Baohong et al. 2005, Sannino et al. 2009, Vijayalaxmi et al. 2014). Although the body possesses complex feedback mechanisms and robust intrinsic DNA repair networks that may be capable of counteracting genetic damage induced by RF exposure, further investigations at the genomic level are required to be addressed.

Effect on pregnancy & reproduction:

In contrast to ionising radiations, although mobile associated non-ionising radiations are less energetic and they operate primarily in the radiofrequency (RF) spectrum, yet they have been reported to be associated with subtle biological changes related to reproduction (Figure 4). In 2011, International Agency for Research on Cancer (IARC) has referred mobile phone-associated radiations to be “possibly carcinogenic” (Frei et al. 2011; Zahid 2014), although its impact on foetal development demands further investigations.

In several meta-analyses and systematic literature reviews on the adverse effects of RF-EMF exposure during pregnancy in experimental animals reveals that EMR exposure could cause genetic changes. Such changes can have long-term implications in terms of altering critical gene expression patterns required for foetal development, and may have predisposition to developmental disorders or chronic diseases (Cordelli et al. 2023; Chatha et al. 2025).

Boileau N. et. al. (2020) has shown that using a mobile phone for long hours per day during pregnancy is associated with a higher frequency of growth restrictions at birth (Boileau et al. 2020).

Many studies provide evidence on the negative effect of radiofrequency electromagnetic field (RF-EMF) on male fertility, but at the same time, other studies also disprove the above. Veerachari S. B. et. al. (2012) investigated that mobile phones-emitted electromagnetic waves cause oxidative stress in human semen and DNA fragmentation, which in turn affect spermatozoa motility and viability and lead to impair male fertility (Veerachari and Vasan 2012; Gorpichenko et al. 2014).

In another *in vivo* experiment, the development of premature capacitation-induced infertility has been encountered outside the vaginal tract, due to low frequency EMFs (of ~43-kHz) exposure. Moreover, *in vitro* exposure of semen to these EMFs resulted in enhanced hyperactivity and capacitation of the spermatozoa, which was done before performing the assisted reproductive therapies (Wdowiak et al. 2018).

In an earlier study by Dasdag S. et. al (1999) on the effects of microwave exposure emitted by cellular phones on the testicular function of male rats revealed increase in rectal temperature and changes in seminiferous tubules histology among the exposed groups, when compared to sham groups (Dasdag et al. 1999). Such changes (in the exposed group) can be attributed to the significant level of increase in ROS and lipid peroxidation, which are simultaneously associated with adverse impacts such as: decreased sperm count and alterations in sperm tail morphology, as observed (Gautam et al. 2019).

Effect on mental health and behaviour:

Social media's impact on behaviour and mental health is multifaceted, since different behaviours accomplish different purposes, and varied usage patterns leads to diverse outcomes (Khalaf et al. 2023) (Figure 5). According to the available findings from different meta-analysis, cross-sectional, longitudinal and empirical research, it is evident that smart mobile phones, internet availability and social media usage among teenagers is highly corelated to an increase in mental distress, depression, self-harming behaviours and even suicidal tendency.

Observational study on adolescents using questionnaire on sleep-wake rhythm, duration of sleep and use of mobile phones has evidenced the negative impact of social media access, especially in a cell

phone, on sleep quality, mood and daytime functioning among teenagers (Royant-Parola et al. 2018). The precision of memory recall is significantly affected by the frequent thoughts about smartphones or by its presence only. Such experiments demonstrate that enhanced cognitive load interferes with the memory processes of individuals (Tanil and Yong 2020).

Above hypothesis was further supported by the experiment of Skowronek et. al. (2023), which demonstrated that distraction from smartphones causes reduced attention and performance in carrying out a given task (Skowronek et al. 2023, Thornton et al. 2014, Schwaiger et al. 2022).

Effect on the ecosystem and environment:

With the increase in electromagnetic pollution, a sudden decline in bee populations was noted, a process commonly referred to as Colony Collapse Disorder (CCD). Such persistence electromagnetic background interferences appear to disrupt the intercellular communication within individual bees, which results in failure of navigation of the bees back to their hives (Kumar S., 2018). Additionally, the lives and species diversity of several birds in the region is being continuously threatened by vast usage of upgraded cell phones services, as evidenced by limited number of studies and reports (Dhami KK., 2020). Microwave radiation from telecommunication towers could extremely confuse birds using earth's magnetic field for navigation. Similarly, another study shows that EMF generated by mobile phone alters the bone mineralization processes and the bone turnover intensity, which compromises the mechanical strength of bones in mammals like rats (Sieroń-Stołtny et al. 2015). Moreover, the batteries, integrated circuits, speakers, screens etc used to manufacture smartphones are themselves mass-produced, creating carbon footprints, heat emissions, and environmental pollution of their own.

