Electromagnetic Field Measurement Method to Generate Radiation Map

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Abstract- **An electromagnetic field monitoring method is proposed and tested during measurement campaigns at urban zone of Bucaramanga city, Colombia. Communication tools are used integrated with a Geographic Information System, an online server and the access to data base by means of web services. A set of measuring equipment is connected to the communication system in order to manage a great amount of information and to analyze it, but specially to establish whether the international recommendations are being met or not. It is also possible to know which kind of factors are contributing to radiation level increasing by using NARDA field meters, Spectrum analyzers and other possible equipment, all of them controlled remotely through fixed or mobile terminals. Based on measured points, a continuous surface of radiation levels is plotted on a geographic map by using an interpolation algorithm.**

Keywords- **Electromagnetic field meter, electrosmog, exposure levels, ITU-T K.52 recommendation, NIR, Non-ionizing electromagnetic radiation.**

I. Introduction

Radio-based technologies bring two factors that must be well managed in order to increase a real quality of life in our society. One of them is the great set of opportunities for social development that these technologies provide and the other is the need of an environmentally friendly technology deployment for anticipating what some people call electrosmog [1]. Both of them have the same high level of importance because all technological development implies a new commitment to the environment and society.

So then, spectrum managements, and standards and regulations for Non-ionizing radiation need to be implemented in each country where wireless telecommunications demand is being increased continuously like in Colombia [2]. For instance, the number of active mobile subscriptions in Colombia increased in 6,4% in one year from 2010 to 2011 [3]. For the first topic mentioned above, there is an ITU Handbook for national spectrum management that begins highlighting the importance of radio-frequency spectrum and national spectrum management processes around the world [4]. For the second topic are three important international organizations, IEEE, ICNIRP and also ITU agency, who are working on these regulations and standards, they have developed exposure guidelines for workers and for the general public, except patients undergoing medical diagnosis or treatment. These guidelines are based on a detailed assessment of the available scientific evidence. One of those documents is IEEE 95.1 standard [5] and complemented with IEEE 95.3 [6] and IEEE 95.7 [7] recommendations by International Committee on Electromagnetic Safety (IEEE ICES). The other one is K.52 recommendation by ITU, based on the document [8] by ICNIRP. Colombian government published a decree law 195 of 2005 that is based on this K.52 recommendation, and through the telecommunications regulatory commission the government issued a document called “Código de buenas prácticas” [9] about good procedures to deploy new infrastructure of telecommunication in Colombia. In this way, this country adopts and implements recommendations of the Telecommunication Standardization Sector (ITU-T) on behalf of the International Telecommunication Union (ITU).

Electromagnetic fields produced by mobile phones are classified by the International Agency for Research on Cancer as possibly carcinogenic to humans (Group 2B), a category used when a causal association is considered credible, but when chance, bias or confounding cannot be ruled out with reasonable confidence [10]. On the other hand, electromagnetic fields produced by the base stations have been less questioned, but are seen by people as a threat.

Most of the difficulties that derive from Non-Ionizing Radiation (NIR) in Bucaramanga city and other developing cities of Colombia are due to misinformation. People make many complaints and demands when communications towers are installed near their homes. This is the main indicative of population concern about RNI levels control; the lack of a tool to socialize RNI monitoring, frequently makes the people to turn against technology development.

In this paper, the result of a detailed method designed to measure electromagnetic field in urban environment is presented based on ITU guidelines and recommendations. The iterative process for planning and setting the equipments is shown, also it is analyzed some decisions to be chosen in order to take a measure process more dynamic. After that, the next section describes the data analysis and the sector of the city with high level values where a frequency-selective measurement is done with the spectrum analyzer in order to determine the cellular frequency band contribution. Finally a real example of the method is shown with its results in a continuous radiation surface over Bucaramanga city map.

