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The Greek hailpad network 2008 to 2019: Analysis of the hailpad data - the Equivalent Hail Diameter

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ABSTRACT: *The Hellenic Agricultural Insurance Organization – ELGA - implements the Greek National Hail Suppression Program – GNHSP - in order to mitigate the hail and consequently the indemnities payed to farmers. In the context of the Program a hailpad network is in operation every year. In this paper the hailpad data of the years 2008 to 2019 are studied, with the analysis focusing on the temporal and spatial distribution of certain hailfall parameter variables. The parameter Equivalent Hail Diameter - EHD is introduced too in this paper, which is the value of the diameter should have all the hailstones if they were all equal in size. The EHD is a virtual global parameter variable which could serve as an objective tool, along with the global kinetic energy, for estimating the severity of the point hail-fall events. For the temporal analysis of the data, the hail period from march 21st to September 30th divided into periods of almost ten days, while for the spatial analysis of the data the IDW interpolation technique has implemented. The temporal and spatial data analysis has concluded that the hailfalls in the study area have moderate to weak characteristics.*

KEYWORDS –*Hailpad, Hail, Hailfall, Equivalent Hail Diameter, Temporal Analysis, Spatial Analysis*

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I. INDRODUCTION

Hail is one of the most destructive atmospheric phenomena for the agricultural crops in Greece, resulting in significant economic losses. The phenomenon concerned the Hellenic Agricultural Insurance Organization – ELGA, which is the main insurer of agricultural production in Greece. For the protection of crops against the hail, ELGA is implementing the Greek National Hail Suppression Program – GNHSP or Program, in two areas of the country; (a) the Administrative Region of Central Macedonia in northern Greece, and (b) the Administrative Region of Thessaly in central Greece, seeding the storms with AgI artificial Ice Nuclei by airborne means, aiming to mitigate the hail and therefore to reduce the insurance indemnities [1]. For the continuous evaluation of the Program a hailpad network is installed which operates inside the protected area in northern Greece.

The hailpad is a simple and cheap, yet effective, instrument for recording the hail [2], introduced in 1959 [3]. Since then many networks developed in various countries in the context of different projects. The hailfall data collected in the hailpad networks represent a small fraction of hail data available in all over the world because the networks cover usually a small geographical area, but the quality of the data stimulates the interest of the researchers leading to numerous research works based on that kind of data. The most known hailpad networks are the networks operating in Greece [1,2,4,5], France [6,7], Spain [8,9], Argentina [8], Italy [10,11] and USA [12].

1.1. Presentation of the study region.

The protected area of northern Greece is located in the Administrative Region of Central Macedonia in Northern Greece. A hailpad network is in operation from March to September every year inside this protected area for the continuous evaluation of the GNHSP [1].

The protected region of northern Greece, where the network of 154 hailpads is installed, has an area of 2.700 km^2 with each hailpad roughly corresponding to a mean area of 17.5km^2 or 4.2kmX4.2km [1,2]. For fast and easy service of the network, the installation locations of the hailpads are besides to roads of good condition, so the real mesh of the hailpads is not even, with the distance between two consequent hailpads varying from 2km to 7km in some cases. Every hailpad of the network is given a number starting from 1 and ending in 159, with some numbers of this range missing because the corresponding hailpads stopped operating before the start of the operation of the network in the year 2008. The altitude of the stations varying from approximately 20m to 200m above mean see level.

In the Figure 1.1, the polygon of the protected area of Central Macedonia is depicted with black solid line, the locations of the hailpads are depicted with orange dots and the height contours of 100m, 200m and 1000m are depicted with orange solid lines.

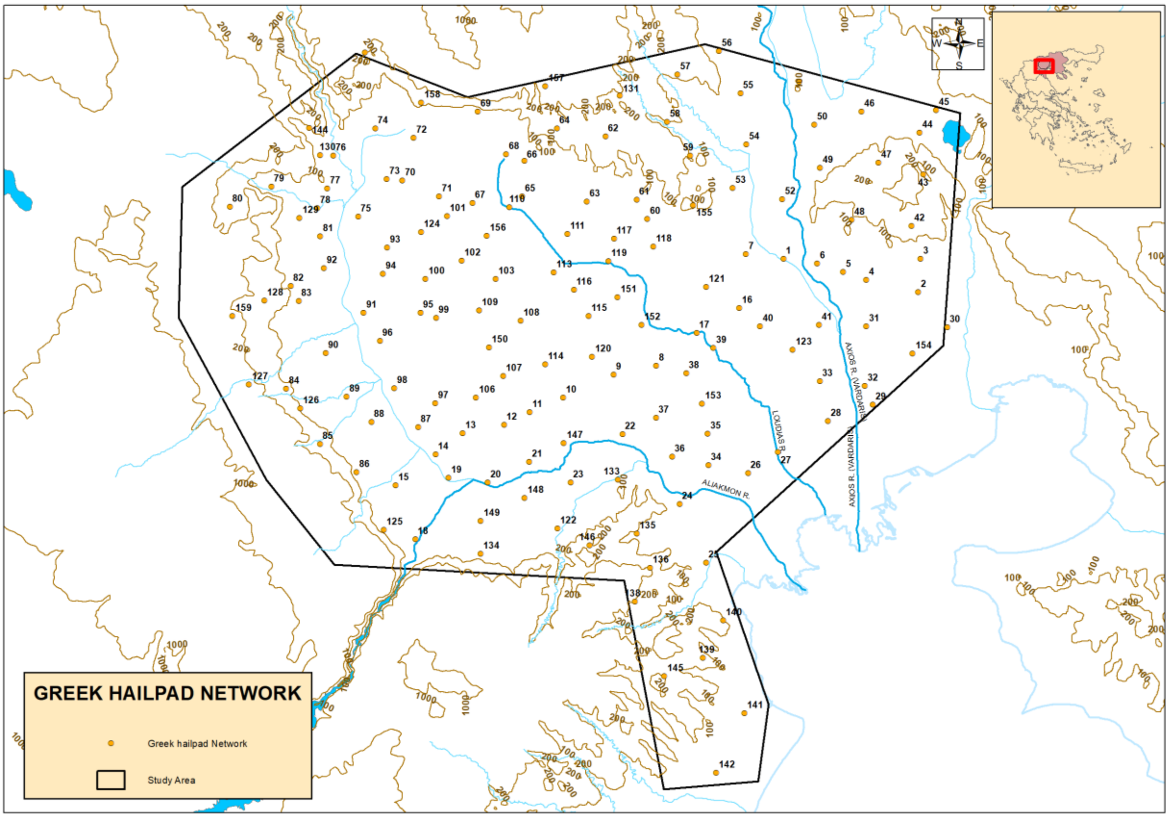


Figure 1.1. The protected area of Central Macedonia and the locations of the hailpads.

