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# A COMPARISON OF AMBIENT RADIOFREQUENCY ELECTROMAGNETIC FIELD (RF-EMF) LEVELS IN DIFFERENT OUTDOOR AREAS IN ROMANIA

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**Abstract**

The recent development of wireless communications in Romania has caused concerns among the population regarding how it can affect health. ANCOM has implemented a nationwide monitoring network of electromagnetic emissions with sensors located in over 100 localities that collect data on the ambient level of the electric field. Until now, there has not been an evaluation of this information at the national level and the present work pursues three objectives using data collected over a period of 12 months, from a sample of 44 localities from all historical regions.

The first objective is to establish a average values of the electric field level over a wide area in Romania and comparing it with the reference level in the public health legislation.

The second objective is to make some comparisons between the annual averages of the electric field level in four groups of 11 localities established on the population density criterion.

The third objective is the verification of a supposed increase in the electric field level with the implementation of 5G technology.

Using statistical evaluation methods, the results obtained show an average level of exposure for the 44 localities of 5.78 % of the maximum exposure limit established by OMS1163/2006, the statistical hypothesis regarding the homogeneity of the average values of the electric field for the four groups of localities cannot be rejected either. Multivariate analysis of broadband electric field level composition data cannot demonstrate a greater contribution of the level generated by the deployment of 5G technology. .

## 1 Introduction

The new wireless communication technologies have experienced an accelerated development in Romania as well as in the rest of the economically developed



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countries, with a negative consequence and an increase in the level of electromagnetic pollution coming mainly from the base stations of mobile communication operators. In response to the population's concerns regarding how the limits imposed by the national legislation on exposure to electromagnetic fields are respected, ANCOM has implemented a network of sensors that measure these levels in real time and make them available to those interested on a public portal (emfmonitor .ro).A fear among an important part of the population has particularly induced the widespread use of mobile communications in more and more regions. Thus, a survey carried out in 2006 at the level of the European Union shows that over 60 % of the respondents believe that wireless communication systems would affect health to some extent [1] and through numerous recent studies an attempt has been made to clarify some aspects regarding these fears.

In Europe and beyond, studies were conducted that aimed to verify some hypotheses on how the noxiousness generated by new technologies have a negative influence on health. Thus, a 2014 study done following the International Agency for Research on Cancer's declaration of radiofrequency electromagnetic fields as possible causes of cancer [2], by researchers Michael Carlberg and Lennart Hardell, highlighted a direct relationship between the increased level of electromagnetic noxes and the survival rate of patients with Astrocytoma Grade IV [3]. A study carried out in Saudi Arabia verified the existence of a positive correlation between exposure to RF-EMF (Radiofrequency-Elecromagnetic Fields) and increased levels of glycated hemoglobin (HbA1c) in 250 volunteer subjects who were students at a university in Riyadh. The results of the study indicated an increased risk of diabetes in students who were exposed to electromagnetic noise compared to the control group [4].

Other studies have checked the possible changes over time in the levels of exposure of the population due to the technological changes in the field of wireless communications such as the one in Switzerland [5] which followed the evolution of the RF-EMF level compared between the years 2017 and 2021. The study was done in different areas representative for population density (Rural, suburban and urban) and in different micro environmental environments including in different means of public transport. The results obtained from the evaluation by statistical means of the data obtained from the measurements showed insignificant changes between the two years in terms of RF-EMF values.

Closer to us, a study from Serbia aimed to verify EMF levels near mobile communication stations and the results showed that on the one hand the general level of noise contains all the components generated by mobile communication stations, and on the other hand that the maximum of the electromagnetic field level measured is below the reference limit of the legislation in Serbia although the distance between the emission antenna and the measurement point was 60 m [6].

A 2020 study by researchers from the Gheorghe Asachi University in Iași, in

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collaboration with ANCOM, formulated conclusions regarding the level of exposure to EMF at the level of the municipality of Iași [7] The data were taken from the 4 ANCOM sensors installed in populated areas from the city for the whole year 2020 and the average and maximum values were used for comparison with reference levels in Romaninan national legislation (OMS 1193/2006)

According to the data published by ANCOM in a synthesis of the electronic communications market from the first half of 2023 in Romania, a growth rate is maintained in the internet segment and data that express the trend of digital transformation of the data transmitted through these systems. From the same synthesis, a 4 % increase in mobile internet traffic is observed, most of it being done on 4G networks (94 %) but also a doubling of traffic on 5G networks [8]. Thus the legitimate question arises whether this increase is reflected in an increase in the level of electromagnetic pollution over a wide area and a scientifically based answer is desired to be made in the present work.

