Review of Literature

In the environment, natural Earth's magnetic field is about 50μT for living organisms (Belyavskaya, 2004). However, the role of man-made electro-magnetic fields and their influence on functioning of biological organisms are still insufficiently understood and not yet actively studied.

Not only static field and extremely low frequency field (ELF) but high frequency non-ionizing electromagnetic field radiations (EMFr) are also becoming common in the environment because of widespread use of wireless technologies which are continuously emitting radiation (300 MHz to 300 GHz) particularly exponential use of mobile phone technology and other wireless communication devices (800–2100 MHz). Various biological effects of EMF exposure have been documented; however, very little work has been done on plant system. Effects of pulsed electromagnetic field on plant growth and development are still unclear and contradictory.

Interestingly, most of the work relates to electric field or radio frequencies lower than those of cell-phones. However, the irony of the situation is that as on 1st January 2010, 4.6 billion people accounting for ~67% of the world’s population uses mobile phones (ITU, 2010). To provide service, correspondingly huge number of cell-towers has been erected in all cities. These cell-towers continuously keep emitting EMF radiations exposing majority of the world’s biota. Animals and humans are also getting exposed to EMF radiations. Interestingly, in spite of such a huge electro-smog a few studies explore the ill-effects/implications of such a wide usage/presence of EMF radiations in the environment. The enhanced EMFr levels have increased the exposure and associated risks towards living organisms (Goodman et al., 1995).

Of late, epidemiological and experimental studies have documented a close relation between EMFr exposure and their biological effects and (Sage and Carpenter, 2009). Due to increasing awareness and toxicological concerns scientists world over
have initiated a range of studies to evaluate the biochemical effect of EMFr on living organisms. Some of the work which has been conducted to evaluate ill-effects of EMFr on living organisms, particularly plants, birds, insects (specifically bees) and embryo development is reviewed hereunder:

**Impact of EMFr on Plants**

Most of the studies pertaining to ill-effects of cell-phone radiations have been conducted on animals, including humans or microorganisms (Busljeta et al., 2004; Meral et al., 2007) and not much has been done in plants. However, the studies have been conducted with electromagnetic fields generated from electrical installations or radio frequency that is lower than mobile phone frequency. Vian et al. (2008) opined that since in plants the number of cells at the interface between organism (Plant) and EMFr are greater, the effect of EMFr should be studied on plants. In spite of this, hardly any study is available that demonstrates the effect of cell-phones on the growth and development, and/or physiology of the plants. Nevertheless, whatsoever the work that is available in literature highlighting ill-effects of EMFr radiations, mostly from power lines or magnetic fields, is reviewed hereunder:

**Effect on Seed Germination and Seedling Growth**

Brauer (1950) reported that radiations with power density of 0.0027μW/cm² caused a growth inhibition in *Vicia faba*. Kursevich and Travkin (1973) observed inhibition in root growth of *Vicia villosa*, *Hordeum sativum*, *Panicum miliare* and *Pisum sativum* measured 48 and 72 h after exposure to weak magnetic forces. Bigu-Del-Blanco et al. (1977) documented that low level microwave radiation at a power density 10–30 mW/cm² inhibited germination and growth rate in corn seeds. Lebedev et al. (1977) demonstrated that exposure of weak magnetic fields to barley seedlings decreased fresh and dry weight of shoots and roots. Further, the seedling development was slow in the exposed seedling (Lebedev et al., 1977). Shiyan (1978) reported that exposure to 10 nT weak magnetic field delayed germination of pea seeds. Johnson et al. (1979) reported that an electric field strength of over 20 kV/m damages plant leaf tips.

Selga and Selga (1996) reported that radio frequency EMF generated from Radio Station in Latvia accelerated resin production and promoted senescence of pine trees.
due to stress generated by EMFr. They reported premature aging of pine needles at 0.000027 μW/cm² power density. Balodis et al. (1996) reported that radiofrequency radiations (at power density 0.0027 to 0.065 μW/cm²) from Skrunda Radio Station reduced the radial growth of pine trees and the tree growth rings were smaller in exposed trees. These workers observed a negative correlation between the intensity of the electrical field and the increment in tree growth (Balodis et al., 1996).

Celestino et al. (1998) reported that extremely low frequency (ELF) of 50 Hz (15mT) from Helmholtz coil exposed to isolated somatic embryos of Quercus suber for 8 weeks affected the morphogenic behaviour during embryogenesis and reduced the number of detachable embryos produced. Aksenov et al. (2007) reported that prolonged treatment with electromagnetic fields (50 Hz) to wheat seeds during the imbibition retarded germination and reduced seedling growth.

Soja et al. (2003) investigated the wheat and corn cultivation under high tension electric power line (ELF) between Austria and the Czech Republic and found ~7% reduction in wheat production in the fields next to the electric line. Sandu et al. (2005) observed a decrease in chlorophyll content in leaves of black locust (Robinia pseudoacacia L.) with the treatment of 400 MHz EMFr and the effect was dependent upon the exposure time.

Tkalec et al. (2005) reported a growth inhibition in duckweed (Lemna minor L.) exposed to 900 MHz modulated field for 2 h. Pazur et al. (2006) demonstrated that a static and alternating magnetic field of 50 Hz significantly reduced shoot growth and pigment content in barley seedlings (Hordeum vulgare L. var. Steffi). The effect corresponded to calcium ion cyclotron resonance. Velazquez-Martí et al. (2006) demonstrated the effect of microwave radiations at 21MJ⁻² and 80 MJ⁻³ inhibited the germination of weed seeds under soil. Huang and Wang (2007) demonstrated sinusoidal pulse modulated radiations at 50 Hz inhibited the growth of mung bean.