The almost flat protected area is surrounded by mountains to the south, west and north. In the northeast and east the terrain is a sequence of flat and hilly areas. To the southeast edge of the protected area there is the delta of the rivers Axios, Loudias and Aliakmon at the west shore of the Thermaic Gulf. The area is also crossed by other rivers and many irrigation canals, but the three major rivers mentioned above flow throughout the year, supplying the area with irrigation water and also contributing to the increase in the average relative humidity of the atmospheric air. The geographical and soil characteristics and the climatic conditions, differ from coastal areas to areas closer to the mountains, contributing to a variation in the type of cultivation. In the southeastern areas near the coast of Thermaic Gulf, arable cultivation dominate, while closer to the mountains, tree crops and grapes predominate. The sea breeze blowing from southeast in afternoon hours is carrying worm and humid air mass from Aegean Sea via Thermaic Gulf, inside the protected area, while cooler air masses enter the area from the valleys between the mountains, or slipping from the slopes of the mountains. In this environment thunderstorms are developing during the warm season of the year from April to September, producing hail sometimes very destructive. The present study focuses only on the hailfalls as they recorded in the hailpad network, without any effort to make correlation to the synoptic conditions dominating in every hail event. Certainly some other hailfalls occurred between the locations of the hailpad stations and outside the mesh of the hailpads as well, which are either not recorded at all or they are recognized indirectly from the damage statements submitted by the farmers to ELGA.

In the year 2008, before the start of the operation, the hailpad network of the GNHSP reorganized by the author by increasing the number of hailpad stations from 144 to 154 and at the same time stopping the operation of few stations installed in inaccessible locations, aiming to make the mesh of the network more accessible. At the same time some improvements in the infrastructure occurred, well described in Tsitouridis [2], like the establishment of a hailpad laboratory where accurate calibration of the hailpads and preparation for digital analysis is performed and the introduction of new procedures for the analysis of the hailpads and the data reduction, based on the use of the Image-Pro® Plus software [13]. With the new procedures the hailpads were digitally analyzed in a uniform way, contrary to the previous inaccurate method of the manual analysis using a ruler.

The study of the period 2008-2019 was chosen because the data of this period have significant homogeneity and high reliability for the reasons referred above and because from the year 2008 to the year 2019 no remarkable changes occurred in the network.

In the year 2008 the road network was in a better condition compared to that of the year 1984 when the hailpad network was established. So the opportunity of the complete rearrangement of the hailpad network arisen during the reorganization, in order for the network to become more even, something that was considered bold, as it would result in the interruption of the hailfall time series in certain locations. For this reason, only minor changes occurred.

Despite the fact that the mesh of the hailpad stations is not even, in the GNHSP there is the practice of estimating the affected area multiplying the number of impacted hailpads in a hail day by the mean corresponding area of 17.5km^2 per hailpad. This practice is generally acceptable and it is very useful for ELGA. For example if 4 hailpads are hit during a hailfall episode then the corresponding affected area is estimated to 70 km^2 (4X17.5km^2), giving an initial indication of the spatial extent of the possible hazard.

The main purpose of the present study is to showcase temporal and spatial characteristics of certain parameters of the hailfalls, useful in the context of the hail suppression operations and in the context of insurance too, along with the introduction of the new parameter **Equivalent Hail Diameter** – EHD. The EHD can serve as an index of the severity of the point hailfalls in the study area along with the kinetic energy of the hailfalls, already used as a performance index upon the GNHSP [1].

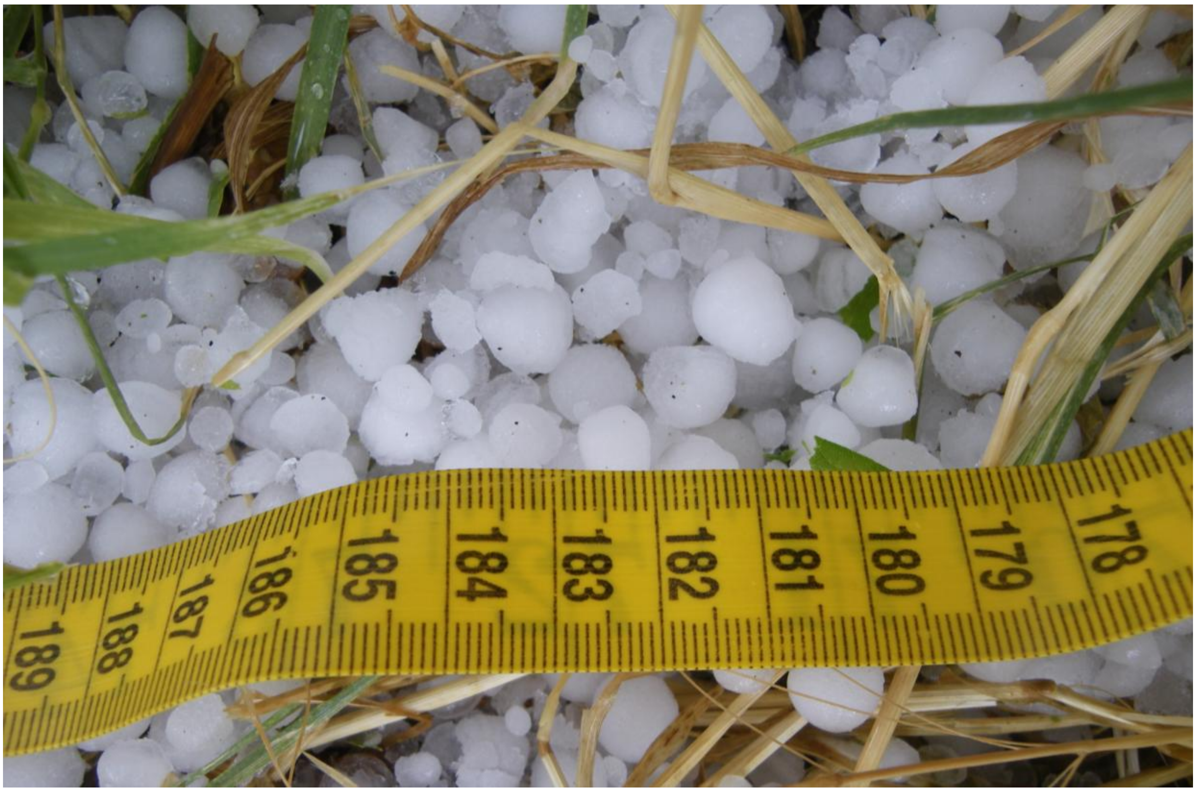


Figure 1.2. Hail in 2013, June 2nd (photo: courtesy of Agathangelos Tsitouridis).

