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Research Article

Prediction of electromagnetic power density emitted from GSM base stations by using multiple linear regression.

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ABSTRACT

Today, smart phones based on different mobile communication technologies such as GSM, GPRS/EDGE, 3G, 4G, 5G and 6G have become an indispensable element for various services such as communication, entertainment, and banking. In this context, determining the base station power level is important in terms of limit values and public health, especially in places with high power density. In this study, electromagnetic power density of 31 different base stations was measured at 900 MHz frequency at 20, 40 and 60 meters distances from base stations. Since it is practically not possible to measure each base station from every distance, 3 different distances were chosen randomly. Then, using the power density values measured from different distances, electromagnetic power density estimation was made with multiple linear regression (MLR) analysis method for distances at intermediate distances (25, 30, 35, 45, 50 and 55 meters). In this study, MLR analysis method was applied for power density estimation for the first time in the literature and adjusted R-square value above 0.99 was obtained for each intermediate distance.

1. Introduction

Existing technologies and wireless communication services have become the source of electromagnetic pollution due to electromagnetic radiation [1]. Considering that mobile communication technologies such as 6G, 5G, 4G and 3G [2]will continue to develop in the future, it is an undeniable fact that this situation has become a part of our daily lives [3]. With the increase in population in recent years, the number of base stations has increased rapidly in parallel with the significant increase in the usage rates of these services [4]. In 2021, it is estimated that the total number of mobile subscriptions has increased to 8.6 billion worldwide [5]. There are millions of kilometers of power lines, millions of antennas transmitting radio frequency radiation, billions of devices and satellite networks that bathe the planet with unnatural radiation, affect living things and create a very different energy environment [3]. Visual identification of RF points around antennas requires detailed measurements or computer simulations [6].

Despite the lack of clear and conclusive evidence of the negative effects of low-level electromagnetic fields operating below 300 GHz, this issue is still a matter of public debate. To address these concerns and to provide reliable and objective scientific answers, the WHO initiated a broad and multidisciplinary research program in 1996 [7]. In addition to these, a report was published by the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a subsidiary of the European Commission, in 2007. In this report, it was emphasized that it is extremely important to address the concerns caused by the electromagnetic field in terms of public health [8].

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According to Pubmed statistics [9], around 212 scientific publications have been published on average every year on the keywords "electromagnetic power density" or "electromagnetic pollution" or "electromagnetic radiation" in the last 10 years (see Fig. 1). Hundreds of studies conducted every year are proof of the continuing interest in this field.

When Fig. 2 is examined, the top five countries with the highest number of publications on related keywords are as follows: China (299 studies), Russia (160 studies), USA (129 studies), India (84 studies) and Turkey (73 studies) [10]

In addition, this report identified significant research needs in all frequency bands, emphasizing that the lack of good quality data is insufficient to determine whether a single exposure standard is appropriate to protect all living