**Effect on Cell Division**

Haider et al. (1994) documented that short-wave EMFr (10-21MHz) show genotoxic effects in chromosomes of Tradescantium. Plant cuttings bearing young flower buds when exposed (30 h) to cell-phone tower / antenna (300/500 kW, 40-170 V/m)
showed increased micronucleus frequency thereby indicating clastogenic effects of EMFr. Seiga and Selga (1996) documented that radiofrequency EMF generated from the Skrunda Radio Location Station, Latvia, affected mitotic division, and induced cytological and ultrastructural changes in pines.

Pavel et al. (1998) reported that low intensity EMFr with frequency of 9.75 GHz exposed *Triticum aestivum* seeds showed mitotic irregularities such as chromosomal aberrations, delayed chromosome movement, increased micronuclei, interchromosomal bridges, and formation of chromosomal fragments. Belyavskaya (2004) reported that magnetic fields caused ultra-structural changes in distribution of condensed chromatin and nucleolus compactization in nuclei of pea. Recently, Tkalec et al. (2009) reported that exposure to 900 MHz radiofrequency waves (41 and 120 V/m) increased mitotic index, caused impairment in mitotic spindle, and hence mitotic abnormalities in root meristematic cells of *Allium cepa*.

**Effect on Cell Ultrastructure**

Selga and Selga (1996) reported that EMFr from radio station induced accelerated resin production and promoted senescence of pine trees. It was accompanied by ultrastructural changes in mesophyll of chloroplasts of second year needles. EMFr induced dense stroma with a compact granal membrane system, increased the amount of plastoglobules and altered the structure and export products of Golgi apparatus. Due to EMFr, function of Golgi apparatus was switched from the synthesis of predecessors of cell wall precursors to formation and export of resin predecessors.

Belyavskaya (2004) reported that weak magnetic field (EMFr) caused accumulation of lipid bodies, development of a lytic compartment, and reduction of phytoferritin in plastids in meristem cells of pea roots. EMFr induced an increase in size and relative volume of mitochondria with reduced cristae and electron-transparent matrix.

Bitonti et al. (2006) reported that exposure of *Zea mays* seedlings to EMFr for 30 h induced a precocious structural disorder in differentiating metaxylem cells and root cap cells. EMF treatment caused a significant reduction in the size of the quiescent centre in the root apical meristem.
**Effect on Physiological / Biochemical Processes**

Ellingsrud and Johnnson (1993) studied the effect of pulsed EMFr (27.12 MHz) on the rhythms of the lateral leaflets of *Desmodium gyrans*. They observed that EMFr induced temporary changes in the amplitude, period, and phase in the leaflet rhythms and leading to complete cessations of the rhythms.

In a long-term experiment, Schmutz *et al.* (1996) exposed the young spruce and beach trees to 2450 MHz microwave radiations of power flux densities ranging from 0.007 to 300 W/m². They observed that EMFr caused a significant decrease in concentration of calcium and sulphur in beech leaves during the initial two years of exposure.

Alasonati *et al.* (2003) demonstrated that 900 MHz EMFr induced perturbations in the chloroplast membrane in the moss *Physcomitrella patens* thereby indicating interference with photosynthesis process. Belyavskaya, (2004) demonstrated that root inhibitory effect of magnetic field involves intensification of protein synthesis and disintegration in peat roots. Further, cytochemical studies showed that cells of EMFr exposed pea roots depicted over-saturation of Ca²⁺ in organelles and cytoplasm unlike the control (Belyavskaya, 2004).

Sandu (2005) studied the ultra high frequency field effect on black locust chlorophylls. Seedlings exposed to low power density of 400 MHz frequency for different time duration found that chlorophyll *a* and *b* levels were found to decrease, except the exposure time of two hours. where a considerable enhancement was noticed. It was revealed that the ratio of the two main types of chlorophylls was decreasing logarithmically to the increase of daily exposure time.

Yao *et al.* (2005) reported that EMF radiations enhanced lipid peroxidation like other environmental / abiotic stress. Parola *et al.* (2005) showed that exposure to sinusoidal varying magnetic fields induced metabolic stress in *Spirodela oligorrhiza* (an aquatic plant) through the production of free radicals which reduced upon exogenous addition of radical scavengers. Tkalec *et al.* (2007) investigated the physiological effects of EMFr in duckweed. They observed that exposure to 400 and
900 MHz EMFr for 2 h (at the field strength of 23 and 120 V m\(^{-1}\)) significantly enhanced lipid peroxidation and H\(_2\)O\(_2\) content in duckweed. It was associated by alterations in the activities of catalases (CAT), pyrogallol peroxidases (PPX) and ascorbate peroxidases (APX).

Abdolmaleki et al. (2007) reported that exposure of cell-suspension of tobacco to static magnetic field (10 mT and 30 mT) for 5 h/day caused a reduction in cell growth, and increased cell death. It was accompanied by an increased activity of peroxidases and enhanced lignification of cell walls. Racuciu et al. (2008) studied the biochemical effect of extremely low frequency EMFr (50 Hz) on 2-month-old seedlings of arbor (Robinia pseudoacacia) during early development. They observed a slight stimulation of chlorophyll biosynthesis (upon 0.5 to 2 h exposure) and an inhibition of nucleic acid biosynthesis.

