1-INTRODUCTION

In Brazil, the Federal Law 11.934/2009 sets the limits of human exposure to electric, magnetic and electro-magnetic fields, associated with the functioning of radiocommunication transmitting stations, user terminals, and electric power systems at frequency bands ranging from 9 KHz to 300 GHz, seeking to ensure protection of human and environmental health (ANATEL,2002). The Brazilian norms follow the recommendations of the ICNIRP (InternationalComission on Non-IonizingRadiation), an organization recognized by the WHO (World Health Organisation). The major concern of environmental control bodies with regard to Non-Ionizing Radiation has been translated into the requirement of previous licensing for the establishment of Mobile Systems Base Stations, but there are other relevant sources of NIR (Non-Ionizing Radiation). Other services, such as TV and Radio Broadcasting, also contribute to the exposure to NIR (WHO, 2002).

In December 2019, there were 226.6 million mobile accesses functioning (not including iPads and similar gadgets), which correspond to 107.4 accesses in operation for every 100 inhabitants (TELECO, 2020). According to the data provided by ANATEL, the city of Natal (the capital of the state of Rio Grande do Norte), in November 2015, possessed a total of 882 Mobile Systems Radio Base Stations, 18 open TV Stations, 17 FM Radio Stations, 6 MW (MediumWave) AM Radio Stations. Experiments designed to study the interaction of electromagnetic fields and radiation with biological systems and the possible effects of such fields on the system can be divided into three categories: (1) in vitro biological experiments, (2) in vivo animal experiments, and (3) laboratory or epidemiological studies on humans (LIN, J.C., 2016).

The scientific knowledge about the effects on human health of the exposure to electro-magnetic fields is considerable and based on a vast number of epidemiological studies (FRIEDMAN, J.K. et al., 2004).

Heating is the main biological effect caused by the non-ionizing radiation. The levels of exposure due to the fields generated by radio stations normally are below the limits that could cause significant heat. The present debate is centred on whether long-term, low level exposure below the exposure limits can cause adverse health effects or influence people's well being (WHO, 2002, AESS, 2020).

Many health outcomes ranging from reproductive defects to cardiovascular and neurodegenerative diseases have been examined, but the most consistent evidence to date concerns childhood leukemia on low frequency (ELF-EMF) fields exposition. On the basis of statistical associations observed in epidemiology, the International Agency for Research on Cancer (IARC) in 2002 ranked the ELF-EMF in category 2B: possible carcinogen for humans (IARC, 2020).

Studies demonstrated that microwaves emitted from the cell phone, i.e. RF-EMW, do not produce thermal effect at specific absorption rate (SAR) of 1.6 Watts/kg. However, researchers have demonstrated that RF-EMW from commercially available cell phones have non-thermal effects. The literature contains controversial reports on the effects of RF-EMW on mitochondria, apoptosis pathway, heat shock proteins, free radical metabolism, cell differentiation, DNA damage and the plasma membrane (IARC, 2020). Capri et al. (2004), demonstrated that exposure at a frequency of 900 MHz was associated with a significant growth in annexin-positive human lynphocytes. Friedman et al (2004) proved that NIR may lead to carcinogenesis. This work aims to highlight the attention which should also be given to the radiation emitted by television (TV) broadcast towers, which utilize higher power levels with continuous emissions.

2- METHODS AND MATERIALS

2.1 Modelling of the Electric Field generated by TVs

Considering the finding that the greatest contribution to electromagnetic pollution in the city of Natal stems from the radiation emitted by the TV stations, and that, unlike the radiation emitted by the cellular stations, and that, there is a considerable variation in the intensity resulting from the stations TV in different areas of the city, a model was developed to better characterize the variation of this intensity. The main objective of this modeling is to allow the extrapolation of probable average values of Electric Field Intensity anywhere in the urban area of Natal.

The logic flowchart in Figure 1 illustrates the sequence to be adopted, where the four equations can be applied to estimate the Electric Field Intensity in relation to the area where the point is located.

The modelling for the calculation of the Electric Field Intensities using the Multivariable Regression technique is an instrument that can be useful for mapping the electromagnetic non-ionizing radiation in urban areas. Possession of this tool may allow better preventive conditions forenvironmental control bodies to monitor the degree of radiation to which the population is exposed so as to authorize or limit new developments in each part of the city.

The identification of the areas with the highest intensities of radiation also allows for the rational implementation of more frequent monitoring, thus ensuring more reliable preventive data.

In an open space propagation environment, the Electric Field Intensity (farfield) generated by the radiation emitted by a transmitter is related to the Power RF received using the equation 1 (LIN, J.C., 2016).

$$P_r(d) = \frac{|E|^2 G_r \lambda^2}{480\pi^2}\ W \quad (1)$$

E: Electric Field Intensity

Pr: RF Power received.

