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Assessment of RF Exposure Levels Occur Due to Mobile Base Station Antennas in Sri Lanka

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Abstract

During the last decade, the installation of macrocell mobile telephone base station antennas in residential areas has been increased significantly and therefore much more attention is being paid to radio frequency (RF), electromagnetic radiation (EMR) and its effects on human health. The rapid growth in the number of mobile phone subscribers has resulted in an increased number of base stations all over the world. As a result, in Sri Lanka, more base stations are being installed in every part of the country. This paper presents the RF exposure levels of major cities in Sri Lanka occurred due to the mobile base station antennas belong to the different network providers. In this research the mobile cellular transmitting antennas in 900 MHz, 1800 MHz and 2 GHz of all five network providers were considered. Field strength measurements were made at 31 locations in main cities around the country which represent highly populated flat urban environment, the coastal belt of the country and hilly areas at high elevation. The present exposure levels were found to be below the maximum limits set by the internationally recognized FCC (Federal Communication Commission) standards.

Keywords: *electric field strength; power density; radio frequency; exposure quotient; maximum permissible exposure.*

1. Introduction

Electromagnetic (EM) radiation is a form of energy exhibiting wave-like behavior as it travels through space. It has both electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. When referring to biological radiation exposures, EM radiation is divided into two types: ionizing and non-ionizing. Because the human body is composed of about 60% water, ionizing and non-ionizing radiations refer to whether the RF energy is high enough to break chemical bonds of water (ionizing) or not (non-ionizing). Technically, all radiation and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter, characterized by energy per photon less than about 12 eV, wavelengths greater than 100 nm, and frequencies lower than 3×10^{15} Hz is termed as non-ionizing radiation (Singh, 2011). Clearly, radiation that has enough energy to move atoms in a molecule around or cause them to vibrate or pump an electron to a higher energy state but not enough to remove electrons is termed as non-ionizing radiation.

Exposure to very high levels of RF radiation can be harmful due to the ability of RF energy to rapidly heat biological tissues. Adverse effects (tissue damage) in humans could occur during exposure to high RF levels because of the body's inability to cope up with or dissipate the excessive heat that could be generated. The eyes, knee caps and testes are particularly vulnerable to RF heating because of the relative lack of blood flow in these organs to dissipate the excessive heat (Singh, 2011). Under certain conditions, exposure to RF radiation with power densities of approximately 10 mW/cm^2 or more could result in measurable heating of biological tissue (James, 2003). The extent of heating would depend on several factors including frequency of the radiation; size, shape and orientation of the exposed object; duration of exposure; environmental conditions and efficiency of heat dissipation. Biological effects that result from heating of tissue by RF energy are referred to as "thermal" effects.

From a source of RF radiation, whole-body absorption of RF energy by humans will occur at a maximum rate when the frequency of the radiation is between 30 and 300 MHz (FCC Std., 1996). Therefore the most stringent standards are in this frequency range. Body absorption of RF radiation is due to a resonance phenomenon and RF safety standards take this frequency dependence into account (FCC Std., 1996). Safety guidelines for exposure of the public to the RF radiation from transmitting antennas are set by different organizations such as the Institute of Electrical and Electronic Engineers (IEEE) (IEEE Std., 1999), International Commission on Non-Ionizing Radiation Protection (ICNIRP**)** **(**ICNIRP Std., 1999), National Radiation Protection Board (NRPB) (Mann *et al*., 2000) and The Federal Communications Commission (FCC**)** (FCC Std., 1996).

Significant concerns have been raised about possible health effects from exposure to RF electromagnetic fields, especially after the rapid introduction of the mobile telecommunication systems. The rapid growth in the number of mobile phone subscribers has resulted in an increased number of base stations all over the world. As a result, in Sri Lanka, more base stations are being installed in every part of the country and according to the TRCSL's (Telecom Regulatory commission in Sri Lanka) statistics, the estimated number of mobile phone subscriptions in March 2017 is around 27.2 millions. Base stations operating in densely populated cities in the GSM (Global System for Mobile telecommunication) 900, 1800 and UMTS (Universal Mobile Telecommunication System) 2000 MHz frequency bands are continuously evolving due to the conditions of competition and the need for a better response to increasing customer demand. Up to now, over 7000 mobile base station antennas are installed in the country by five main network providers. These installations give rise to widespread concerns among the population regarding possible detrimental effects on human health due to exposure to the electromagnetic waves radiated by these base station antennas. Therefore, it is necessary to determine the exposure levels of main cities due to RF radiation transmitted by the mobile base station antennas (downlink stream) with respect to the three frequency bands. Finally, these exposure levels are compared with the international standards for RF safety issues.

