academicJournals

Vol. 10(2), pp. 79-85, 30 January, 2015
DOI: 10.5897/SRE2014.6025
Article Number:769F19C49799
ISSN 1992-2248

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Assessment of non-ionizing radiation from radio frequency energy emitters in the urban area of Natal City, Brazil

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Received 25 June, 2014; Accepted 12 January, 2015

The massive increase of wireless communications in the world calls for responsible actions by governments in order to prevent possible health hazards. In addition to cellular towers overcrowding in urban areas, it is also important to consider other radio frequency radiations from different sources. The electric field intensity is one of the fundamental parameters to assess the exposure of human beings to Non-Ionizing Radiation (NIR). In this study, all main non-ionizing radiation sources in the urban area of Natal, Brazil (a city of about 860.000 inhabitants) were located and characterized with respect to frequency band, telecommunications service and integrated electric field strength. Measurements of far electric field intensity with frequency ranging from 30 MHz to 3 GHz were made in a survey of 140 outdoor points spread across all the 167.26 km^2 area of the city. The results obtained have made it possible to draw a map of the regions of the city according to different electric field and exposure ratio (ER) intensities. In 71.4% of the sampled outdoor points, the highest exposure ratio measured were originated from TV broadcasting services, 22.1% from Transmissions Cellular Towers and 6.4% from Frequency Modulated Broadcasting.

Key words: Non-ionizing radiation, electric field intensity, TV broadcasting, radio frequency radiation, measurement of radio frequency radiation, propagation in Urban Areas, International Commission on Non-Ionizing Radiation Protection (ICNIRP).

INTRODUCTION

Non-ionizing radiation (NIR) is the radiation in the part of the electromagnetic spectrum below 300 GHz where there is insufficient energy to cause ionization (ANATEL, 2002). The United Nations Conference on Environment and Development held in 1992 in Rio de Janeiro established the Precautionary Principle which has become the basis for environmental policies carried out by many countries, besides being the landmark for the

structuring of the Environmental Law.

The Precautionary Principle is part of Principle 15 of the Declaration of Rio (2013) and states that “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation”.

Reactive oxygen species (ROS) concentration increase within the cell caused by RF/MW radiation seems to be a biologically relevant hypothesis to give clear insight into the RF/MW action at non-thermal level of radiation (Gotsis et al., 2005).

Environmental protection norms set limits to existing non-ionizing radiation emission and are inspired mainly by documents issued both by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the American National Standards Institute (IEEE/ANSI). The limits have been established essentially based on thermal effects of electromagnetic fields, which are well known. Lately, the non-thermal effects of non-ionizing radiation (effects on the nervous, cardiovascular and immune systems, etc.) have been under research, and special attention is being drawn to a World Health Organization (WHO) project which involves scientists from 45 different countries in an attempt to address the issue (ICNIRP, 1998).

The ICNIRP (1998) defined guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields. In establishing exposure limits, the commission recognizes the need to reconcile a number of differing expert opinions.

Electromagnetic fields with wavelengths longer than 10 m (frequencies lower than 30 MHz) have interaction properties which differ greatly from those with wavelengths that are approximately equal to or less than the physic dimension of the human body. A radiofrequency band of 0.3-30 MHz, for example, is used in medicine for ablation, coagulation and tissue cauterization (LIN, 2012).

On the other hand, considerable controversy surrounds the possibility of a link between exposure to Extremely Low Frequency (ELF, ranging from 3 to 30 Hz) magnetic fields and an elevated risk of cancer. Although, results suggest that indeed the magnetic field may play a role in the association with leukemia risk, there is uncertainty because of small sample numbers and also due to a correlation between the magnetic field and proximity to power lines (ICNIRP, 1998).

The intensity of the electromagnetic radiation is typically measured by the power density per square meter (w/m^2) or by the intensity of the electric field (V/m).

The effects of the absorption of the NIR by human body tissues present distinctive characteristics for different radiation frequencies. On that account, the laws made to limit the exposure to NIR are parameterized by the frequency of the wave operation (Table 1).

Every tissue of the human body has a different energy absorption rate. This energy absorption can be characterized by a parameter known as specific absorption rate (SAR). In practice, there are some difficulties in performing SAR measurements, the most important of them being the difficulty to measure inside the living tissue. Therefore, the radiation measurements in air are accepted. These levels will in general be smaller inside the biological tissue mainly due to attenuation of the radiofrequency energy traveling through various material media (Pérez-Vega and Zamanillo, 2005).

The SAR (especially in the head of mobile phone users) may be simulated using Mathematical methods, for example the Finite Difference Time Domain – FDTD (Salles et al., 2003).