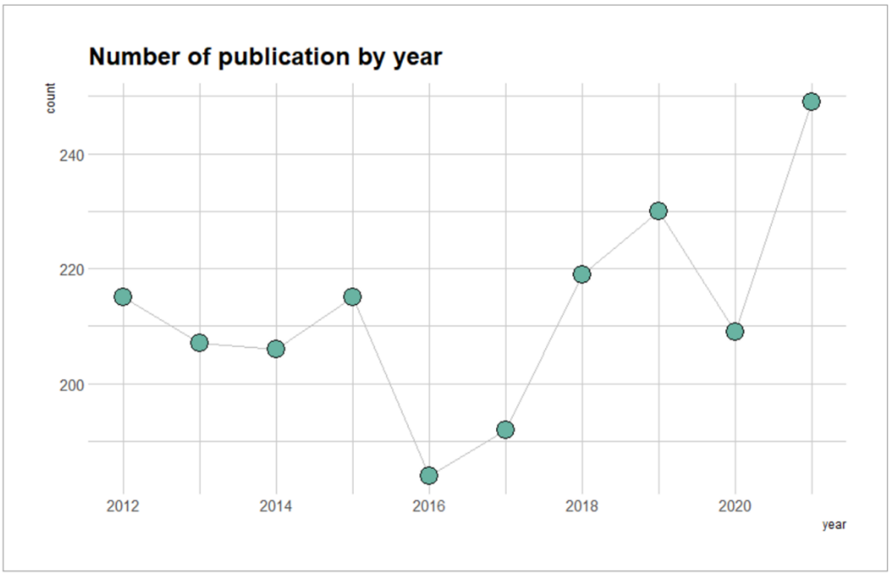

Figure 1. According to PubMed statistics, the number of scientific publications in the last 10 years containing the keywords "electromagnetic power density" or "electromagnetic pollution" or "electromagnetic radiation" [9].

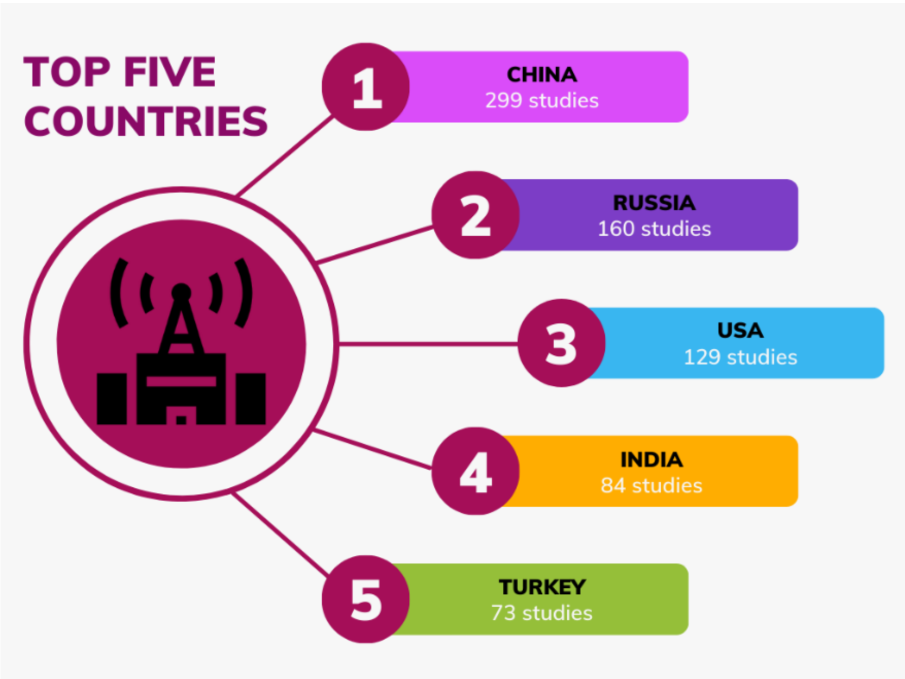

Figure 2. According to the Web of Science (WoS) Core Collection query [10], the distribution statistics of scientific publications containing the keywords "electromagnetic power density" or "electromagnetic pollution" or "electromagnetic radiation" by country in the last 10 years.

things from EMF. To reduce the possible negative effects of this situation, which is considered as a kind of environmental pollution, restrictions and laws have been enacted by various regulatory institutions in developed countries. One of these institutions, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has determined the allowable limits for radio frequency (RF) (see Table 1). ICNIRP's guidelines have been adopted by most countries of the world, especially developed countries [2], [11], [12]