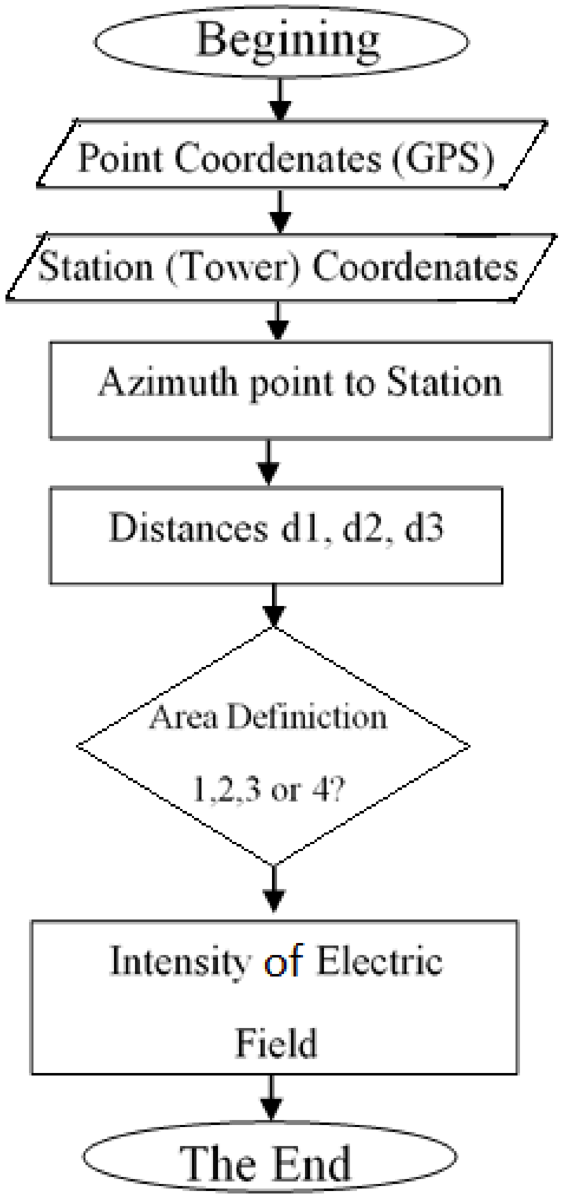
G_r: Gain of the receiving antenna.

λ: Wave Length.

The mean RF Power in environments with obstruction can be represented by the equation 2 CAPRI. M. et al, 2004).

$$\frac{P_r}{P_t} = \frac{\gamma}{d^n} \quad (2)$$

Figure 01 – Logic flowchart for the estimate of the Electric Field generated by TV stations.



Source: created by the authors.

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E: Electric Field Intensity

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The mean RF Power in environments with obstruction can be represented by the equation 2 (HAYKIN, S., MICHAEL M., 2008).

$$\frac{P_r}{P_t} = \frac{\gamma}{d^n}\ (2)$$

In equation 2, γ represents the loss in relation to the frequency, the height of the antenna and other factors. The exponent n is the mean attenuation factor in the path. P_t is the output power effectively radiated by the transmitter in a given direction. In relation to equations (1) and (2), and considering Gr=1 (Electric Field Intensity in a given point without the influence of the receiving antenna). The Tabel 1 shows the Patth loss exponent **n** for different environments (HAYKIN, S., MICHAEL M., 2008)

$$|E| = \frac{21.9}{d^{\frac{n}{2}}}\sqrt{\gamma P_t}(3)$$

Table 1 – Path loss exponent **n** for different environments

Environment Path loss exponent	n
Free Space	2
Rural Area(plain)	3
Rural Área (mountainous)	3.5
SuburbanÁrea (plain)	4 to 6
Dense Urban Área(tall buildings)	4.5

Source: Haykin and Michael (2008)

The intensity of the eletro-magnetic field generated by TVs in any given point in the city will be the result of the vectorial sum of the fields generated from the 3 locations that concentrate all TV transmittors in town (figure 2).

The Electric Field Intensity generated by 18 TVs anywhere in the city will be the result of the vectorial sum of the fields generated from the 3 Sites, where all TV transmitters in the city are concentrated. The 18 TV Broadcasting Towers in Natal are found in 3 areas (Sites 1, 2 and 3) located in the East side of the city. The Electric Field Intensity generated by TVs at any given point in the city is the result of the vector sumof the generated fields of the 3 Sites, as shown in Figure 2. This calculation, strictly following the Theory of Electromagnetism, becomes difficult due to the difficulty in finding precise data on buildings, trees, variations of terrain relief, automobile traffic, circulation of people and powers effectively radiated along each RF propagation line.