Effect on the human microorganisms:

The human microbiome — encompassing gut, skin, and oral microbial communities — plays a critical role in immunity, metabolism, and overall human health (Figure 6). The radiofrequency electromagnetic fields (RF-EMF) emitted by mobile phones and Wi-Fi devices may affect the microbiome's composition and function. For instance, chronic exposure of mice to 4.9 GHz RF radiation (a frequency known to be used in 5G systems), resulted in reduced gut microbial diversity and significant alterations in microbial community structure, including changes in Firmicutes-to-Bacteroidetes ratios and *Lactobacillus* abundance, and metabolic alterations (correlated with these microbial shifts) (Wang et al. 2024). Likewise, exposure of *Enterococcus faecalis* to RF-EMF modified its growth rate and changed its antibiotic susceptibility profile (Mortazavi et al. 2022). In contrast, cultured probiotic strains (*Lactobacillus acidophilus* and *L. casei*) exposed to 2.4 GHz RF-EMF showed increased proliferation and elevated lactic acid production —suggesting that RF-EMF effects may vary by species (Amanat et al. 2020). Although limited, other reports suggest RF-EMF exposure may favour pathogenic bacteria such as *E. coli*, while reducing beneficial genera like *Lactobacillus* and *Bifidobacterium*, potentially increasing gut permeability and triggering inflammation (Luo et al. 2021).

Effect of the evolving technologies:

Telecommunication technology is evolving rapidly, and the nature of associated biological effects is also changing parallelly. For instance, the expansion of the internet is widely promoted for its potential to provide more comfortable, convenient, and efficient way of life. However, unlike earlier wireless communication technologies such as 2G, 3G, and 4G, the fifth-generation technology standard (5G) also utilizes the millimeter-wave (MMW) portion of the radiofrequency (RF) electromagnetic spectrum, characterized by extremely high frequencies ranging from 30 to 300 GHz (Grigoriev YG, 2017). These frequencies may have significant ecological and public health implications.

A pilot survey conducted in a regional town in northern New South Wales (NSW), Australia, suggested that the highest community exposures were originated from Wi-Fi, transport, and military frequencies. Substantial exposure levels were also observed in the 1.2 GHz range, which is commonly

used for GPS, satellite, and radar systems. Experimental studies indicate that Wi-Fi sources emit signals with a pulse rate of approximately 10 Hz, which is a biologically active frequency that overlaps with the alpha range of human brain waves (Leach et al, 2025). Research further suggests that such pulsed electromagnetic fields can interact with voltage-gated ion channels in cell membranes, potentially leading to their dysfunction, thereby affecting the cell's electrochemical balance and homeostasis (Panagopoulos et al. 2015). This imbalance can lead to excessive generation of reactive oxygen species (ROS), causing direct damage to DNA, lipids, and proteins (Leach et al, 2025).

DISCUSSION:

Recent reviews and research studies increasingly indicate the possibility that radiofrequency electromagnetic fields (RF-EMF) may produce adverse biological effects, even at exposure levels below those prescribed by current international safety limits. The WHO-commissioned systematic reviews and meta-analyses (conducted between 2023-2025) found close associations between RF-EMF and multiple health endpoints, including cancer, male fertility, birth outcomes, and oxidative stress. However, these reviews also highlighted substantial methodological limitations, study heterogeneity, and, in many cases, a low certainty of evidence. (Melnick et al. 2025).