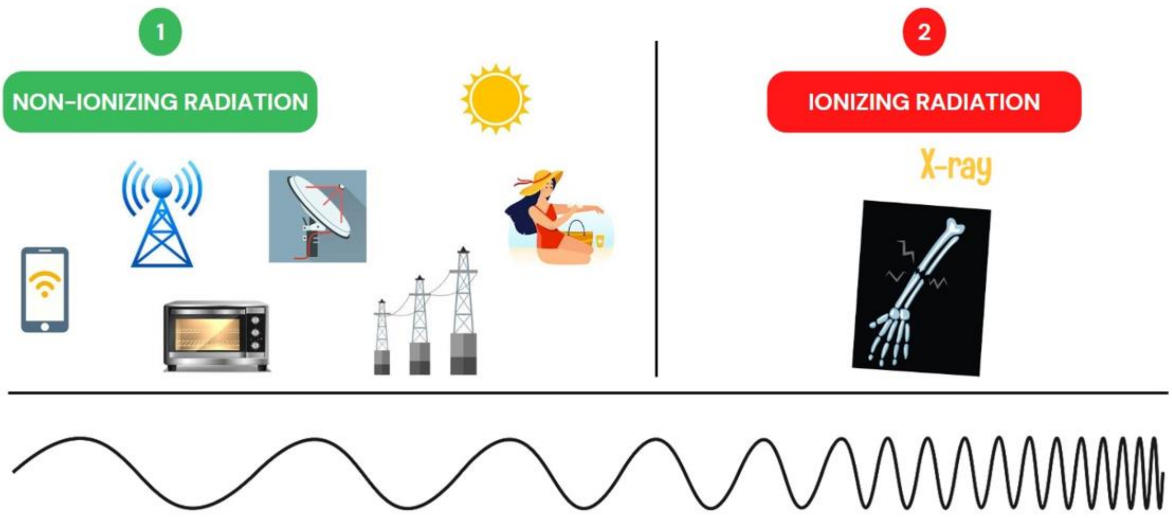

Figure 3. Types of EMR [41]

Table 1. The Maximum Permissible Exposure Limit of PD [12]

Institution/Country	PD ($\mu W/m^2$) for GSM-900
ICNIRP	4500
India	450
Poland, China, Italy	50
Austria, Salzburg City	0.5

Where GSM is Global system for mobile communication

Each country has limit values for electromagnetic radiation according to its own standards. For example, in the United States, the Federal Communications Commission (FCC) is the commission that authorizes most RF telecommunications services, facilities, and devices used by the public and industry [13]. While some countries apply the limit values established by ICNIRP, some European countries such as Italy apply limit values below the ICNIRP security limits.

It is expected that the existing and future mobile equipment infrastructure of countries implementing the limit values set by ICNIRP will comply with the ICNIRP guidelines [14].

The regulation issued in 2001 regarding the installation and operation of GSM and radio-TV transmitters in Turkey is implemented under the responsibility of the Information Technologies and Communications Authority (BTK). In 2009 and 2015, this regulation was revised and republished. This regulation has been prepared based on limit values regulated by ICNIRP [15].

The process by which energy moves in the form of waves or particles in space is defined as radiation. "Electromagnetic radiation" on the other hand, refers to the wave-like mode of transport in which energy is carried by electric and magnetic fields perpendicular to the direction of energy propagation [16]. Sources of electromagnetic radiation (EMR) are of two types according to their ionizing properties: ionizing radiation and non-ionizing radiation (see Fig. 3). Ionizing radiation is a potentially deadly stream of high-energy particles, while non-ionizing radiation carries less energy [17]. In this study, GSM900 communication systems, that is, non-ionizing EMR, were examined by the authors.

The 900 MHz band provides good coverage for GSM networks. However, operators typically have very limited spectrum, from only 5 MHz to 10 MHz in the 900 MHz band. Higher frequency bands around 2 GHz are used in urban areas to offer more capacity than the 900 MHz band [18]. The uplink (UL) and downlink (DL) bands of the GSM system in Europe, which uses frequency division duplex with a channel bandwidth of 200 kHz, are 890-915 and 935-960 MHz [19].

There are many studies that talk about the hazardous effects of electromagnetic pollution [20]–[23]. Panagopoulos et al. [20] used the technique to detect cell death in a biological model. In their in vivo study, they exposed the flies to GSM 900-MHz or DCS 1800-MHz radiation. Ultimately, they found that GSM radiation caused a reduction in the flies' egg laying.

Studies show that electromagnetic field-related diseases can have short and long-term effects. Intense stress and fatigue, loss of attention, warming of the ears, reversible hearing problems, headaches and similar symptoms can be seen as short-term effects of EMF. Common long-term effects include irreversible hearing problems, damage to embryonic development, increased risk of miscarriage, decreased sperm count, damage to brain tissue, heart-related problems, impaired memory, lymphoma, and genetic damage [24].