At the photograph of the Figure 1.2 hailstones appear in a yard, in a distance of about 800m from the hailpad #139, at Sfendami Commune shot at 11:03 UTC, few minutes after the hailfall of the June 2, 2013. The hailpad #139 recorded hail at this day with the following characteristics. Hailfall density 3,743 hailstones per square meter, Max diameter 9.713mm, KED=27.117j*m-2, MD=0.482kg*m-2, and diameter distribution (5/6/7/8/9/10 mm)=(974/1,224/926/475/83/24 hailstones per square meter). The measurements at the hailpad look similar to the photograph.

The remainder of the work is organized as follows: In section 2, the digital analysis of the hailpads, the structure of the data set and the definition of the Equivalent Hail Diameter are presented. In section 3 the definition and the temporal and spatial analysis of the examined parameter variables are presented, and in section 4 the conclusion of the findings is presented.

II. DATA SET AND METHODS

The Greek hailpad network was in operation and the data were collected during the hail period from March to September every year from 2008 to 2019. All the procedures of the preparation and the service of the hailpad network, the description and calibration of the hailpad and the data reduction procedures are described in detail in Tsitouridis [2]. In the context of the present work, the basic assumptions accepted upon the GNHSP for the calibration of the hailpads and the data reduction are summarized briefly as the following [2]: *“(a) hailstones have a spherical shape; (b) hailstones that impact the ground are rigid; (c) the density of all hailstones is ρ_h=890kg/m^3; (d) the drag coefficient of hailstones is C_d=0.6; (e) hailstones fall vertically onto a hailpad with their terminal velocity and (f) hailstones hit the hailpad once”. Within the GNHSP an inverse regression method is used to derive the calibration equation of the form $y=\beta_0+\beta_1\cdot x$. according to which the minimum diameter of the dent is considered to be the independent variable “x” and the diameter of the hailstone is considered to be the dependent (response) variable “y”.*

The digital analysis of the impacted hailpads is performed using the Image-Pro® Plus software [13] and some parameters are extracted directly while others are calculated. The directly extracted parameters are the sampling area, the number of hailstones, the minimum, mean and maximum diameter of each dent, the dent area and the orientation of the maximum diameter of each dent. The minimum diameter of each dent is then used as input to the calibration equation in order to estimate the diameter of the hailstone responsible for the dent and consequently to estimate the Mass, the Momentum and the vertical component of the Kinetic Energy of each hailstone [2]. From the sampling area and the number of hailstones the hailfall density has calculated. Finally the diameters of all the hailsones are classified in size classes differing by 1mm, starting from the diameter 5mm, which is the minimum diameter of precipitated ice that is characterized as hailstone [14]. The number of a size class is the center of the class, for example all the hailstones with diameters from 11.500mm to 12.499mm are classified in the size class of 12mm. All the results are included in a record starting with the hailpad code yyyymmddppp containing the date of the hail event – the first eight digits and the impacted hailpad – the last three digits, for example all the data reduced from the analysis of the hailpad number 92, which affected by hail at June 24th, 2009, included in a record starting with the hailpad code 20090624092.

For all years between 2008 and 2019, the end of operation of the network was on September 30th every year, but the starting day would vary. The starting day was the April 10th for the years 2008 to 2013, the May 1st for the year 2014 and the March 20th for the years 2015 to 2019. During the study period a total number of 1,050 hailpads of the network impacted by the hail during 197 hail days and a number of 78,231 hail stones recorded. A day was designated as hail day if at least one hailpad was affected by the hail. In the Greek network there is not any threshold in the number of dents on a hailpad and that’s why an impacted hailpad is not discarded even if just one dent is recorded on the surface of it.

The number of the impacted hailpads of the study period is 1,050 so the data set is consistent of 1,050 records, one record for every impacted hailpad, each record containing the values of all the parameters measured or estimated as mentioned above. Only a part of the parameters of each record was used in the present study. Specifically, the parameters’ date of the event, the number of the hailpad, the sampling area of the impacted hailpad, the number of hailstones recorded, the mass (M) of all the hailstones, the vertical component of the kinetic energy (KE) of all the hailstones, the hailfall density (HFD) expressed in hailstones per unit area, the mass density (MD) expressed in kg*m^{-2}, the kinetic energy density (KED) expressed in j*m^{-2} and the classification of the diameters in classes of one mm are used.

2.1. Definition of the Equivalent Hail Diameter.

In the present work, along with the study of the analyzed parameters, the new parameter **Equivalent Hail Diameter – EHD** is introduced, which is defined as the diameter should have all the hailstones impacted a hailpad if they were all equal in size.

The calculation of the value of the EHD of the hailstones hit a hailpad is performed by the following procedure: The total estimated mass of the hailstones recorded in a hailpad is divided by the total number of hailstones. The result is the mass that should have all the hailstones impacted a hailpad if they were all equal in size - Equivalent Mass. Dividing this value of hail mass by the density of hail (ρ=890kg*m^{-3}, see the assumptions above [2]), the Equivalent Volume $V_{eq}=m_{eq}/\rho$ results and consequently, using the formula $V_{eq}=(\pi/6)*EHD^3$, results the value of the EHD, expressed in mm.

The **EHD** is a kind of global parameter like the global kinetic energy density.

For this work, the EHD has estimated for each one of the 1,050 hit hailpads and the resulted value added at the end of the corresponding record.

For the temporal and the spatial analysis, the examined parameters are described in the Analysis and Results section. For the spatial analysis of the data using GIS software, the latitude and longitude of each hailpad included in the data when it was necessary.

III. ANALYSIS AND RESULTS

3.1. Temporal analysis of the hailfall parameters.

During the 12 years, the maximum estimated diameter of the 78,231 recorded hailstones was 32mm, with only two hailstone outliers having diameter of 30mm. The highest cumulative number of hailstones in a hailpad (1,477 hailstones) was recorded at the hailpad #45, while the lowest cumulative number of hailstones in a hailpad (23 hailstones) was recorded at the hailpad #36. The largest maximum diameter (32mm) was recorded at the hailpad #140, while the smallest maximum diameter (9mm) was recorded at the hailpads #151 and #152.

Table 3.1 below, shows the hail days and the impacted hailpads for each year from 2008 to 2019. As can be seen in the Table 3.1, the number of hail days – NHD ranges from the minimum of 12 in 2012 to the maximum of 23 in 2019, with the average annual number to be 16.5 hail days. The number of the impacted hailpads – NHP ranges from year to year, from the minimum of 35 in 2012 to the maximum of 152 in 2014, with the average annual number to be 87.5 hit hailpads per year.

Table 3.1. Hail days and impacted hailpads from 2008 to 2019.

