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ANALYSIS OF THE EFFECTS OF GSM BANDS TO THE ELECTROMAGNETIC POLLUTION IN THE RF SPECTRUM

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Abstract—In this study, electromagnetic (EM) pollution measurements in crowded residential areas were performed, and statistical analysis of values recorded for the EM sources causing pollution was carried out. The actual measurement values and estimated values by the analysis model obtained through the statistical analysis were compared. Also, amplitude fluctuations of the electromagnetic radiations from EM pollution sources were detected for a long time, and statistical analyses were made. EM field levels were measured in the districts of Turkish capital, Ankara where cellular base stations and TV/Radio stations are densely populated. EM radiation levels were measured for the GSM900, GSM1800, FM, UHF4, VHF4 and VHF5 stations for certain spectrum ranges under far-field conditions by utilizing isotropic field probe and selective spectrum analyzer. The measurements were fulfilled by using NARDA SRM3000 radiation meter with isotropic antenna that can be utilized in 75 MHz–3 GHz frequency range. The obtained measurement levels were compared with the limit values given by International Commission for Non-Ionizing Radiation Protection (ICNIRP). The measurement results for each pollution sources were compared, and their contributions to the combined radiation were analyzed. The values for the EM pollution in the measurement regions were embedded over the digital maps created for the related places. During this process, comparisons of the pollution maps were made by utilizing Natural Neighbour (NN) interpolation technique.

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1. INTRODUCTION

The potential health effects of EM radiation from the transmitters for broadcasting of radio/TV and mobile communication are the subject of on-going researches [1–4] and a significant amount of public debate. Many researches and studies [5–9] about the EM radiation effects of the devices operating especially in GSM bands indicates the importance of the topic. The distribution and levels of EM pollution in the crowded residential areas are very important.

From the statistical analysis of the measurement results, EM radiation levels can be modeled through various calculations and formulas retrieved under certain conditions and within acceptable correctness. EM pollution measurement results are examined by means of time series analysis whether these results are suitable for predicting future EM pollution levels through the created model. Estimation or determination of the dependant variable *total EM pollution* is realized as based on the modeling.

Environmental EM pollution maps are produced by processing the obtained EM field strength values and interpolating them by using the Geographical Information System (GIS) ArcGIS software's analyst module.

EM pollution measurements within the scope of this study were executed in a chosen pilot region, the city centre of Ankara, Turkey. The measurements were specifically in Dikmen Caldagı Hill and Yenimahelle Sentepe regions where many EM pollution sources are located. Environmental EM pollution measurements were executed in the highly populated areas.

2. EM POLLUTION MEASUREMENT METHOD

EM pollution measurements are fulfilled in a particular, populated residential area where EM pollution is expected over a wide range of frequency spectrum. In this EM pollution study

- It is impossible to determine the effects of the transmitting sources when only looking at the static data.
- Reliability of the pollution maps using distribution modeling is low, since distribution modeling is based on probability distribution.
- The terrain modeling and related data can be obtained in many countries and in Turkey. However, it is almost impossible to find up to date information and reliable data about the modeling of buildings, structures and other obstructions located in the region.

Table 1. Variation of the far field distance according to the frequency of GSM sources.

Frequency (MHz)	Far Field Distance
GSM900 (900 MHz)	6.4 (m)
GSM1800 (1800 MHz)	2.6 (m)

Figure 1. Some EM pollution sources in the measurement areas.

- During the EM pollution measurements for GSM900 and GSM1800 base stations, the distances in Table 1 are considered. It is assumed that only far field conditions exist since it is not possible to reach closer to these sources as far as these distances.
- Same approach is applied to the FM radio transmitters in city centers since those sources are also installed on high buildings in order to provide maximum coverage.
- Again, it is assumed that only far field conditions exist for the TV and FM radio transmitters since these installations are, most of the time, mounted on high towers or hills.
- Making accurate measurements for the near field requires high number of measurements in the near field. Therefore, even this requirement itself may eliminate the accurate measurement results. Near field conditions provide more realistic results for measurements in laboratory environment and for a certain source [10].