Figure 2 – Location of the TV Broadcasting Towers in the city of Natal (Sites 1, 2 e 3) and illustration of the incidence of the Electric Field Intensity produced by TVs at a given point in the urban area.

Source: created by the authors using Google Maps

The Total Electric Field Intensity at any given point in Figure 2 is obtained from the equation (3).

$$|E|_t = \sum_{i=1}^{3} \frac{21.9\sqrt{\gamma P}_{ti}}{{d_i}^{n/2}} \quad (3)$$

$|E|_t$: Total electricfiel data given point (V/m), Pti: Effectively Radiated Power by transmitter from Site i towardsthe point locatedat a distanced_i. The Powers Ptidepend mainly on the effective power of each transmitter and on the radiation pattern of each antenna. The calculation of the Electric Field Intensity directly using equation (3) at a given point of an urban area is quite imprecise due to the difficulty in obtaining correct data on the characteristics of the obstacles, terrain relief, presence of automobiles and RF powers effectively transmitted in each direction by each antenna. These factors influence the values of n and P_{ti}in each direction of propagation.

The TV transmitters in the city of Natal operate with a maximum Effectively Radiated Power (maximum ERP) between 14.87 KW and 102.63 KW (data provided by ANATEL), with the utilization of antennas with horizontal polarization. The figures 3A, 3B and 4 show the main open TV Broadcasting Towers in Natal.

Figure 3A–Towers inMãeLuíza Hill. (Site 1) Figure 3B–Tower in Parque das Dunas (Site3)

Source: Authors

Figure 4 –TV Broadcasting Towers alongside Mobile Systemsand FM Radio Towers (Site 2).

Source: Authors

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For the modelling of the equationwhich gives us the Electric Field Strenth, the following general expression was used (4)

$$|E|_t = \beta_0 + \beta_1\, {d_1}^{\frac{-n}{2}} + \beta_2\, {d_2}^{\frac{-n}{2}} + \beta_3\, {d_3}^{\frac{-n}{2}} + \beta_4\, {d_4}^{\frac{-n}{2}} + \cdots + \beta_k\, {d_k}^{\frac{-n}{2}} (4)$$

There are 20 TV Broadcasting Stations in Natal. 12 of the transmitters are located in the same area of dunes called Morro do Tirol in the East side of the city. The 8 other transmitters are grouped in 2 other areas also in the East portion of the city. Thus, although there are 20 transmitters, it is possible to simplify equation (4) and make k=3. Equation 5 illustrates this simplification.

$$|E|_t = \beta_0 + \beta_1\, {d_1}^{\frac{-n}{2}} + \beta_2\, {d_2}^{\frac{-n}{2}} + \beta_3\, {d_3}^{\frac{-n}{2}} (5)$$

For the application of the Regression technique, the independent multivariables are the distances of each point from the radiation transmitting stations. The identification and location of these were done according to ANATEL's official records.

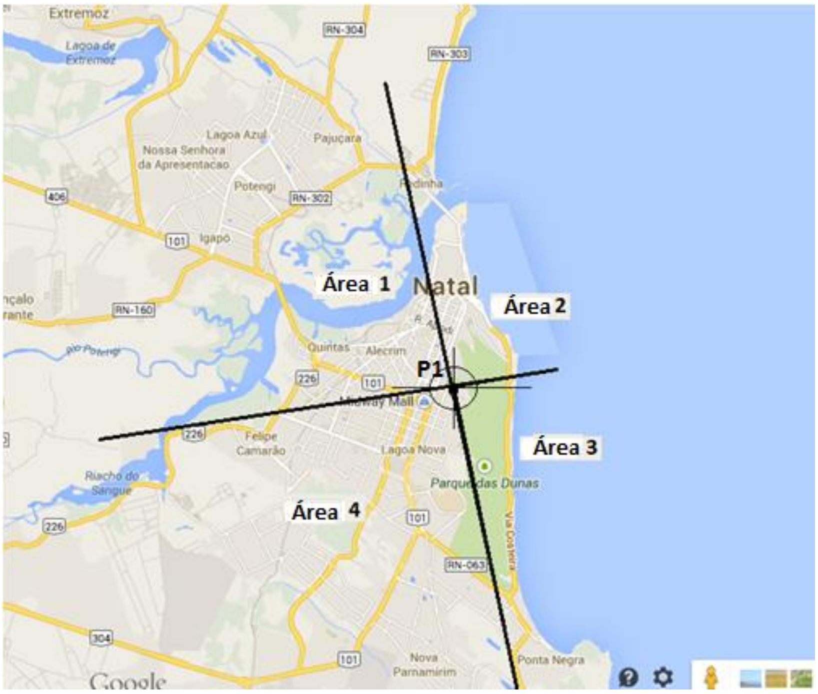
The coefficients $\boldsymbol{\beta}_i$ were obtained using the Multivariable Regression technique considering 160 samples of electric field intensity measurements (V/m) at several points in the urban area of Natal-RN. A database was created from the coordinates of each point, the Electric Field Intensity measurements, and the distances to the TV Broadcasting Towers. The estimated coeficients generate the lowest mean squared error of the equation (5) in relation to the measurements performed.