# 2 Materials and methodes

## 2.1 Equipment used for measurements

To measure the electric field level, specialized sensors for electric field level measurements like the one in Figure 1 were used. The Narda AMB module is con-




Figure 1: Narda AMB 8059/03 module and EB-4B-02 probe

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nected to a specialized isotropic triaxial antenna for broadband measurement (100KHz-7GHz) which, together with the sensor's active filters, also allows measurement on three distinct bands (942MHz, 1842MHz and 2140MHz) used by mobile communications operators in Romania. With few exceptions, it can be said that most applications using wireless technology are covered, such as mobile communication networks, AM and UUS radio transmitters, DVB-T2 transmitters, Wi-Fi networks, mobile or fixed transmitters for point-to-point communications. ANCOM sensors are equipped with autonomous energy supply systems (solar panel) and GSM modem used to transmit data once a day to the server. I mention that I removed the data recorded during the transmission period from the database used in order not to influence the calculated average value. More details about the equipment used can be found in Table 1

Table 1: AMB 8059 Tehnical specification

| AMB-8059 Multi-band EMF Area Monitor Tehnical specification | |
|---|---|
| Measurements units | Wm, kV/m, nT, VT, mT, % |
| Field measured | Total field, average and Peak (MAX) |
| Sampling | 1 measurement every 1 s |
| Memorization interval | Programmable from 30 sec to 15 min |
| Memory | Over 128 MB |
| Max data storage capacity | Over 364d with 1 acquisition/min |
| Field strength alarm | Two programmable field strength thresholds |
| Clock | Real time internal clock |
| Sensor | Display of model and calibration date |
| Battery management | Every record includes Battery Voltage and Charge Current value |
| Temperature management | Every record includes Internal Temperature value |
| Humidity management | Every record includes Internal Humidity value |
| GPS coordinates | Programmable record |

## 2.2 Location and measurement conditions ( measured frequency bands

Location of the the sensors was done in compliance with the ITU-T K.83 recommendation regarding the monitoring of electromagnetic field levels. Sensors are usually placed on building roofs or higher locations to have an unobstructed line of sight to electromagnetic field sources, in more densely populated areas such as public buildings, university campuses, public squares, hospitals, transport stations. The measured values can be negatively influenced by the existence in the

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immediate vicinity of the sensors of some metal structures or even by the own modem at the time when the data is transmitted to the server, so these aspects were taken into account at the time of data processing. An example of the location of a sensor is the one shown in Fig.2




Figure 2: Senzor EMF in Timisoara

Taking into account that from the point of view of the share of electromagnetic field sources in the exposure level of the population, the mobile communication systems are in the first place, also the ANCOM's sensor network was designed to monitor these systems.

The frequency bands allocated in Romania for this type of communications were auctioned and allocated to the five main operators as can be seen in Fig. 3

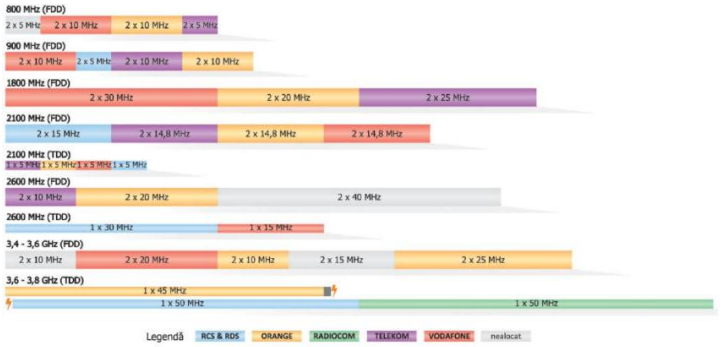



Figure 3: Mobile comunication frequency spectre used in România

Outside of these bands, radio transmitters transmitting in the medium-wave

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(UM) and ultra-short-wave (UUS) bands and television transmitters transmitting in the ultra-high frequency (UHF) band have a smaller share. The values measured and recorded by the ANCOM sensors represent the total value of the electric field level measured on the three propagation planes with the formula:

$$E_{TRMS} = \sqrt{E_{XRMS}^2 + E_{YRMS}^2 + E_{ZRMS}^2} \tag{1}$$

and each of the three components are calculated in turn with the formula:

$$E_{RMS} = \sqrt{\frac{1}{T}\int_0^T E(t)^2, dt} \tag{2}$$

where E(t) is the electric field as a function of time, and T is the time period over which the integration is done.