II. Methodology to Generate Georeferenced Maps of Non Ionizing Radiation in a City

This section describes a methodology to generate continuous maps of non-ionizing radiation distribution made from samples of electromagnetic field measurement gotten at

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measured points which were uniformly distributed along city streets, which was followed in this research. The methodology is based on ITU guidelines titled "Spectrum monitoring handbook" [11] and on recommendations by ITU-T K.52 [12], K.83 [13], K.61 [14] and K.70 [15]. The methodology consists of three fundamental processes: pre-engineering, Measurements, analysis data.

A. Pre-engineering process

Objective: Defining actions to perform planning of EMF measurement process in representative area of the city, as described below.

1) Segmentation of the city: It means to divide the city in zones with common characteristics, such as residential, commercial, industrial and educational. It is important because allows to analyze by groups of people who deserve a special care when is exposed to radiation, like for example children, elder and unhealthy people or under medical treatment [5]

2) Extracting a map of georeferenced antennas in the city: It entails detect, tabulate and reference geographically the main communication antennas located inside of the city that are used by network and service providers. The data to be tabulated for each antenna are: service type (cellular mobile telephony, trunking system, radio voice channels, FM or AM among others), antenna type, a rough antenna length, rough carrier frequency, geographic coordinates, height above ground and optional parameters like provider name among others.

3) Definition of measurement routes: Set a criterion to define the measurement routes in all zones, the measurement points have to be uniformly distributed (equidistant).

4) Determination of type of electromagnetic field region (near or far) Measured on the streets at 1.70 meters height above ground. A basic algorithm is used for estimation of field region type. It takes the data from antennas map (approximate frequency, height and antenna dimension) and it compares each wavelength with height through (1) and (2), which calculates boundary distance *di* where near field ends and far field begins, that means that the inner boundary of the radiating far field region is defined by the larger value between 3λ and $2D^2/\lambda$ if the maximum dimension D of the antenna is large compared with the wavelength λ such as defined by recommendation ITU-T K.61. [14] (Section 6.3.1)

$$di = Max\left\{3 * \lambda_i, \frac{2*Di^2}{\lambda_i}\right\} \tag{1}$$

$$hi > di \tag{2}$$

$$Max\left\{3 * \lambda_{max}, \frac{2*Dmax^2}{\lambda_{min}}\right\} < hmin \tag{3}$$

Where *Di* is the dimension of antenna i, λ_i is the wavelength of antenna *i*, *hi* is height above ground for antenna *i*, λ_{max} and λ_{min} is the maximum and minimum wavelength respectively among all antennas registered, D_{max} is dimension of bigger antenna found and *hmin* is the height of the lowest antenna found.

The inequality (2) defines the field region type that is on streets around the antenna *i* with height *hi* and boundary distance of field *di*. If (2) is true, then there is only far field; otherwise there are also near field at ground level.

The estimation algorithm has two stages: a) Stage of fast estimation. b) Stage of iterative estimation.

The inequality (3) is used in the stage of fast estimation, here the critical case is analyzed; it means to assume that an antenna has the minimum wavelength λ_{min}, the maximum dimension *Dmax* (it is supposed to be large compared with the wavelength) and the smallest height *hmin*. With these characteristics, the boundary distance *di* of this hypothetical antenna would be the highest value between all antennas. Therefore, if (3) is true, then it will be concluded that there is only far field region in all city streets.

When (3) is not true, the stage of iterative estimation will happen; and it is necessary to analyze separately each antenna through (2). Now, if each antenna height *hi* is higher than each boundary distance *di,* then the field region type in streets city will be only far field

5) Determining the field to be measured (electric and/or magnetic): For broadband measurement, the field component is selected through the type of field region (it was estimated at the step before); If region is far field, one component will be only measured (electric field or magnetic field), because in this region the electric field is proportional to the magnetic field, such as it is shown in (4). We propose to measure only the electric field. Now, If there are near field and far field, both the electric and magnetic field shall be measured in all routes, because (4) is not true for near field, according to recommendations ITU-T K.61 [14] (section 7.6) and ITU-T K.83 [13] (section 6.1)

$$\frac{|E|^2}{Z_0} = Z_0 * |H|^2 \tag{4}$$

6) Selection of equipment and probes for broadband measurement: Broadband electromagnetic field meter and probes are selected according to frequency ranges used by radio services located in the city and also depending on the field region type (whether near or far field).

