MULTIVARIATE STATISTICAL ANALYSIS OF FOG PHENOMENON IN NORTHWESTERN ROMANIA

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ABSTRACT:
In the present study a statistical analysis of annual, seasonal and monthly data series with number of fog days was made in order to identify the main factors, which decide the spatial variability of the phenomenon. In order to investigate the behavior of fog phenomenon in the Northwestern part of Romania, several statistical techniques were applied to time series. Hierarchical cluster analyses and principal components analyses (PCA) were used to explain the spatial distribution. The datasets spread over 46 years in 8 weather stations from Northwestern Romania, located in the plain and hilly areas. Thus, in the area, there are two types of variability, and among the local factors, the vicinity of water resources is the most important one. There are three principal components identified which explain more than 92 % of the variance for the spatial distribution of fog phenomenon in the area. Among them, seasonal numbers of fog days are associated to general climatic conditions of the analyzed region and distance from water resources, altitude and relief unit type are considered local factors which influence the spatial distribution of the fog phenomenon.

Keywords: *fog, cluster analysis, principal components analysis, local factors, Northwestern Romania.*

1. INTRODUCTION

Fog is one of the most important weather phenomena that influence human activity. Fog effects range from delays, particularly in aviation, marine, and surface transportation to serious accidents caused partly by poor visibility. This is the reason why fog phenomenon has become an interesting scientific topic for tens of years all over the world. While, first important scientific studies on fog were written, internationally, during the first half of the XXth century (*Ward, 1923; Stone, 1936*), in Romania, first scientific papers on fog were published in the second half of the XXth century. Usually, scientific papers published abroad cover different genetic types of fog: radiation fog (*Lala et al., 1975; Meyer and Lala, 1990*), high-inversion fog (*Holets and Swanson, 1981*), valley fog (*Pilie et al., 1975*). In Romania, the most important part of studies was focused on local areas, especially, on big cities of the country with airports nearby. Actually, the studies are made especially for airport use. Synoptic conditions, which could generate fog or technical methods for fog dissipation in the airports areas, were also main topics they dealt with (*Şorodoc, 1961; Chertic and Lorentz, 1964; Şorodoc and Cristodor, 1965; Grama, 1965; Bogdan and Mihai, 1972; Sârbu, 1983; Ţâştea and Sârbu, 1984; Maier, 2007; Bogdan and Marinică, 2007*).

Considered as a passive phenomenon because formation and dissipation processes are usually generated by a combination of a multitude of general and local factors (*Pinheiro et*

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al., 2006), fog is difficult to be studied in scales larger than those occurring locally. Great variety of local conditions, which might explain the differences that appear in fog phenomenon spatial occurrence, is one of the most important reasons that have not encouraged researchers to approach scientific studies at regional or national scale (*Bogdan and Mihai, 1972*).

Climatic studies on fog often appear as chapters of complex climatic studies of urban climate (*Erhan, 1979*) or of different Romanian regions (*Teodoreanu, 1980; Gaceu, 2005a*). At the same time, the most part of analyzed data series in the up-mentioned papers cover very short time data series, usually, less than 10 years. Regional studies referred to larger areas have been recently written using data sets spread on periods longer than 30 years (*Gaceu, 2005b; Mureşan and Croitoru, 2009*). The average number of fog days and frequency of occurring have been calculated in the most part of the up-mentioned studies. *Mureşan and Croitoru (2009)* determined middle term trends for annual and seasonal data series. The main aim of this study is to identify some common features of fog phenomenon and to find responsible factors for spatial distribution of the phenomenon in the analyzed area.

2. DATA AND METHODS

2.1. Data

Data recorded in 8 weather stations from Northwestern Romania have been used in elaborating the present study. All of them are located in the hilly and plain areas (**Fig. 1**, **Table 1**). Data for mountain stations have not been available so far.

