Summary

During the last 10-12 years there has been an accelerated and widespread use of different wireless technologies. It has tremendously enhanced the levels of high frequency non-ionizing electromagnetic field radiations (EMFr) in the environment causing EMF smog a novel type of pollution. These technologies continuously emit a wide range of radiations resulting in an enhanced exposure of living organisms to electromagnetic fields (EMF). Among these, mobile phones or cellular phones are used indiscriminately and have become an integral part of modern telecommunication. In fact, the users of cell-phones are increasing rapidly and so the antenna/towers, which are haphazardly erected in the living areas. However, there have been growing concerns over EMFr due to their potential ill-health effects. Enhanced EMFr levels in the environment have increased the exposure risks and hazardous effects. A few studies have been conducted on animals, including humans, to assess ill-effects or risk-analysis of cell-phone radiations. These have documented a close relation between EMFr and their biological effects. Yet, no extensive work has been carried out on biological systems including plants, honey bees and development of chick embryo. To fill this gap, the present investigation was undertaken and the results are summarized below:

1. Two surveys were conducted in and around Chandigarh to find out the actual position of cell-phone towers/mast/base stations and the levels of electromagnetic field radiations (EMFr) emitted from them. The 1st survey conducted during September 2005 to March 2006 recorded a total of 199 towers. The 2nd survey was conducted during September 2008 to March 2009 showed 68% growth in cell-phone towers / base station over that of 1st survey. Of these, 85% were located/ installed in the city and 15% in the surrounding villages. The number of towers witnessed a sharp rise in villages with highest number in Manimajra. During both the surveys, the numbers of towers were the maximum in Sector 34.
The average EMF emanating from these cell-phone towers/base stations in city was 1.235 μW/cm² (12350 μW/m²) during 1st survey and it increased to 1.274 μW/m² (12740 μW/m²) in the 2nd survey. In general, power density was lowest in open areas (garden, parks, valleys and Sukhna Lake) and greater in and around commercial places. The EMF power density levels increased with rise in the number of towers.

2. In order to assess the effect of EMF on plant growth, development, and differentiation, a series of experiments were conducted to study the effect of cell-phone EMF in a realistic ‘talk+listen’ mode on seed germination, early seedling growth and development, including mitotic activity, and associated biochemical changes in plants. It was observed that exposure to EMF (for ½ h, 1 h, 2 h and 4 h) emitted from cell-phone inhibited germination of mung bean in a time-dependent manner. The inhibitory effect of cell-phone EMF was greater on radicle growth than on the plumule growth. It was observed that cell-phone EMF inhibited the mitosis in growing onion root tips. EMF treated root tips were distorted in shape with swollen tips and exhibited disintegration of cells.

The biochemical analyses were undertaken to explore the underlying cause for EMF-induced growth inhibition in plant seedling. EMF caused a significant reduction in total protein and carbohydrate contents, enhanced the activities of enzymes-proteases, amylases (α- and β-), polyphenol oxidases and peroxidases in roots of 7-days old seedlings. Further, EMF exposure significantly enhanced malondialdehyde (MDA, a thiobarbituric acid reactive substance and an indicator of lipid peroxidation), hydrogen peroxide (H₂O₂) and root oxidizability content in roots. It was accompanied by enhanced electrolyte leakage indicating membrane disintegration due to EMF exposure.

Another experiment was performed to evaluate the impact of cell-phone EMF on root differentiation in mung bean hypocotyls and explore alterations in biochemical processes during rhizogenesis. It was observed that cell-phone EMF severely affected the rooting potential of mung bean hypocotyls. The number of roots and length of emerged roots declined in EMF-exposed hypocotyls. Further, the activities of key enzymes peroxidases and polyphenol oxidases involved in rooting increased in response to EMF exposure. In contrast, the endogenous phenolic content in exposed
hypocotyls decreased significantly. It was further observed that cell-phone EMFr interfered with the oxidative metabolism during the rhizogenesis. A significant increase in the amount of MDA, H$_2$O$_2$, and proline was observed indicating a reactive oxygen species (ROS)-mediated induced oxidative damage in mung bean hypocotyls.

EMFr induced membrane damage was further evident from histochemical studies in exposed roots. It was observed that EMFr exposed roots stained darker with Schiff’s reagent indicating increased membrane peroxidation. Likewise, the cell-phone exposed roots stained darker with Evans blue dye indicating a greater loss of membrane integrity due to cell-phone EMFr. It confirmed the interference of cell-phone EMFr with membrane integrity that was also clear from enhanced electrolyte leakage from the root tissue in response to cell-phone EMFr.