In the context of exposure to electromagnetic radiation, RMS values of the electric field are worldwide used to assess exposure levels and ensure compliance with safety standards.

## 2.3 The locations of the sensors

In Romania, the EMF monitoring network includes a number of more than 70 localities where more than 140 sensors are located and used for monitor 24/7 the level of the electric field and the data collected by them is available on the monitor-emf.ro [9] platform. An interactive map with the location of the sensors on the national territory is presented in Figure 4

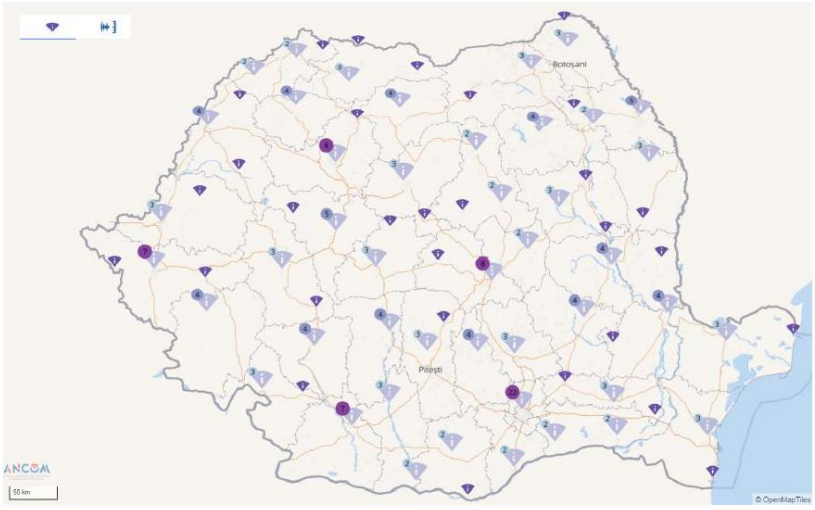



Figure 4: The locations of ANCOM sensors from Romanian cityes

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On the web page accessible for free when accessing a location, the electric field values of the last 3 days are displayed in a window in the form of a graph as seen in the screenshot shown in Figure 5




Figure 5: Prezentarea informațiilor unui senzor din rețeaua EMF prin accesarea hărții interactive

For this study, we obtained with courtesy of ANCOM the electric field level value data from 44 localities, mainly county seats or municipalities in all historical provinces to have an overview of the RF-EMF level at the national scale. From the initial volume of data, we extracted average and peak electric field level values in broadband (100KHz-7GHz) and on the three bands assigned to mobile communications (925-960MHz, 1805-1880MHz, 2110-2170MHz). In addition to these data, we also retrieved information regarding the moments when the recording was made (timestamp) and the ambient temperature values from those moments. The data were initially processed in excel where we did a filtering of non-compliant values (values recorded at the time when the sensors were transmitting data to the server, or exaggerated values also possibly caused by recording/transmission errors).

In order to verify a supposed connection between the electric field values measured in the localities and the population density, we added data on the number of permanent residents in the respective localities with data taken from the romanian population census carried out in 2021 [10]. The 44 localities we then grouped in 4 categories of 11, each based on the population density criterion as can be seen in Table 2

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Table 2: Grouping of localities according to the number of residents

| **EMF monitored localities table** | |
|---|---|
| Cityes group names | Number of permanent residents |
| Municipii 1 | 10000-35000 |
| Municipii 2 | 35100-72000 |
| Reședințe 1 | 73000-183000 |
| Reședințe 2 | 200000-1717000[a] |

[a]Bucharest included

# 3 Statistical data processing and results

## 3.1 RF-EMF values measured at national level

The first data processing consisted in calculating the means of annual values for the CE level measured in broadband to visualize a possible correlation between it and the population density, a bar graph with the recorded values is shown in Figure 6.