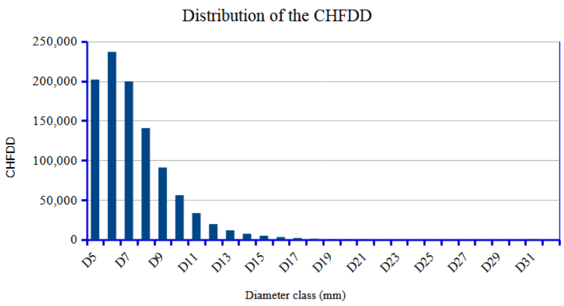
Year	NHD	NHP	Year	NHD	NHP
2008	14	70	2014	21	152
2009	19	109	2015	14	87
2010	13	52	2016	14	68
2011	17	56	2017	13	77
2012	12	35	2018	23	119
2013	14	105	2019	23	120

In Table 3.2 below, the Cumulative Number of Hailstones – CNHS and the Cumulative Hailfall Density per Diameter class – CHFDD appear for each diameter class - Dc of the hailstones expressed in mm. The CHFDD is the sum of all the values of the hailfall density expressed in hailstones per square meter per diameter class. For example, the number of hailstones recorded during the study period and classified in the diameter D9=9mm is NHS=7,051 and the corresponding cumulative hailfall density is CHFDD=90,807 hailstones per square meter fallen in the class 9mm.

Table 3.2. Distribution of cumulative number of hailstones and cumulative hailfall density per diameter class.

Dc	CNHS	CHFDD	Dc	CNHS	CHFDD	Dc	CNHS	CHFDD
D5	15,453	202,032	D15	369	4,709	D25	6	73
D6	18,335	236,916	D16	240	3,082	D26	8	96
D7	15,521	199,692	D17	152	1,946	D27	1	12
D8	10,927	140,686	D18	83	1,075	D28	1	13
D9	7,051	90,807	D19	54	688	D29	2	25
D10	4,341	55,957	D20	42	534	D30	1	12
D11	2,594	33,365	D21	26	330	D31	0	0
D12	1,513	19,479	D22	23	295	D32	1	12
D13	901	11,616	D23	11	138			
D14	566	7,291	D24	9	113			

As can be seen in the Table 3.2 and the figure 3.1 the highest values of the CNHS and the CHFDD appear for the diameter class 6mm.



a. b.

Figure 3.1. Distribution of the CNHS (a) and the CHFDD (b).

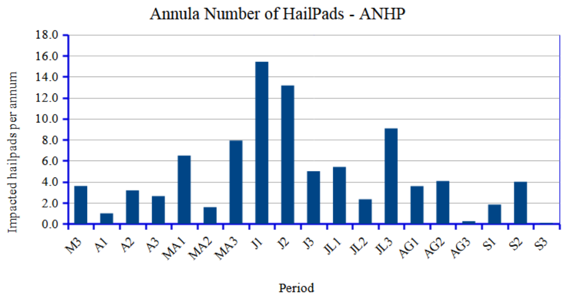
The examination of the monthly distribution of the data is the most common approach of temporal analysis. In the present study, a more detailed analysis was preferred, using shorter intervals of about one third of the month. For this purpose, every month of the hail period has divided into three sub-periods: month_name1 [month day 1 to month day 10], month_name2 [month day 11 to month day 20] and month_name3 [month day 21 to month day 30(31)], except April where the first two periods are A1 [April 1 to April 9], A2 [April 10 to April 20], because until the year 2013 the network operated from April 10th to September 30th, so the 10th day of April has included in the middle period of the month. For March, the 20th day of the month excluded from this study, as there is not any hail event occurred in this day during the study period. In addition to the purely climatology interest, the subdivision of the month into tree periods is of great importance for the seeding operations and in the context of the insurance, because different crops have different harvest seasons on the one hand and on the other hand, they move rapidly from one vegetative stage to the next showing different sensitivity to the hailfall. It has been observed that the loss of production due to the hail varies depending on the vegetative stage, thus, two different hailfalls with identical spatial extent and hail characteristics they cause different economic loss at different periods of the growing season. By the end of July, for example, a large part of the production of fruit trees and almost the total production of cereals and other arable crops has been harvested, resulting to less significant losses due to hailfalls at this period.

Table 3.3. Temporal distribution of annual values of some hail parameters.

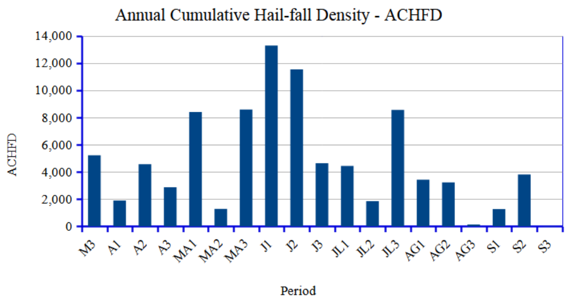
Period	**ANHD**	**ANHP**	**ACNHS**	**ACHFD**	**ACKED**	**ACMD**
M3	0.4	3.6	382	5,229	71	0.989
A1	0.6	1.0	139	1,897	235	0.411
A2	0.8	3.2	333	4,569	74	0.980
A3	0.4	2.6	210	2,877	33	0.477
MA1	1.3	6.5	634	8,398	85	1.335
MA2	0.9	1.6	97	1,283	19	0.265
MA3	2.3	7.9	661	8,583	119	1.695
J1	2.0	15.4	1,065	13,292	271	3.190
J2	2.0	13.2	898	11,536	348	3.794
J3	1.1	5.0	378	4,645	86	1.121
JL1	1.2	5.4	337	4,438	113	1.300
JL2	0.5	2.3	151	1,848	51	0.593
JL3	0.9	9.1	659	8,555	210	2.357
AG1	0.9	3.6	265	3,431	45	0.649
AG2	0.4	4.1	259	3,223	131	1.295
AG3	0.2	0.3	11	134	1	0.016
S1	0.4	1.8	97	1,269	21	0.280

Period	ANHD	ANHP	ACNHS	ACHFD	ACKED	ACMD
S2	0.8	4.0	292	3,804	50	0.701
S3	0.1	0.1	1	16	0,1	0.002

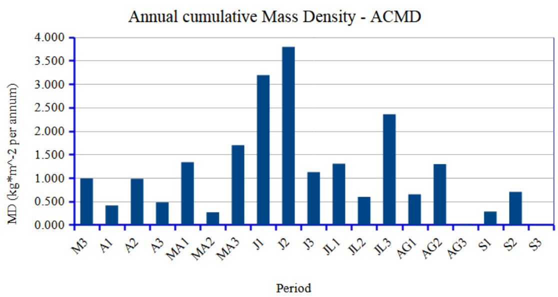
Table 3.3 contains the temporal distribution of the annual values of certain hail parameters. The annual values calculated from the cumulative values of all studied years, taking into account the different years of operation of the network for March and April. In Table 3.3 appear the Annual number of Hail Days – ANHD, the Annual Number of hit Hailpads - ANHP, the Annual Cumulative Number of Hail Stones - ACNHS, the Annual Cumulative Hail Fall Density - ACHFD expressed in hailstones per square meter, the Annual Cumulative Kinetic Energy Density - ACKED expressed in $j*m^{-2}$ and the Annual Cumulative Mass Density - ACMD expressed in $kg*m^{-2}$.



a. b.



c. d.



e. f.