Wireless radiation has been widely introduced to the general population without comprehensively understanding its long-term biological effects, which may have implications for human health. The current ICNIRP 2020 guidelines set limits based on preventing thermal effects, relying on fixed averaging times (6 minutes for localized and 30 minutes for whole-body exposure), and emphasizes on acute exposure scenarios (ICNIRP Guidelines 2020). But critics contend that these guidelines fail to adequately address potential non-thermal effects, long-term exposure, and risks to vulnerable populations (including children and pregnant women). For example, the epidemiological findings obtained while examining genotoxic effects indicated significant DNA damage at extremely low SARs level of approximately 3.19×10^{-7} W/kg, as well as *in vivo* experimental evidence at around 3×10^{-6} W/kg — values far below the exposure limits established by ICNIRP (Weller et al. 2025). Similarly, in human cell line experiments, continuous 1.7 GHz LTE exposure at SAR of 1–2 W/kg led to decreased proliferation, induced cellular senescence, and delayed cell-cycle transitions. It is suggested that these are non-thermal effects because no DNA double-strand breaks or apoptosis were observed (Choi et al. 2020). Another report argues that the assumptions underlying the FCC and ICNIRP exposure limit guidelines are flawed, as they are largely based on contested premises, such as the attribution of biological effects is solely due to excessive tissue heating, and that no effects could occur below a defined threshold SAR etc. Such guidelines deliberately ignore the non-thermal induction of reactive oxygen species, DNA damage, cardiomyopathy, carcinogenicity, sperm damage, and neurological effects, including electromagnetic hypersensitivity (Access O., 2022).

To address perceived gaps in the ICNIRP 2020 guidelines, the Russian National Committee on Non-Ionizing Radiation Protection (RNCNIRP) has undertaken extensive efforts to incorporate non-thermal safety factors aimed at protecting against long-term health effects of RF-EMFs into national regulations. In Russia, the “Sanitary-Epidemiological Regulations and Norms” (SanPiNs) are legally binding public and occupational health standards, designed to safeguard long-term population health. Risk assessments developed by this Committee for the general public have been disseminated by the WHO to numerous countries worldwide. Nevertheless, the ICNIRP framework — as supported by the WHO and major telecommunications stakeholders — continues to underpin exposure guidelines for most countries. Notably, some nations have independently adopted more stringent limits, and in certain cases exceeding even the long-standing Russian standard of $10 \mu\text{W}/\text{cm}^2$, which has remained in place for over three decades (Grigoriev YG, 2017)

Anyway, it is to be noted that these studies vary considerably in several aspects of defining RF-EMF exposure measurement (as done using metrics such as SAR, power density, or field strength) and differ in parameters including continuous versus pulsed signals, modulation patterns, frequency bands, exposure duration, and distance from the source. This methodological heterogeneity complicates cross-study comparisons and limits the reliability of meta-analyses. Moreover, many investigations

lack detailed characterization, dosimetry or fail to adequately control for confounding variables such as temperature fluctuations and background environmental EMF, further contributing to inconsistencies in reported outcomes.

Furthermore, while conclusive evidence is still lacking for many health outcomes, emerging studies suggest that biological effects of RF-EMF exposure may not be limited solely to thermal mechanisms. Non-thermal effects from chronic, low-level exposure — particularly those linked to genotoxicity, reproductive function, and potential cancer risk — demand serious scientific and regulatory attention. To better protect public health, current guidelines, including those of ICNIRP and other regulatory bodies (such as RNCNIRP), should broaden their frameworks to incorporate non-thermal mechanisms, long-term exposure scenarios, and vulnerable populations. Future research must prioritize precise exposure quantification, standardized methodologies, and transparent reporting to enhance the evidence base, and guide the development of more comprehensive and protective safety standards.

CONCLUSION:

In these modern days of digital era, people are using mobile phones efficiently due to necessity, not by choice. In order to promote social interaction or relation skills for the fast-growing economies and policies, using new age smartphones and/or developing more updated telecommunication networks has become necessary. Under such circumstances, restricting exposure to these spectra of radiofrequency associated with cellular phone/networks may become ineffective.

Besides, the effect of mobile phone related non-ionizing electromagnetic radiation (EMR) on various dimensions of human health and social life is in its early stages. Although available data usher low toward the adverse effect of such exposure. It demands much more research investigations before we can make concrete conclusion and device recommendations for parents, educators or institutions.

Depending on the meta-analysis of existing literatures, few precautionary steps could be taken to avoid the nuisance of these mobile phone-emitted EMF, as discussed below:

Reducing RF- EMF exposure from mobile/ cell phones:

In order to place more distance between one's head and the cell phone, speaker mode, head phones or ear buds could be used. Even placing the thumb between the phone and the ear could be done. Refraining from making calls in poor service conditions because this makes cell phones increase their RF transmission power. Texting could be considered rather than talking. Short phone calls could minimize exposure time, particularly when the user is not utilizing hands-free technology. People need to be aware of the adverse consequences of radiation and the steps must be taken by the concerned Authorities to address them (Kühn et al. 2019; Wall et al. 2019). Mobile phone users can reduce their exposure to radiation by choosing to switch off their devices at night or by keeping them at a safe and considerable distance from their sleeping area, especially during extended periods of rest. Besides, another mechanism for exposure reduction may be achieved by modifying polling (or beacon) frequencies, which are the low-frequency control signals — approximately 10 Hz for Wi-Fi, 217 Hz for 2G, and ~100 Hz for 3G/4G (Leach et al, 2025). These signals enable continuous synchronization and connection maintenance, producing persistent background EMF exposure even in idle states. Reducing polling frequencies by an order of magnitude could substantially lower chronic exposure with minimal impact on service performance. Current exposure limits prioritize engineering efficiency over biological considerations, despite evidence that optimizing low-frequency components could improve biocompatibility.