Table 1. Electromagnetic radiation reference levels for General public according to FCC standards.

Frequency Bands	EMR Reference level Power Density, S (W/m^2) [frequency f in MHz]
900 MHz	$f/150$
1800 MHz	10
2 GHz	10

Studies carried out by other countries, such as Saudi Arabia, maximum and minimum power densities in the reported sites were 0.0981 W/m^2 and 0.0007 W/m^2, respectively. Based on these figures, the maximum electromagnetic radiation was approximately 4.9% of the national guidelines of Saudi Arabia (Nahas *et al*., 2011). In United Kingdom, from 118 locations maximum power density reported was 8.3 mW/m^2 (Mann *et al*., 2000).

1.1 Electric Field Intensity and Power Density

The electric field intensity, *E*, and power density, *S*, of an electromagnetic field are two quantities whose limiting values are specified by international standards for public safety. If the maximum electric field at a particular location due to all RF sources in the environment can be obtained by measurement, then the power density, of the electromagnetic field at that location can be estimated from equation (1).

$$S\ (\mathrm{W/m^2}) = \frac{E^2}{\eta} \qquad (1)$$

where η is the intrinsic impedance of free space = 377 Ω.

The electromagnetic radiation reference levels of power density as given by FCC standards for the general public is given in Table 1 (FCC Std., 1996). In Sri Lanka, TRC uses FCC standards for RF safety issues.

If the experimental values of *E* and *S* are less than the safety standards specified by the accepted international organizations, then it is assumed that exposure measurement wise there is no health risk**.**

In order to ensure compliance with the Maximum Permissible Exposure (MPE) for the environment, a dimensionless quantity known as the *exposure quotient* is calculated **(**ICNIRP Std., 1999). This quantity is expressed in terms of the calculated power density S from measured results of the field strength and the MPE in power density. Thus,

$$\text{exposure quotient} = \frac{S}{MPE} \qquad (2)$$

For a certain location all the signals from different networks with respect to the three frequency bands were considered. The sum of the ratios of the measured power density to the corresponding MPE of the power density should not exceed unity (IEEE Std., 1999) to ensure safety. That is

$$\sum_{i=1}^{n} \frac{S_i}{MPE_i} \leq 1 \qquad (3)$$

If this condition is not met, the environment is not safe. It is also the usual practice to estimate how many times the present EMR level is below the safe limit (Mann *et al.*, 2000). 'Times Below Limits' abbreviated as TBL is easily obtained from equation (4):

$$TBL \;\; for\; Power\; Density = \frac{1}{\sum_{i=1}^{n} \frac{S_i}{MPE_i}} \qquad (4)$$

where,

S_i - Power Density at the i^{th} frequency, frequency given in MHz

MPE_i - Reference level of the Power Density at the i^{th} frequency

n - Total number of transmitting signals

2. Methodology

The measurements of field intensity were made at different locations, which represent highly populated flat urban environment, such as Colombo, Gampaha, Jaffna and Kurunegala. Measurements were also made along the coastal belt from Jaffna to Trincomalee which are urban, and therefore densely populated areas. Kandy, Matale, Nuwara-Eliya, Badulla and Bandarawela are hilly areas at high elevation and measurements were taken from other areas of the country as well. These cities are shown in Fig.1. The measurement set up used is shown in Fig. 2.