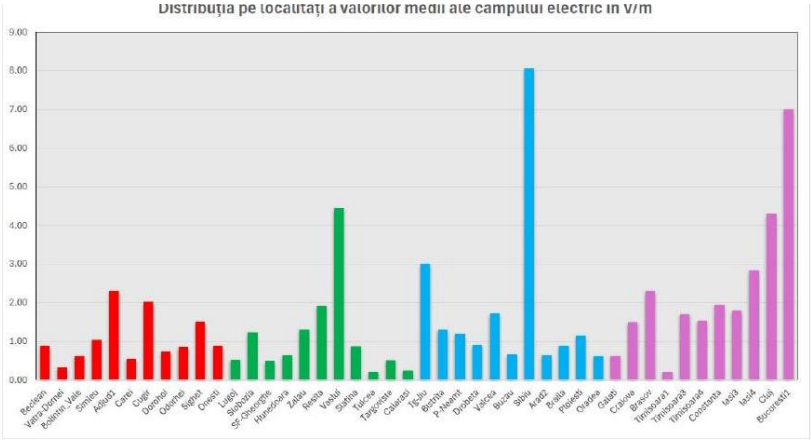



Figure 6: Recorded means CE values in 44 localities; Municipii 1 -Red, Municipii 2 - Green, Reședințe 1 - Blue, Reședințe 2 - Violet)

The values related to each locality represent the average annual value of the electric field and as can be seen they fell within the range of 0.20 - 8.05 [V/m].

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The average annual EC value for the 44 localities was 1.53 [V/m] which represents a percentage of 5.56 % of the maximum exposure limit imposed by legislation [11].

In order to better observe the distribution of values in each group of localities, as well as the median values, quartiles and outliers, we created a boxplot type graph presented in Figure 7.

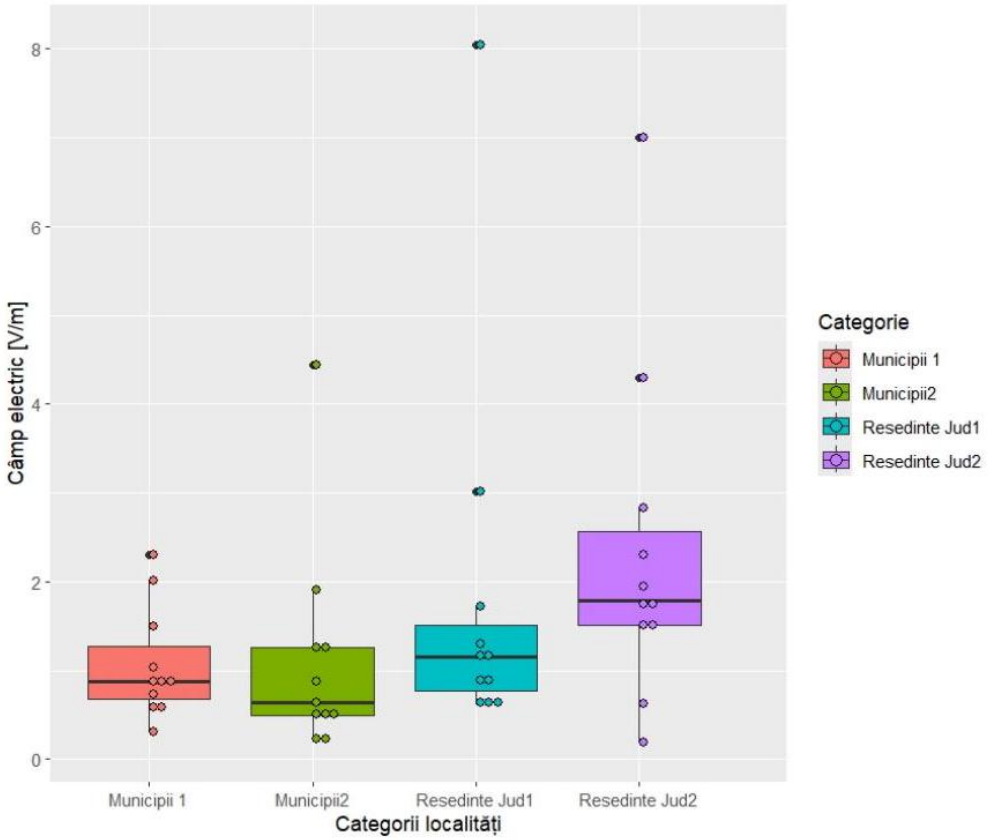



Figure 7: Boxplot of CE levels by locality groups

## 3.2 Hypothesis testing

In the statistical analysis by groups of localities, we started from the hypothesis of the existence of a significant difference between the means and variances for the 4 categories of localities, these data being included in the Table 3.