Monselise et al. (2003) documented that exposure to low intensity EMFr (60 and 100Hz) induced alanine production in duckweed (Lemna minor L.). However, addition of vitamin C, a radical scavenger, reduced alanine production by 82%. Based on the study, the workers concluded that alanine generation act as a stress signal in response to EMFr (Monselise et al., 2003). Rochalska and Grabowska (2007) reported that exposure of wheat seeds to magnetic field of low frequency (16 Hz) for 2 h reduced the activities of amylases, whereas the activity of glutathione-S-transferases was enhanced as a strategy to provide protection against induced oxidative stress. In a recent study, Roux et al. (2008a) reported that exposure to low level 900 MHz EMFr decreased ATP levels (by 27% after 30 min) and decreased adenylate energy charge by 18% indicating the role of ATP as a stress signal in EMFr-induced stress.

**Effect on Gene Expression**

Paul et al. (2006) investigated the molecular impacts of high magnetic fields using transgenic *Arabidopsis thaliana* plants engineered with a stress response gene consisting of the *alcohol dehydrogenase* (*Adh*) gene promoter driving the β-glucuronidase (GUS) gene reporter. These scientists demonstrated that magnetic fields (≥15 T) induced stress-related genes and transcription factors, and caused a depressor of genes associated with cell wall metabolism. Using a microarray analyses they revealed that 14 genes (out of 8000) were over expressed (by ≥2.5-
folds) compared to unexposed plants (Paul et al., 2006). Based on the study, it was concluded that strong magnetic fields induce metabolic perturbations.

Roux et al. (2006) demonstrated the existence of a direct relationship between 900 MHz EMFr (similar to mobile phone signal) and gene expression in tomato (Lycopersicon esculentum Mill. VFN8). They observed that a short period (10 min) exposure of EMFr induced a very rapid molecular response and stress-related transcripts in intact tomato plants. The levels of three stress-related mRNA (calmodulin-, protease inhibitor-, and chloroplast mRNA-binding protein) was increased four- to six-folds 15 min after EMFr exposure, dropped to initial levels after 30 min, and then increased again after 60 min indicating a typical environmental stress type response to EMFr.

Vian et al. (2006) reported that high frequency low amplitude 900 MHz EMFr enhanced expression of mRNA encoding the stress-related bZIP transcription factor parallel to that caused by mechanical stimulations. Later, Beaubois et al. (2007) reported that exposure of EMFr to a wild type tomato evoked a rapid accumulation of basic leucine-zipper transcription factor (bZIP) mRNA in terminal leaf and it was similar to the response against wounding. It was observed that treatment of Ca antagonists completely abolished the evoked accumulation of bZIP transcript. Later, Roux et al. (2008b) concluded that the observed responses in tomato plants to EMFr exposure are similar to that of wound response in plants, thereby suggesting that EMFr is perceived by plants as an injurious stimulus.

**Effect on Plant Ecology**

Selga and Selga (1996) reported that EMFr at power density of 0.000027 μW/cm² caused premature aging of pine needles. The top of the trees that are in line of main beam of towers are dried-up due to EMFr from cell towers (Belyavskaya, 2001).

Volkrodt (1991) hypothesized that EMF radiations upon absorption by trees and their leaves induced a downward flow of electrical charge into the roots and inhabiting soil. It results in soil acidification that greatly influences associated vegetation. Komissarov and Dmitriev (1993) opined that the relative positions of the Sun, the Earth, and the Moon have a profound effect on the rate of plant growth. Any
fluctuation in the geomagnetic field is likely to alter the hydrogen peroxide content in the natural water and thus will affect plant growth (Komissarov and Dmitriev, 1993). Belyavskaya (2001) opined that trees are most vulnerable to EMFr if their roots are closer to the water.

**Impact of EMFr on Animal System**

Masts or towers erected in human-habitation as well as in remote and wild areas for communication process continuously emit radiations. It has been argued that not only the plants but even the animals including rats, birds, and even wildlife suffered behavioural and reproductive alterations due to radiations (Balmori, 2009). Balmori (2009) opined that EMFr from cell-phone towers and other sources are one of the potential causes for the decline of animals in human-dominated and wild areas. Some of the studies highlighting ill-effects of EMFr on animals are described below:

**Effect on Birds**

Migratory birds are known to use the geomagnetic field as a source of compass information (Ritz et al., 2004). The first case of negative effects of microwaves on the birds was reported in 1956, while military radar engineer working on the Sussex Downs observed the effect of 3 GHz microwave radiation on migrating birds (cited from HESE Project, 2010).

Bruderer et al. (1999) observed that radar’s pulsed X-band EMF does not induce relevant changes in flight behaviour of birds, however, switching on and off a strong beam of light provoked important changes. Shire et al. (2000) reported the killing of 230 bird species, mostly migratory, in US near the communication towers. However, the report did not mention the exact reason for such a large scale death of birds near towers.

Fenie and Bird (1999) reported that long and short-term EMFr affected the body mass of only male American kestrels (*Falco sparverius*) and not reproducing females, and EMF exposed birds responded to longer photoperiod. Further, it was observed that captive American kestrels bred under the controlled EMF conditions had higher fertility, but lesser hatching success (Fenie et al., 2000). EMFr exposed eggs were
large-sized with thinner egg shells but greater yolk, albumen and water content compared to control eggs (from unexposed kestrels). EMF altered the reproductive success of kestrels. enhanced embryonic development and fledging success (Fernie et al., 2000). Later, Fernie et al. (2000) reported captive behavioural changes in American Kestrels during courtship and brood rearing phases under the influence of 735 kV EMF power lines; however, there was no effect on egg laying or clutch size.

Balmori (2009) reported EMFr pollution (smog) has resulted in a decline in population of birds in the urban areas, as birds tend to avoid places with high EMFr levels. It was noticed that birds like Kestrel (*Falco tinnunculus*), White Stork (*Ciconia ciconia*), domestic Rock Dove (*Columba livia*), Magpie (*Pica pica*), and Collared Dove (*Streptopelia decaocto*) gradually left the areas with high EMFr levels and migrated to EMFr-free areas. Further, some of the carrier pigeons lost their way and disappeared due to interference by EMFr (Balmori, 2009).