Table 1 gives the far field starting distances for a 1 m length antennas and bands GSM900/GSM1800. For the reasons mentioned above, the measurements carried out in order to create the distribution maps were fulfilled based on far field conditions in this study.

It is essential to measure the combined field levels for all different signal sources in the environment as shown in Figure 1 and to quickly collect data as much as possible. In practice, many of the directional antennas with high gains are not suitable for this purpose since they do not allow measurements of signals from all directions and different polarizations and therefore not allowing quick measurements. In the measurements, the wide band spectrum (75 MHz–3 GHz) antenna probes that can measure from all directions and different polarizations [11, 12] were used.

E field values were recorded during the measurements. Coordinates of each measurement location were also recorded by using a Global Position System (GPS) for mapping process. The measurement locations were decided according to the density of mobile users since it is an important factor [10, 13]. Measurement results recorded by the SRM3000 and related GPS coordinates were saved to a computer [14]. Numbers of measurements for crowded locations were more than other places. The experimental set-up and vehicle are depicted in Figure 2. The electric field probe was based at 3.3 m height from the ground level. Measurement device and probe were mounted on the vehicle's insulating ceiling made of nonreflective fiber material. The duration of each measurement was 6 minutes [13, 15]. For each measurement E_{ave} (V/m) was recorded.

Environmental EM pollution measurements were carried out for certain regions with possible high pollution rates in city centre by means of the mobile measurement setup while the vehicle was moving at a fixed speed of 30 kph as possible as the traffic allowed. The measurements include the sources listed in Table 2 and the other sources within the spectrum up to 3 GHz.

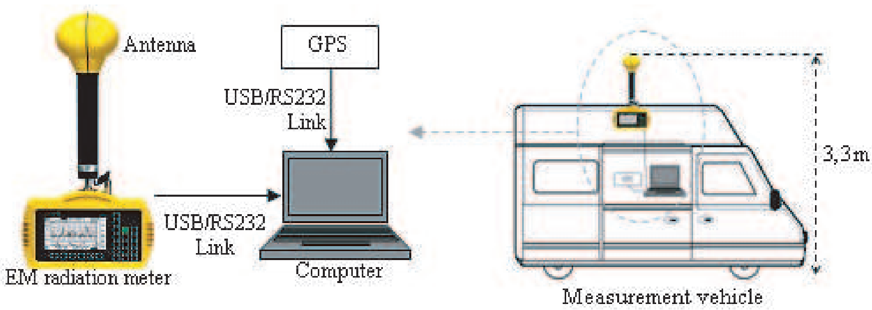


Figure 2. Equipment and vehicle used for the measurements.

Table 2. Measured EM pollution sources and their frequency ranges.

EM Source	Frequency Range
FM	88–108 MHz
UHF5	605–861 MHz
VHF4	174–230 MHz
UHF4	605–861 MHz
GSM900	870–960 MHz
GSM1800	1.77–1.85 GHz

3. STATISTICAL ANALYSIS OF POLLUTION MEASUREMENTS

The measurement results are analyzed by means of the SPSS 17.0 and E-Views software. In the first stage, stability of the obtained time series was examined using Dickey-Fuller (D-F) test in order to determine if the time series are suitable for estimation. In the second stage, the relationship between the variables was examined using correlation and regression analyses. Finally, variance analysis was utilized to determine the model's significance, and the prediction model for total pollution was obtained.

A time series is a group of measurement results recorded over a time for a certain variable in hand. The purpose of this analysis related to time series is to understand the reality represented by the observation set and determination of the predicted values of the variables in the time series. First step of predicting is to test the stability of the series. If the average or variance of the time series does not present a symmetrical change, or the series are free of periodical fluctuations, they are called "stable time series" [15]. D-F test is utilized for stability tests.