Reducing RF- EMF exposure from mobile cell towers:

One of the first steps to be taken is to tighten the radiation norms (yet it should be cost effective & should not cause too much inconvenience to the users). All operators must be given clear guiding instructions that the power density in homes, workplaces, schools, hospitals, and other regularly

visited locations must adhere to these standards. Also having more cell towers with lower transmitted power is an additional alternative.

Additionally, in areas with weak signals, telecommunication repeaters, signal enhancers, or boosters may need to be deployed. Operator self-certification must be eliminated right away, and measurements must be completed by a third party that is reliable and independent. Finally, in order to prevent operators from increasing the transmitted power during peak hours, radiation readings must also be frequently verified ([Kumar et al. 2009](#)).

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FIGURES:

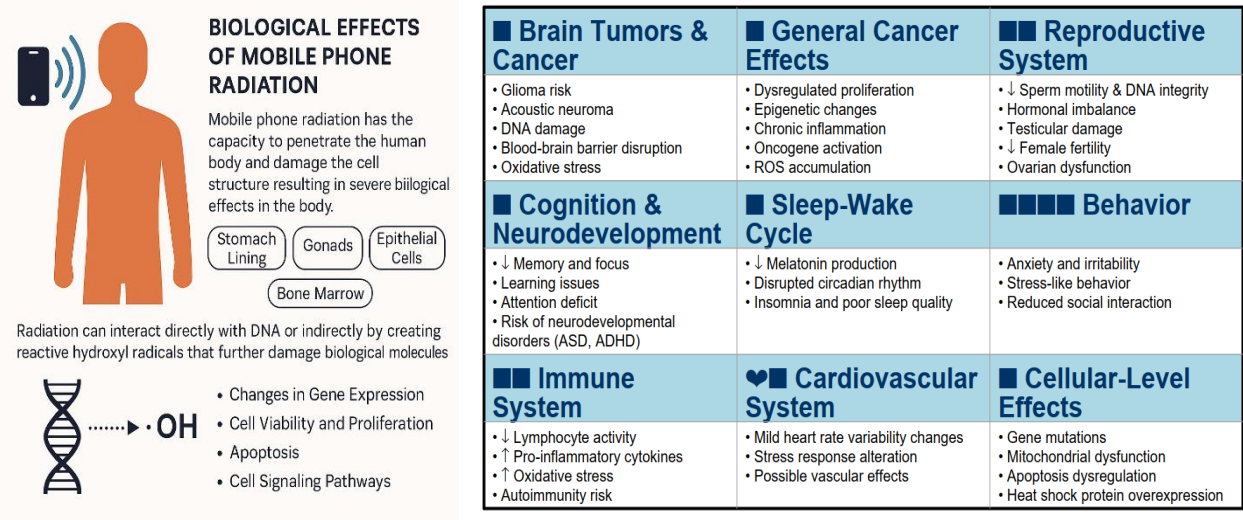
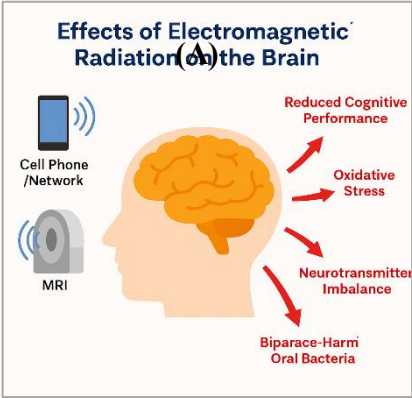


Figure 1. Illustrates the common biological effects of mobile phone radiation and its association with major human diseases.