The quality analysis of the adjustment was made using the coefficient of determination $R^2$and p-value. The evaluation of the results took into consideration the statistical collinearity, and made sure that the errors showed a distribution near the Normal Curve (ARANGO, H.G., 2009).

In order to minimize the differences in urbanization and terrain relief, the modelling process was applied separately forthe four distinct areas of the city. These areas were defined according to their azimuths in relation to the main TV tower concentration site, as shown in Figure 5. Thus, each area may present distinct $ERP_i$and attenuation exponent n values. The Table 2 shows delimitation of the four areas for the application of statistical modelling criatede based on information on emitted power was estimated based on the antennas radiation diagrams registered at ANATEL.

The point (P1) of highest concentration of TV Towers in the city, the dunes in Morro do Tirol, has the following geographic coordinates: Lattitude (05`0 46` 00``S) and Longitude (350 12`00``W).

Figure 5 – Four chosen areas for the modelling of the Electric Field Intensity in the city of Natal.



Source: created by the author using Google Maps

Table 2 – Delimitation of the four areas for the application of statistical modelling

AREA	AZIMUTHS	% RF POWEREMITTED IN DIRECTION
Area1	252 to 342 degrees	28
Area2	342 to 72 degrees	24
Area3	72 to 162 degrees	18
Area4	162 to 252 degrees	29

Source: created by the authors

2.2 Procedures for Field Measurements

In order to measure the intensity of the electric field emitted by the existing towers and projected onto the population (downlinks), the Services and Frequency Bands object of this study were established according to Table 3. Thus, the measurements were carried out in four distinct groups: Mobile Telecommunication Systems, Television, FM Radio, and IEEE 802.11 Systems (WLANs - Wireless Local Area Networks). In each of the groups, the readings were performed with measurements that captured all the different sources (packages) operating simultaneously in their respective global frequency bands.

Table 3 – Frequencies and Services measured

Frequency Band (MHz)	Service
88-108 MHz	Rádio FM Broadcast
54-72 (VHF Channels 2-4)	TV Broadcast
76-88 (VHF Channels5-6)	
174-216 (VHF Channels7-13)	
470-890 (UHF Channels14-69)	
824-960	Mobile Systems (2G e 3G)
1805-1890	
1975-2165	
ISM 2400 MHz band (*non- overlapping channels 1,6 and 11*)	WLAN (IEE 802.11bg)

Source: created by the authors

During the period comprising the execution of the measurements, 882Mobile Systems Base Stations, 23 stations operating in Frequency Modulation (FM) and 18 TV broadcasting transmitters were registered, a total of 939 stations (ANATEL, 2019).

The measurements of Electric Field Intensity were performed using the following equipment and accessories: an isotropicprobewith a frequency range from 30MHz to3GHz (directivity close tounity in linear scale), a woodentripod (1.65m), a Rohde& Schwarz FSH6 spectrumanalyzer; a GPS and a notebook computer. The notebook ran proprietary software by R&S to communicate with the Spectrum Analizer. Table 4 summarises the settings of the measurement packages.

The features adopted in the measurements are : composition in quadratic fields; polarization through three-axis probe, with measurement in three axes. Short-length cable set, Trace Mode / Detector: Max Hold / RMS.