The result obtained by a group of researchers who aimed to learn the psychological and psychobiological reactions of the residents living close to the cell phone base transceiver stations in the city of Isfahan, Iran, showed that the side effects increased significantly in those who lived closer than 300 meters from the base station. These side effects are nausea, headache, dizziness, nervousness, sleep disturbance, memory loss and decreased libido [25]. According to another study, it was concluded that short-term exposure to radiated radio frequency radiation emitted as a non-ionizing radiation from mobile phones can cause genotoxic effects [26].

A study conducted in the city of Stockholm identified the sources and causes of exposure to RF radiation. The results obtained showed that the level of exposure to RF radiation increased [27]. According to a study conducted in Abuja, where the population is dense, the measurement of radiation power density was carried out with the broadband analysis method. According to the results obtained, 59.02 mW/m2, 39.76 mW/m2 and 46.70 mW/m2 values were measured, respectively. The result revealed that the average power density decreases as the distance increases [28]. In another study on the brain, researchers concluded that EMR may play a role in the neurotransmitter disorder of the brain [29].

As it can be understood from the literature summary above, there is a very serious relationship between electromagnetic fields, which are known physical risk factors [27], and the human body. There are numerous studies in the literature to investigate this relationship.

In this study, the power density of 31 base stations has been measured 20, 40 and 60 meters' distances from base stations at the frequency of 900 MHz. The measured values were used in the MLR analysis method to estimate the measurement results at randomly determined intermediate distances (25, 30, 35, 45, 50 and 55 meters). The MLR analysis method was used for the first time in the literature to determine the base station power level. The main motivation of this study is the efficient estimation of EMR measurement results at certain distances.

2. Materials and Methods

In the 21st century, electromagnetic fields are becoming more and more widespread, and the number of public concerns and scientific studies is increasing accordingly. The electromagnetic effect is increasing day by day due to different applications in different frequency bands. It is not possible to see this effect with the naked eye, so it is often seen as a neglected phenomenon. On the other hand, as mentioned above public concern is also increasing with increasing electromagnetic field intensity. To evaluate all these cases, measurements related to base stations were made within the scope of this study.

In the first step of study, randomly selected 31 base stations are investigated in this study. Although the base stations were chosen randomly, different base stations were selected to test the accuracy of the mathematical approach to be used in the next step. As a matter of fact, some of the selected base stations are in crowded areas, while some are in secluded areas. Also, some base stations are in urban areas while others are in rural areas.

An electromagnetic field meter device (Spectran HF-6080) is used, which is frequency-locked and capable of measuring the maximum electromagnetic power density in the measuring zone. With this device, the electromagnetic field intensity in the desired frequency band can be measured, while the electromagnetic field effect in the unwanted region can be eliminated. Before starting the measurement, it should be ensured that the device is calibrated. For this reason, the device was calibrated before the study. Also, to ensure the safety of the measurements taken, the measurements made for 10 base stations are taken in a circular radius. In Fig. 4, an instance measurement is presented.

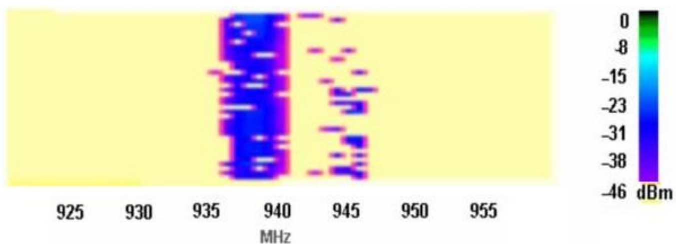

Figure 4. Electromagnetic power density according to frequency band.

As can be seen in Fig. 4, although measurements were made in the 900 MHz frequency band within the scope of this study, the measurement density is in the 935-940 MHz frequency band. However, the presence of other base stations broadcasting in the 940-945 MHz frequency region was also seen on the measurement screen. Also, this indicates that more than one base station is active at the measurement point. The presence of more than one base station affects the measurement results. Indeed, in the second step of this study, it is mentioned that measurements are made at different distances from a base station.