In a detailed study conducted in Valladolid (Spain) to evaluate the impact of cell­phone towers on a population of White Stork, (a bird of urban areas), it was noticed that either adults do not build nests near antennas or the nests were without chicks (Balmori, 2009). It was concluded that EMFr could be affecting either one or all the stages of reproduction. including nesting, egg number, the embryonic development, the hatching or death of chicks and young in their first stages (Balmori, 2009).

Later, Balmori and Hallberg (2007) reported a large-scale decline in the populations of house sparrow (*Passer domesticus*) in UK and western European countries and ascribed it as one of the reasons for decline of the bird. Everaert and Bauwens (2007) did a survey of house sparrows during the breeding season in six residential districts in Belgium. They observed that there existed a negative relationship between EMFr and abundance / behavior of male house sparrow with later moving away from high EMFr areas.

Ritz et al. (2004) demonstrated that oscillating magnetic fields disrupt the magnetic orientation behaviour of migratory birds. It was noticed that if the oscillating fields are parallel to the geomagnetic field, birds follow normal migratory pattern; however, if these fields are disoriented by a 248° or 488° angle, the birds are
disoriented (Ritz et al., 2004). Fernie and Reynolds (2005) reported that EMF exposure changes the behavior, reproductive success, growth and development, physiology, and endocrinology in birds and even induced oxidative stress.

**Effect on Chick Embryos**

The first paper in medical literature highlighting negative effects of EMF on development of vertebrates dates back to 1893 (Windle, 1893). However, there have been conflicting reports about the ill-effects of EMF on chick embryo developments. These differences are largely due to variations in frequencies of EMF used. Jose et al. (1982) reported that extremely low frequency (ELF) of 100 Hz (1.2 μT) inhibited the chick embryogenesis. Later, it was reported that a weak magnetic field (1 μT), pulsed or sinusoidal, increased the morphological alterations in Leghorn chick embryos by 2- to 3-folds over control (Farrell et al., 1997). However, Martin (1992) reported that 60-Hz (bipolar, unipolar, or split-sine waves) pulsed magnetic fields at 3 μT did not induce any malformation in chicken embryos during the first 48 h of incubation.

Berman et al. (1990) did a large multinational experimental effort (Henhouse project) and studied the impact of pulsed low frequency EMF on the development of chick embryos simultaneously in Canada, Spain, Sweden and USA. These workers reported that 1.2 μT EMF induced structural abnormalities in embryos (Berman et al., 1990). However, Veicsteinas et al. (1998) reported that exposure of low frequency 50 Hz intermittent with 200 μT magnetic field to chick embryos did not cause any developmental anomalies.

Jove et al. (1999) based upon their experiments involving exposure of chick embryos to static EMF (18 or 36 mT) for 5, 10 or 15 concluded that effect of EMF on development and growth of embryos unequally and their action can depend upon the intensity, period of exposure and the developing organ. Youbicier et al. (2000) demonstrated that exposure of eggs to microwave and ELF fields of mobile phones (900 MHz) with attenuated microwave for 21 days induced higher mortality than in unexposed eggs. Grigorev (2003) reported that exposure of chicken embryos to GSM mobile phone EMF for 21 days increased the embryo mortality rate by five-folds over control.
Beraldi et al. (2003) compared the sensitivity of pre-implantation embryos obtained by natural breeding (NB) or in vitro fertilization to ELF-MF (50 Hz and intensities of 60, 120 and 220 µT) and concluded that IVF-derived embryos are more sensitive than NB-generated embryos and the sensitivity occurs earlier in development. Shafey et al. (2005) reported that exposure of chicken eggs (Leghorn and Baladi) during incubation to electric field (30 kV/m, 60Hz) enhanced the water loss. Later, these workers reported an increase in spleen weight (Shafey et al., 2006). Ingole and Gosh (2006) demonstrated that 900 MHz cell-phone EMF increased the mortality and damaged the developing kidneys in chick embryos (Gallus domesticus). Zareen and Khan (2008) reported that EMF significantly delayed the developmental, induced malformations, and enhanced mortality in fertilized chicken eggs of Egyptian Fayoumi breed. Likewise, Batellier et al. (2008) reported enhanced embryo mortality in fertile chicken eggs exposed to cell-phone EMF.

Lahijani et al. (2007, 2009) demonstrated the histopathological and ultrastructural changes in liver and brain, particularly the telencephalon and eye of preincubated white leghorn chicken embryos exposed to 50 Hz EMF (at 1.33, 2.66, 5.52, and 7.32 mT) for 17 days. The exposed embryos were asymmetrical, exencephalic, with shorter upper beak, crossed beak, and had deformed hind limbs, gastrochisis, anophthalmia, and microphthalmia (Lahijani et al., 2009). SEM and TEM studies indicated that liver cells have fibrotic bands, severe steatohepatitis, vacuolizations, swollen and extremely electron-dense mitochondria, reduced invisible cristae, crystallized mitochondria with degenerated cristae, myelin-like figures, macrophages engulfing adjacent cells. Further the nuclei were dentated with irregular envelopes, hepatocytes were degenerated with abnormal lipid accumulations resulting in shifting of nuclei to the corner; there were cellular infiltrations with release of chromatin into cytosol (Lahijani et al., 2009). Recently, Zareen et al. (2009) demonstrated that EMF from mobile phone induce histopathological alterations in retinal differentiation of chick embryos.