Table 4 – Settings adopted in the measurement packages

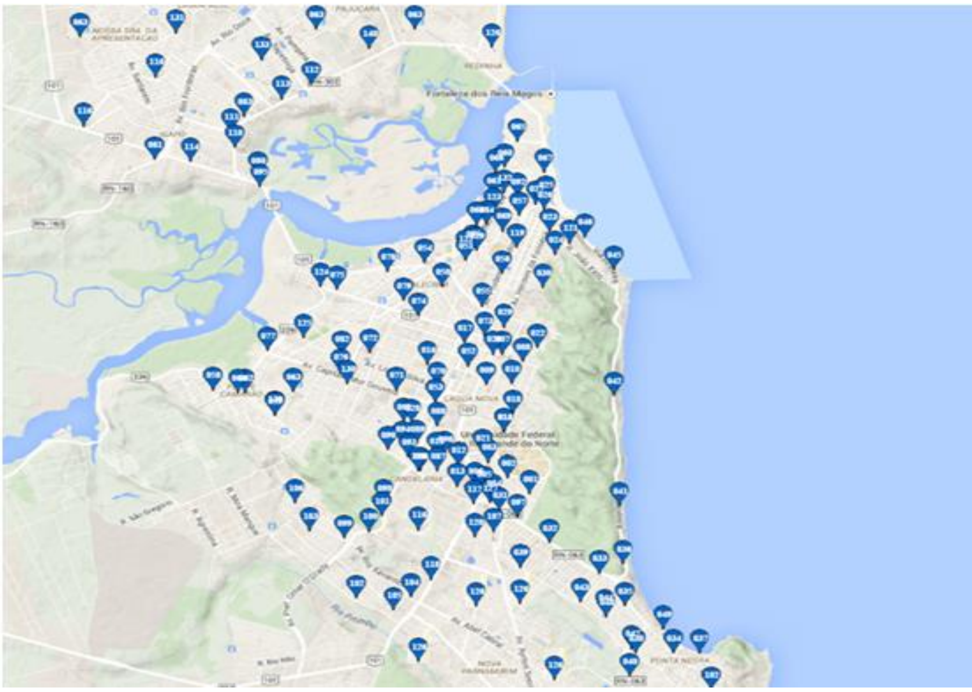
Services / Parameters	FM Radio	IEEE 802.11 b/g	TV	2G Mobile (GSM)	3G Mobile (UMTS)
Video BW	-	-	Auto	-	-
Dwell time	50 ms	5000 ms	50 ms	1000 ms	50 ms
BW for each central frequence	200 kHz	22 MHz	6 MHz	200 kHz	5MHz

Source: createdbytheauthor

The measurements were performed between 10:00 a.m.and 12:30 a.m. and 3:00 a.m. and 7:30 p.m., in far-field zone in 160 outdoor points covering all districts. Only the downlink emissions were measured. Figure 6 show the distribution of the points where the measurements took place. In some uninhabited areas of dunes and mangroves, access for the measurements was not possible.

At each point, the Total and PerServiceElectric Field Intensities were measured and recorded. Using a GPS, it was also possible to verify the geographic coordinates which allowed the identification of the Distances in relation to the transmitting towers.

Figure 6 – Location of the 160 points where the measuments of Electric Field Intensities were carried out in the city of Natal-RN.



Source: created by the author using Google Maps

The measurement packets of the software were adjusted according to Rhode &Schwartz User-Manual Instructions: dwell time was adjusted in 50 milliseconds for TV and FM radio, 1 second cyclically over 6 minutes, 13 times each point for GSM /UMTS, and 5 seconds for IEEE 802.11b/g. The RMS mean was computed automatically by the instrument considering all loops. The radio broadcasting services normally present little variation, as opposed to mobile telecommunication systems. The Figure 7 A and B shows the instruments used in the measurements.

Figure 7A–FSH6 Spectrum Analyzer and antenna used Figure 7B–Measurement in a public square.

Source: Rohde& Schwarz (7A) and Athors (7B)

The measurements of Electric Field Intensity indicated that the service with the greatest contribution in the urban area of the city of Natal is the TV. Table 5 shows a comparative summary of the measurements obtained. In 77.2% of the measured points, the NIR from TV Towers were higher than the other services tested.

Table 5- Summary of Electric Field Intensity measurements

Service	**Mean (V/m)**	**Highestvalues (V/m)**	**% ofhighestvalues**
TV Broadcasting	5.14E-01	4.18E+00	77.2
Mobile Systems (2G / 3G)	3.79E-01	4.19E+00	13.0
FMRadio	2.15E-01	1.35E+00	9.8
WLAN (IEE 802.11bg)	1.85E-01	2.24E-01	0.0

Source: created by the author

3 RESULTS

The application of equation 5 to several points in an urban area in which measurements were made resulted in characteristic error equations that relate the values actually measured with those calculated based on the model developed, as explained in (PINHEIRO, 2015). Multivariate regression processes the above model in search of parameters β0, β1, β2 and β3 that enable the minimum square error. This processing is done from the partial derivatives of the quadratic errors. The quality analysis of the adjustment was made based on the determination coefficient R^2 (Hair et al., 2005), the critical evaluation of the results took into account aspects of statistical collinearity, and it was also verified that the errors had a distribution close to the Curve Normal.