After the base stations to be measured are determined, all measurements have been carried out for three different distances from base stations. Since it is practically impossible to present all measurement results in this paper, some of measurements are shown in Table II. Base stations are numbered from 1 to 31 and the power density of each base station is measured 20, 40 and 60 meters distances. All measurements are carried out with directional antenna.

Table 2. Electromagnetic Field Measurements of Base Stations (μW/m^2)

	Distance from Base Stations (meter)		
Base Station Number	20m	40m	60m
1	15,46	7,11	0,95
2	0,15	0,02	0,05
3	191,31	157,73	179,32
4	827,75	306,52	557,82
5	24,97	31,24	113,24
6	111,39	200,23	32,05
7	16,13	18,62	21,85
8	256,21	150,33	122,89
9	22,13	58,20	27,27
10	39,72	40,59	18,11
11	69,72	60,59	38,11
12	281,31	143,73	129,32
13	317,63	134,41	281,76
14	57,24	54,71	29,26
15	0,95	0,42	0,34
16	1,18	1,05	1,05
17	6,28	10,37	3,49
18	11,53	8,65	15,77
19	0,19	0,10	0,92
20	4,23	0,93	1,17
21	17,13	12,62	11,85
22	0,53	0,23	0,19
23	205,76	13,80	332,03
24	146,41	113,45	132,13
25	371,17	209,81	55,41
26	103,58	59,36	40,16
27	87,96	13,67	24,03
28	24,15	22,20	4,96
29	2,47	3,68	4,37
30	1,10	2,75	0,40
31	0,16	0,13	0,03

When Table 2 is examined, it is seen that different electromagnetic power densities are measured. This shows that the selected base station samples are independent from each other. For example, at base station 1, the electromagnetic field intensity value at the twentieth meter is 15.46 μW/m2, while the electromagnetic field value at base station 4 is 827.75 μW/m2. In Table 2, different measurement results are read, and it is seen that these measurement values are lower than the limit values determined by ICNIRP. Some of the data in Table 2 were used by the second author in a previous study [30].

Another remarkable aspect is that the electromagnetic field intensity is expected to decrease as you move away from the base station. However, as can be seen in base station 2 and 24, the electromagnetic field density can first decrease and then increase. Many reasons such as antenna perspective, reflection in the environment can be effective in this regard.

Measuring at all distances for each base station is not appropriate in terms of work practice and scientific research culture. In this context, in the second part of this study, the electromagnetic field density values in the non-measured region can be determined mathematically by using the electromagnetic field density values at the measured distances.

2.1. Multiple Linear Regression

MLR, which has many uses, enables the creation of a linear equation containing the x variables to determine variable y [31].

The multiple regression equation for sample estimates takes the form [32] :

y = b1x1 + b2x2 +…+ bnxn + c

The bi's are called the regression coefficients. They measure the association between the predictor variable and the outcome. The c is the constant or where the regression line intercepts the y–axis [32].

In this study, electromagnetic power density at the 20, 40. and 60 meters away from the base stations were accepted as input variables, and power density values at intermediate distances such as the 25m, 30m and 55m were accepted as output variables. Accordingly, the necessary calculations were made with the MLR and the measurement results were compared with the MLR results. The MLR analyses and data visualization were carried out using RStudio version 2021.09.2 Build 382 [33].

If the measurement results are examined before these procedures, as can be seen in Fig. 5 the measurements made are in a distance dependent manner. The highest value for power density (PD) for the distance of 20 meters was recorded as 827,75 μW/m2, 557,82 μW/m2 for 60 meters and 306,52 μW/m2 for 40 meters. While the measured values are below the limit recommended by ICNIRP, they are above the limit accepted by some countries (Table 1). In such places where EMR levels are high, it may be recommended to reduce the propagation distances between nodes, reduce the transmission power, and deploy smaller cells such as micro and pico cells to reduce potential health risks [34].