EMFs have been reported to not only induce structural abnormalities but also induced enzymatic changes. For example, activity of enzyme ornithine decarboxylase (ODC) was reduced in EMF exposed embryo with morphological abnormalities (Farrell et al., 1997). Rajendra et al. (2004) demonstrated that ELF EMF changed
circadian rhythm in developing chick embryos and significantly increased glutamine synthetase activity, which may influence the developmental changes in the chick embryo.

**Effect on Human Health**

Various studies have been carried out and/or are in progress about different effects of radiations emission on behaviour, cancer, central nervous system, sleep, cardiovascular system, immune function, reproduction and development (Repacholi, 2001; Blank and Goodman, 2009; Kundi and Hutter, 2009; Sage and Carpenter, 2009). It has been documented that EMFr induce cellular stress and evoke stress response genes (Blank and Goodman, 2009).

Ruediger (2009) opined that EMFr have ample potential to induce genotoxicity via free radical generation and damage DNA. Hardell et al. (2009) based upon an epidemiological study among Hardell group in Sweden concluded that EMFr from mobile phone are not safe and have potential risk of causing brain tumours such as glioma and acoustic neuroma. Johansson (2009a) opined that EMFr have a great potential to disturb the immune system resulting in various allergic and inflammatory response leading to increased risk of diseases. In fact, the potential ill-effects of EMF on human health have long been a concern, particularly the various kinds of cancer/tumours related to cell-phone use.

Of late, based upon long-term epidemiological data (≥ 10 years) it has been reported that cell-phone caused central nervous system tumors and enhanced the risk of acoustic neuroma, glioma and parotid gland tumors (Shoemaker et al., 2005; Lahkola et al., 2007 and Sadetzki et al., 2008).

**Effect on Reproduction**

Pourlis (2009) has given an extensive review on reproductive and developmental effects of EMFr in vertebrate animal models. Nevertheless, some of the reports indicating effects of EMFr on reproductive systems in mice/rat and humans are discussed below.
In Rat / Mice

Kowalczuk et al. (1983) demonstrated that 30 min exposure of 2.45 GHz microwaves induced abnormalities in shape of sperms and caused post-implantation embryo death in adult male mice. Guy et al. (1985) reported that long-term low level radio frequency exposure caused a 4-fold increase in primary malignancies in rat. Dasdag et al. (1999) reported that cell-phone EMFr treatment @ 3 min / h for 2 h / day caused a significant change in structure of mice testis including decrease in diameter of seminiferous tubules. Likewise, Magras and Xenos (1997) reported a decrease in reproductive function in mice exposed to EMFr of 0.16 –1.053 μW/cm². Aitken et al. (2005) demonstrated that 900 KHz EMFr exposure at 12 h/day for a week damaged mitochondrial genome in mice testis.

However, there have been some conflicting reports wherein no changes have been detected in mice testis. For example, Dasdag et al. (2003) reported that cell-phone microwaves have no effect on mice testes upon whole body exposure. Likewise, no morphological alterations were noticed in testis, epididymis and prostrate in male NMRI mice exposed to 1800 MHz GSM (Forgacs et al., 2006). Similarly, no change was noticed in total sperm count in mice testes exposed to 1.9 GHz frequency for 3½ h / day for 18 weeks (Yan et al., 2007).

On the contrary, the studies on impact of EMFr in female genital system are less. Oral et al. (2006) reported that exposure of female rats to 900 MHz radiation @30 min/day for 4-weeks induced endometrial apoptosis. Later, Guneý et al. (2007) reported histological changes in endometrium, diffused and severe apoptosis in female rats exposed to 900 MHz EMFr.

In Humans

Of late, studies have been conducted to evaluate the effect of EMFr upon human genital system, particularly the spermatogenesis and sperm behavior in men. For example, Fejes et al. (2005) based upon a survey of 371 men using cell-phone concluded that prolonged use of cell-phones has negative effects on the sperm motility. Indulski et al. (1997) based upon an extensive review of epidemiological literature concluded that though no conclusive / accurate data highlighting ill-effects
of EMFr on human reproduction process is available, yet the EMFr can induce negative effects.

Bastes et al. (2008) based upon a survey among 10,497 military men of Royal Norwegian Navy with varying exposure to equipment emitting EMFr reported that army men who worked closer (up to 10 m) to EMFr have higher incidence of fertility and there was lesser proportion of boys to girls to fathers who worked closer to higher EMFr.

Agarwal et al. (2008) reported that exposure to cell-phone EMFr decreased the human semen quality by in terms of sperm count, motility and viability of sperms and the effect increased with duration of usage. Likewise, Li et al. (2009) demonstrated the a daily exposure of EMF level ≥1.6 mG to men (aged 18—45 years) at Shanghai metropolitan area increased the risk of abnormal sperm motility by two folds. De Iullis (2009) reported that cell-phone EMFr (1800 MHz) exposure to purified human spermatozoa decreased their motility and viability, enhanced reactive oxygen species (ROS)-generation, and stimulated DNA base adducts formation resulting in DNA fragmentation. Of late, Agarwal et al. (2009) reported that neat semen samples from normal healthy donors exposed to cell-phone radiation (in talk mode) for 1 h, showed a significant decrease in sperm motility and viability, increase in ROS level, and decreased total antioxidant capacity.

**Effect on Immune System**

It has been suggested that EMFr alter endocrine and immune system in animals including birds, rats and humans (Johansson, 2009a). The disruption of immune system induces various allergic and inflammatory responses resulting in induction / increased risk of various pathophysiological disorders (Johansson, 2009a).