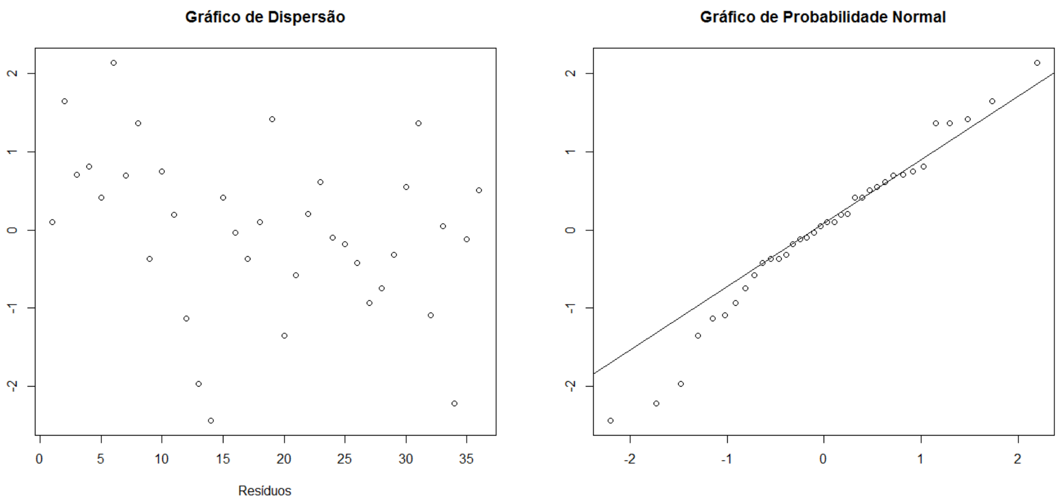
Table 6 indicates the best results obtained for the$\boldsymbol{\beta}_i$coeficientsusing the software R (*R Development Core Team*, 2015). For each area, attenuation exponents of propagation (n) between 2.2 and 3.0 were tested. The table shows the values of n that provided the best R^2values. In all cases, the values of $p<0.02$ were excluded: 1 outlier point in area 3 and 2 outlier points in area 1.

Table 6 – Summary of Results Obtained for the Coeficients using Regression Method and the Multivariable Data Analysis (Best results)

Area	β0	β1	β2	β3	n	R^2
1	0.1771	1.4838	0.3869	0	2.6	0.998
2	0.1323	0.9714	0.5095	0.4280	3.4	0.999
3	0.0279	2.0840	0	0	3.8	0.997
4	0.179	1.7327	0.3743	0	3.0	0.923

Souce: created by the authors.

Figura 08 – Residual analysis for the best result in area 1.



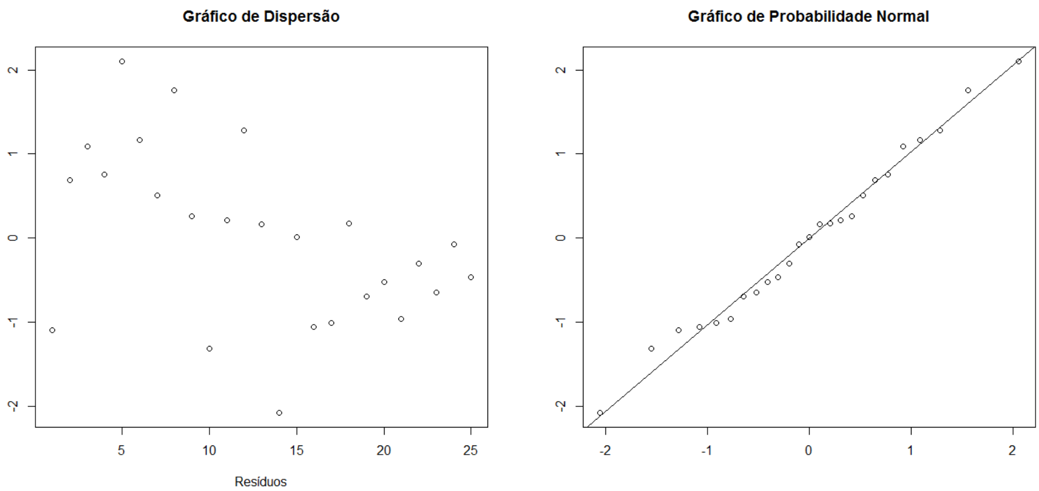


Figure 09 – Residual analysis for the best result in area 2.

