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Experimental Observations & Comparison on RF Emissions 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 attention is being paid to radiofrequency (RF) electromagnetic radiation and its effects on human health. High intensities of RF radiation can be harmful since RF energy can heat biological tissues rapidly. This paper presents the RF exposure levels of major cities in Sri Lanka occurred due to the mobile base station antennas belong to 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. The results were compared with the FCC (Federal Communication Commission) guidelines and the present exposure levels were found to be below the maximum limits set by the standards. RF exposure levels due to mobile base station antennas obtained at present and in 2005 were compared.

KEYWORDS: Radio Frequency Radiation, Exposure Quotient, Mobile Base Station Antennas, Maximum Permissible Exposure, Electric Field Intensity

I.INTRODUCTION

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 [1]. Under certain conditions, exposure to RF radiation with power densities of approximately 100 W/m^2 or more could result in measurable heating of biological tissue[2]. 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[3]. 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 [3]. 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) [4], International Commission on Non-Ionizing Radiation Protection (ICNIRP**) [5]**, National Radiation Protection Board (NRPB)[6] and The Federal Communications Commission (FCC**) [3]**. Telecom Regulatory Commission in Sri Lanka (TRCSL) uses FCC guidelines for safety issues.

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. Exposure from mobile phone base stations is basically divided into the near field and the far field exposure, where far field exposure measurements are used for public exposure level assessment. The radiation from a mast depends on its antenna characteristics, like the antenna gain, emitted power, directivity, height and the tilt angle of the antenna. Also, it is known theoretically that at the far field of the antenna the radiation intensity reduces according to the inverse square law. Typically, radiation from the GSM antenna reaches the ground level at 50 to 300 m [7]. Thus it is expected that under the mast, low radiation levels can be found.

As a result, in Sri Lanka, more base stations are being installed in every part of the country and according to the TRCSL's 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.

In Sri Lanka in the year of 2005, from the same cities considered in this research, the maximum exposure quotient was reported at Badulla and it was 0.0228% from the permissible level [8]. At that time, only 900 MHz band was in operation from four network providers.

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 [9]. In United Kingdom, from 118 locations maximum power density reported was 0.0083 W/m^2 [6]. A study conducted in Israel shows that there is an association between increased incidence of cancer and living in the proximity of a cell phone transmitter station (within 350 m radius), with the obtained power density far below 0.0053 W/m^2 [10].

A study involving roughly 1,000 patients in Naila, Germany, concluded that the proportion of newly developing cancer case was significantly higher among those patients who lived up to 10 years at a distance within 400 m from cellular transmitter site, compared to those patients living farther away [11]. A similar study conducted in a remote part of a town in Westphalia, Germany involving 575 inhabitants, showed a statistically significant increase of the cancer incidence within a 400-metre radius of a mobile base station five years after it was established there [12].

A. 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 (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 (EMR) reference levels of power density as given by FCC guidelines for the general public are given in Table 1 [3].

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

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 [5]. 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,

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

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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 [4] to ensure safety. That is

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

If this condition is met, the environment is safe and otherwise there may be a risk in future. It is also the usual practice to estimate how many times the present EMR level is below the safe limit [6]. 'Times Below Limits' abbreviated as TBL is easily obtained from (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

II. METHODOLOGY

The measurements of field intensity were made at different locations, which represent highly populated flat urban environment, such as Colombo, Gampaha, Galle and Kurunegala. Measurements were also made along the coastal belt from Puttalam to Matara 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 Figure 1. The measurement set up used is shown in Figure 2.