3.1. Dickey-fuller Unit Root Test

Unit root test analyses are applied to each time series of different measurement variables (GSM900, GSM1800, etc, ...) by using Equation (1) which is also utilized when testing the stability of series using D-F test [16].

$$\Delta Y_t = \beta_1 + \beta_2 \cdot t + \delta \cdot Y_{t-1} + \sum_{i=1}^{m} \alpha_i \cdot \Delta Y_{t-i} + \varepsilon_t \qquad (1)$$

In Equation (1), Δ is the first difference processor and represents the difference between two consecutive values. Here, ε_t is the consecutive independent probable error term with zero average and unchanged σ^2 variance and conforms to classic assumptions. $\delta = \rho - 1$ and ρ is a significance coefficient. If $\rho = 1$, then Y_{t-1} becomes zero, and this indicates that the time series is unstable meaning that it does not have a unit root. β_1 is a constant, and β_2 is the coefficient at t time. t represents trend, and m is maximum delay [14]. Whether the series has a unit root while using D-F test or not is determined by trying the following hypothesis.

H_0: $\rho = 1$ or $\delta = 0$ (Series has unit root, are not stable)

H_1: $\rho < 1$ or $\delta < 0$ (Series does not have unit root, are stable).

Critical values for testing stability are the τ statistical values calculated by the D-F method. Acceptable limits (critical values) of this test according to the **5%** level are calculated according to the Monte Carlo Simulation by MacKinnon. These values are called *MacKinnon critical values*. Known t statistics calculated by the statistical analysis programs are called *τ statistics* or *D-F test statistics* in this hypothesis test [16].

If the D-F test statistics' absolute values are smaller than the MacKinnon Critical Values' absolute values, H_0 hypothesis is accepted and this indicates that the series is not stable. If the D-F tests statistics' absolute values are greater than the MacKinnon Critical Values' absolute values, H_0 hypothesis is rejected, and this indicates that the series is stable. If the original state of the series is not stable, first difference of the series is taken, and the D-F test is applied again. If this is also not stable, second difference of the series is taken, and the D-F test is re-applied [16, 17].

Table 3. D-F unit root test results for series.

Series	**D-F Test (τ) Value**	**Critical Value**
Total	**3.526**	**2.907**
FM	3.954	2.906
VHF4	3.787	2.905
UHF4	5.438	2.905
UHF5	4.322	2.907
GSM900	**3.218**	**2.906**
GSM1800	**3.231**	**2.907**
Others	5.465	2.905

According to the results in Table 3, when the values of each series are examined, absolute values of τ statistics are greater than the absolute values of the critical values at **5%** significance level. Therefore, the H_0 hypothesis is rejected for the level values of each series examined [15]. In other words, all of the series (Total, GSM900, etc., ...) do not have unit root at level and are called stable. Using these data, multiple regression can be utilized, and future predictions can be made.

3.2. Regression and Correlation Analysis

Regression analysis is an analysis method used to examine the relation between a dependant variable and one or more independent variables [17]. With multiple regression the relation between a dependant variable Y and more than one independent variables (X_1, X_2, ..., X_n) is examined (Equation (2)).

Multiple Linear Regression Model: If Y is total EM pollution value, multiple linear regression model is given by

$$Y = \beta_0 + \beta_1\chi_1 + \ldots + \beta_n\chi_n + \varepsilon \tag{2}$$

where β_0 is a constant; β_1 is the correlation coefficient of 1st variable; χ_1 is the actual measurement value of the 1st variable; ε is the error term.

The slope direction and the degree of the relationship among the variables contributing to the EM pollution in the environment are examined graphically and analytically by means of the correlation test and comparisons of the variable pairs. The influences of variables on each other are analyzed as shown in Figure 3 and Table 5 for this study.