There is a scientific debate on whether or not a long exposition to electromagnetic radiation levels lower than the limits could cause harmful effects on health. Many research projects are involved in this investigation by *in vivo*, *in vitro* and epidemiological studies (Feychting et al., 2005).

Eskander et al. (2012) published a case-study report as follows: “Persons of ages 14–22 years or 25–60 years who were exposed, for time intervals extended to 6 years, to RFR either from mobile phones or from base stations suffered significant decreases in their plasma ACTH and serum cortisol levels as compared to the control group. High significant decrease (Pb0.01) in plasma ACTH and serum cortisol levels was observed for persons exposed to RFR from base stations at distances extended from 20 to 500 m for a period of 6 years as compared to the control group”.

The definition of human exposure limits (ICNIRP, 1998) is the main reference used for ANATEL (2002) in Resolution Number 303 (Table 1). The Federal Law 11.934 (Brazil, 2009) defines minimum distances of at least 50 m from Radio Transmission Stations to “critical areas” (hospitals, schools, asylums, nurseries, clinics).

Measurements of RF level very close to 4 Base Cellular Stations (near field, 5, 15 and 25 m) in Benin City (Nigeria) at frequency 1800 MHz, shows higher values at 15 m away (Black and Henry, 2010).

In Italy (Region Valle d’Aosta), measurements of the electromagnetic fields (EMF) emitted by 3 UMTS base stations have been correlated with network counters related to traffic variation and radiated power in order to obtain a more realistic yet conservative calculation of the

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Table 1. Exposure limits to NIR (General population) ANATEL.

Frequency range	Electric field strength (E) (V/m)	Magnetic field strength (H) (A/m)	Plane-wave equivalent power density (Seq) (W/m2)
9KHz- to 150 KHz	87	5	x
0.15 to 1 MHZ	87	0.73/f	x
1 MHZ to 10 MHz	$87/f^{1/2}$	0.73/f	x
10MHz to 400MHz	28	0.073	2
400MHz to 2000MHz	$1.375\ f^{1/2}$	$0.0037f^{1/2}$	f/200
2GHz to 300 GHz	61	0.16	10

EMF emitted from a UMTS base station. The highest value of power obtained from the data averaged over 6 min was approximately the 75% of the maximum theoretical power that a radio base station can transmit (Bottura et al., 2012).

MATERIALS AND METHODS

In this study, the electric field intensities in the urban area of the city of Natal were measured with a Rohde & Schwarz FSH6 spectrum analyzer connected to an isotropic probe with a frequency range from 30 to 3000 MHz. The probe was fixed to a wooden tripod (1.65 m). A GPS and a notebook computer completed the system in order to run the proprietary software and to communicate with the spectrum analyzer. Three-axis polarization probe measurement in x, y and z and quadratic composition of the fields. Antenna Cable Set (only without connectorization) and short length, provided. Trace Mode / Detector: Max Hold / RMS.

The adopted frequency ranger covers most of the radio broadcasting services, the entire mobile telephony service and the IEEE 802.11 b/g systems. The isotropic probe has directivity close to unity (in linear scale), which means that it receives the signals coming from every direction almost equally, it is controlled by proprietary Rohde & Schwarz software allowing the user to configure the "measurement packets" for each service and therefore to run the entire setup with just a few commands.

Measurements were done preferably at peak mobile telephony times in order to maximize the probability of getting higher signal levels (10.00 am to 12.30 am and 3.00 pm to 7.00 pm), in far-field zone in 140 outdoor points covering all districts including the main streets and the neighborhoods of Cell Towers (including line of sight points), shopping malls, hospitals and schools, defined basically according to population density criteria. The chosen points are at an average distance of 320 m from the nearest tower base station. Figure 1 illustrates the measurements equipments. Figure 2 shows the measurement points in Natal City Area.

The equipment comes with proprietary software designed with some specialized features to perform NIR measurements. Particular characteristics of each service require different measurement packets to be configured. Frequency range, modulation type and transmission dynamics are among the main characteristics affecting measurement setup. Since the interest was in the analysis of EMF radiation from base stations, only the downlink emissions were measured.

The measurement packets of the software were adjusted according to Rhode Schwartz User Manual Instructions to our specific needs (different signal variability for different services and Brazilian service regulation / ICNIRP). The “dwell time” and bandwidths were adjusted according to Table 2. Hardware and software of FSH6 Spectrum Analyzer used are dedicated to this type of measurements. The mean was computed considering all loops and there was measurement uncertainty (mean) of 0.14 dB.