B. Measurement process

Objective: Executing the process to measure electromagnetic radiation in georeferenced mode called "drivetest" through each zone selected according to the previous process. Technological systems and advanced tools are used to speed up the process and to reduce some critical error introduced by the instrument operator. General method to measure EMF is shown in Fig. 1. Method steps are described below

1) Automatic taking of broadband measurement: The process of EMF broadband measurement has to be very autonomous and systematic, such as it is indicated by recommendation ITU-T K.83 [13] in section 8.5.3, therefore computer systems of telemetry are used, which take advantage of modern information and communication technologies. At this stage it is necessary to: a) Set all systems to be used and b) Perform broadband EMF measurement by route, here it is important to consider the radiating region type in city streets; if the field region in the city is near and far field, the electric and magnetic fields are measured at all routes. If the far field predominates in the city, the electric field is only measured. This stage is shown in Fig. 2.

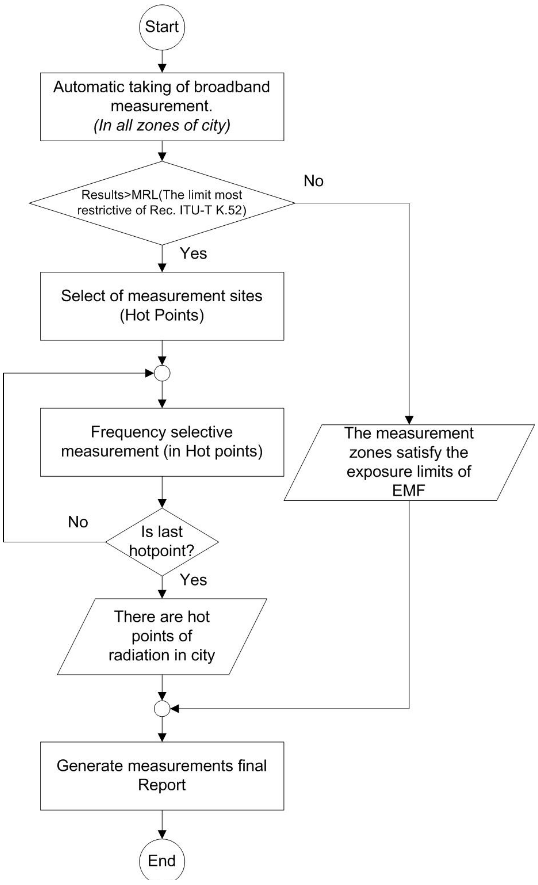

Fig. 1. General method of EMF measurement

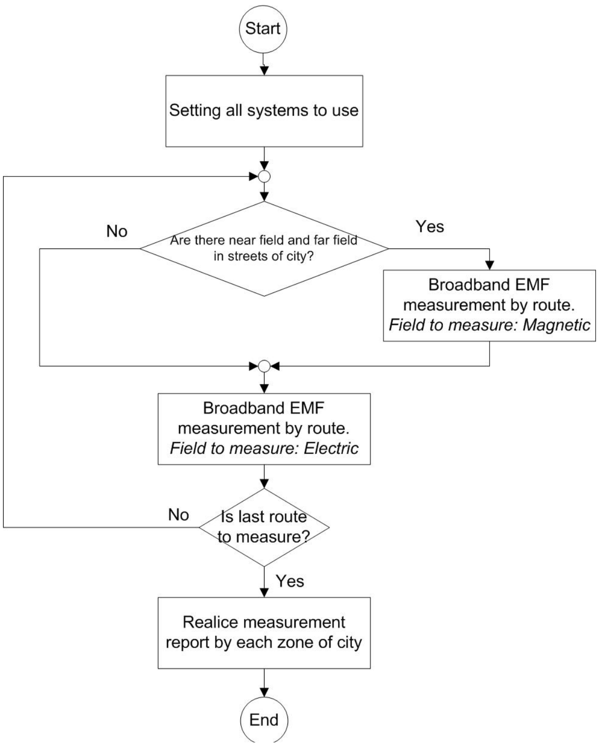

Fig. 2. Subprocess: automatic taking of broadband measurement

2) Frequency selective measurements for hotpoints: Results of the broadband field measurement in all routes are compared with the most restrictive limit (MRL) of recommendation ITU-T K.52 [12] by general public (28 V/m). If field value exceeds the MRL in one point, frequency selective measurements will be performed in each point found; these sites are named “hotpoints”. A spectrum analyzer is used in this stage, in order to identify significant radiation and quantifies field contribution per frequency; such as it is indicated by recommendation ITU-T K.83 in section 6, the Handbook Spectrum Monitoring of ITU in section 5.6.5.4 and resolution 001645 of Ministry of ICT of Colombia (article 5 pp 8).

The steps for frequency selective measurement are: a) identifying the radiation sources (antennas) nearer to measurement site (hotpoint). b) Selecting the proper antennas to spectrum measurement, according to frequency range. c) Measuring for 6 minutes with spectrum analyzer and software of automatic spectrum measurement (Example: GeoSpectScanner [16]). d) Saving the data. e) Sending to measurement web server. This process is repeated by each hotpoint of the city.