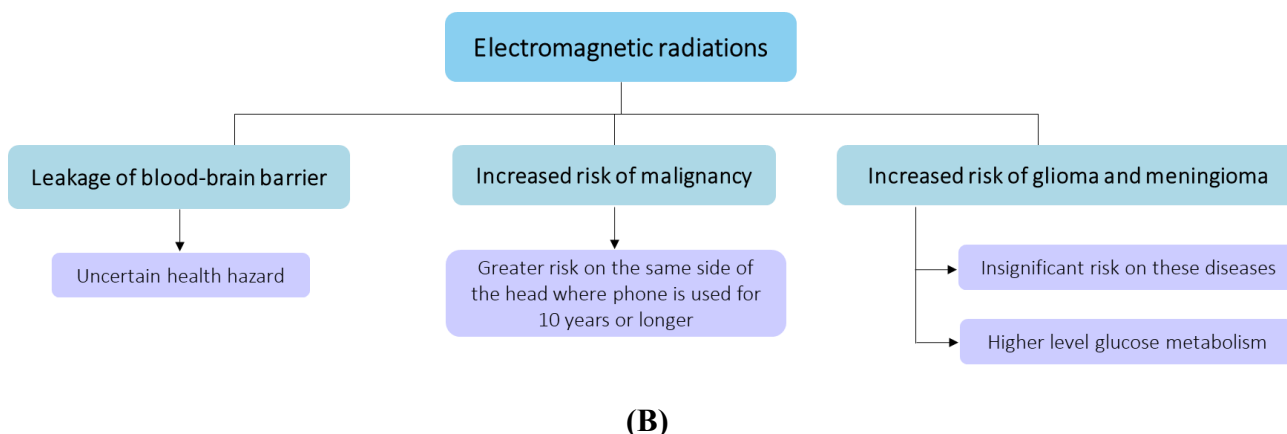


Figure 2. Effects of electromagnetic radiations from different sources (cellular phone/network or MRI). (A) effect on brain; (B) flow chart showing associated risk on brain.