The electromagnetic field intensity created by each base station in a distance dependent manner is also presented in Fig. 6. Measurements were made at many base stations and the average of the measurements taken from 20 meters is 103.74 μW/m2, the average of the measurements taken from 40 meters is 59.27 µW/m2, the average of the measurements taken from 60 meters is 70.33 µW/m2. Furthermore, there are also extreme examples. For example, a very high electromagnetic power density has occurred at base station 4.

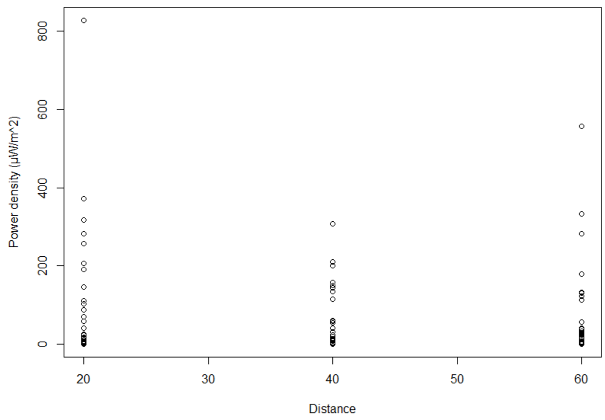

Figure 5. Base station power density distribution according to distances.

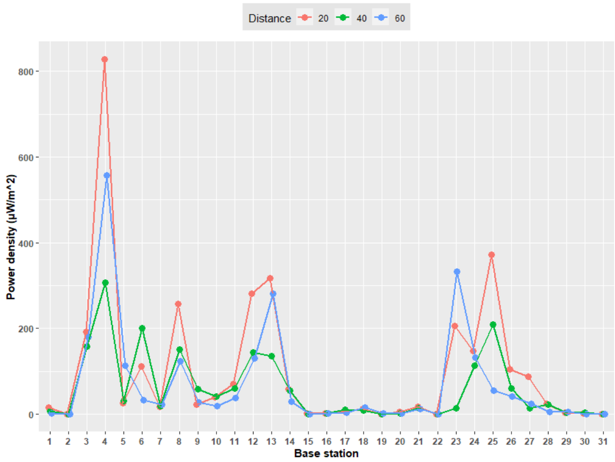

Figure 6. Power density measured by base stations and distances.

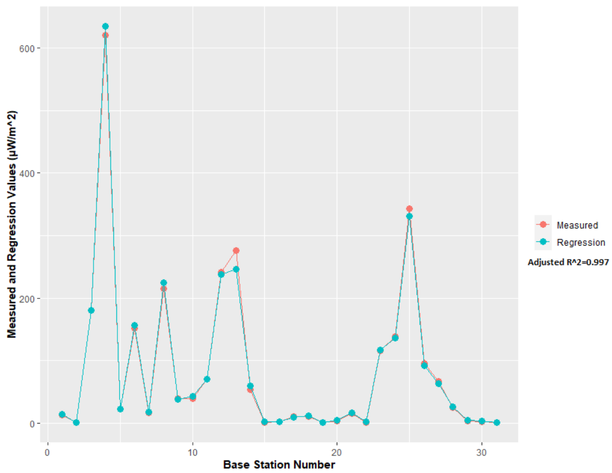

Figure 7a. MLR Results for 25 m distance.

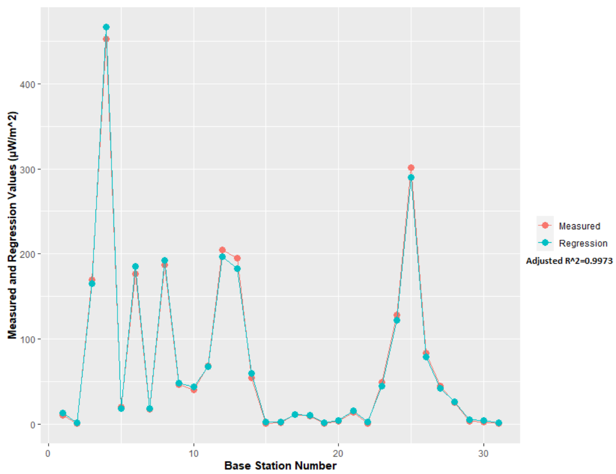

Figure 7b. MLR Results for 30 m distance.