Table 1. ***The geographical location of the weather stations in the analysis area***

Weather station*	Latitude	Longitude	Absolute height (m)	Relative Height (m)	Relief unit type
Baia Mare	47.39. 39	23.29.29	216	27	Depression
Bistrița	47.08.56	24.30.49	366	1	Valley
Cluj-Napoca (a) **	46.47.00	23.42.00	313	2	Valley
Cluj-Napoca (b)	46.46.39	23.34.17	410	65	Interfluve
Dej	47.07.40	23.53.56	236	1	Valley
Ocna Şugatag	47.46.37	23.56.25	503	42	Depression
Satu Mare	47.43.17	22.53.13	123	1	Plain
Sighetu Marmației	47.56.21	23.54.15	275	3	Depression
Zalău	47.11.41	23.02.48	295	46	Depression

Weather stations are ranged in alphabetical order. ** Seconds for active weather stations were recently determined and because Cluj-Napoca (a) does not work anymore, data on seconds were not available. The available data refer mostly to the monthly or annual number of fog days without mention the exactly hours or day of the month when it occurred, so we could not identify the period of the day or the synoptic conditions which were responsible for fog genesis to introduce them as variables in the multivariate statistical analysis.

Cluj-Napoca Weather Station changed its location in 1967, January 1, and because the new location is completely different from the old one, we considered them as different stations: Cluj-Napoca (a) for the old location and Cluj-Napoca (b) for the new location.

The height difference between them is about 100 m. Thus, for Cluj-Napoca location two data series have been used: one short series, spread over 6 years, for Cluj-Napoca (a) and a 40 year-long series for Cluj-Napoca (b).

Annual and monthly data have been used to analyze the average and the maximum number of fog days, while annual and seasonal data have been used in order to identify common features in the spatial distribution of fog days occurring in a period spread over 46 years (1961-2006). The number of values in the data sets varies from 39 to 45 for winters and from 40 to 46 for monthly, seasonal other than winter and for annual values. Cluj-Napoca (a) is considered to be an exception, with 5 values and respectively 6 values.

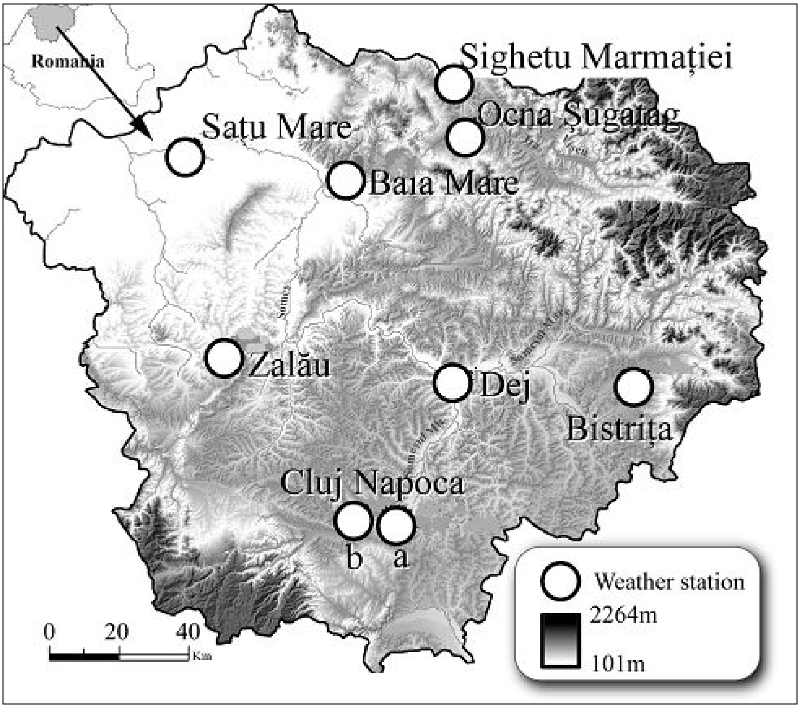

Fig. 1 Northwestern Romania and the analyzed weather stations

2.2. Methods

Based on monthly number of fog days, maximum and average monthly, seasonal and annual numbers of fog days have been calculated.

To calculate the distance from water resources we have considered the first two aquatic areas next to each weather station on topographic maps. Than the average value between them has been calculated and the average distance has been finally obtained.

Relative altitude or vertical distance (ΔH) has been computed as difference between absolute altitude of the weather station and the absolute altitude of the nearest low area (usually, the nearest water resource).

Direct correlation coefficient was computed between annual average number of fog days and the main “local” variables (absolute altitude, relief unit type, distance from water resources).