Cell-phone EMFr induced oxidative damage was accompanied by a significant alteration in the activities of scavenging enzymes – superoxide dismutases (SOD), ascorbate peroxidases (APX), guaiacol peroxidases (GPX), catalases (CAT) and glutathione reductase (GR). Activities of all these scavenging enzymes increased significantly in cell-phone EMFr exposed seedlings possibly to provide protection against the damage induced by cell-phone EMFr.

3. Another series of experiments were performed to explore the effect of cell-phone EMFr on the development of chick embryo, particularly during early developmental stages. Fertile hen eggs (*Chabro*) obtained from Central Poultry Breeding Farm, Chandigarh were exposed to EMFr of cell-phone in a talk mode for ½ h, 1 h, 2 h and 4 h, respectively. Eggs were divided in five groups (G-I to G-V). G-I was kept as normal control group, whereas other four groups, viz. G-II, G-III, G-IV and G-V were exposed to EMFr of cell-phone for ½ h, 1 h, 2 h and 4 h, respectively, after 23 h of initial incubation at 38±5 °C. After 28 h of total incubation, the maximum mortality of eggs was observed in G-V followed by G-IV, G-III and G-II, respectively.

The whole mount of chick blastodisc stained in borax carmine exhibited normal development in G-I group as recorded in comparison to Hamilton scale of 26-29 h embryo development. However, a disruption in embryo development was observed with increase in EMFr exposure time. A maximum distortion was observed in 2 h and
4 h EMFr exposed eggs, where development of blastodisc was delayed. The differentiation of brain and optic vesicles and heart was hampered. The development of somites was abnormal and less in number. This observation was further confirmed by histological studies. Haemotoxylin/Eosin (H/E) stained transverse sections of G-I (control groups) blastodisc exhibited a normal development. A folding of neural tube with distinct columnar cells was visible and somite and coelom differentiation was also distinct. However, T.S. of G-II to G-V groups exhibited distorted cells and level of distortion increased with increasing EMFr exposure duration. The embryos exposed for ≥2 h exhibited the maximum distortion in development. The blastodisc was at an early stage of differentiation showing epiblast and hypoblast only with disorganized and disrupted cells. However, no differentiation of coelom, somites or neural plate was visible. The posterior part of blastodisc lacked the presence of yolky cells required for normal growth of embryo. The observed level of disruption in embryo growth was directly proportional to the duration of EMFr exposure.

4. In another set of experiment, it was observed that EMFr from cell-phone altered the biology and behavior of honey bees (*Apis mellifera*). Two sets of experiment were conducted, first during March–May and second during September–November, which are the periods of intense honey bee activity. During the first experiment (March–May) cell-phone EMFr exposure was given for 15 min, whereas in the experiment conducted during September–November the exposure duration was 30 min. The bee colonies were given exposure for 15 or 30 min twice a day per week for 8-weeks during peak bee activity (11 h to 15 h). A significant decline was observed in brood area and queen prolificacy (egg laying rate) in exposed colonies compared to control. The EMFr exposed colonies recorded a decline in number of bees leaving the hive per minute as compared to control colonies. Even the returning ability of the bees to colony was also reduced due to EMFr exposure. There was a decline in pollen foraging efficiency of exposed colony’s worker bees. The bee strength in cell-phone EMFr exposed colonies was reduced by half compared to control. The area under honey stores in exposed colony was reduced by ~75%. There was a significant decline in pollen stores in EMFr exposed colonies compared to the control ones. In the colonies exposed to cell-phone EMFr for 30 min there was neither brood, nor honey/pollen stores at the end of experiment. It pointed to deleterious effect of cell-phone EMFr on biological aspects and growth of honey bee colonies.
From the present study it is evident that cell-phone EMFr induced adverse effects are certain and increased with exposure time in a dose–dependent manner. The obtained results bear immense significance in view of the rapid increase in cell-phone EMFr in the natural environment and its possible impact on natural ecosystem process and environmental health. It implies a need for environmental risk assessment due to EMFr and development of proper management strategies to check EMFr pollution in the natural environment. Therefore, in order to minimize the ill effects of cell-phone EMFr certain precautionary measures need to be undertaken.