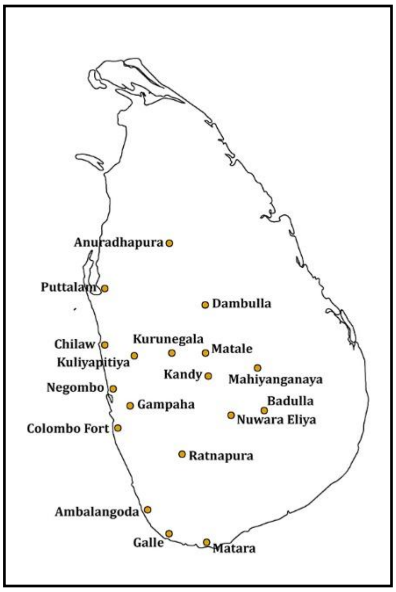

Figure 1. Site survey map.

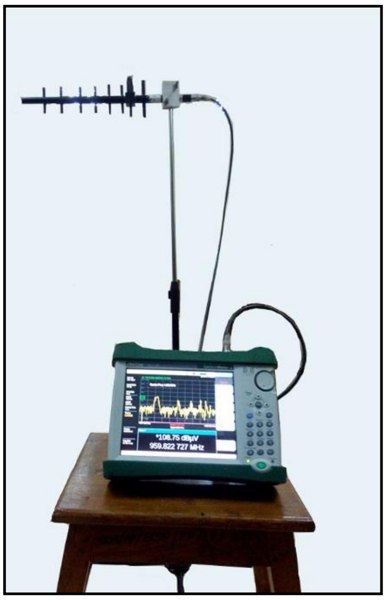

Figure 2. Measurement set-up.

It consists of standard Yagi-antenna (Telewave product – USA) of different frequency ranges and a spectrum analyzer (Anritsu MS 2712 E – 100 kHz to 4 GHz). Three different antennas are used to measure the signals in 900 MHz, 1800 MHz and 2 GHz bands.

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 location of each city. This particular location was selected by considering the most populated area of that city such as public bus stands, railway stations, playgrounds, etc. This location was

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selected by avoiding the large buildings where interferences might be caused. The antenna was mounted 1.4 m above the ground level (i.e., the approximate height of all human beings) and it was replaced according to the frequency band considered. For a particular signal, the maximum received voltage; V_m in dBμV, was obtained from the spectrum analyzer, by rotating the antenna in 360^0. For instance, table 2 shows some of the data of maximum strengths received at Colombo Fort (measurements were done at the railway station) from one of the leading network providers operated in 1800 MHz – LTE band. Likewise for a particular location, all the signals from five different network providers were considered. For one frequency band, all signals received belong to different network providers within the allocated frequency slots were scanned. Figure 3 shows the frequency slots allocated to the network providers in all frequency bands. This was repeated for other two frequency bands as well. For a particular city, large number of signals were considered. A typical spectrum analyzer measurement is shown in Figure 4.

Table 2 : Data sample of maximum received strengths at colombo fort w.r.t the 1800 MHz – LTE band.

Frequency	Received maximum Strength (dBμV)
1862.5	141.2667
1862.7	139.3387
1862.9	147.2827
1863.1	157.8027
1863.3	162.5347
1863.5	162.5467
1863.7	162.6267
1863.9	162.5707
1864.1	161.5027
1864.3	167.2707

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

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

Where K (dB/m) is the antenna factor which is the ratio of electric field strength of the antenna to the voltage produced at antenna's connector and L (dB) is the antenna cable loss. The cable loss was measured experimentally using a synthesized signal generator and it was observed that L = 8 dBμV. The value of K is given by the antenna manufacturer.