Hierarchical cluster analysis using the Ward method on seasonal and annual fog data series has also been used in order to identify whether some stations behave similarly or not and whether a typology is likely to be made. Thus agglomerative hierarchical clustering (AHC) with Ward's method and an Euclidean distance matrix has already been calculated (*Legendre and Legendre, 1998; Rebetez and Reinhard, 2008*). Each sample is initially treated as a cluster and the method proceeds stepwise, systematically merging clusters whose fusion results in a minimum loss of information. This procedure attempts to identify relatively homogeneous groups of variables based on fog characteristics, using an algorithm that starts with each variable in a separate cluster and combines clusters until only one is left. Distance or similarity measures are generated by proximities procedure.

Using Principal Components Analysis (PCA), we could identify and explain how important one variable or another was in the variation and distribution of data sets. The entire subject of statistics is based on the idea that there is a big set of data, and it is advisable to analyze that set in terms of the relationships between the individual points in that data set. It is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences (*Smith, 2002*). Since patterns in data can be hard to find in data sets of high dimension, PCA is a powerful tool for analyzing data. Another advantage of PCA is that once these patterns found, the data can be compressed by reducing the number of dimensions, without much loss of information. At the same time, the method allows to emphasize the main variables that influence most of the datasets used.

3. RESULTS

The highest average numbers of fog days are specific to the coldest months, January and December, at the most part of the analyzed locations (**Table 2**, **Fig. 2**). The single weather station where the maximum value is recorded in September is Dej. The values recorded, are usually double or triple as compared to the other stations for the same months. The highest monthly average numbers of fog days are specific to Cluj-Napoca (a), for January and December, and to Dej, for September and October, when more than 10 fog days/month are recorded, as average.

Table 2. ***Monthly average number of fog days (1961-2006).***

Weather Station	J	F	M	A	M	J	J	A	S	O	N	D
Baia Mare	8.1	5.7	2.0	0.8	0.8	0.4	0.5	0.9	1.7	3.4	5.1	8.2
Bistrița	6.9	4.0	1.4	0.3	0.5	0.3	0.3	0.4	1.0	1.8	4.1	7.3
Cluj-Napoca (a)	10.8	6.7	3.3	1.3	1.5	1.0	1.3	2.0	4.8	6.3	7.2	11.3
Cluj-Napoca (b)	8.6	5.3	1.5	0.7	0.4	0.5	0.5	0.7	1.4	3.5	7.2	8.6
Dej	8.0	7.4	3.1	2.0	3.6	4.3	5.7	8.2	10.8	11.1	8.4	9.5
Ocna Şugatag	7.7	5.9	3.8	2.0	1.3	1.8	1.4	1.9	2.3	2.6	6.8	9.0
Satu Mare	9.4	6.8	2.8	0.8	1.3	1.0	1.2	1.8	2.7	4.6	6.2	9.0
Sighetu M.	8.3	5.5	2.2	0.5	0.8	0.7	0.8	1.3	2.0	2.5	4.8	9.8
Zalău	3.7	2.2	1.1	0.3	0.3	0.2	0.1	0.3	0.8	1.3	2.7	4.1

June, July and August are characterized by a low number of fog days in the whole area, with frequent values less than 2 fog days/month. The only exception is also Dej weather station where fog occurs 4 to 9 days/months even during these months. This means that fog days in Dej are twice to four times more frequent as compared to the other stations.

The lowest monthly average number of fog days has been recorded every month in Zalău weather station.