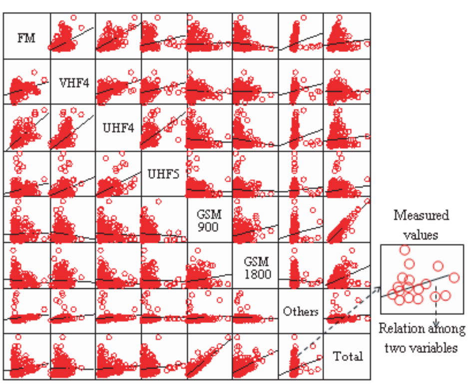


Figure 3. Relations among all variables.

Distribution graphics in Figure 3 present the relations between all variable pairs (VHF4, UHF4, UHF5, GSM900, GSM1800, Others, Total) taken into consideration during the measurements. Figure 3 indicates the course of observations over a time forming the time series. It also assists usage of the same pattern during statistical modeling process [17]. A close linear relationship between the GSM900/GSM1800 and the total variables was observed. GSM900 and GSM1800 base stations contribute most to the environmental total EM pollution as shown in Figure 3.

As shown in Table 4, total pollution value was recorded average **0.61** V/m, and its standard deviation was recorded **0.204** according to the **500** measurement results taken from various locations in the city centre. GSM1800 average pollution value was calculated **0.208** V/m while GSM900 average pollution value was **0.325** V/m.

According to Table 5, GSM900 was found being the highest correlation relation of **0.914** with total variable. GSM1800 was the second highest variable with correlation of **0.464**.

Functional form of the relation between the variables is examined using regression analysis, and its reliability degree is determined using correlation analysis. In Table 6, R^2 multiple certainties factor and corrected multiple certainty factor $R^2_{corrected}$ are used to determine the best regression model.

Model's explanation strength is determined using the R^2 multiple certainty factor. R^2 value is a measure indicating what percentage of the total variation of a dependant variable can be explained by variations of the independent variables [17].

Durbin Watson test is utilized while testing the assumption of successive dependency (autocorrelation) between the data set observations requirement in order to apply the multiple linear regression method. R^2 which is an indication of how well the independent variables describe the dependant variable was **%96.8 (0.968)** meaning that the EM pollution changes by **%96.8** depending on these factors. R^2 increases by adding more variables to the model, but this alone is not sufficient for testing the significance of the model. If the Durbin Watson Value is between **1.5** and **2.5**, then autocorrelation does not exist, and the prediction model is considered

Table 4. Descriptive statistics related to the variables.

Variable	Total	FM	VHF4	UHF4	UHF5	GSM900	GSM1800	Others
Average E Value	**0.610**	0.154	0.108	0.116	0.167	**0.325**	**0.208**	0.307
Standard Deviation	**0.204**	0.062	0.002	0.023	0.064	**0.255**	**0.142**	0.019

Table 5. Correlation related to the variables.

Correlation	Total	FM	VHF4	UHF4	UHF5	GSM900	GSM1800	Others
Total	1.00	0.147	–0.019	0.097	0.132	0.914	0.464	0.195
FM	0.147	1.00	0.393	0.705	0.226	0.036	–0.091	0.197
VHF4	–0.109	0.393	1.00	0.501	0.308	–0.114	–0.055	0.177
UHF4	0.097	0.705	0.501	1.00	0.608	–0.060	–0.133	0.158
UHF5	0.132	0.226	0.308	0.608	1.00	–0.064	–0.026	0.054
GSM900	**0.914**	0.036	–0.114	–0.060	–0.064	1.00	0.209	0.126
GSM1800	**0.464**	–0.091	–0.055	–0.133	–0.026	0.209	1.00	–0.044
Others	0.195	0.197	0.177	0.158	0.054	0.126	–0.04	1.00

Table 6. Regression model summary for significance test.