To test the statistical hypotheses, I decided to use the paired T-test on two groups of localities to verify the null hypothesis "There are no significant differences between the means of the two groups". I used the specialized R program

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Table 3: Means and Variance by locality groups

| | Mun 1 | Mun 2 | Res 1 | Res2 |
|---|---|---|---|---|
| AVG | 1,06 | 1,12 | 1,83 | 2,34 |
| VAR | 0,06 | 0,28 | 0,27 | 0,41 |

for statistical studies, available in the free edition, and after running the test with the data presented above, I obtained the values from Table 4

Table 4: Results of paired T-tests for groups of localities

| **Tested groups** | **test T** | **df** | **p -Val** |
|---|---|---|---|
| Mun1 vs Mun2 | -0,15 | 14,93 | 0,88 |
| Mun1 vs Res1 | -1,13 | 11,63 | 0.28 |
| Mun1 vs Res2 | -2.13 | 12,15 | 0,05 |
| Mun2 vs Res1 | -0,94 | 15,69 | 0.36 |
| Mun2 vs Res2 | -1,80 | 17,07 | 0.09 |
| Res1 vs Res2 | -0,59 | 19,61 | 0.56 |

It can be seen that the p-values of the 6 tests are greater than the 0.05 level of significance and the p-value of 0.8832 from the first test suggests that there is an approximately 88.32 % probability that the observed difference is due to chance, in other words we can say we don't have enough evidence to reject the null hypothesis.

Another variant of statistical testing of the data from the 4 groups was by using the multiple paired T-test. After running this test using the Benjamini and Hochberg method, we obtained the results from Table 5.

Table 5: Multiple paired T-test results

| - | Mun1 | Mun2 | Res1 |
|---|---|---|---|
| Mun2 | 0,93 | - | - |
| Res1 | 0,46 | 0,46 | - |
| Res2 | 0,24 | 0,24 | 0,55 |

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Table 5 contains only the p-values calculated for a significance level of 0.05 which apparently differ from the p-values calculated with the simple paired T-test but lead us to the same conclusion that we do not have enough evidence to reject the null hypothesis.

To deepen the statistical research, we also ran on the same data set one-way ANOVA tests as an alternative to the multiple paired T-test, Bartlett test to check the homogeneity of variances, the Shapiro-Wilk test to check the data distribution and a non-parametric test, the Kruskal-Wallis test to improve the result the ANOVA test.

The results of running these tests in R are shown in Tables 6, 7, 8 and 9.

Table 6: Rezults of ANOVA unidirecțional test means 4 groups

| - | SumSq | MeanSq | Fvalue | **Pr(¿F)** |
|---|---|---|---|---|
| Variab | 12,28 | 4,09 | 1,61 | **0,20** |
| Resid | 101,5 | 2,53 | - | - |

Table 7: Rezults of Bartlett test of variances for 4 groups

| Bartlett test of homogenity of variances | | |
|---|---|---|
| Date : Mun1, Mun2, Res1, Res2 | | |
| K-squared=**14.004** | df=**3** | p-value =**0.0029** |

Table 8: Rezults of Shapiro-Wilk normality test

| Shapiro-Wilk normality test | |
|---|---|
| Date : Reziduale test ANOVA | |
| W = **0.73848** | p-value = **1.701e-07** |

Table 9: Rezults of Kruskal-Wallis rank sum test

| Kruskal-Wallis rank sum test | | |
|---|---|---|
| Date : groups means Mun1, Mun2, Res1, Res2 | | |
| K-W chi-sq = **6.98** | df = **3** | p-value = **0.073** |

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For the ANOVA test, as in the case of the T-tests, and in this case the null hypothesis states that there are no statistically significant differences between the means of the four groups of localities. A p-value of 0.202 obtained in this test convinces us that we cannot reject this hypothesis. To validate this model we used the graphical method using the Residuals vs Fitted and Q-Q graphs and when analyzing them we observed an inhomogeneity of the variance which led to the conclusion that the ANOVA test is not the most suitable for analyzing the data underlying this study.

By running the Bartlett test we obtained a result (p-value 0.0029) that confirms the inhomogeneity of the variance.

Next we checked the data for distribution using the Shapiro-Wilk test to check whether it follows a normal distribution or not. The result of this test confirmed beyond any doubt that the data does not follow a normal distribution (the p-value of the test was 5 orders of magnitude lower than the classical significance level)

The complementary, non-parametric test recommended to be used in cases where ANOVA is not suitable is the Kruskal-Wallis test, which verifies the homogeneity of the medians. After running this test, the obtained p-value confirms the fit of the null hypothesis of homogeneity of the medians.