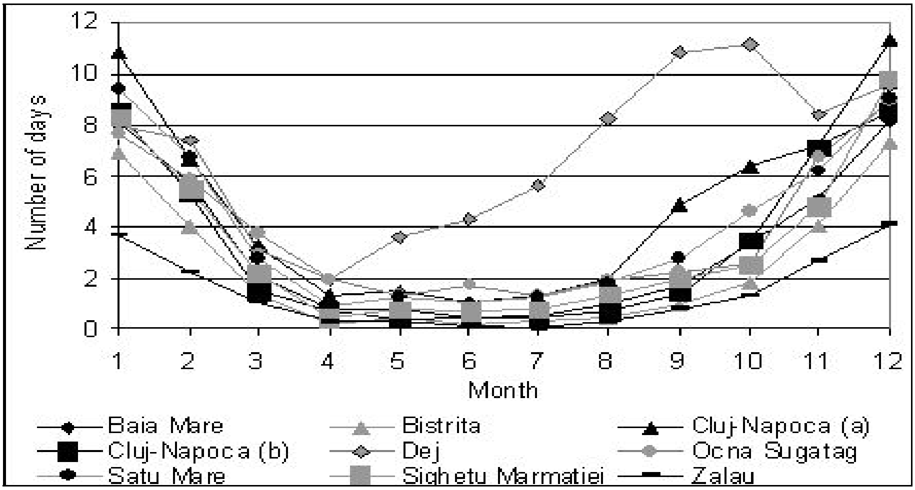

Fig. 2 Monthly average number of fog days (1961-2006)

The monthly maximum numbers of fog days are usually more than double as compared to the monthly average ones (**Table 3**, **Fig. 3**).

The distribution throughout the year of the maximum number of fog days is almost similar to that of the average numbers.

Table 3. ***Monthly maximum number of fog days (1961-2006).***

Weather Station	J	F	M	A	M	J	J	A	S	O	N	D
Baia Mare	17	13	5	5	4	3	3	4	6	15	11	17
Bistrița	16	13	6	2	10	2	2	2	4	9	15	18
Cluj-N. (a)	15	15	9	3	4	3	4	5	8	11	10	16
Cluj-N. (b)	22	13	5	3	2	4	4	4	5	10	15	15
Dej	16	18	9	7	7	9	12	15	21	20	20	16
Ocna Șugat	24	16	13	11	6	8	6	8	9	8	21	24
Satu Mare	19	17	11	4	4	6	5	5	12	17	11	23
Sighetu M.	19	13	7	4	3	3	4	5	7	9	19	20
Zalău	14	7	5	3	3	1	2	2	3	7	7	13

The annual numbers of fog days varies from 17.1 to 82.1 in the case of the average values and from 67 to 170 for the maximum ones (**Table 4**, **Fig. 4**). The lowest values have been recorded in Zalău and the highest in Dej.

To explain the spatial distribution of the phenomenon, first direct correlation coefficients between the average number of fog days and main local factors as absolute altitude, relative altitude, distance from water resources have been computed. The values of all those coefficients have quite low values and none of them can explain the spatial distribution of the fog phenomenon alone: -0.199 for altitude, -0.442 for relative altitude, and -0.391 for distance from water resources. That is the reason we have decided to use multivariate statistical methods.

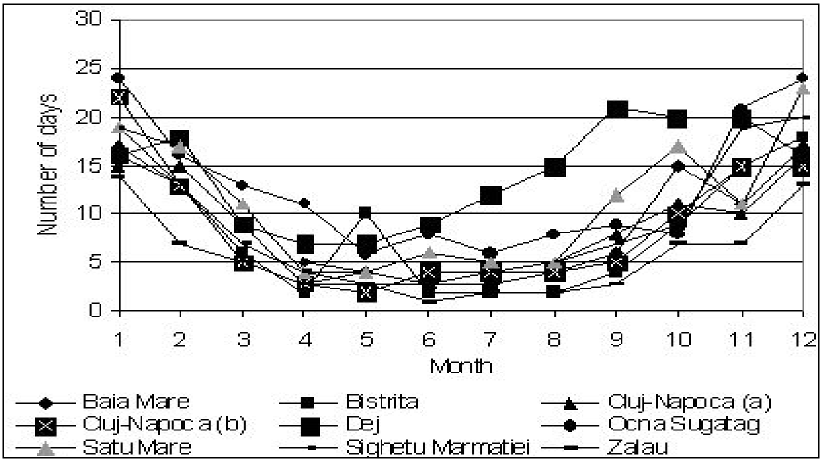

Fig. 3 Monthly maximum number of fog days (1961-2006)

Table 4. ***Annual average and maximum number of fog days.***

Weather Station	Number of fog days	
	Average	Maximum
Baia Mare	37.6	103
Bistrița	28.3	99
Cluj-Napoca (a)	57.5	103
Cluj-Napoca (b)	37.9	102
Dej	82.1	170
Ocna Șugatag	46.5	154
Satu Mare	47.6	134
Sighetu Marmației	39.2	113
Zalău	17.1	67