RESULTS

In Urban Area of Natal of September 2014, there were about 875 cellular Base Stations (358 Towers), 18 TV Broadcast Stations, 6 OM and 12 FM Broadcast Radio Stations. Most of the broadcast stations are located at east side of the city.

The highest values for electric field intensity were observed for TV Broadcast Service in 68.6% of the measured points (Table 3). Figure 3 shows the Total (broadband) Electric Fields Intensities in different points. The "exposure ratio" (ER) is one meaningful parameter to be analyzed. It is a quadratic relation between the measured electric field in a specific center frequency and the exposure limit for that frequency (Table 1). The ER is recommended by both ICNIRP (1998) and ANATEL (2002) for this kind of measurement.

$$ER = \sum_i \frac{E_{m,i}^2}{E_{L,i}^2} \leq 1 \quad (1)$$

In Equation (1), for each channel centered on frequency i, $E_{m,i}$ is the measured electric field, whereas $E_{L,i}$ is the limit for that frequency according to Table 1. So in the measurement point, the sum of all individual ERs (each one computed using electric field values –measured and limit – for a single frequency) must be less than or equal to the unity (Equation (1), which presents the overall ER). It means that the contribution of the ensemble of services to human exposure to NIR is below or equal to the limit. TV Broadcast Service dominates the ER composition (Table 4).

DISCUSSION

In spite of having about 340 Radio Base Stations Towers spread across the urban area, the Mobile Telephony is not the principal source of non-ionizing electromagnetic radiation in Natal. Radiation from TV Broadcast is the

Figure 1. Measurement equipments near a beach in the city of Natal.

Figure 2. Points of measurements in the urban area of Natal.

Table 2. Configuration of packages (FSH6 S. ANALYZER).

Services / Parameter	TV	FM Radio	Wi-Fi (2,4 GHz)	2G (GSM)	3G(UMTS)
Video BW	Auto	-------	-------	------	------
Dwell time	50 ms	50 ms	5000 ms	1000 ms	50 ms
BW for each central frequency	6 MHz	200 kHz	22 MHz	200 kHz	5 MHz

Table 3. Summary of electric fields measurements.

Service	Mean (V/m)	Highest values* (V/m)	% Highest Values **
TV Broadcast	8.14E-01	6.11E+00	68.6
Mobile Telephony (2G / 3G)	6.25E-01	4.39E+00	27.1
FM Radio Broadcast	2.25E-01	1.35E+00	4.3
WLAN (IE 802.11 bg)	1.83E-01	2.24E-01	0.0

* Maximum for each service in all measured points. ****** Percentage in which each service has the greatest electric field compared to other 3 services researched.