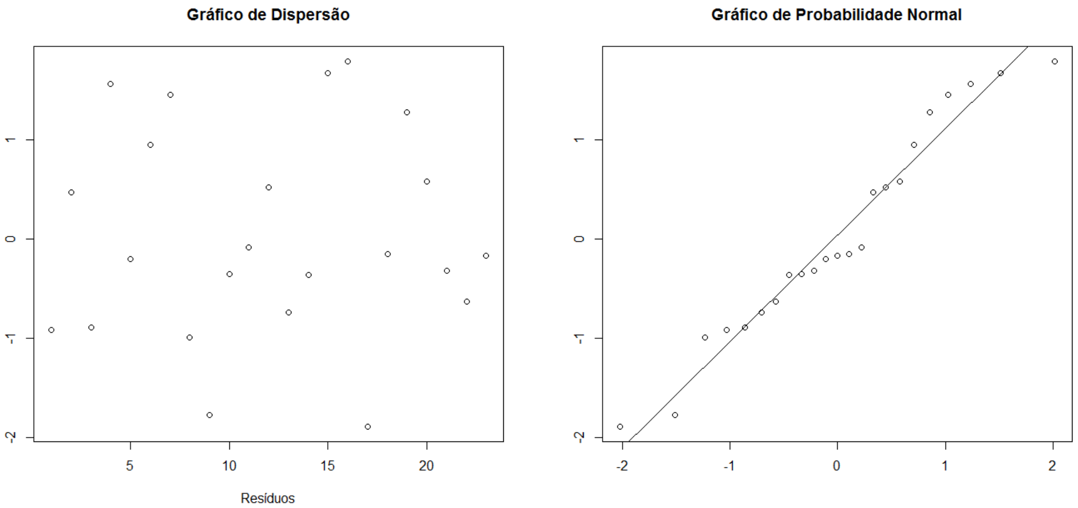


Figure 10 – Residual Analysis for the best result in area 3.

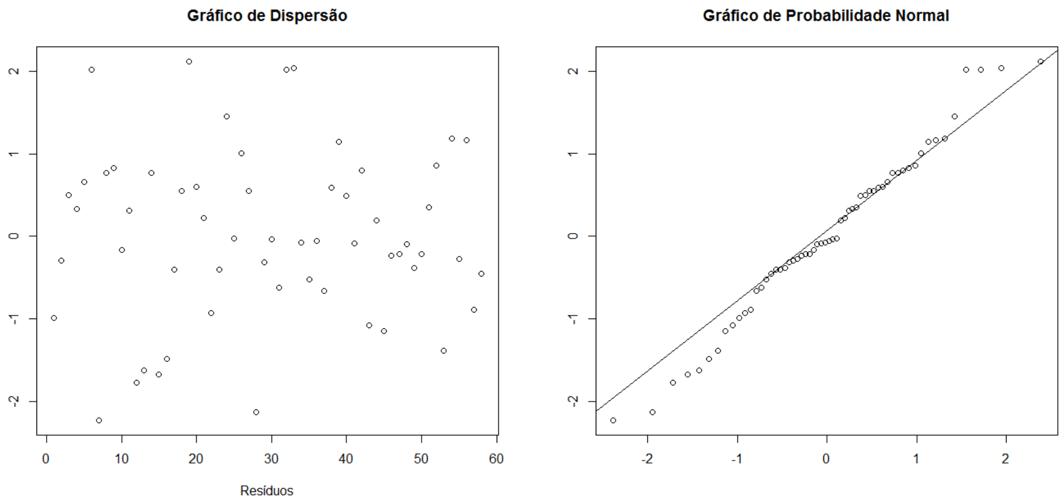
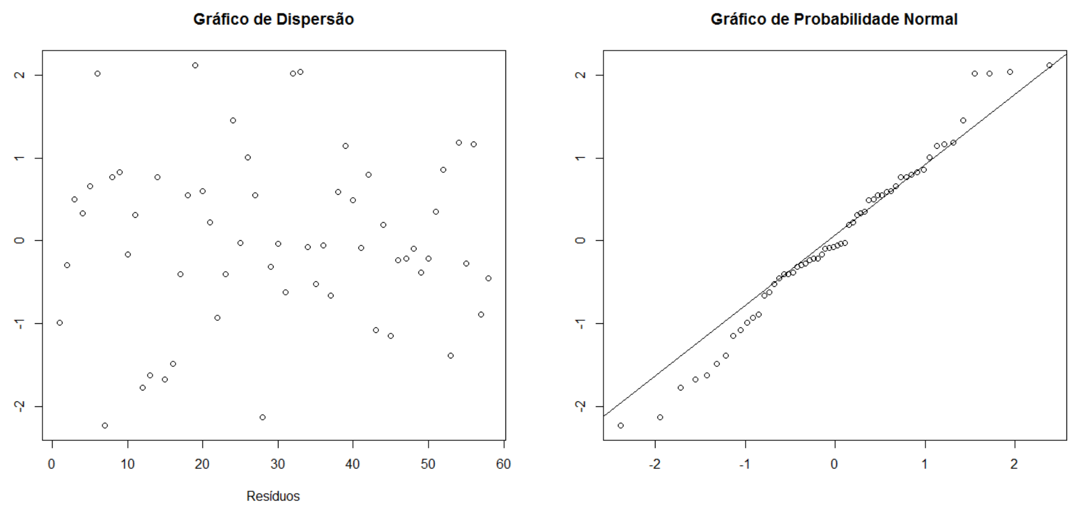
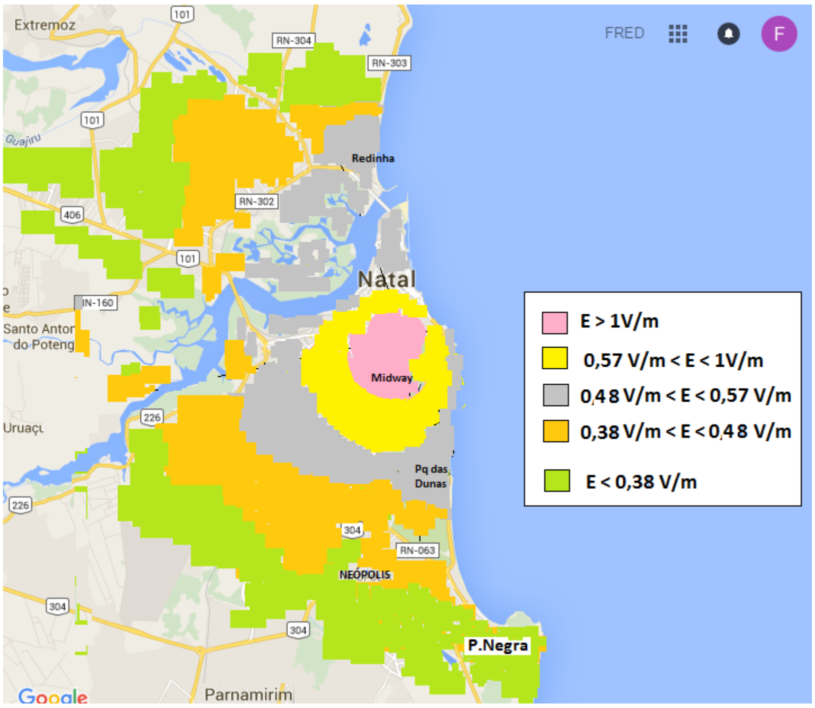