3) Broadband EMF measurement by route: This procedure is included in subprocess called “automatic taking of broadband measurement” and it indicates how to perform the broadband measurement by a route. This procedure has to be strictly used by each route of the city. EMF measurement software are utilized in order to achieve a process agile, efficient, systematized and minimum errors, the steps are shown in Fig. 3 and they are described below.

- Set Measurement Plan by route: It is necessary to define reference of field meter and probes, amount of sites or points to measure, time of data capture by site, sampling rate, start time, component of electromagnetic field to measure (or electric or magnetic.

- Set measuring instrument according to Measurement Plan: Broadband Field meter and GPS are initialized; the setting parameters and the parameters of remote connection are adjusted in equipments (capture time, sampling rate, and field component to measure)

- Place instruments in a site of the route: The equipments have to be installed on vehicle. Furthermore, the Broadband EMF meter has to be far over 20 centimeters from any metallic surface, such as it is recommended in ITU-T K.61 [14]. The vehicle and instruments have to be motionless in site in order to avoid alterations and noise in the measurement; also, in this case each site of a route is located at the midpoint of each street block.

- Capture and tabulate data from instruments: To take data from EMF meter and GPS as preset time marked in the Plan. The electromagnetic field and geographic coordinates are automatically captured by a computer with the measurement software at set times.

- Check data: The data are reviewed in this step, the operator looks up that there are not errors in data, null data and the process has finished correctly. If the data are not correct, the measurement process will be repeated in site.

- Send data to a database server: If there is Internet connection in site, data shall be send to a central measurement server so that the general public can access to this information, such as it is recommended by ITU-T K.83 [13] in section 10.

- Tabulate and geo-reference the data in a map, and generate report: After it has been measured the end site of route, then the data have to be organized at tables. Finally, a measurement report of route is generated (including Measurement Plan, results, tables with average, maximum and minimum, and map)