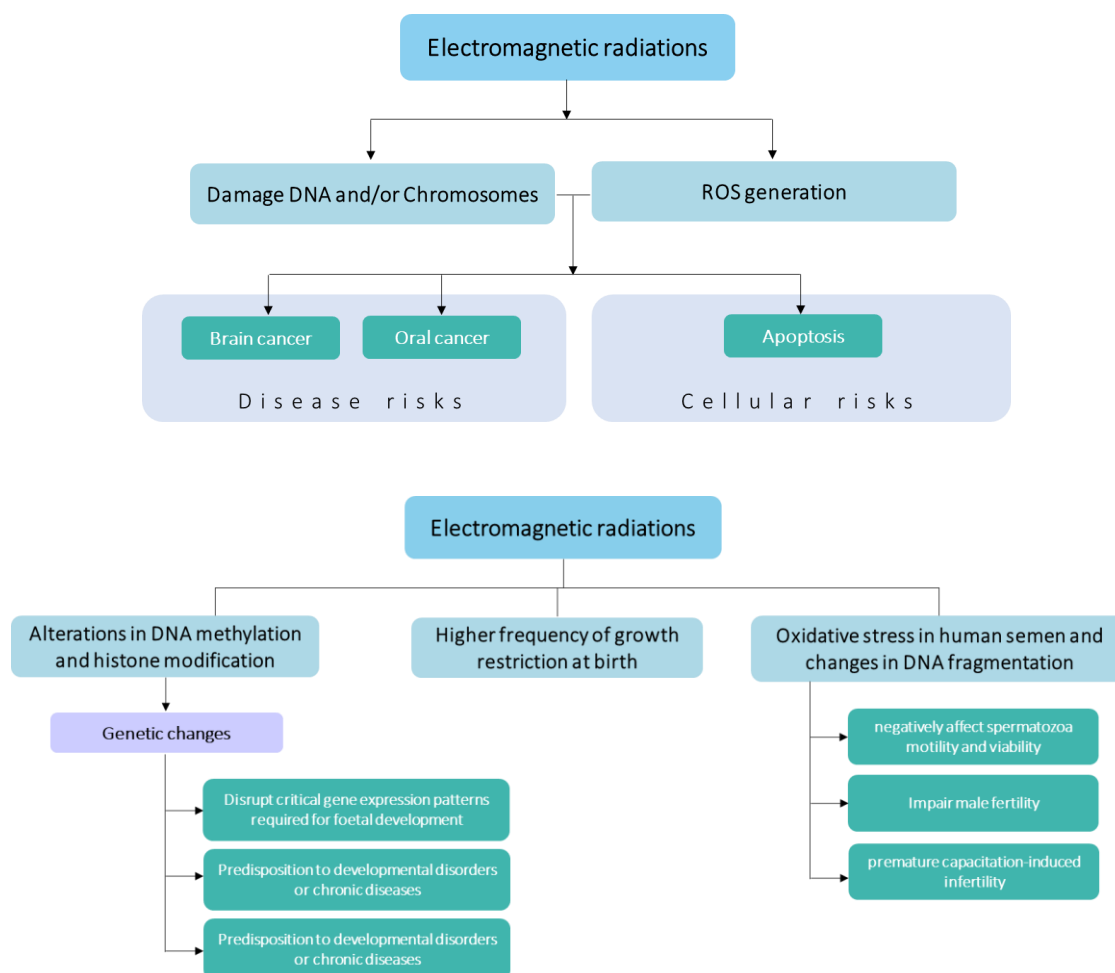


Figure 4. Effects of mobile phone/network associated electromagnetic radiations on reproduction.

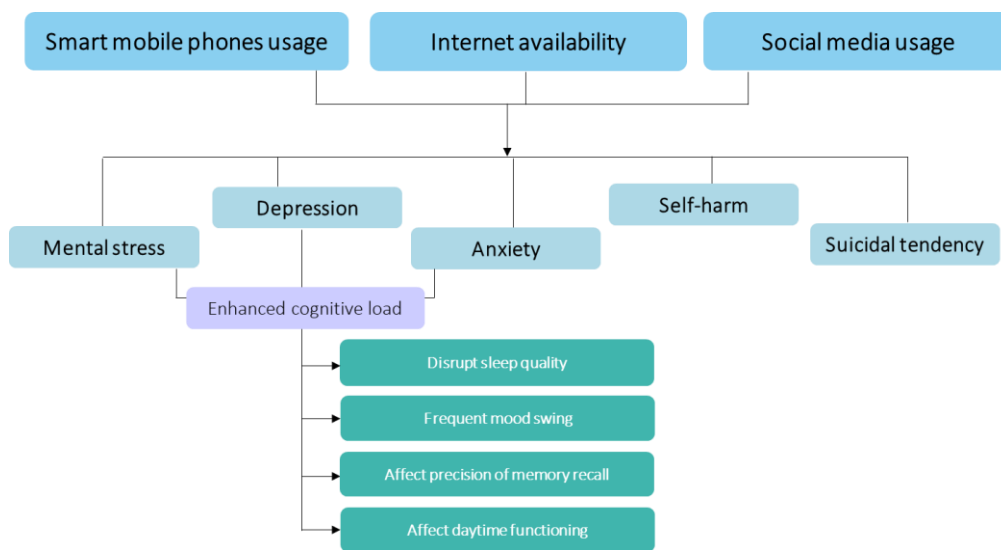


Figure 5. Effects of mobile phone/network associated electromagnetic radiations on mental health & behaviour.

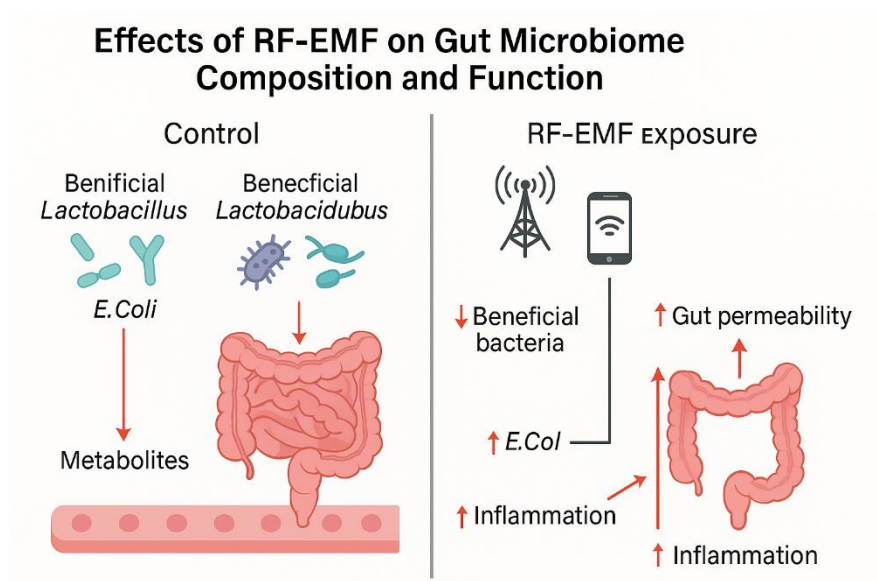


Figure 6. Effects of mobile phone/network on gut microbiome composition and functions.