Figure 3.2. Temporal distribution of the hailfall parameters.

In Figure 3.2 the temporal distribution of the parameters of Table 3.3 is depicted, namely the annual number of hail days - ANHD (a), the annual number of impacted hailpads ANHP (b), Annual cumulative number of hailstones - ACNHS (c), the annual cumulative hail-fall density - ACHFD (d), the annual cumulative Kinetic Energy Density ACKED (e) and the annual cumulative Mass Density ACMD (f).

Table 3.4 shows the distribution of 197 hail days from 2008 to 2019, in relation to the number of impacted hailpads. The first column of the Table 4 contains the number of the impacted hailpads - NHP in a hail day, while the second column contains the Number of the Hail Days - NHD with that number of impacted hailpads.

Table 3.4. Impacted hailpads vs Hail days.

NHP	NHD	NHD(%)	NHP	NHD	NHD(%)
1	65	33.0	14	2	1.0
2	29	14.7	15	4	2.0
3	20	10.2	16	1	0.5
4	18	9.1	17	1	0.5
5	11	5.6	18	3	1.5
6	11	5.6	19	1	0.5
7	6	3.0	20	3	1.5
8	3	1.5	27	1	0.5
9	2	1.0	30	1	0.5
10	2	1.0	32	1	0.5
11	3	1.5	33	2	1.0
12	4	2.0	54	1	0.5
13	2	1.0			

As shown in Table 3.4, in 65 out of 197 hail days, 33% of the hail days, only one (1) hailpad out of the 154 of the hailpad network impacted by the hail. This means that for 33% of the hail events the spatial extent of the hail is limited to a maximum average area of 17.5 km^2. The highest number of hailpads impacted in the same day was 54 hailpads on 2013, June 10th. As can be seen in the Table 3.4, in 47.7% of the hail days – almost the half of all the hail days, only one or two hailpads impacted, while the number of days with more than 10 impacted hailpads represents only 15.2% of the hail days. These findings show that, in the largest percentage of hail events, the hailfall is limited spatially, while the number of hail days with large spatial extent is small. In fact, in many cases of days with a small number of impacted hailpads, these are scattered in the area of the network and not adjacent, so, rather hailfall spots are formed instead of distinct hail swaths. The results of the above analysis appear graphically in the following Figure 3.3.

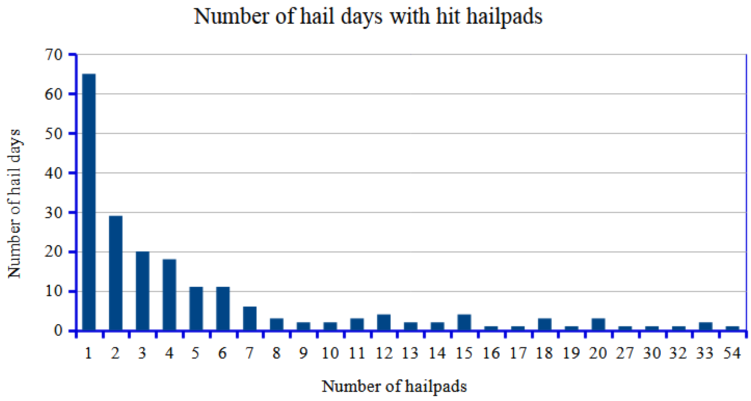


Figure 3.3. Distribution of hail days with the number of hit hailpads in a hail day.

Table 3.5 below contains the temporal distribution of the impacted hailpads based on the hailfall density – HFD. The HFD is classified in classes of 1,000 hailstones per square meter. The numbers at the limits of the classes at the header of Table 3.5 must be multiplied by 1,000, so the symbol [7,8) means [7,000 to 8,000) hailstones per square meter and in this class only two(2) hailpads are fallen, one on the period M3 and another one on the period MA1. In Table 3.5 the cumulative number of impacted hailpads – CNHP for every hailfall density class also appears.

Table 3.5. Temporal distribution of the hit hailpads in relation to the HFD.

HFD class	**[0,1)**	**[1,2)**	**[2,3)**	**[3,4)**	**[4,5)**	**[5,6)**	**[6,7)**	**[7,8)**	**[8,9)**	**[9,10)**	**[10,11)**	**[11,12)**
M3	11	3		1	2			1				
A1	4									1		
A2	20	6	3	2	2	1					1	
A3	19	5	3	1			1					
MA1	53	12	4	4		1	1	1			1	1
MA2	15	3				1						
MA3	71	8	6	3	2	4				1		
J1	128	35	11	5	3	1	2					
J2	114	25	10	5	1	2	1					
J3	40	10	6	3	1							
JL1	48	11	2	1	1	2						
JL2	21	3	3	1								
JL3	76	15	12	3	1	1	1					
AG1	29	10	1		2		1					
AG2	37	5	6		1							
AG3	3											
S1	18	2	1		1							
S2	35	7		3	1	2						
S3	1											
NHP	743	160	68	32	18	15	7	2	0	2	2	1
NHP(%)	70,8	15,2	6,5	3,0	1,7	1,4	0,7	0,2	0,0	0,2	0,2	0,1
CNHP	743	903	971	1.003	1.021	1.036	1.043	1.045	1.045	1.047	1.049	1.050
CNHP(%)	70,8	86,0	92,5	95,5	97,2	98,7	99,3	99,5	99,5	99,7	99,9	100,0

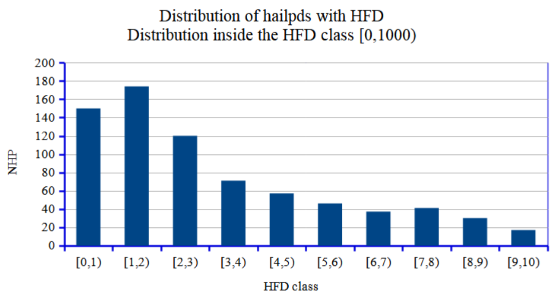
As can be seen in Table 3.5, there areno values falling in the class [8,9) and there are only 5 cases falling inthe higher classes [9,10), [10,11) and [11,12). The majority of the hailfalls had a HFD less than 1,000 hailstones per square meter, namely the 743 out of 1,050 cases (70.8%), fall into the first class [0,1), so thisclasshas further analyzed in sub-classes of 100 hailstones per square meter, as shown in Table 3.6 below, where the numbers at the limits of the classes must multiplied by 100.

Table 3.6. Temporal distribution of the hit hailpads in relation to HFD less than 1,000.