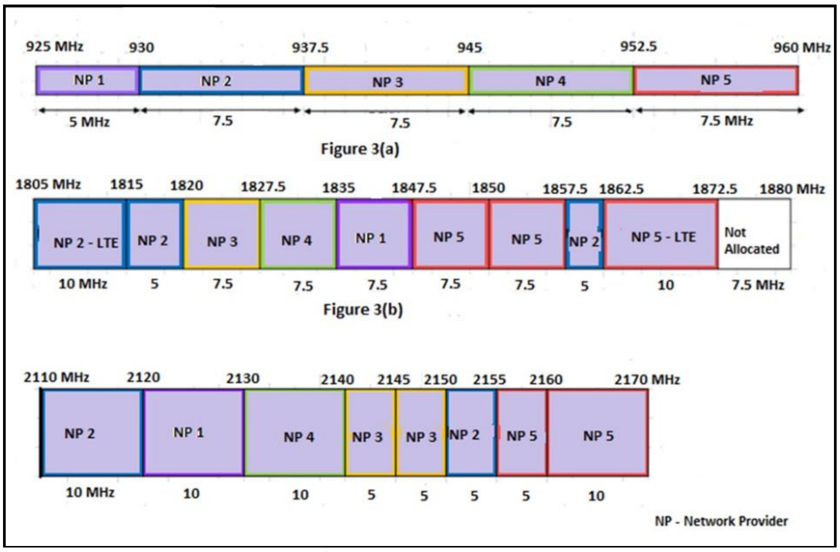

Figure 3. Frequency slots allocated for the network providers in downlink stream [Figure (a) in 900 MHz band, Figure (b) in 1800 MHz band, Figure (c) in 2 GHz]

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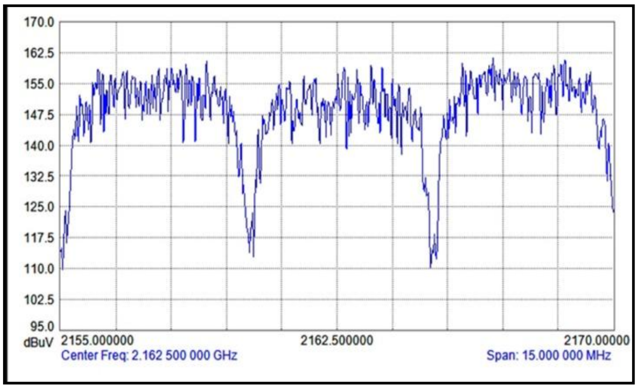

Figure 4. Spectrum analyzer measurement of 2 GHz frequency band signal at Galle.

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

$$E_{Worst}^2 = E_X^2 + E_Y^2 + E_Z^2 \quad ; \quad E_X = E_Y = E_Z = E_{Max}$$

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

From (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 (5) to (7). Since a large number of data had to be processed, a Java program was written to incorporate (5) to (7) and to get the results from (3). The calculated values of field intensity and power density were compared with FCC electromagnetic radiation reference guidelines given in Table 1.

III. RESULTS AND DISCUSSION

Table 3 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 [13]:

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 3 show the maximum possible exposure levels because these results are based on the worst-case condition and they are below the FCC guidelines.

Table 3 also shows the comparison between the exposure quotients due to mobile base station antennas in 2005 & 2017. Figure 5 illustrates the comparison of exposure quotients in the years of 2005 and 2017.

Among the locations considered, Figure 5(a) shows the highest exposure level is at Ratnapura and measurements were taken at a place close to the public bus stand. From Table 3, the highest contribution to RF absorption by the human body at this site is due to 2 GHz band.

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Table 3.Exposure quotients of main cities w.r.t. different frequency bands.

City	Exposure Quotient $\times 10^{-3}$ in 2017				Exposure Quotient $\times 10^{-5}$ in 2005
	900 MHz	1800 MHz	2 GHz	Total	
Ratnapura	00.267	04.915	74.832	80.014	00.210
Gampaha	08.142	26.539	09.873	44.554	02.120
Badulla	18.294	01.005	19.679	38.978	22.800
Kandy	13.282	07.373	08.278	28.933	00.206
Kurunegala	04.151	02.191	13.518	19.860	00.235
Anuradhapura	07.025	01.913	10.063	19.001	11.000
Galle	02.200	01.850	13.820	17.870	14.090
Ambalangoda	01.406	02.085	11.456	14.947	00.356
Matara	00.480	12.886	01.213	14.579	03.210
NuwaraEliya	01.837	00.440	09.057	11.334	00.475
Colombo Fort	00.787	03.794	01.758	06.339	09.520
Matale	03.106	00.400	01.979	05.485	00.030
Negombo	01.887	00.392	01.326	03.605	00.513
Kuliyapitiya	01.907	00.855	00.674	03.436	00.005
Dambulla	00.894	00.303	02.231	03.428	00.227
Chilaw	01.601	00.638	01.103	03.342	12.100
Mahiyanganaya	00.230	00.124	01.429	01.783	00.118
Puttlum	00.372	00.037	00.411	00.820	02.260