R	R^2	Corrected R^2	Std. Error of the Estimation	Durbin-Watson Value
0.984	**0.968**	0.967	0.0373	**1.612**

as deterministic [15]. Durbin Watson test statistics being **1.612** indicates absence of autocorrelation.

3.3. Variance Analysis and t Test

Significance column value (or p value) of variance analysis table (Table 7) indicates that the relationship between the variables is statistically significant if it is at ($p < 0.05$) level. The model's overall significance is tested by F test [15]. Hypothesis:

H_0: Coefficients are greater than **0.05**. The model is not significant.

H_1: Coefficients are little than **0.05**. The model is significant.

If the relationship in Table 7 is formulated, the probability value F calculated according to $p = 0.05$ is $p = 0.000 < 0.05$, then the H_0 hypothesis is rejected, and the model is called to be significant.

The test is applied to the significance of the coefficients in the regression model, and the insignificant values are taken off from the model. For this purpose, t test is applied. When the t values calculated according to $p = 0.05$ in Table 8 are tested, the H_0 hypothesis is rejected for each coefficient.

Table 7. Variance analysis.

	Sum of Squares	**Degree of Freedom (df)**	**Mean Square**	F	p
Regression	11.120	7	1.589	**1136.89**	**0.00**
Residual	0.373	267	0.001		
Total	11.493	274			

Table 8. Variable coefficients for EM pollution analysis model.

Variable	**Unstandardized Coefficients**		**Standardized Coefficients**	t	p
	Beta (β)	**Standard Error**	**Beta**		
Constant (β_0)	**0.010**	0.097		0.106	0.916
FM	**0.246**	0.056	0.075	4,430	0.000
VHF4	−1.056	0.925	−0.015	−1.142	**0.255**
UHF4	0.309	0.183	0.036	1.690	**0.092**
UHF5	**0.500**	0.048	0.156	10.473	0.000
GSM900	**0.679**	0.009	0.849	73.504	0.000
GSM1800	**0.437**	0.016	0.305	26.701	0.000
Others	**0.801**	0.121	0.076	6.610	0.000

H_0: Regression coefficients are greater than 0.05. Relationship is not significant.

H_1: Regression coefficients are little than 0.05. Relationship is significant.

Whether the significance level of independent variables is sufficient for the model or not is decided by looking at the p probability values. If $p < 0.05$ then the variable affects the dependent variable and is included on the model. Otherwise, it is assumed that it does not statistically affect the dependent variable and is not included in the model [15].

According to the results retrieved from the environmental measurements values, since the probability values of FM, UHF5, GSM900, GSM1800 and other variables (p values) are smaller than **0.05**, they are included in the model, but it is concluded that the VHF4 and UHF4 variables are not significant for the model. As shown in Table 8, VHF4 and UHF4 variables' p probability values are respectively **0.255**, **0.092** and are greater than **0.05**. Hence they cannot be included in the prediction model. The obtained multiple

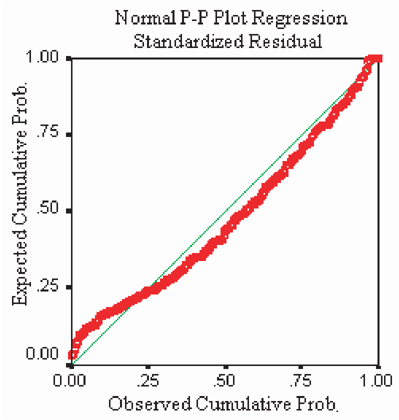


Figure 4. Observed and expected cumulative probability graphics for total EM pollution.

regression model:

$$\begin{aligned}\textbf{Total Environmental EM pollution value} &= 0.01+0.246\text{FM}+0.5\text{UHF5}+0.679\text{GSM900}\\ &\quad +0.437\text{GSM1800}+0.801\ \text{Others} \qquad (3)\end{aligned}$$

The independent variables that affect the total variable were tested using the multiple linear regression analysis were included in the model and studied. According to the data collected during the environmental measurements, the impact of FM frequencies on the overall total pollution is around **0.246**. The impact of UHF5 on the total pollution is about **0.5**; GSM900 is about **0.679**; GSM1800 is **0.437**; the other variable's contribution to the overall pollution is around **0.801**.