HFD class	**[0,1)**	**[1,2)**	**[2,3)**	**[3,4)**	**[4,5)**	**[5,6)**	**[6,7)**	**[7,8)**	**[8,9)**	**[9,10)**
M3	2	4	3		1		1			
A1	4									
A2	3	9	2	1		1		3	1	
A3	6	1	3	2	3			1	1	2
MA1	11	8	10	7	2	2	4	6	3	
MA2	4		1	1	4	1	2		1	1
MA3	13	13	13	8	6	6	5	2	4	1
J1	26	34	28	9	8	8	4	5	4	2
J2	17	33	12	12	10	8	5	9	3	5
J3	6	11	6	5	4	3	3	2		
JL1	6	16	7	8	3	2	1	1	2	2
JL2	5	5	5		1	2	1	2		
JL3	14	17	18	5	6	5	5	2	2	2
AG1	10	5	2	3		1	2	3	2	1
AG2	8	8	3	4	4	3	4	1	1	1

HFD class	**[0,1)**	**[1,2)**	**[2,3)**	**[3,4)**	**[4,5)**	**[5,6)**	**[6,7)**	**[7,8)**	**[8,9)**	**[9,10)**
AG3				1	1				1	
S1	6	2	2	4				2	2	
S2	9	7	5	1	4	4		2	3	
S3		1								
NHP	150	174	120	71	57	46	37	41	30	17
CNHP	150	324	444	515	572	618	655	696	726	743
NHP(%)	20,2	23,4	16,2	9,6	7,7	6,2	5,0	5,5	4,0	2,3
CNHP(%)	20,2	43,6	59,8	69,3	77,0	83,2	88,2	93,7	97,7	100,0
CNHP(%) based on 1050	14	31	42	49	54	59	62	66	69	71

As shown in Table 3.6 above, 515 out of 743 cases of the first class, or 515 out of 1050 (49% of the total cases) represent hailpads with a recorded hailfall density less than 400 hailstones per square meter. This finding shows that for the largest percentage of the hit hailpads, the hailfall density is very low and consequently the hail damage is expected to be low too. The findings are depicted graphically in Figure 3.4, namely the distribution of the number of the impacted hailpads - NHP for all the 1,050 cases in (a) and for the 743 cases of the first class [0,1) of Table 3.5 (b).



a. b.

Figure 3.4. Distribution of NHP with the HFD.

3.1.1. Equivalent Hail Diameter.

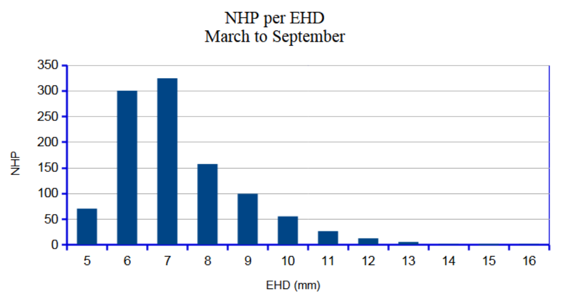
As mentioned in section 2, in the context of this paper the Equivalent Hail Diameter – EHD has calculated for each impacted hailpad and the resulted values of the EHD classified in classes of 1mm in the same way as the hailstone diameters, starting from 5mm. The two highest values of EHD estimated for the same hail event onAugust 11, 2009, one at the hailpad #11 (Kampohori Commune) with EHD=16.172mm, fallen in the class 16mm and another one at the hailpad #23 (Agia Triada Commune) with EHD=13.621mm fallen in the class 14mm. The minimum value EHD=4.675mm estimated for the hailpad #31 (Anatoliko Commune) on April 24, 2016 and fallen in the class of 5mm. There is not any value of EHD fallen in the class 15mm.

In Table 3.7 below, the temporal distribution of the 1,050 impacted hailpads in relation to the EHD is shown. In every column of Table 3.7, the temporal distribution of the corresponding EHD is appeared. In every line of Table 3.7, the classification of the values of the estimated EHD for the corresponding time period in classes of 1mm is appeared, till the line S3. The rest of the lines show the classification of the parameters number of hailpads – NHP and cumulative number of hailpads - CNHP in classes of 1mm. The last column of the table shows the maximum observed value of the EHD for each period.

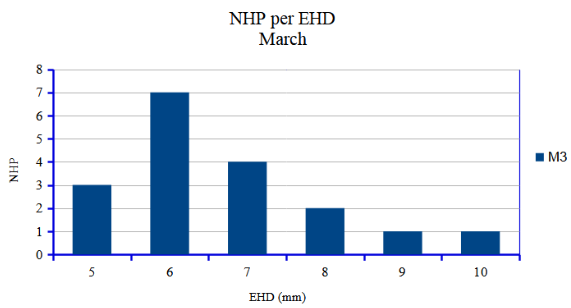
Table 3.7. Temporal distribution of the values of EHD, classified in classes of 1mm

EHD class	**5mm**	**6mm**	**7mm**	**8mm**	**9mm**	**10mm**	**11mm**	**12mm**	**13mm**	14mm	15mm	16mm	Max EHD
M3	3	7	4	2	1	1							10
A1		1	3	1									8
A2	3	16	9	4	1	2							10
A3	6	11	8	1	2	1							10
MA1	5	34	22	11	3	3							10
MA2	1	7	7	3		1							10
MA3	6	30	37	13	6	2		1					12
J1	24	41	55	30	19	6	6	3	1				13
J2	2	42	47	13	27	15	6	4	2				13
J3	3	18	15	14	4	4	2						11
JL1	2	14	21	14	5	7	1	1					12
JL2		4	8	8	3	4			1				13
JL3	4	28	38	16	13	4	5	1					12
AG1	3	19	11	7	3								9
AG2	2	3	11	10	8	4	6	2	1	1		1	16
AG3		1	2										7
S1	3	4	7	5	2	1							10
S2	3	19	19	5	2								9
S3		1											6
NHP	**70**	**300**	**324**	**157**	**99**	**55**	**26**	**12**	**5**	1	0	1	16
NHP(%)	6.7	28.6	30.9	15.0	9.4	5.2	2.5	1.1	0.5	0.1	0.0	0.1	
CNHP	70	370	694	851	950	1,005	1,031	1,043	1,048	1049	1049	1050	
CNHP(%)	6.7	35.2	66.1	81.0	90.5	95.7	98.2	99.3	99.8	99.9	99.9	100.0	

As can be seen in Table 3.7 and in Figure 3.5, the value 7mm of the EHF is observed more frequently for all the period fallowed by the value 6mm. The values 6mm and 7mm are generally prevailing in every month. This fact means that in most hailfalls the hail is small. The proposed method of comparing the severity of the hailfall by the EHD instead of the maximum observed diameter, has the advantage that the comparison is performed taking into account the total number of the hailtones and not only the maximum observed diameter which represent a tiny fraction of all the diameters observed



a.



b.