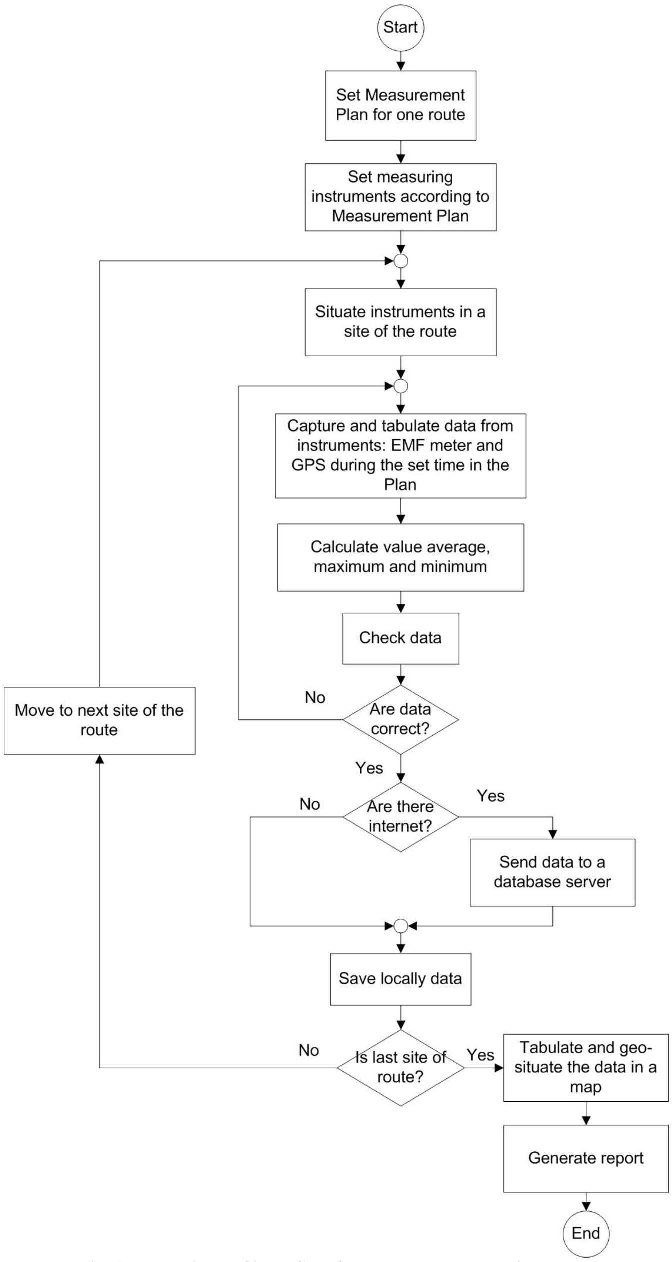

Fig. 3. Procedure of broadband EMF measurement by route

C. Analysis data process

1) Statistic analyze of measurement: It performs the descriptive statistic to all data, average, maximum and minimum values, standard deviation, variance and uncertainty are calculated; probability distribution and accumulative probability graphs are realized in order to analyze EMF strength of all measurement sites and to compare them with limits for human exposure to electromagnetic field of recommendation ITU-T K.52 [12].

2) Performing of continuous radiation map of the city: A map of continuous radiation is performed through the measured data of electromagnetic field in each site which they are related with geographic coordinates. Then, advanced techniques of spatial interpolation are used, for example: surrogate models (kriging method), Inverse distance weighted (IDW), spline method, etc. Kriging Method is used in our case because exactitude and behavior data.

III. Measurements

The objectives were to review the Non Ionizing Radiation (NIR) levels in Bucaramanga city, to find out hot points, sensitive places and to generate a non-ionizing radiation map of the city (the first in Colombia), in order to show truthful information to citizen through a free website and to offer tranquility.

A. Tools and systems used to measurement process

The campaigns of non-ionizing radiation measurements in Bucaramanga city were performed using several technological systems and services designed by RadioGis Group, such as: RadioGIS Services Platform, automated measurement software which are named “GeoRadScenner v2.5” [17] and “GeoSpectScanner v2.0” [16], consultation geoportal.

The objective of all systems and tools is automatically performed georeferenced measurements of non ionizing radiation in many sites of the city, the methodology of section II is followed in process. The results are tabulated, organized, mapped and sent on line server of RadioGis in order to that the general public can consult them by internet (http://telecomunicaciones.uis.edu.co/mediciones) or mobile device.