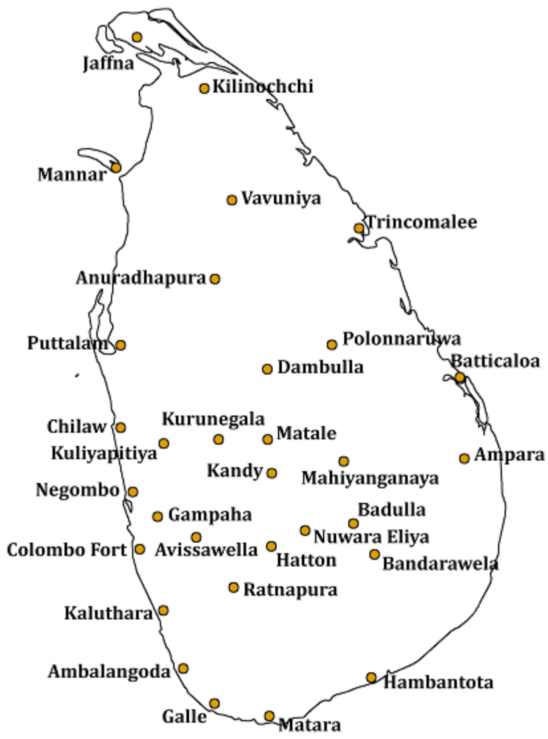

Figure 1. Site survey map

Figure 2. Measurement set-up

All measurements were taken during day time when most of the mobile phones are normally in use. These measurements were done at a one particular spot of each city. Therefore the measured values may vary at the different places of the same city. This particular spot was selected by considering the most public access places of that city such as public bus stands, railway stations, play grounds, etc,. The antenna was mounted 1.4 m above the ground level and the antenna was replaced with respect to the frequency band. For a one particular signal, the maximum received voltage; V_m in $\text{dB}\mu\text{V}$, was obtained from the spectrum analyzer, by rotating the antenna. This was repeated for all signals in three frequency bands of five network providers in mobile cellular communication. A typical spectrum analyzer measurement is shown in Fig.3.

The measured value of V_m was converted to field intensity E (V/m) using Eq. (5).

$$E\ (\text{dB}\mu\text{V/m}) = K\ (\text{dB/m}) + V_m\ (\text{dB}\mu\text{V}) + L\ (\text{dB}) \qquad (5)$$

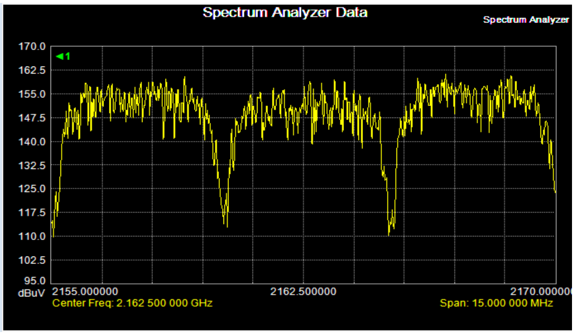

Figure 3: Spectrum analyzer measurement of 2 GHz frequency band signal at Galle

where, K (dB/m) is the antenna factor which is the ratio of electric field strength at antenna to the voltage produced at antenna connector and L (dB) is the total system loss. The system loss was measured experimentally using a synthesized signal generator and it was observed that $L = 8\ \text{dB}\mu\text{V}$. The value of K is given by the antenna manufacturer.

This signal is only from one direction and it is in the direction of maximum received signal. For the **worst case** situation we suppose that this field comes from three orthogonal directions. Hence,

$$E_{Worst}^2 = E_X^2 + E_Y^2 + E_Z^2$$

$$E_X = E_Y = E_Z = E_{Max}$$

Therefore,

$$E_{Worst}\,(\text{V/m}) = \sqrt{3}E_{Max} \qquad (6)$$

From Eq. (1), the power density in **worst-case** situation becomes,

$$S_{Worst}\ (\text{W/m}^2) = \frac{E_{Worst}^2}{\eta} \qquad (7)$$

The Electric field strength and the Power density were calculated using Eq. (5) to (7). The calculated values of field intensity and power density were compared with FCC standards given in Table 1.

Table 2: Exposure quotients of main cities w.r.t. different frequency bands.