**In Rat/ Mice**

Veyret et al. (1991) demonstrated that low power pulsed EMF exposure significantly affected the immune system in mice. Elekes et al. (1996) reported that microwave radiation (2.45 GHz) exposed for 6 days (3 h / day) enhanced the number of antibody-producing cells in the spleen of male Balb/c mice; however, no change was observed
in female mice. Likewise, Elekes (1996) observed an induced elevation of antibody production in male mice (not in female mice) upon exposure to 2.45 GHz radiations. A similar observation has been made by Fesenko et al. (1999) in male mice exposed to microwave radiation (1 μW/cm²). Later, Novoselova et al. (1999) demonstrated that low intensity RFR (0.001 mW/cm²) affected the functions of the immune system.

**In Humans**

Lyle et al. (1983) reported that 450 MHz RF field modulated with 60 Hz ELF inhibited / reduced the immune function in cells. Maes et al. (1993) reported exposure of 2.5 GHz non-thermal microwaves to human peripheral blood lymphocytes induced chromosomal damage, increased frequency of chromosome aberrations and micronuclei. Boscol et al. (2001) reported that radio frequency radiations (0.005 mW/cm²) from radio stations affected immunological system in women.

Kolomytseva et al. (2002) demonstrated that EMF (42 GHz daily for 20 min) suppressed the phagocytic activity of peripheral blood neutrophils thereby suggesting interference with immune system. Gandhi (2005) demonstrated that microwave frequency (800 to 2000 MHz) induced genetic damage in peripheral blood lymphocytes of mobile phone users as indicated by enhanced micronucleated cells frequency.

**Effect on Biochemical Changes and Oxidative Stress in Animals**

Simko and Mattsson (2004) reviewed the biochemical effects of EMFr in animals and opined that EMF exposure induced acute and chronic effects are mediated by increased free radical levels. A short-term exposure results in phagocytosis and thus free radical production and also increased the life-time of free radicals. George et al. (2008) demonstrated that 2450 MHz microwaves induced enhanced protein unfolding compared to conventional thermal stress in protein solutions heated to the same maximum temperature.

The International Agency for Research in Cancer (IARC) has classified extremely low frequency (ELF) electromagnetic field as “possible carcinogenic” based on reported effects (IARC, 2002). It has been suggested that a magnetic field acts as co-
inductor of DNA damage rather than as genotoxic agent and the ELF-EMF do not have enough energy to produce direct DNA breakage.

**In Rats/Mice**
Detlavs *et al.* (1996) reported that exposure of wistar rats 53.53 GHz and 42.19 GHz EMFr (without modulation) for 30 min daily during the first 5 days after wound infliction decreased the amounts of glycoprotein macromolecules, diminished the inflammatory exudation. It was further observed that exposure to 42.19 GHz EMFr with modulation band of 200 MHz enhanced the concentration of hexoses, particularly sialic acid, thereby indicating exudative phenomenon.

Forgács *et al.* (2005) demonstrated that GSM-like microwaves induce hematological and endocrine processes such as extended prothrombin time, decreased activity of factor Xa and platelets level in male mice. Ciejka *et al.* (2005) reported that low magnetic fields used in magnetotherapy altered blood coagulation in rats. Chater *et al.* (2006) observed that pregnant rats exposed to static magnetic field (128mT) for 1 hour/day during day 6 to day 19 of pregnancy induced hypoxia as evidenced by increased hematocrit, hemoglobin and LDH levels, and increased blood glucose and decreased insulin release resulting in a diabetic like state. Yurekli *et al.* (2006) observed that 945MHz exposure EMFr induced oxidative stress in rats in terms of enhanced MDA (malondialdehyde) level and decreased GSH (reduced glutathione).

**In Humans**
Kwee *et al.* (2001) reported that a weak microwave field (GSM 960 MHz, simulated) evoked the induction of heat-shock protein (Hsp-70) in human epithelial amnion (AMA) culture cells. Likewise, and increased level of Hsp-70 was observed in MO54 cells in response to high frequency EMF (Tian *et al.*, 2002). Valbonesi *et al.* (2008) reported that HF-EMF (1817 MHz) enhanced the expression of proteins (HSP70 and HSC70) and the levels of HSP70A, B and C transcripts in human trophoblast cell line HTR-8/SVneo. De-luliis (2009) and Agarwal *et al.* (2009) reported that cell-phone EMFr exposure to male sperms induced ROS generation, and decreased total antioxidant capacity.
Effect on Honey Bees

Amongst insects honey bees provide ideal material for studying and understanding this influence. That honey bees were affected by the current flowing the high tension electric field has been known for some time. Warnke (1976) found that bees exposed to low frequency field (10-20 KHz) showed stress reactions, increased aggression and a reduced capability to return to the hive. At 110 volts/cm, the bees ceased to store honey and pollen and began to kill each other. Under strong electric field bees became aggressive, started stinging each other to death and communication was disturbed.

Wellenstein (1973) reported that bees exposed to extremely low frequency electromagnetic fields stopped making honey, sealed up their hives and committed social suicide. Greenberg et al. (1981) reported that an increased activity was found among bees when exposed to 60 Hz at 4.2 kV/m. It has been demonstrated that at 275–350 nano ampere (nA) single bees are disturbed, at 600 nA bees begin abnormal propolization behavior, whereas stinging occurs at 900 nA (Bindokas et al., 1988). Carstensen (1987) observed that beehives located near high voltage power lines in fields (4 kV/m) produced less honey and had higher mortality rates among bees.

The behavioral pattern of honey bees was disturbed on exposure to low EMF (Smith, 1989). Kirschvink et al. (1997) demonstrated that free flying honey bees were able to detect static intensity fluctuations as weak as 26 nT against the background earth-strength magnetic field. Alternating fields (10 and 60Hz) exposure to honey bees showed that the sensitivity of the honey bee magnetoreception system decreases rapidly with increasing frequency (Kirschvink et al., 1997).