However the exposure level is approximately one – tenth of the accepted limits and therefore it is not much less than the specified limits. The minimum exposure level reported from Puttlum and is 1220 times lower than the permissible level.
According to Table 3, it also appears that in 11 sites out of 18, 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 additional features given. Among these, most recently system upgraded sites such as Ratnapura transmitted higher power levels to have a maximum coverage area. The exceptions are the sites at Gampaha, Matara, show comparatively higher exposure levels from 1800 MHz band and Kandy for 900 MHz band.

The other significant point is that in most populated areas such as Colombo Fort, 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.

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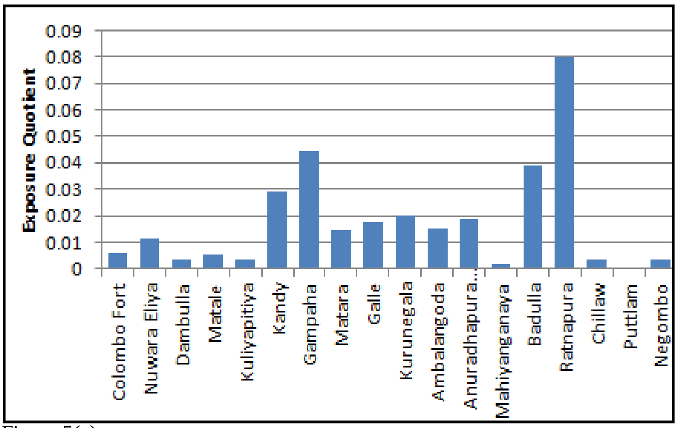

Figure 5(a)

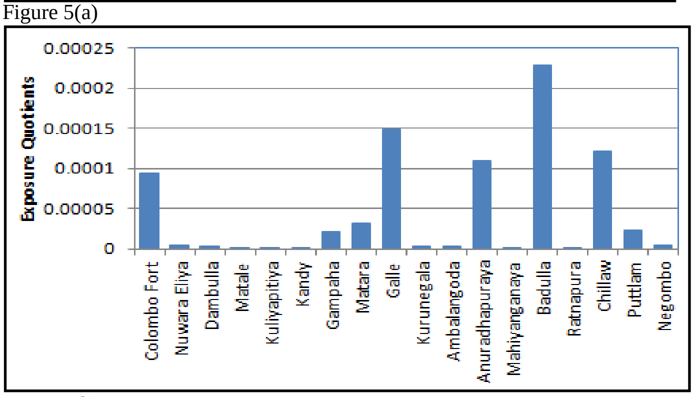

Figure 5(b).

Figure 5.Exposure Quotients of main cities in Sri Lanka due to mobile base stationantennas. [Figure5(a) in 2017 & Figure5(b) in 2005]

For the hilly areas such as Badulla and NuwaraEliya, 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 cities considered, the maximum signal received with respect to each band is given in Table 4.

Table 4: Maximum received signal strengths in all measured cities w.r.t each frequency band

Frequency Band	Location	Signal Frequency (MHz)	Signal Strength (dBµV)
900 MHz	Gampaha	946.4	200.502
1800 MHz	Gampaha	1859.4	196.127
2 GHz	Rathnapura	2112.4	181.307

With comparison of the results obtained in 2005, as in Figure 5(b), results showed that at present, the exposure factor in each of the cities has increased drastically. In 2005, only 900 MHz band was in operation and four network providers were functioned at that time. At present, most of the cities such as Kandy, Matale, Kuliyapitiya, Kegalle, Ratnapura, Kurunegala and NuwaraEliya show several thousand times increase in exposure quotient than the results in 2005. Since the proper cell planning at Colombo Fort, increase in exposure quotient is below hundred times.