Fig. 4. Measurement System

The used instruments are shown at table II, also a GPS was used to georeference the data of radiation in each registered site. These are connected to a laptop and transported by a vehicle, such as it is shown at and Fig. 4

B. Measurement results

In four zones are segmented the city: north (residential and educational), west central (commercial and industrial), east (residential and commercial), south (commercial); which are composed by 23 neighborhoods with area 10,8 km2 (length 4 km and width 2.7 km), then this represent 70% of city.

TABLE I. ANTENNAS INVENTORY INSIDE AND OUTSIDE OF BUCARAMANGA CITY

# Antennas	Service type	Approximate frequency
78	Cellular telephony	850, 900, 1900 Mhz
12	Broadcasting on FM	90 - 104 Mhz
11	Broadcasting on AM	880 - 1390 khz
2	Trunking system	800 Mhz

One hundred and three antennas are identified inside and outside of the city, table I is shown a summary antennas inventory; high directivity antennas are not taken into account, for example microwave antennas, parabolic antennas for satellite TV reception, neither access point of WI-FI.

The type of electromagnetic region at Bucaramanga streets is only *Far field region*, this result was gotten by estimation algorithm, the AM antennas are located outside of city and the near region them does not cover the urban zone. Therefore, component of electric field is only measured in all city zones, it is not necessary to measure magnetic field.

TABLE II. TECHNICAL SPECIFICATIONS AND GENERAL MEASUREMENT PLAN

Description	Details
Measured variables	Electric field and spectral power
Measure equipment	Broadband field meter NARDA NBM-550 and Spectrum Analyzer R&S ZVL-6
Broadband probe	Electric field Probe EF0391 **100khz-3Ghz**
Antenna of 3.5 dBi	Model HG2404CU (800 to 3000 MHz)
Amount measured sites	564 sites (33 routes)
Time for data capture per site	1 minute
Sampling rate (for Narda)	1 second
Start and end date	from 26/05/2011 to 14/06/2011

TABLE III. RADIATION LEVEL OF BUCARAMANGA CITY

Radiation Level	Range [V/m]	Description
Low	0 - 0.8	Residential and educational areas and four main hospitals. North zone.
Medium	0.8 - 2.0	Business district and shopping areas at old city (commercial areas). West central, east and south zones.
High*	over 2.0	Specific sites: Court house, City Hall and around 2 important shopping centers.
Hotpoint	over 28	None.

*These are the highest values found in the city, but they are not beyond the limits of recommendation ITU-T K.52

Technical specifications and General Measurement Plan are shown in table II, 564 specific sites at 33 routes were measured the electric field on streets during peak hours for different days using the Procedure of broadband EMF measurement by route and the subprocess for automatic taking of broadband measurement, which are shown in Fig. 2 and Fig. 3. Also, the measurement system is described at before section.

Three ranges of radiation level were detected and they are grouped at particular kind of places, such as it is shown in Table III.

The electric field results of broadband measurement in 564 sites are compared with the most restrictive limit of recommendation ITU-T K.52 [12] by general public (28 V/m), in order to detect the hotpoints, such as it is described at general method of EMF measurement of Fig. 1. None hotpoints were found.

C. Spectrum Measurement

After identifying high electric field zones, it was taken spectral measurements in order to determine a direct relation between rising of electric field and some channel contributions located from 800 MHz to 3GHz, which is a frequency range of special interest where radio communication bands are located, used for cellular transmission, wifi, trunking among others.

The equipments used are shown at table II, the parameters set for Spectrum Analyzer are: Resolution bandwidth (RBW): 100 kHz, video bandwidth (VBW): 300 kHz, sweep time: 2.5 ms, measured time: 1 minute per point.