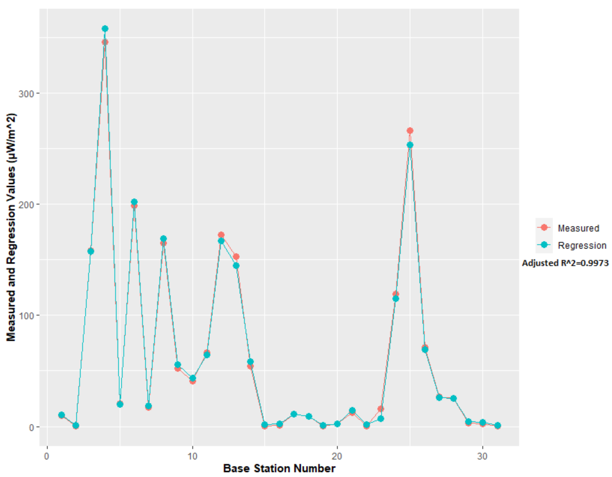

Figure 7c. MLR Results for 35 m distance.

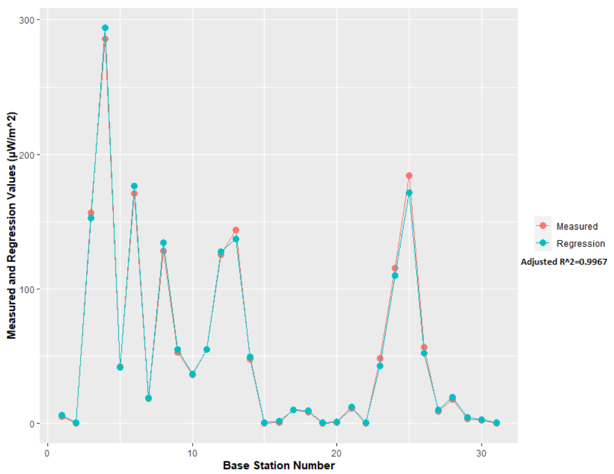

Figure 7d. MLR Results for 45 m distance.

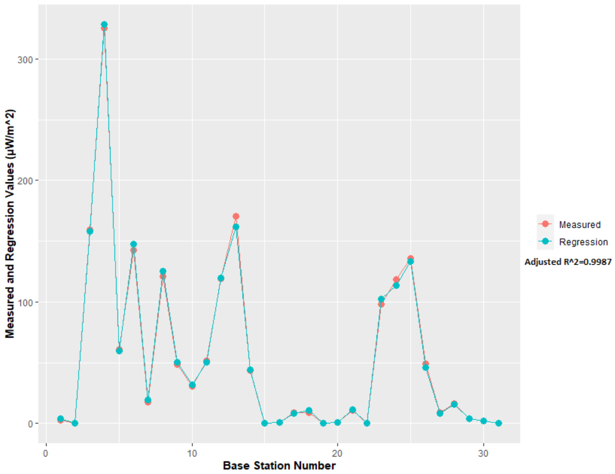

Figure 7e. MLR Results for 50 m distance.

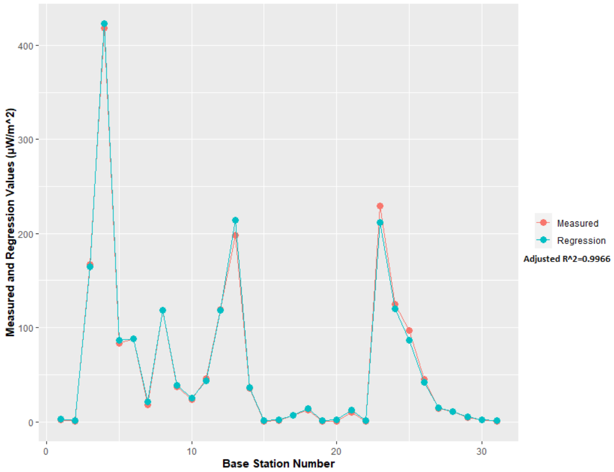

Figure 7f. MLR Results for 55 m distance.