It is necessary that the errors are distributed normally in order for the obtained model to be meaningful. It is concluded that the distribution of the total pollution errors is normal since the measurement values are scattered around a 45° linear line when tested with the P-P (Probability-Probability) graphics method. A probability plot is a graphical technique for comparing two data sets, either two sets of empirical observations, one empirical set against a theoretical set, or more rarely two theoretical sets against each other [18, 19]. Distribution of the values for the estimated regression models is shown in Figure 4.

The estimated model is valid when the observed and expected values' distribution is examined.

3.4. Comparison of the Measurement Results by Means of Statistical Model

As a result of the D-F unit root tests applied to the measurements taken from the measurement region in general, the H_0 hypothesis is rejected for level values of each series examined (as shown in Table 3). This indicates that the series do not have unit root at the level and are stable. Consequently, it is possible to utilize multiple regressions using the obtained results, and it is concluded that predictions for future can be made.

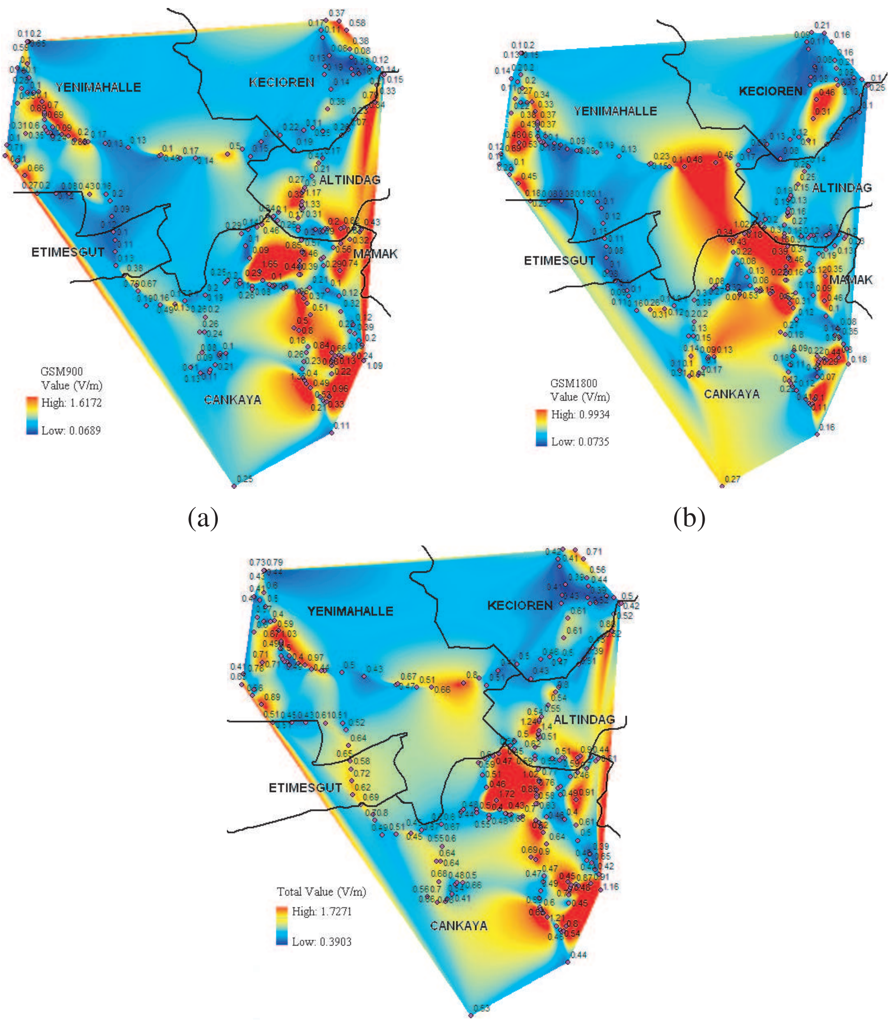
The calculated value by the model (Equation (3)) is **0.475** V/m while the actual total pollution value is **0.46** V/m (as shown in Table 9). Hence, the predicted model is significant and valid when the observed and estimated values' distribution is examined. Having valid models obtained for the measurement regions indicates that the EM pollution values are suitable for predicting future pollution levels. The studies indicate that very close values are recorded when comparing the prediction result of the model obtained from the analysis made by using the SPSS17.0 analysis program and the actual measurement results.