As a result, some relevant values with higher recorded spectral power during the measurement campaign are shown at table IV where can be found frequency bands between 820 MHz and 895 MHz with maximum power density above -20 dBm and bands from 1.9 GHz to 2 GHz with maximum power above -30 dBm. The remaining frequency bands show a minimum power contribution, most of them at noise floor level. On the other hand, city zones with a medium and low Electromagnetic field level shows a spectral power below -30 dBm in the broadband range. The table IV shows results of spectrum measurement.

TABLE IV: LIST OF MAXIMUM SPECTRAL POWER FOUND.

Sites:	Shopping Center	Court House	Business District
Span	800 to 2000 Mhz	800 to 3000 Mhz	800 to 2000 Mhz.
Freq. Range: Max Volts Max Power	835 to 895 MHz 70 to 90 dBμV -37 to -17dBm	820 to 880 MHz 70 to 90 dBμV -37 to -17dBm	830 to 895 MHz: 80 to 90 dBμV -27 to -17dBm
Freq. Range: Max Volts Max Power:	1.85 to 2 GHz 60 to 80 dBμV -47 to -27dBm	1.93 to 1.99 GHz 60 to 80 dBμV -47 to -27dBm	1.93 to 1.99 GHz 60 to 80 dBμV -47 to -27dBm

D. Statistical analysis of Electric Field

The measured data of broadband were analyzed such as it is proposed at methodology. The histogram is shown in Fig. 5 which indicate that the radiation level of measured sites is predominantly low (down 0.8 V/m). The arithmetic mean of electric field is 0.5384 V/m with variance 0.113 V^2/m^2; this shows that electromagnetic radiation average in Bucaramanga city is 1.92% respect to the most restrictive limit of recommendation ITU-T K.52 (where 100% indicate that field value is at the limit 28 V/m). The maximum value is 2,475 V/m that it was measured around of City Hall in west center zone, it is 8.84% respect to limit, and the minimum value is 0.1 V/m (0.36% of limit).

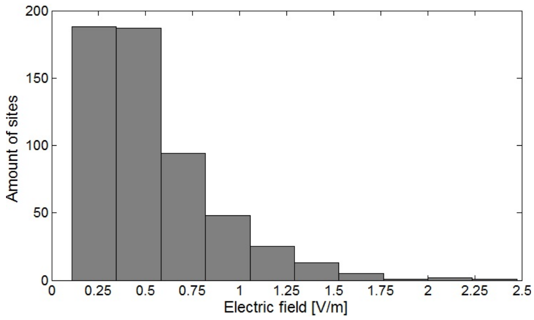

Fig. 5. Histogram of electric field measurements

The Nakagami probability distribution function was function best fitted measured data of electric field, such as Fig. 6, where the estimated parameters were: mu= 0.879998 and omega=0.402362 with errors of 4.561% and 1.806%. The mean for the distribution is 0.553592 V/m and variance 0.0958981 V^2/m^2, which show better dispersion of information. This distribution is used to model scattered signals that reach a receiver by multiple paths, the radiation have same behavior.

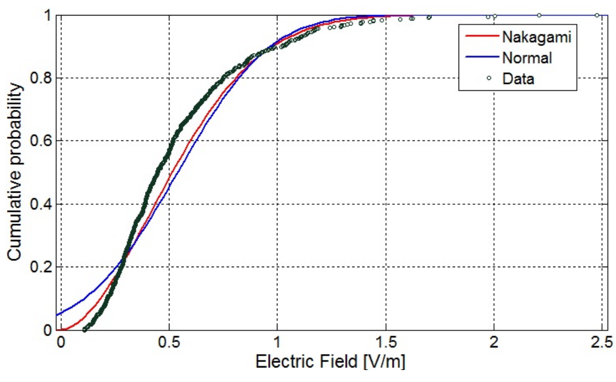

Fig. 6. Cumulative probability function of electric field of Bucaramanga City

Figure 6 shows that the probability of not exceeding a electric field of 0.9767 V/m is 90% and 99.998% that for not exceeding 2.16429 V/m. Therefore, the radiation levels in measured sites satisfy the recommendation of ITU and the national regulations. Similar conclusions were obtained at [18] where Santander city (Spain) was studied.