Looking at the Fig. 7a, 7b, 7c, 7d, 7e and 7f in Fig. 7, it can be seen that the regression result fits perfectly with the real values. Finally, error analysis was performed to confirm the results.

Table 3. MLR Analysis Model Summary

Distance From Base Stations (meter)	Residual Standard Error (RSE)	Adjusted R-squared	F-statistics	p-value
25	7,380	0,9970	3362	
30	5,511	0,9973	3710	
35	4,629	0,9973	3682	2.2e-16
45	4,160	0,9967	2994	
50	2,702	0,9987	7614	
55	5,356	0,9966	2927	

2.2. Error Analysis

The performances of the MLR analysis models created in this study were compared using different statistical criteria. These criteria are statistical parameters such as Residual Standard Error (RSE), Adjusted R^2, F-statistics and p-values (see Table III). Adjusted R^2 gives only the percentage of variation explained by independent variables that affect the dependent variable [35].

When examining the F-statistic and the associated p-value, it can be seen that the p-value of the F-statistic is 2.2e−16, which is highly significant [36] so this model can be used to determine the electromagnetic power density.

3. Discussion

Various studies have been carried out in the literature on the measurement, estimation and analysis of base station electromagnetic radiation and power density. Yang et al. [37] proposed a prediction model for the electromagnetic radiation of a multi-system base station. In their studies, they pointed out that near field conditions and power control should be analyzed for more accurate prediction values to be obtained by using systems with different working mechanisms and power controls such as GSM, CDMA, WCDMA, TD-SCDMA. Osahon et al. [38] measured the power density of base station masts in Nigeria and analyzed them to check if they were within the ICNIRP. For this purpose, a total of 40 mobile phone base station masts were examined and values such as power densities, magnetic field strength and electric field strength were determined by means of a digital Electrosmog meter. Measurements were made at 25, 50, 75 and 100 m distances from the base of the masts, respectively. The results showed that the power density values obtained at different distances and locations were well below the ICNIRP general exposure limits, which ranged from 2000 to 10000 mW/m2 in the frequency range of 10 MHz to 300 GHz. Miclaus et al. [39] discussed both the measurement results and the factors affecting the measurements in their studies on radiofrequency radiation power density. In situ measurements were mostly made in sensitive areas and both peak and mean values were monitored. They noted that the measured values were well below the maximum permissible exposure levels in Romania. Hamiti et al. [40] carried out a study to determine the exposure levels and minimum safe distances to electromagnetic fields generated by GSM 900, GSM 1800 and 3G base stations in urban areas. They compared the experimental research results with other studies. They stated that the power density values obtained in Kosovo were higher, but below the safety standard limits many times. Unlike these studies in the literature, our study successfully estimated the intermediate distance values of electromagnetic power density emitted from GSM base stations using MLR.

4. Conclusions

This paper used the MLR method to estimate measurements at intermediate distances using measured electromagnetic power density measurements for distances of 20, 40 and 60 meters from 31 different base stations.

Since measuring for each distance will be time consuming and laborious, estimating the values in the intermediate distances with a mathematical method is the main motivation of our study to overcome this problem. So that, the power density (µW/m2) of 31 base stations were measured 20, 40 and 60 meters distances from base stations, respectively. Estimates for intermediate distances (25, 30, 35, 45, 50, 55 m) were obtained by MLR analysis method and the results were compared with actual measurement values. The estimated measurement values for intermediate distances are below the limit values determined by ICNIRP. For the first time in literature, a MLR analysis approach has been applied successfully to determine the power density in different distances. Based on the observations in this study, the MLR method can be applied for any other settlement for different distances from the base stations. The MLR model used to predict the power density emitted from the GSM base stations came out to have a very strong predictive capacity (Adjusted R-square value: above 0.99, p-value: < 2.2e-16). As a future extension of this study, analysis of the results to be obtained using hybrid approaches will be performed.

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