### 3.3 Multivariate analysis

Another statistical approach to the data I made using multivariate analysis, trying to make an inference on the average value of CE according to 6 variables of 44 observations related to localities. We considered the response variable to be the average annual value of the electric field measured in broadband, and as predictor variables we used the average annual temperature, the number of inhabitants, the average annual value of the peak values of the electric field also measured in broadband as well as the values annual averages of the electric field measured in the three bands used in mobile communications. I also performed the analysis with the R program, the first step being the calculation of the correlation matrix between the variables and the displayed result is shown in Figure 8.

Although the data structure used in the paper is not complex, we also considered useful a principal components analysis (**PCA**) to verify the possibility of simplifying the analysis and even the possibility of visualizing the data in two or three dimensions. After running the PCA analysis in R we obtained the data on the proportion of variability of each principal component in the general regression model.

Thus, as can be seen in Figure 9, the first 4 components explain a proportion of 95 % of the variation of the regression model. Also, to verify the structure of each main component, we ran the PCA analysis in R and obtained the structure for Component 1 that explains the most variability of the regression model.

On the graph in Figure 10, you can see the weights of the predictor variables

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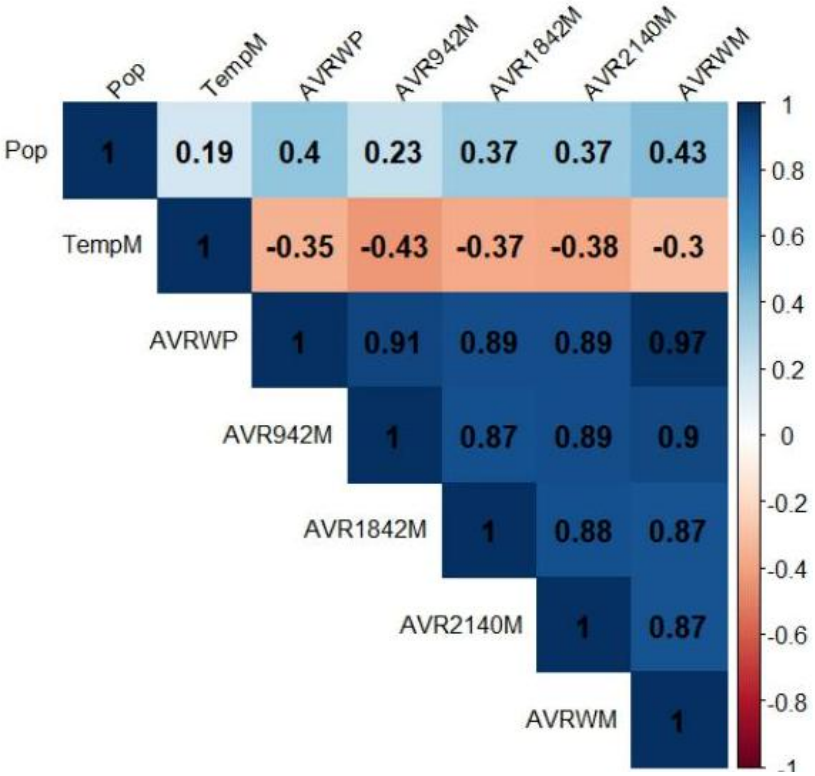



Figure 8: Spearman‘s corelation matrix

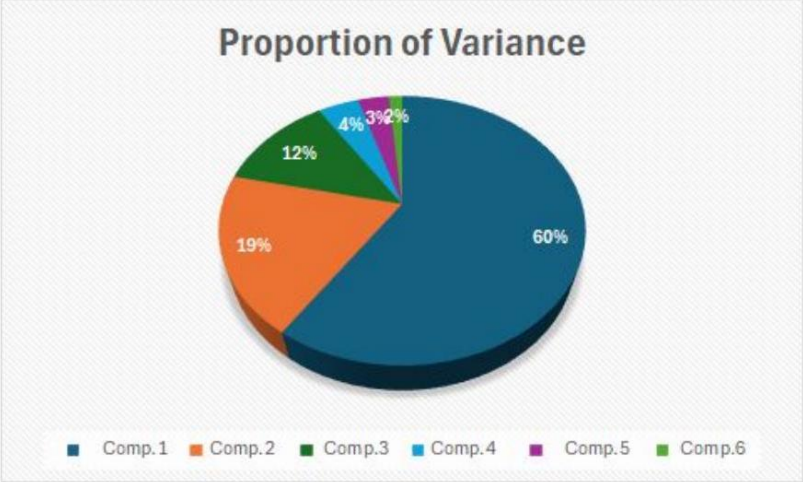



Figure 9: Proportion of Variance

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within it.