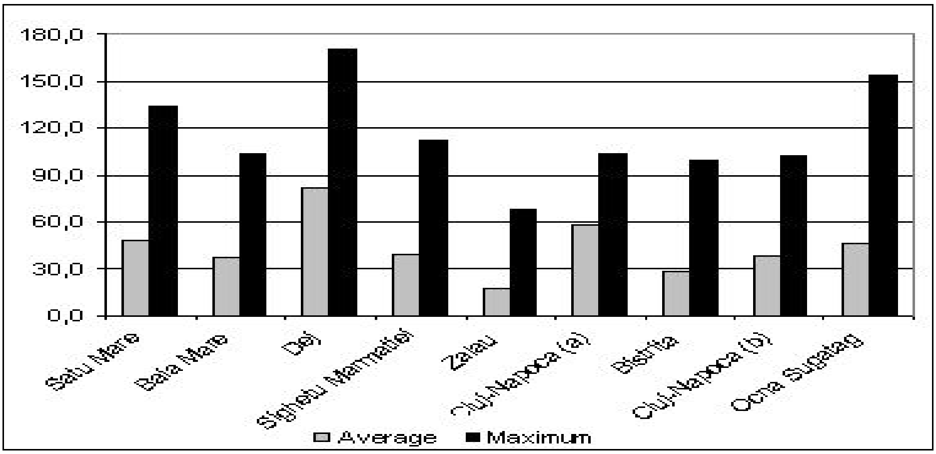

Fig. 4 Annual number of fog days
(Stations are ranged in the increasing order of the altitude)

Table 5. ***Characteristics of the two water resources considered as variables for each weather stations.***

Weather stations[1]	WRP[2]	Name	WSAA[3] (m)	Distance[4] (m)	Av.D[5] (m)	Type	Origin
Baia Mare	I	Borcutului Br.[6]	189	240	432.5	Stream	Natural
	II	-[7]	215	625		Lake	Anthropic
Bistrița	I	-	367	220	310.0	Lake	Anthropic
	II	Bistrița R.[8]	360	400		Stream	Natural
Cluj-Napoca (a)	I	Zăpodie Br.	311	250	320.0	Stream	Natural
	II	Someşul Mic R.	310	390		Stream	Natural
Cluj-Napoca (b)	I	Nadăş R.	345	770	782.5	Stream	Natural
	II	Someşul Mic R.	346	795		Stream	Natural
Dej	I	-	237	370	535.0	Stream	Anthropic
	II	Sărat Br.	237	700		Stream	Natural
Ocna Şugatag	I	-	461	730	1050.0	Lake	Natural
	II	Cosău Br.	434	1370		Stream	Natural
Satu Mare	I	-	122	80	380.0	Stream	Anthropic
	II	Homorodul Vechi R.	122	680		Stream	Natural
Sighetu Marmației	I	Tisa R.	272	370	617.5	Stream	Natural
	II	-	278	865		Basin	Anthropic
Zalău	I	Zalău Br.	249	865	1277.5	Stream	Natural
	II	Miței Br.	234	1690		Stream	Natural

1 - Weather stations are ranged in alphabetical order; 2 – Water Resources Position (WRP) compared to weather stations location; 3 – Water Surface Absolute Altitude (WSAA); 4 – Distance between water resource and weather station; 5 – Average distance (Av.D) between the first two water resources and the weather station; 6 – Br.= brook; 7 – If the name of the water resource is not mentioned in the table, it have been identified on the map, but without any name; 8 – R = river.

To identify regional behavior, the hierarchical cluster analysis with 7 variables has been used. Thus, four time variables (seasonal data series), two altitude variables (the absolute altitude above sea level and the relative altitude of the weather station) and one variable concerning distance from water resources (the average distance of the two most close water resources) (**Table 5**) have been taken into account.