Honey bees communicate through waggle dances which make the honey combs vibrate (Nieh and Tautz, 2000; Tautz et al., 2001) at the frequency between 200–300 Hz and information can be transported to honey bees far away from source. Mobile phones (GSM) work at 900 and 1800 MHz band with pulsing frequency of 217 Hz, which corresponds to waggle dance of honey bees. This non-thermal irradiation of bees causes changes in learning ability and forgetting the direction of food (Tautz et al., 2001; Stever and Kuhn, 2003). Eskov and Sapozhnikov (1976) found that bees generate modulated electromagnetic signals (180 and 250 Hz) when they do their
communications dances. GSM mobile system is modulated with 217 Hz. Hungry bees reacted to these frequencies by erecting their antennae (Eskov and Sapozhnikov, 1976).

Stever and Kuhn (2003) conducted a pilot study on the returning behaviour of bees as well as the weight and surface development of the comb under the influence of electromagnetic radiations. Honey bees were exposed to Digital Enhanced Cordless Technology (DECT) phone base stations which were put into the hive and constantly emitted radiations. It was observed that there was significant decrease in number of returning bees.

Carstensen (1987) reported that bees exposed to strong electric fields (4 kV/m) under a 380 kV high voltage line, produce less honey and show increased mortality. Harst et al. (2006) studied the non-thermal influences of high-frequency radiation on the comb building behaviour of the bees (Apis mellifera carnica) within the beehive, weight of the comb and their returning behaviour. Bees were exposed to cordless DECT mobile phones (1900 MHz) placed at the bottom of beehive. The average weight of the exposed honeycomb decreased by 21.1% compared to control. At no time of the experiment more than six exposed bees arrived, several times none came back to the hive within 45 minutes, however, returning of non-exposed honey bees could be observed. Stefan et al. (2007) reported significant variations in the behaviour of Apis mellifera under the influence of DECT telephones (1900 MHz) non-ionizing radiation. A significant difference in the number of returning bees were reported wherein 39.7% non-irradiated bees came back compared to 7.3% of the irradiated ones.

Recently, a new phenomenon of sudden disappearance of bees with a little sign of disease or infection is reported from the world over. Bees simply leave the hives and fail to return (Hamzelou, 2007). Colony collapse disorder (CCD) is the latest name given to this problem. Earlier, bee colony collapse has been reported due to attack by viruses and parasitic mites, use of pesticides and genetically modified (GM) crops, and of late climate change (Eccleston, 2007). But now on the basis of widely reported influences on honey bee behaviour and physiology, electromagnetic field is emerging as a potential culprit candidate.
Over the last few years, colony collapse disorder has been reported from many countries and the phenomenon of disappearing hive populations has now spread to many countries in Europe including Switzerland, Austria, Germany, Spain, Poland and New Zealand (Cramer, 2007; Lean and Shawcross, 2007; Reilly, 2007). In USA, 25 to 50% of beekeepers have reported losses due to CCD (Reilly, 2007). During a period of six months, ~50 to 90% of bees disappeared and the rest of the colonies were too weak to produce any honey. Cramer (2007) reported that bee hives in more than half of the US have mysteriously been losing billions of bees. Melville (2007) reported that due to CCD in Oklahoma 80% colonies out of 13000 were lost and in Florida there were 40–80% losses. CCD caused adult honeybees to abandon the hive and disappear, leaving the queen and a remnant of younger bees.

In spite of these latest reports on the possible influence of EMF on different aspects of honey bee behavior, there exists a wide lacuna with respect to systematic studies confirming the impact of mobile telephony on the life of honey bees and the related environment.

**EMF Survey**

As regards the EMF survey in different areas near / close to human habitation, not much has been done. In fact, there have been very few studies.

Grigoriev (2000) surveyed the EMF exposure level of Base Stations in Moscow, Russia during 1977–1979. They observed that intensity level of EMF measured close near base stations, inside buildings and last floor of the buildings where antennas were transmitting did not exceed maximum Russian standard limit (10 μW/cm²), whereas in 91% stations it was 0.17 μW/cm².

Bangay and Henderson (2004) studied the exposure level of 60 mobile phone base stations around Australia in relation to antenna power, orientation and gain. It was observed that the average exposure levels at the location of the highest predicted level were 0.021% of the Australian (ICNIRP) limits.
Homer (2004) conducted a survey of EMF level in relation to mobile phone installation located on the roof of No. 102 High Street, Harrow-on-the-Hill in London. The highest EMF levels were found at the installation at No. 100 High Street and it was only 0.0006 W/m², which is 16,600 times below the ICNIRP limits. In the flats at remote distance from the installation, EMF level was only 0.0016 W/m², which is 6,250 times below the ICNIRP limits.

Jakes and Shaw (2006) conducted a survey of exposure to radio frequency electromagnetic field (30 MHz to 3 GHz) around Walmley telephone exchange, Sutton Coldfield, Birmingham, UK. They observed that mobile phone antenna contributed 9.3% from 91.5% of the total exposure whereas the rest came from TERA, TV, radio and other miscellaneous transmitters.

Comar (2000) opined that though EMF exposure from cell-phone base stations are normally far below the recommended guidelines, yet, the exposure on rooftops from the antennas is very high and can be fatal to persons with heart pacemakers or other implanted devices. He suggested that access to those areas should be restricted and appropriate signs be posted.