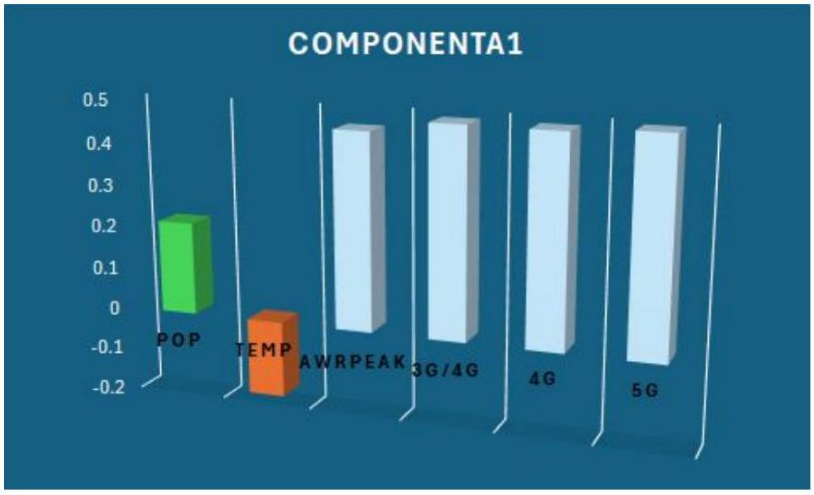



Figure 10: Component 1 structure of variables

The final step of the PCA analysis was to determine a multiple linear relationship between the principal components and the response variable **AVRWM**. The ***lm*** (linear model) function in R is used to fit linear regression models, and when applied to principal components, the goal is to use these components (which are linear combinations of the variables originals) as predictors in a regression model.

The result obtained after running this analysis in R confirmed the futility of using component 6 in building the model, the p-value of the T test related to it being higher than the level of significance, for which we removed it from the model and the result obtained was that of Table 10

Through the prism of comparing the p-values, a fit of the model is clearly observed, a confirmed situation and both the value close to the maximum for the adjusted R-squared coefficient and the p-value of the F-test.

## 4 Discussions

It can be seen on the graph in the figure 7 the average value of the electric field is slightly higher for the category of localities with a larger number of inhabitants (Residence Jud 2) and for the other groups the average values are quite close. There are two possible explanations for this situation, both of which are based on the characteristics of the sources that generate the electromagnetic field.

The first explanation is related to the fact that an increased population density is positively correlated with an increased number of mobile communications and this can only be achieved through a higher density of mobile phone base stations.

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Table 10: Linear PCA model optimized for 5 components

| **Residuals**: | | | | |
|---|---|---|---|---|
| **Min** | **1Q** | **Median** | **3Q** | **Max** |
| -0.41706 | -0.04321 | 0.00881 | 0.06202 | 0.51178 |
| **Coefficients**: | | | | |
| - | **Estimate** | **Std. Err** | **t value** | **Pr(¿—t—)** |
| (Intercept) | 1.63179 | 0.02166 | 75.351 | ¡ 2e-16 |
| Comp.1 | 0.71881 | 0.01147 | 62.683 | ¡ 2e-16 |
| Comp.2 | 0.41357 | 0.02022 | 20.451 | ¡ 2e-16 |
| Comp.3 | 0.34592 | 0.02514 | 13.762 | 2.4e-16 |
| Comp.4 | -1.20084 | 0.04234 | -28.362 | ¡ 2e-16 |
| Comp.5 | -0.16913 | 0.04865 | -3.476 | 0.0013 |
| Residual standard error: 0.1436 on 38 degrees of freedom | | | | |
| **Multiple R-squared: 0.993–Adjusted R-squared: 0.992** | | | | |
| **F-statistic: 1071 on 5 and 38 DF, p-value: ¡ 2.2e-16** | | | | |

An increase in the number of mobile stations, on the other hand, automatically leads to an increase in electromagnetic noise within the radius of the respective localities. From the analysis of the localities, most of those with a higher level of the electric field have a high population density and are university centers (Bucharest, Iași, Brașov, Sibiu, Constanța, Timișoara).