IV. Non-Ionizing Radiation Map of Bucaramanga

After processing collected data, a continuous radiation surface was created by using a geostatistical interpolation method called Kriging which is based on statistical models that include autocorrelation; it means the statistical relationships among the measured points. It weights the surrounding measured values to derive a prediction for an unmeasured location [19].

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. In this case it is known that the radiated energy decay with de distance but also it is known that depends on the obstacles like buildings or vegetation which is not included by this interpolation method, however, it would be a good estimation to create a continuous radiation spot [20].

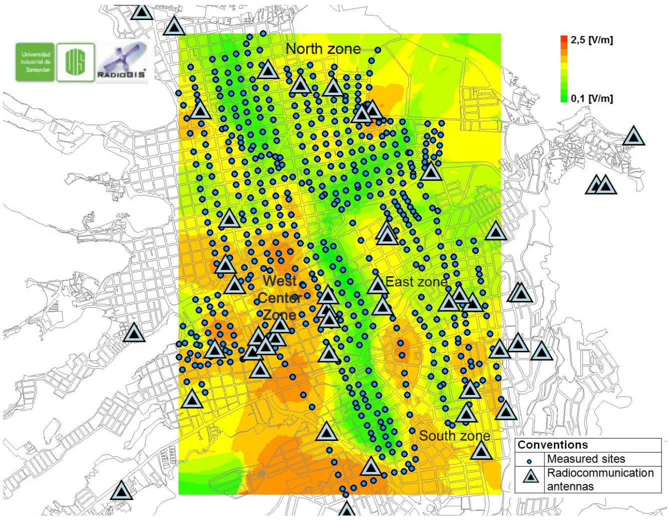

Fig. 7. Map of non-ionizing electromagnetic radiation in Bucaramanga city

The radiation map of Bucaramanga is shown in Fig. 7, the green color indicates that the electric field level is low (minimum value) and red color indicates that the electric field level is the strongest of the city (maximum value). The north zone has mainly a low level of radiation, this zone is residential and academic, and there are four universities, six high schools and two big hospitals. The west central zone has mainly a medium level of radiation, but this zone has the maximum values around of Court house and City Hall, high concentration of mobile telephony antennas is characterized this zone. The east zone has low and medium levels. Finally the south zone has low level, but it has a region with medium-high level around of an important Commercial Center, where there are some less height antennas.

V. CONCLUSION

A radiation monitoring method was designed and tested during measurement campaigns at city urban zones by covering 70% of Bucaramanga city area; it was registered around 52 points per Km2 for a total amount of 564 measured points. An iterative and agile process was explained and accomplished into a practical and semi automatic way to record field strength of electromagnetic waves by using both broadband field meter and spectrum analyzer in order to establish whether regulation norms are being met and to know which factors are contributing to radiation level increasing by means of a spectral view. Also a telecommunications service was developed to measure, send and request on-line for measured data in real time and integrated into a Geographic Information System supported by RadioGis R&D Group with a web platform of Telecommunication services.

The non-ionizing radiation measurement results have proved that there are no violations of Colombian Decree law 195 of 2005 in Bucaramanga, although the electromagnetic contribution of Cellular antennas is relative high, the maximum electric field of the city is below 10% of the strictest electric field limit recommended by ITU-T K52 and average is 1.92% respect to this limit. The probability of not exceeding an electric field of 0.9767 V/m is 90%. A radiation level map was generated by using a interpolation method called Kriggin in order to get a continuous surface that shows the characteristics of electric field in a better way to analyze it. This result shows that residential and educational zones and four main hospitals of the city present a values range of low level, whereas business district and shopping areas (commercial zone) at old city show a relatively medium level of radiation strength between 0.8 and 1.5 V/m. Finally, there was found a high level spot located around the Court house, City Hall and around 2 important shopping centers with radiation levels over 2.0 V/m.

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