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IV.CONCLUSION

Measurements indicate that the exposure levels due to all mobile cellular network providers as at August 2017 for the general public at locations considered in this work are below the FCC specified safety guidelines. But in some places such as Ratnapura and Gampaha exposure levels are bit significant with comparing to the other sites. From the sites measured, highest exposure level is reported at Ratnapura mostly due to the 2 GHz band but still at the one-tenth of the permissible level. Colombo Fort shows comparatively lower values due to the installation of micro cellular base station antennas by replacing macro cellular base station antennas. The total exposure from all sites considered, about 75% of it is due to the 2 GHz band. Some of the hilly areas show comparatively higher exposure levels than flat terrains. With the comparison of the results obtained in 2005, it can be concluded that the exposure quotient has increased considerably at present. 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 due to the competition among the network providers. 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 exposure levels as they transmit lower powers. Also after the installation of a new base station, the governing body should monitor the signal strengths transmitted by that antenna and make the public aware of the outcome.

REFERENCES

[1]. E. Singh, “Cell phone hazards and recommendations”, *J. Telecommunications (India)*, Vol.59, no.6, pp. 44-50, 2011.
[2]. James C.Lin, “Biological Bases of Current Guidelines for Human Exposure to Radio-Frequency Radiation’, *IEEE Trans. Antennas Propagat*, Vol.45, No.3, June 2003.
[3]. FCC Std.,Guidelines for Evaluating the Environmental Effects of Radio Frequency Radiation, FCC 96-326, Washington,DC,1996.
[4]. IEEE International Committee on Electromagnetic Safety, “IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300GHz,” (IEEE C95.1-2005) 2006.
[5]. ICNIRP Std., Guidelines for Limiting Exposure to Time-varying Electric, Magnetic and electromagnetic Fields (Up to 300 GHz), Health Physics, 74, 1998,pp.494-522.
[6]. S.M. Mann, T.G. Cooper, S.G. Allen, R.P. Blackwell and A.J. Lowe, “Exposure to Radio Waves near mobile Phone Base Stations”, NRPB-R321, June 2000.
[7]. Mann, S.S., T.G. Cooper, S.G. Allen, R.P. Blackwell, and A.J. Lowe. 2000. *Exposure to Radio Waves Near Mobile Stations.* National Radiological Protection Board: Chilton, Oxon.
[8]. M.A.A. Karunarathna and I.J. Dayawansa, "Human Exposure to RF radiation in Sri Lanka", Sri Lankan journal of Physics, vol.6, pp19-32, March 2005.
[9]. M. Nahas, T. Mohammed and Simsim, “Safety Measurements of Electromagnetic Fields Radiated from Mobile Base Stations in the Western Region of Saudi Arabia”, *Wireless Engineering and Technology*, Vol. 2, pp. 221-229, 2011.
[10]. Wolf, R., and D. Wolf. 2004. “Increased Incidence of Cancer near a Cell-Phone Transmitter Station”. *International Journal of Cancer Prevention*. 1(2):1- 19.
[11]. Eger, H., K.U. Hagen, B. Lucas, P. Vogel, and H. Voit. 2004. “The Influence of Being Physically Near to a Cell Phone Transmission Station Mast on the Incidence of Cancer”. *Umwelt. Medizin. Gesellschaft*. 17:1-7.
[12]. Eger, H. and F. Neppe. 2009. “Incidence of Cancer Adjacent to a Mobile Telephone Basis Station in Westphalia”. *Umwelt MedizinGesellschaft*. 22(1): 55-60.
[13]. Consultation document (2017, August), Radio Frequency spectrum allocations of Sri Lanka, Telecommunications Regulatory Commission of Sri Lanka (TRCSL). Available: http://www.trc.lk.