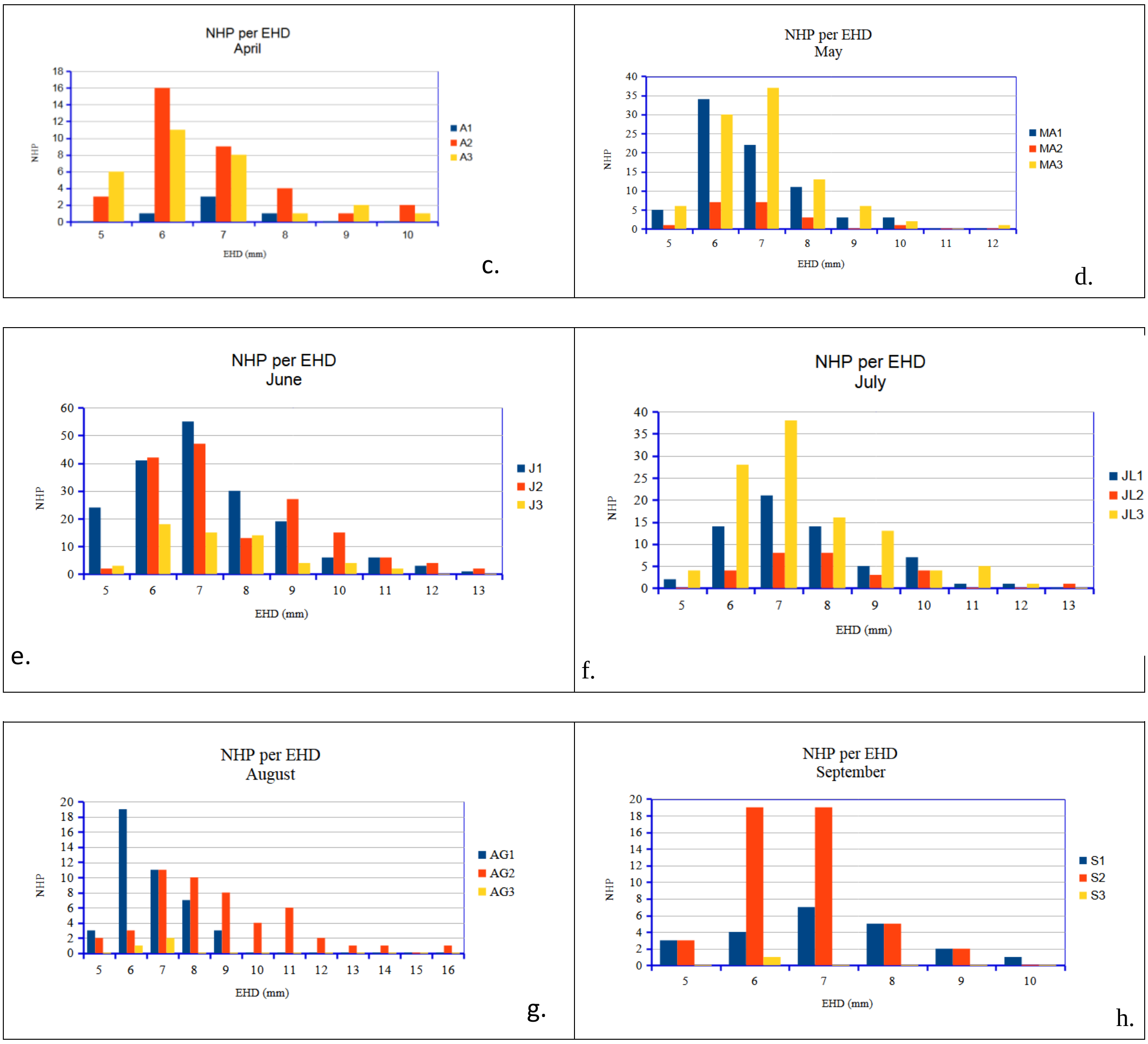


Figure 3.5. The temporal distribution of the NHP with the EHD, for all the hail period March to September (a) and for the seven months from Marxh to September (b to h).

3.2. Spatial analysis of the hailfall parameters.

The measurements in the hailpad network are point measurements and therefore the values of the parameters at the space between the measurement points should be predicted using a suitable method. In this paper, along with the temporal analysis of some hailfall parameters, an attempt is made to estimate the spatial analysis of six parameters of the hail, using the Inverse Distance Weighted (IDW) interpolation method. This method was selected among others because is considered more suitable for interpolating variables having strong local character, like the hailfall.

For the spatial analysis of the selected parameters, the cumulative values of the parameters for every hailpad have calculated by summing the corresponding values of the hailfall recorded at the hailpad. The mean sampling area – MSA for each hailpad has calculated as well. Dividing the cumulative value of the parameter by the MSA, results the density of the parameter, expressed in units per square meter.

In the present study, the spatial distribution of the following six (6) parameters 1) the Maximum Diameter recorded at the hailpad – MaxD (mm), 2) the EHD (mm) estimated for the hailpad, 3) the hailpad impact frequency which is the number of times the hailpad impacted during the study period – HPHITF, 4) the Cumulative Hailfall Density – CHFD expressed in hailstones per square meter, 5) the CKED expressed in j*m^{-2}, and 6) the Mass Density expressed in kg*m$^{-2.}$.

For the execution of the IDW interpolation method, the ESRI's software suite ArcGIS® was used. In the execution of the interpolation the default settings of ESRI used, namely two order polynomials, variable range, max range 10 km, max number of stations 12 and cell size of about 2.03*10^{-3}. The results of the interpolation of the six selected parameters are shown in the images below.

In Figure 3.6 the point values of the hailfall parameter variables are predicted for every point of the study area. The predicted values of the MaxD (a) and the EHD (b) are expressed in mm, the predicted values of the CHFD (c) are expressed in thousands of hailstones per square meter, so the value 6 means hailfall density of 6,000 hailstones per square meter, the values of the HPHITF (d) show how many times occurred a hailfall in a point during the study period, the predicted values of the CKED (e) are expressed in tens of joules per square meter, so the value 20 means 200 $j*m^{-2}$ and the predicted values of the CMD (f) are expressed in $kg*m^{-2}$.