Considering all the variables presented above, two important groups have been identified (**Fig. 5**). The best connection, of 1, is established between two stations located in the same relief unit type - the valley - (Bistrița and Cluj-Napoca (a)). Baia Mare and Dej form a subgroup in the first main group and a connection of 1 has been established between them, too. Both locations experience a very high level of air pollution due to important industrial companies built in the areas. Sighetu Marmației and Satu Mare belong to the same subgroup, with a connection of 2 established with Baia Mare. All the three stations are located in the Northwestern part of the area and the linear distance between them is not very long.

Cluj-Napoca (b) weather station has a fable connection of 8, with the first group, so it can be considered as having different and singular behavior, which seems normal if we consider that it is the only station in the area located on the interfluve.

Ocna Şugatag and Zalău represent the second group. Both of them are located in depression areas and the relative altitudes are similar (**Table 1**).

Stations which are nearby, like Cluj-Napoca (a) and Cluj-Napoca (b) or like Sighetu Marmației and Ocna Şugatag have different characteristics and they do not belong to the same subgroup (first situation) or group (second situation) due to small scale nature of fog phenomenon.

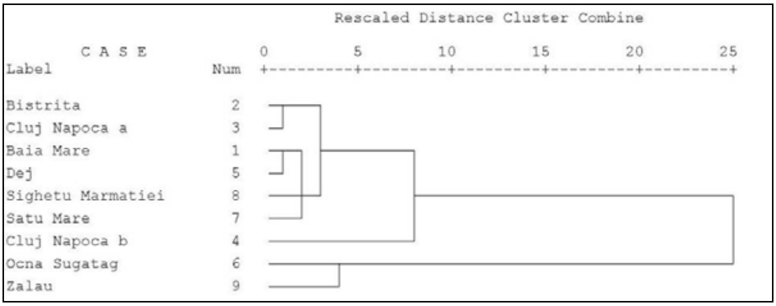

Fig. 5 Hierarchical cluster analyses for Northwestern Romania

PCA method was used to identify factors, which determine the spatial variability of the fog phenomenon in the analyzed area. We considered the same 7 variables and there have been all identified to explain the total variance (100%) (**Table 6**).

Table 6. ***Total variance explained.***

Compo-nent	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative (%)	Total	% of Variance	Cumulative (%)
1	3.815	54.498	54.498	3.815	54.498	54.498
2	1.823	26.046	80.545	1.823	26.046	80.545
3	0.835	11.934	92.478	0.835	11.934	92.478
4	0.293	4.182	96.661			
5	0.146	2.084	98.744			
6	0.070	1.002	99.747			
7	0.018	0.253	100.000			

Legend: 1-annual number of fog days, 2-average distance of the two most close water resources, 3-absolute altitude; 4-relief unit type; 5-winter number of fog days; 6-spring number of fog days; 7-relative altitude; 8-autumn number of fog days; 9-summer number of fog days.

If an eigenvalue of 1 is considered, only the first two components are important, and they explain more than 80 % of the total variance (**Table 6**). They have been identified to be the seasonal number of fog days and the average horizontal distance to the nearest two water resources (**Table 7**). Seasonal numbers of fog days (all seasonal values got very good scores as first principal component, especially that for autumn) explains almost 55 % of the total variance, while more than 26 % of the variance is due to the second principal component identified, average horizontal distance from water resources. When an eigenvalue of 0.5 is chosen, one more component is taken into account, which is the absolute altitude. It explains about 12 % of the total variance. Together, the first three components cover more than 92 % of the variance (**Table 6**).

Table 7. ***Component matrix; extraction method: 3 components extracted as Principal Components.***

Variable	Component		
	1	**2**	**3**
Absolute Altitude	-0.453	0.605	0.575
DJF number of fog days	0.787	-0.025	0.535
MAM number of fog days	0.783	0.553	0.044
JJA number of fog days	0.795	0.482	-0.313
SON number of fog days	0.890	0.376	-0.118
Average distance from water	-0.651	0.642	-0.317
Relative altitude (ΔH)	-0.728	0.603	0.066

4. DISCUSSIONS

Stations that experienced the highest and the lowest value of average fog days are placed, both of them in the central part of the analyzed area, but the difference between them is given by local physical conditions: Zalău station is located on the slope of a hill, while Dej is located in the valley. Thus, Zalău usually stays over the inversion layer that covers the bottom of the depression, while Dej is located down, in the valley. Additionally, for Dej, beyond the two up-mentioned water resources in **Table 5**, other two important rivers flow nearby the city. This means that at Dej, the amount of water vapors is more important compared to that of Zalau. Another cause of this big difference could be the pollution that may be considerably higher in Dej because of a paper company located very close to the city.