Table 9. Sample comparison of environmental measurement results.

Variable	**Measured Electrical Field Levels (V/m)**				
	1	**2**	**3**	**4**	**5**
FM	0.188	0.128	0.244	0.156	0.181
VHF4	0.107	0.101	0.105	0.103	0.103
UHF4	0.098	0.101	0.104	0.103	0.102
UHF5	0.119	0.144	0.142	0.165	0.209
GSM900	0.067	0.105	0.171	0.142	0.196
GSM1800	0.175	0.091	0.184	0.127	0.082
Others	0.296	0.292	0.297	0.291	0.293
Measured Isotropic Total	**0.460**	**0.457**	**0.574**	**0.491**	**0.552**
Model total	**0.475**	**0.458**	**0.575**	**0.512**	**0.563**

4. EM POLLUTION MAPS OBTAINED FOR THE MEASUREMENT REGION

EM pollution maps generated by ARCGIS are shown in Figure 5. EM pollution maps were obtained by utilizing Natural Neighbour (NN) interpolation technique. Interpolation is a process of estimating grid



(a) (b)

(c)

Figure 5. Electric field values E (V/m) measured (a) for GSM900 base stations, (b) for GSM1800 base stations, (c) total E (V/m) values.

values using measured observations taken from a point. The weights used in natural neighbor interpolation are based on the concept of local coordinates. Local coordinates define the "neighborliness" or amount of influence any scatter point will have on the computed value at the interpolation point. EM pollution levels are represented by blue to red color spectrum in the maps. High EM pollution regions are depicted in red color. As shown in the maps in Figure 5, the electric field level of GSM900 base stations were measured maximum **1.64** V/m and minimum **0.06** V/m during the environmental measurements. For GSM1800, maximum **1.01** V/m and minimum **0.07** V/m electric field levels were measured. Environmental average total pollution values were measured as maximum **1.71** V/m and minimum **0.38** V/m.

5. CONCLUSION

This EM pollution measurement study was done in Ankara city centre which is one of the most populated cities with high level of EM pollution expectations based on the population, constructions, industrial intensity.

The study involved 500 measurements to determine the electromagnetic field levels in and around the schools, hospitals, dormitories, residences and high towers with high level of EM pollution estimations in the Ankara city centre.

As shown in Table 4, total pollution value was recorded as average **0.61** V/m, and its standard deviation was **0.20** according to the **500** measurement results taken from various locations in the city centre. GSM1800 average pollution value was calculated as **0.20** V/m, and its standard deviation was calculated **0.142**. GSM900 average pollution value was **0.32** V/m, and its standard deviation was calculated **0.255**. GSM900 average pollution value was found being the highest correlation relation of **0.914** with total EM pollution value. GSM1800 average pollution value was found **0.464** correlation relation with total value. In other words, total EM pollution is affected by **91.4**% due to variation in pollution of GSM900 and by **46.4**% for GSM1800.

Results indicated that the EM pollution levels were below the 41.25 V/m limit for 900 MHz and 58.34 V/m limit for 1800 MHz according to ICNIRP's recommendations [20–22].

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