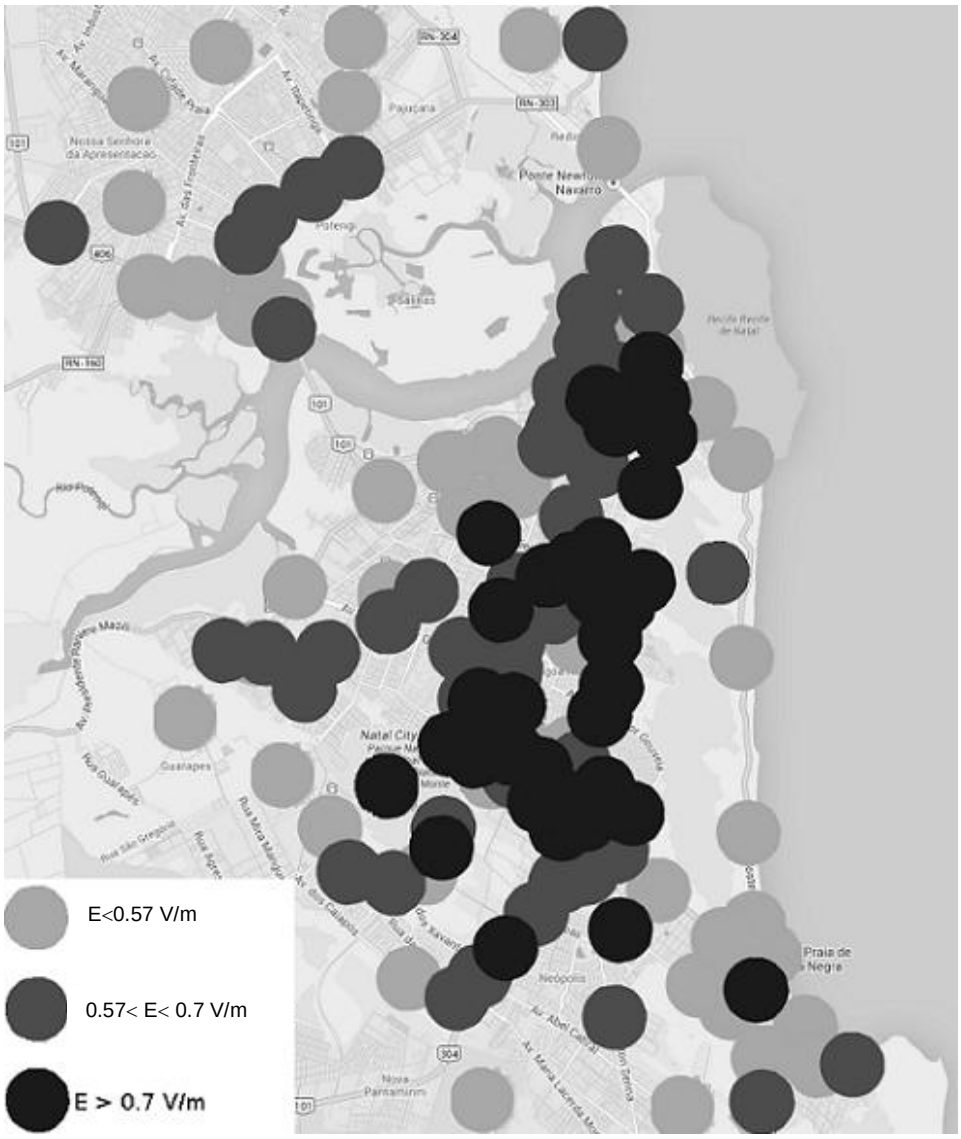

Figure 3. Map of the regions of the city according to different electric fields intensities.

highest in most part of the city.

Non ionizing radiation levels measured in Greece were also significantly below the safety reference levels. Specifically, 90% of the stations have been measuring electric field strength values below 3 V/m (Gotsis et al., 2005).

Table 4. Exposure ratio results.

Service	Mean considering all Points	Highest Values*	% ER Highest Values**
TV Broadcast	2.05E-03	4.77E-02	71.4
Mobile Telephony	5.79E-04	3.29E+00	22.1
FM Broadcast	1.35E-04	1.12E+00	6.5
WLAN (IE 802.11bg)	1,07E-05	1.35E-05	0.0

* Maximum for each service in all measured points. ****** Percentage in which each service has the great ER compared to other 3 services.

Measurements at Sakarya Maltepe in Turkey results to highest reading of electric field strength for FM Radio Services and the highest reading was 2.19 V/m (Tesneli et al., 2011). In Romania measurements of LTE1800 and LTE2600 were done in the city of Iasi.

According to the measurements performed for this preliminary survey, the maximal extrapolated E-field values varied from 0.008 V/m to about 3.5 V/m, which is less than 5.5% of the exposure limit (Lunca et al., 2014). In a practical exposure situation, the effects of simultaneous different NIR frequencies (FM, TV, WIFI and Cellular) are additive. Using Equation (1), the total ER for all points measured is 0.38 below the unity.

Conclusions

Non ionizing radiation levels measured (Electric Fields) in Natal city were below the safety reference levels. The intensity of electromagnetic waves from 18 TV Broadcast stations is higher in 68.6% of the sampled measurement points. TV Broadcast services dominate ER composition even for some points closer to towers of Mobile Telephony. There are some reasons to explain these results: the high power of TV Transmissions (9 to 101 kW ERP in Natal City) and the high technology of Mobile Telephony Transmissions. Most cellular radio systems provide for the use of transmitter power control to reduce co channel interference for a given channel allocation. In this case, the effective power of the Global System for Mobile (GSM) and Universal Mobile Telecommunications System (UMTS) transmissions is dynamic and rationally controlled according to instantaneous traffic of mobile calls and data communications. Cell phone towers are considered as low power installations when compared with broadcast TV (Nworgu et al., 2010).

The highest composed (all services) measured electric field value was 7.78 V/m at P22. Maximum exposure ratios are well below the ICINRP / ANATEL limits for non-ionizing radiations. The highest ER of 4.77 10^{-2} at P22 (TV) is below the unity. More precise assessment about Mobile Telephony radiation must be analyzed with care, such as measurements in points aligned in azimuth and elevation with the base stations' antennas. New field measurements will be necessary to monitor the significant growth of 4G base stations expected for the current and next years.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

This work is partially supported by FAPERN and CNPq under the scope of covenant 005/2011 PPPIV / number 65, and by UFRN – PROGRAD / PROEX / PROPESQ internal project.

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