Unfortunately, there are no historical recordings on solid particles dimensions and number, in order to identify their real influence on the spatial distribution of fog phenomenon in the analyzed area (*Barry and Chorley, 1995; Moldovan, 1999*). Usually, regular and continuous measurements made by Environment Protection Agencies cover only the total amount of solid particles and there are not data available for particles diameter (*Mureşan et al., 2009; personal communications*). Some diameter measurements of solid particles have made in the area since 2007. On the other side, there are not measurements in all locations where fog data were analyzed. Thus, fog data and pollution data cannot be directly correlated for the moment.

Considering stations that are very close one to another, two different situations were identified. Thus, for Cluj-Napoca area, we have chosen to analyze the two locations, because even if Cluj-Napoca (a) is in the vicinity of Cluj-Napoca (b) and the linear distance between them is no more than 10 km, the different geographical conditions generate different small-scale climatic characteristics. The first location was situated in the bottom of the depression, near the valley, and the second one is on the interfluve, which sometimes, especially during the cold season, is situated over the inversion layer. That is why, most probably, in Cluj-Napoca (a) the annual average number of fog days is higher than in Cluj-Napoca (b). But, we do not exclude that the big differences may be caused also by the length of the datasets and by the fact that there are not simultaneous recordings available for the two locations.

If we consider other two stations located very close one to another, Sighetu Marmației and Ocna Şugatag, the situation is very different from the first case: the greater annual numbers of fog days, both average and maximum, is specific to the highest location this time.

Few salt lakes in the proximity of the Ocna Şugatag weather station also may explain the situation.

The time data series (seasonal numbers of fog days) can be associated with general meteo-climatic conditions of Northwestern Romania: temperate climate with ocean influences. Characterized by seasonability with specific air circulations and synoptic situations covering the whole area and thus, generating similar weather events etc. one can emphasize, according to PCA results, that they are dominant factors in the spatial variability of the fog phenomenon in the analyzed area and they explain more than 50% of the total variance.

The other two principal components extracted make part of the larger group of local geographical factors and play an important role in the spatial distribution of the fog phenomenon in Northwestern Romania. Together they explain almost 38 % of the variance in the area. One can remark that distance from water resources is much more important than altitude, which is considered to be the main factor that influence the spatial distribution of fog phenomenon by some authors in previous studies for entire Romanian territory (*Bogdan and Marinică, 2007*) or for regions close to that analyzed in this paper (*Gaceu, 2005a; Gaceu, 2005b*).

5. CONCLUSIONS

Geographical (local) conditions (water resources location, altitude, relief unit type) are important factors for the spatial distribution of monthly and annual number of fog days within the analyzed region. Thus, the highest numbers of fog days are recorded, both for average and maximum values, in locations situated near important rivers or lakes of the region (Dej, Cluj-Napoca (a) and Ocna Şugatag).

Hierarchical cluster analysis indicates that there are two main groups in the area. Small-scale nature of fog phenomenon and thus, local geographical factors, are responsible for the situation that stations located very close one to another do not show a very good connection.

The principal components analysis identified three components, which explain almost 93 % of the total variance: seasonal numbers of fog days, average distance to the nearest two water resources, absolute altitude. Using PCA method, the altitude of the station, often considered in some previous studies as the main factor that influence the spatial distribution of the phenomenon (*Bogdan and Marinică, 2007; Gaceu, 2005a; Gaceu, 2005b*), was identified to be the third principal component as having a role in explaining the total variance with a weight value less than 12 %. Actually, if the eigenvalue of 1 is considered, the altitude is not taken into account at all. It becomes important only if the eigenvalue is 0.5. If time data series are associated with general climatic conditions of the area and linear distance from water resources and absolute altitude are considered as local geographical factors, one can say that general climatic conditions determine more than 54 %, while the main local geographical factors are responsible for more than 37 % of the total variance of the phenomenon in the analyzed area.

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