The second explanation for a higher measured electric field level is related to the existence in or near the towns of high power radio/TV transmitters, which generate higher electric field levels. These transmitters were initially installed (‘50-‘70 years) outside the towns, but with the expansion of the residential areas they were included inside them and therefore the respective areas have a higher level of electromagnetic pollution (Timișoara, Sibiu, Bucharest, Iași)

The inconclusive results of the paired **T** and **ANOVA** tests were due to the fact that the distribution of the data was not suitable for the use of the first two. Finally, the verification of the normality of the data distribution with the **S-W** test and then of the homogeneity of the medians with the **K-W** test supported the hypothesis regarding the homogeneity of the average values of the electric field level in the case of the four groups of localities.

We considered useful the multivariate analysis using as response variable the average value of the electric field measured in broadband because it best reflects the level of exposure of the population to electromagnetic noxes, being taken as a reference in the case of the analysis of the level of exposure in accordance with the legislation in the field .

From the perspective of this analysis, the results of the calculation of the correlation matrix 8 lead us to the conclusion of the existence of a strong link between the response variable **AVRWM** and the predictor variable **AVRWP** and weaker links between the variables **AVR942M**, **AVR1842M**, **AVR2140M**

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and **AVRWM**.

The situation can be explained by the fact that in the composition of the average value of the broadband electric field, the electric field values from the three bands allocated to mobile communications also have a significant weight. The correlation values between the predictor variables related to the electric field values can be explained by the fact that the emission levels of mobile communication base stations are relatively similar. We also observe a weak negative correlation between the variable temperature and the variables of the electric field values, explained by the fact that the propagation of electromagnetic waves is favored by low temperatures.

From Table 9 we can conclude that the first four components explain 95 % of the variability of the model and therefore they are sufficient for further analysis. Component 1 has the largest weight in explaining the variability of the linear model and within it, following the PCA analysis, we noticed that the variables containing average values of the peak electric field and on frequency bands have a similar but higher weight than the average temperature values or population density which comes as a confirmation of the interpretation of the correlation matrix results.

Although from the point of view of the results obtained after running the PC analysis in R, the model with 6 principal components is similar to the one with 5 components in practice simpler models are preferred for possible graphical processing or for the simplicity of the analysis. The efficiency of the PCA analysis can best be seen by comparing it with the model obtained from the linear analysis with the predictor variables in this latter case only two variables passed the T-test and could enter the model, a situation in which the model does not show confidence.

## 5 Summary and conclusions

Data were collected on the levels of exposure of the population to the electromagnetic field in the period September 2022-September 2023 from 44 localities in Romania spread over the entire national geographical area. Annual average values of the electric field level measured in broadband (100KHz-7GHz) and in three bands used by mobile communication operators (925-960MHz, 1805-1880MHz, 2110-2170MHz) were processed in order to use them for various analyzes statistics.

For the first part of the study, the data were divided into four groups selected on the basis of population density, and statistical tests were performed to verify the hypothesis that there are no statistically significant differences between the four means. The paired T, multiple paired T, ANOVA, Bartlett, Shapiro-Wilk, Kruskal-Wallis tests were run in R and their results confirm the homogeneity of

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means, medians and the fact that the data do not have a normal distribution.

In the second part of the study, we did a multivariate analysis with 5 predictor variables containing observations from all 44 localities to obtain a model of variability of the average electric field level in broadband. Following the PCA analysis, we obtained a model that explains 99 % of this variability for the respective cities, the prediction error being very small.

From the point of view of the levels of exposure to electromagnetic pollution of the population at national level, the average value for the 44 localities represents a percentage of 5.78 % of the maximum limit allowed in the legislation (27.5 V/m), the minimum values and maximum exposure being recorded in Tulcea (0.73 %) respectively in Sibiu (29.27 %).

At the present moment, the implementation of 5G technology in Romania is in its early stages, being available only in large towns, the frequencies proposed for use being available on the ANCOM [12] page, but even so it can be stated based on the analysis in this study that no has a significant impact on the share of electromagnetic pollution in the respective localities, so the fears induced to the population through the mass media are unjustified.

As wireless technology develops by leaps and bounds, it is necessary to develop the electromagnetic nox monitoring systems and to continue studies in this field in the future in order to provide safety among the population regarding the correct use of new technologies without affecting the state of health .

## Aknowlegements

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