Bortkiewicz et al. (2004) on the basis of a questionnaire-based survey revealed that people living in the vicinity of base stations have complaints of the circulatory system, sleep disturbances, irritability, depression, blurred vision, concentration difficulties, nausea, lack of appetite, headache and vertigo. A direct relationship was noticed between incidence of symptoms to the level of exposure, and the distance from a base station. Wolf and Wolf (2004) based upon an epidemiological study conducted among individuals (622 in number) exposed to a cell-phone transmitter station at Netanya, Irus (Israel) noticed eight cases of cancer.

de Salles and Fernandez (2006) based upon a detailed measurement of EMF levels around transmitter stations concluded that cell-phone tower should be at least 400 m away from schools and hospitals, where people and children are more sensitive and stay several hours each day. Alanko et al. (2008) did an occupational EMF exposure from base station antenna and suggested that the antennas on the roof tops should be well above the body height to avoid exposure to humans.
EMF Standards

As discussed above, it has been documented/demonstrated that EMFs affect the living organisms and health of humans. In fact, health impact of EMFs falls within the environmental health mandate of WHO (World Health Organization). WHO has started “An International EMF Project” involving over sixty countries to identify criteria for EMF standards. It has encouraged researchers to evaluate effects of EMFs and envisages developing standards/limits based upon non-thermal effects.

In the development of EMF standards and guidelines, International Radiation Protection Association (IRPA) was the first committee formed in 1974 to examine the problems arising from non-ionizing EMFs. Later, in 1977, it was renamed as International Non-Ionizing Radiation Committee (INIRC) and with the coordination of WHO it developed a number of health criteria documents on non-ionizing radiation (NIR). In 1992, a new, independent scientific organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), was established as a successor to the IRPA/INIRC to investigate the hazards of NIR. ICNIRP developed two sets of guidelines for limiting EMF exposure for occupational (workers) and general public. Occupational guidelines were kept higher in comparison to general public exposure limits as occupational workers are aware of EMF exposure and takes precautionary measures while general public remain unaware of these exposure.

At the international levels, a few meetings/conferences have been organized to review the existing thermal-based safety limits/standards for EMF exposure and replace them with suitable biological effect-based limits. These include: Salzburg Resolution (2000), Catania Resolution (2002), Benevento Resolution (2006), BioInitiative Report (2007) and Royal Society, London, meeting on 27th November 2007 (Johansson, 2009b). Salzburg Resolution (2000) strongly recommended lowering the current level of outdoor EMF exposure below 0.1μW/cm² (electric field 0.6 V/m) which is 4500 (9000) times lower than the ICNIRP Guideline for 900 (1800) MHz radiation (Table 1).

Catania Resolution (2002) showed concern about present ICNIRP guidelines and concluded that adverse health effects of EMFs are observed well below ICNIRP...
(International Commission on Non-Ionizing Radiation Protection Board) and IEEE (The Institute of Electrical and Electronics Engineers) guidelines. In Benevento Resolution (2006), scientists endorsed and extended the Catania Resolution and concluded that biological effects can occur from exposures to both ELF-EMF and RF-EMF. Similarly, BioInitiative report (2007) also expressed that existing ICNIRP guidelines/standards to EMF levels are insufficiently protective of public health.

The Royal Society, London meeting of world scientist’s on present ICNIRP EMF standards also showed dissatisfaction of current guidelines. It is known as The London Resolution (Johansson, 2009b). The scientists showed their concerns about the near 100% penetration of mobile phones and vast proliferation of wireless networks and devices. They opined that children, people with epilepsy and heart conditions should not be exposed and the children under 16 should not use mobile phones and cordless phones except emergency calls. It further suggested that public areas, homes and school should be free from Wi-fi, or other forms of wireless networking. It recommended regular independent audits of base stations emissions to ensure that radiations not exceed the new biologically based guidelines (Johansson, 2009b).

In India, until 2008 no EMF standards were implemented. However, in July 2008, Telecom Commission in its order dated 23rd July 2008 approved the adoption of ICNIRP guidelines. It was the outcome of a Public Interest Litigation (PIL) filed before the Supreme Court of India in 2005. However, exact details have not been made public yet.

Different countries have adopted different EMF safety guidelines of various agencies such as ICNIRP (recognized by WHO), NRPB (National Radiological Protection Board, UK), and FCC (Federal Communications Commission, USA) (Table 1). In fact, all the standards are based on thermal effects of EMF and not upon non-thermal effects wherein the researches are being conducted to effects on living forms BioInitiative Report (2007). However, risk from cell-phone EMF is still unresolved.
In view of the health-risks associated with the EMFr and their potential in causing various diseases, of late, scientists have suggested to revise the safety standards of EMFr from thermal basis to actual biological response-basis (Blank and Goodman, 2009; Johansson, 2009a,b). The EMF safety limits / standards adopted in different countries for EMFr from cell-phones are as under:

**Table 1. Safety limits of EMF exposure standards adopted in different countries or organizations**

<table>
<thead>
<tr>
<th>Country/Organization</th>
<th>EMF standards for cell-phone frequency band (800-900 MHz) (μW/cm²)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales, Australia</td>
<td>0.001</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>Salzburg – Austria (Pulsed transmission)</td>
<td>0.1</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>Hungary</td>
<td>2-10</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>4.2</td>
<td>Bioinitiative Report (2007)</td>
</tr>
<tr>
<td>Italy</td>
<td>10</td>
<td>Bioinitiative Report (2007)</td>
</tr>
<tr>
<td>Auckland, New Zealand</td>
<td>50</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>Japan</td>
<td>200</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>Germany</td>
<td>200</td>
<td>Firstenberg (2001)</td>
</tr>
<tr>
<td>*ICNIRP</td>
<td>450</td>
<td>ICNIRP (1998)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>5800</td>
<td>Bioinitiative Report (2007)</td>
</tr>
<tr>
<td>India</td>
<td>As per ICNIRP</td>
<td>COAI (2008)</td>
</tr>
</tbody>
</table>

* Not a country, but an autonomous organization