City	Exposure Quotient ×10^{-3}				
	900 MHz	**1800 MHz**	**2 GHz**	**Total**	**TBL***
Vavuniya	6.521	31.779	240.480	278.780	3.587
Ratnapura	0.267	4.915	74.832	80.014	12.50
Kilinochchiya	0.269	13.109	62.791	76.169	13.13
Mannar	14.656	28.261	24.575	67.492	14.81
Gampaha	8.142	26.539	9.873	44.554	22.44
Badulla	18.294	1.005	19.679	38.978	25.65
Polonnaruwa	0.165	8.719	23.555	32.439	30.83
Kandy	13.282	7.373	8.278	28.933	34.56
Kalutara	4.034	8.463	12.680	25.177	39.72
Hambantota	9.117	1.307	11.004	21.428	46.66
Baticaloa	0.153	4.206	15.596	19.955	50.11
Kurunegala	4.151	2.191	13.518	19.860	50.35
Anuradhapura	7.025	1.913	10.063	19.001	52.26
Galle	2.200	1.850	13.820	17.870	55.96
Ambalangoda	1.406	2.085	11.456	14.947	66.90
Matara	0.480	12.886	1.213	14.579	68.59
Bandarawela	2.256	1.302	10.411	13.969	71.59
Ampara	10.754	0.468	2.243	13.465	74.27
Trincomalee	5.424	0.362	6.965	12.751	78.42
Hatton	1.626	6.892	3.504	12.022	83.18
Nuwara Eliya	1.837	0.440	9.057	11.334	88.23
Colombo Fort	0.787	3.794	1.758	6.339	157.75
Matale	3.106	0.400	1.979	5.485	182.31
Jaffna	0.099	1.569	2.879	4.547	219.92

Negombo	1.887	0.392	1.326	3.605	277.39
Kuliyapitiya	1.907	0.855	0.674	3.436	291.04
Dambulla	0.894	0.303	2.231	3.428	291.71
Awissawella	0.301	1.738	1.367	3.406	293.60
Chilaw	1.601	0.638	1.103	3.342	299.22
Mahiyanganaya	0.230	0.124	1.429	1.783	560.85
Puttalam	0.372	0.037	0.411	0.820	1219.51
TBL* - Times Below Limits					

3. Results and Discussion

Table 2 shows the exposure quotients in different cities from different frequency bands in descending order. These measurements are based on the frequency spectrum allocated for the mobile cellular network providers in Sri Lanka by the TRC. Frequency allocation for mobile communication in downlink stream is as follows (TRCSL Consultation Document, 2017);
900 MHz band : 925 MHz – 960 MHz
1800 MHz band: 1805 MHz – 1872.5 MHz
2 GHz band : 2110 MHz – 2170 MHz

The values in Table 2 show the maximum possible exposure levels because these results are based on the worst-case condition and they are below the FCC standards.

The results are illustrated in Fig.4. Among the cities considered, the highest exposure level is at Vavuniya and measurements were taken at a place close to the public bus stand. The highest contribution to RF absorption by the human body at this site is due to 2 GHz band. However the exposure level is approximately one third the accepted limits and therefore it is not much less than the specified limits.

In Table 2, last column shows the times below the limits in each of the city. The minimum exposure level reported from Puttalam and is 1220 times lower than the permissible level.

According to Table 2, it appears that the major exposure contribution is due to the 2 GHz mobile base stations. This may be due to the fact that almost all the network providers are upgraded their systems to higher frequency bands because of the immense facilities given. Among these, most recently system upgraded cities such as Vavuniya transmitted higher power levels to have a maximum coverage area.
The other significant point is most populated areas such as Colombo Fort and Jaffna, the exposure level is more than 100 times below the limits. That is due to the installation of micro cellular base station antennas by replacing macro cellular base station antennas. Because of this they can reduce the coverage area thereby reducing the transmitting power.