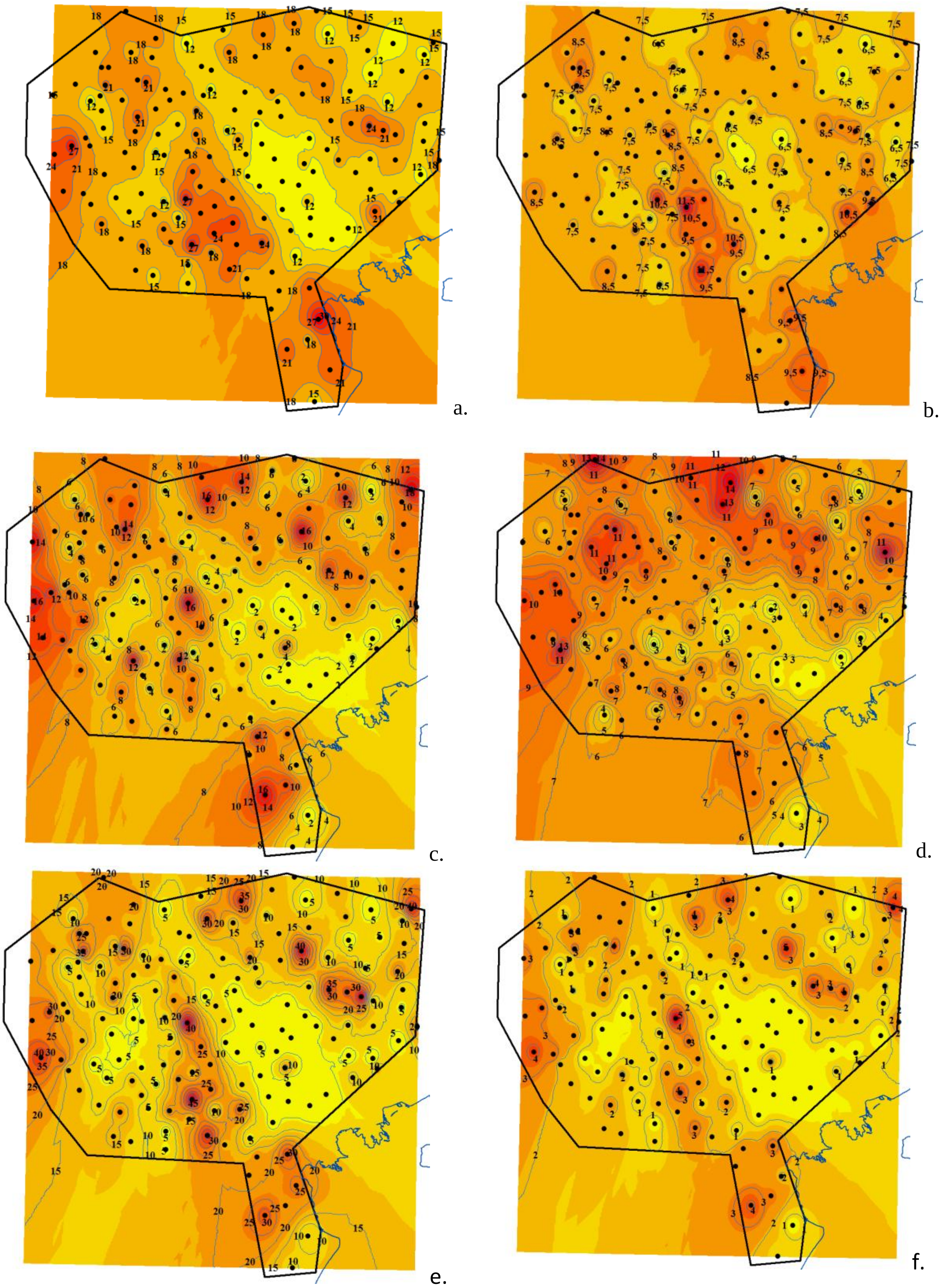


Figure 3.6. Spatial distribution of six (6) hailfall parameter values.

From the spatial distribution of the examined hailfall parameters it is obvious that all the parameters have high values in the regions adjacent to the western and northern mountainous areas, in the middle of the southern flat part and in the north east flat part of the protected area, while the lower values observed in the southeastern flat part of the protected area adjacent to the sea coast.

IV. CONCLUSION

From the analyses of the section 3, the following conclusions have drown.

The last period of May – MA3 and the two first periods of June – J1 and J2, are the most active periods regarding the number of the hail days and the number of the impacted hailpads, with secondary highs appearing in other periods. Although the J1 shows the highest number of hailstones and he highest number of impacted hailpads, the highest values of the CKED and the CMD appear in J2, a finding that is an indication that the hailstones in the period J2 are larger.

Out of the total of 197 days with hail, in the largest percentage the spatial extent of the hail-falls are limited to 2-3 tens of square kilometres and generally they are forming rather hailfall spots instead of distinct hailfall swaths.

From the spatial distribution of the values of the various parameters, areas with maxima and minima emerge.

The explanation of the maxima that emerge from the spatial and temporal analysis of the data is not easy and there is certainly the temptation to resort to conjecture. The combination of the hailpad data with other data, such as the atmospheric conditions prevailing in each hailfall case, the weather radar data and the meteorological satellite data, it is possible to lead to safer conclusions.

What must be taken into account, both in the present work and in the future, is the operation of the Program, which it is believed that has an effect on storms, mitigating the hail. The operational procedures themselves may have a significant effect on the occurrence of maxima in some areas, due to the severe limitations of airborne seeding, especially in cases of temporally and spatially extended storm activity.

The geomorphological and climatic characteristics of the area of consideration, similarly to what happens in other regions of the planet, it is believed that play a role too for the occurrence of maxima and minima of the hailfall characteristics in certain sub-regions of the protected area.

From the data analyzed it appears that the coastal areas are less affected by hail than the areas near the foothills of the mountains.

The new, easy calculated, parameter of the Equivalent Hail Diameter - EHD, introduced in this study, is believed that will serve as an additional objective tool, along with the global kinetic energy, for estimating the severity of the point hail-fall events in the area of study.

The findings of the present study might be useful for improving the operational practices of the GNHSP, and for the farmers too as they will know the mean hail risk at the place of their cultivation.

4.1. Recommendations – further research.

It would be useful to install new hailpad stations at shorter distances between the existing positions, in the areas that affected by the hail more frequently or more vigorously, in order to record hail with greater resolution. This is not very easy mainly due to the increase of the necessary number of employs serving the network fast after the thunderstorm activity, but it will be very useful.

It is recommended too, ELGA to finance the installation and operation of new hailpad networks in regions neighboring to the region of the existing network, where no seeding operations are performed and the hail will come from non seeded storms.

Coastal areas, where rarer and less intense hail is observed, are at the same time areas with arable cultivations of lower crop value. Therefore, when conducting the operations of the Program, emphasis should be given to the areas near the foothills of the mountains and at the center of the protected area, where more expensive crops, mostly fruit trees and grapes, are predominating.

ACKNOWLEDGEMENTS

From this position I would like acknowledge ELGA in investing for the technological infrastructure, namely for the acquisition of the ImageProPlus software for the digital analysis of the hailpads, for the development of the hailpads laboratory and for the stable financing the operation of the hailpad network, without which the creation of the data set of the present study would not be possible. I also would like to express my thanks to the scientific staff of ELGA who dealt with the digital analysis of the hailpads.

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