Figure 11 – Residual analysis for the best result in area 4.



In most cases, the open TV stations have fixed power, some exception occur with power reduction during the night time. The use of equation 5 with the parameters estimated in Table 2 made it possible, from the coordinates of any given point located in the city of Natal, to obtain an estimate of the Electric Field Intensity generated by TV stations. The Figure 12 shows the estimated Electric Field Intisity bands based on the results obtained.

Figure 12 – Mapping of the estimated Electric Field Intensities in the urban area of the city of Natal (Brazil).



Source: created by the author using Google Maps

4 CONCLUSIONS

The research produced modeling using the multiple multiple regression technique to define equations whose results allow the calculation of the field generated by the totality of TV transmitters anywhere in the city, with a comparison of the INRs emitted in the city with the exposure limits officially established. The RNI levels measured in the city of Natal are below the safety reference levels established in the legislation. The electromagnetic radiation generated by TV transmitters represented almost half of the total electromagnetic exposure (48.48%) in the city, being also responsible, punctually, for most of the peak values (maximum). Open TV services dominate the composition of the ER even for some points closer to the mobile phone towers.

The model for the calculation of the Electric Field Intensities using the Multivariable Regression technique is an instrument that can be useful for mapping the electromagnetic non-ionizing radiation in urban areas. Possession of this tool may allow better preventive conditions forenvironmental control bodies to monitor the degree of radiation to which the population is exposed so as to authorize or limit new developments in each part of the city. The identification of the areas with the highest intensities of radiation also allows for the rational implementation of more frequent monitoring, thus saving precius resources.

The application of the model must be fundamentedon the rigorous identification of the coordinates of existing stations and accurate measurement campaigns of the electric field intensity which lead to predictions according to statistical requirement. Some other aspects must be considered in the measurements: the choice of transversal streets, special attention given to areas near schools, kindergartens, hospitals, shopping centers, football stadiums and other points with higher people density.

In more dense urban areas with more relevant vertical growth rates, it is recommended that the measurement process be updated more frequently.´

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