For the hilly areas such as Badulla, Bandarawela, Nuwara Eliya and Hatton most of the base station antennas are mounted on top of the hills and comparatively higher power levels are transmitted to cover the town limits. From all considered cities, the maximum received signal with respect to each band is given in table 3;

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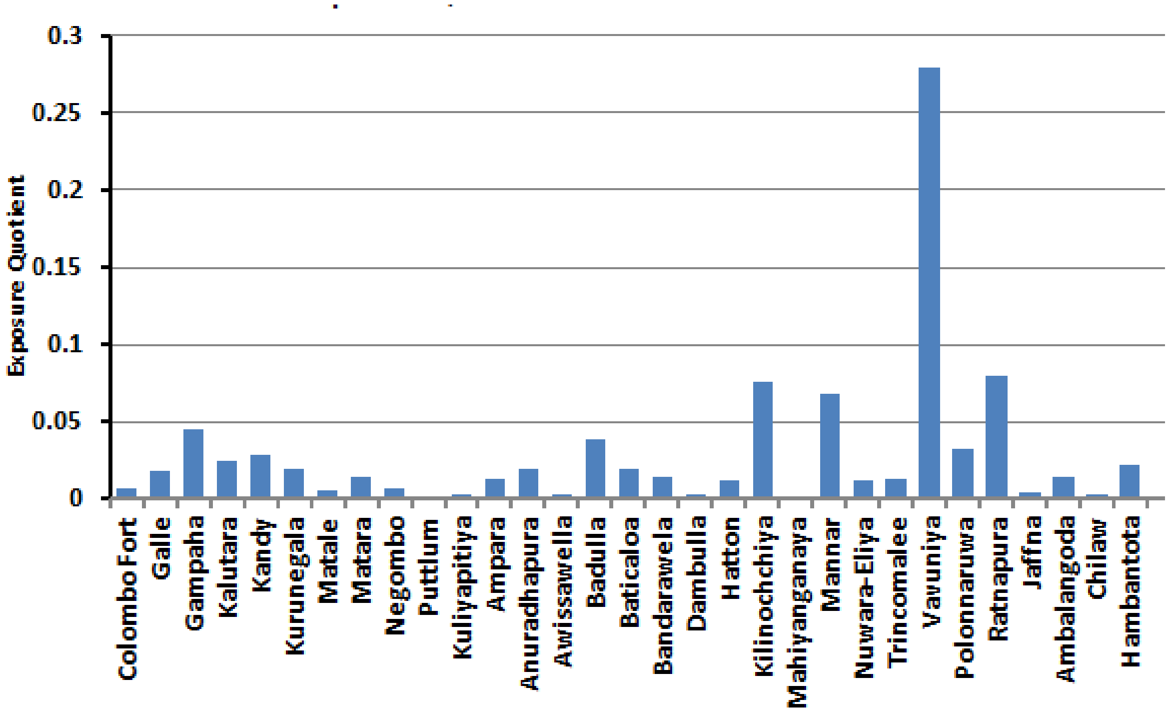

Figure 4: Exposure Quotients of main cities in Sri Lanka.

Table 3: Maximum received signal strengths in all measured cities

Frequency Band	Location	Signal Frequency (MHz)	Signal Strength (dBμV)
900 MHz	Gampaha	946.4	93.513
1800 MHz	Gampaha	1859.4	89.137
2 GHz	Vavuniya	2110.7	79.185

4. Conclusion

Measurements indicate that the exposure levels due to all mobile cellular network providers as at July 2017 for the general public at locations considered in this work are below FCC specified safety standards. In some cities of Northern Province comparatively higher exposure levels have been shown. Colombo and Jaffna show comparatively lower values due to the installation of micro cellular base station antennas. From the measured sites, highest exposure level is reported at Vavuniya mostly due to the 2 GHz band but still one-third of the permissible level. The total exposure from all considered sites, about 75% of it is due to the 2 GHz band. Some of the hilly areas show comparatively higher exposure levels than flat terrains.
According to the analyzed data, places such as Vavuniya, Ratnapura and Kilinochchiya exposure levels are not very much below the standards. Therefore this kind of exposure assessment should continuously be done at least once in two years since mobile base station antennas are built at a rapid rate. It is advisable to build micro cellular base station antennas by replacing macro cellular base station antennas to have a good coverage without interferences and to minimize the health effects.

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