SPATIAL INHOMOGENEITY OF PRECIPITATION ON SETTLEMENT LEVEL

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Abstract. *When it comes to climate change, the very first thing comes to most of our mind is the rising temperature, even though climate change is having a significant impact on the water cycle. Spatial variability of precipitation is becoming more and more extreme year after year.Our research focused on the spatial distribution of precipitation on horizontal scale up to 1-2 km. We established a low-cost rain gauge network in Csabacsűd located on the Great Hungarian Plain (N46.49°, E20.39°, 85 m above sea level) with 18 plastic rain gauges which is widely used in the Hungarian private sphere. We examined the qualitative and quantitative correlations of the data with the help of the ESRI ArcGIS software. Spatial variance, deviation, an CV values of precipitation were calculated using Microsoft Office Excel. The results show significant areal differences in daily amount of precipitation within the small (1.5 km x 0.8 km) study area. The largest absolute difference in the small settlement reached 17 mm on 12th July 2018. The smallest value was 25 mm, the largest value was 42 mm and the distance between these stations is 1.4 km Precipitation shows a large spatial inhomogeneity especially in daily or shorter timescales. Especially in case of rain showers the operational meteorological/hydrometeorological networks are not dense enough to give the precipitation information that suits to needs of the agricultural sector. So, on-site measurements are needed in the growing season for practical agrometeorological purposes such as irrigation scheduling.*

Keywords: *precipitation, spatial distribution, rain gauge network*

INTRODUCTION

Precipitation is a major source of revenue for the surface water balance. Precipitation information is extremely important in agriculture and water management both of a practical and a research point of view. Due to its ecologically significant role, precipitation is one of the oldest observed and measured climatic elements and the most varied climate element in Hungary. Due to the geographical location and varied topography of the Carpathian Basin, there may be significant differences in the amount of precipitation and its temporal and spatial distribution, especially in case of rain showers.

The spatial variability of the precipitation can be very varied during the growing season, even within a small area there are significant differences.
Pedersen et al. (2010) showed that there can be a difference between 2,5-12,4 mm of precipitation just in 0,25 km^2 area.

Another method approach is to analyze the variability expressed by the spatial coefficient of variation (CV) of the precipitation field, estimated as the ratio of the standard deviation to the arithmetic mean depth. Pedersen et al. (2010) could show an average CV value of 14% in case a very small research field (500x500 m) during the 3-year long period. Some precipitation events with an average amount under 5 mm had CV above 50% (max. 77%).

The structural function gives the characteristic deviations of the precipitation values as a function of the horizontal distance. Determined in the average of a longer period, the structural function provides a basis for optimizing the station network to calculate the area average and the interpolation with sufficient accuracy (CZELNAI, 1981).

The semivariogram is a frequently used function for describing and analyzing the spatial structure of elementary precipitation events. This is essentially the same as the structural function, giving the average of the squared deviations as a function of distance:

$$y(h) = \frac{1}{2 \cdot N(h)} \cdot \sum_{i}^{N(h)} \left(Z_{s_i} - Z_{s_i+h}\right)^2$$

where y is the semi variance value, N is the number of station pairs, h is the distance between station pairs, Z is the amount of precipitation (Ly et al., 2011).

Further information on spatial variability is provided by the Pearson „r”-value of the correlation large number of events. The Pearson „r” values generally show a decreasing trend in a function of the distance of station pairs. (HABIB and KRAJEWSKI, 2001). The value of Pearson's correlation is significantly affected (reduced) by extreme values and is not sensitive to additive and proportional differences in data sets, so its use requires caution.

The goal of our research was to find a cost-efficient method to examine the spatial inhomogeneity of precipitation especially for agricultural use. An essential part of the work was to establish a dense rain gauge network to study the areal distribution of the precipitation on local scale, because the meteorological and hydrometeorological network is not dense enough in Hungary to get proper data for water management and for agricultural. In Hungary the data of station pairs within 2 km in summer and 8-10 km in winter are in good correlation (r>0,9), respectively (CZELNAI et al., 1963).

The World Meteorological Organization has defined the requirements for various instruments and measuring stations at several points in order to obtain the most accurate data possible on the state of the atmosphere and its changes. This requires instruments that can be used to make reliable and accurate measurements over the long term.

Rain gauges are considered by most to be able to provide accurate measurements in all conditions. However it has been long known that precipitation measurement is loaded with errors, most of them are systematic errors. None of these rain gauges are an exception, the difference can only be found in the degree of error. Nowadays the most commonly used tool to preform precipitation measurement is the tipping bucket rain gauge, but this type of rain gauge is also loaded with errors. For medium-intensity 10 mm / h precipitation, HABIB and KRAJEWSKI (2001) showed a measurement error of 6.4% on a 5 minute time scale and 2.3% on a 15 minute time scale. GRZEGORZ J. CIACH (2002) performed similar measurements using 15 tipping bucket rain gauges. During a medium-intensity precipitation he was able to detect an error of a 4.9% for the 5 minute time scale and 2.9% for the 15 minute time scale.

A very good complement to point precipitation measurements is precipitation measurement with meteorological radars. (GOMBOS, 2011) Radars emit electromagnetic pulses in all directions in the sky. After the detection and computer analysis of the signals reflected from the precipitation elements, it can be determined:

- location of precipitation objects
- intensity of precipitation
- other information about the cloud

Research has been conducted in the United States to determine the accuracy of radar measurements compared to traditional rain gauges. HUFF (1970) reported an error of less than 5%, measuring in an area of 1,000 km^2 and placing a rain gauge on every 65 km^2. Based on similar data, WOODLEY et al (1975) reported a much larger measurement error of 10–40% compared to a traditional rain gauge.

The most common measurement error is caused by the wind especially in the case of snow. (FORLEND et al. 1996) Nowadays most of the rain gauges are equipped with windshield, but the measurement error can still be significant.

In the case of snow, the average value of the under measurement can be between 10-50%, in the case of rain these values are only 2-10%, depending on the climate of the area, the exposure of the gauge site and the type of rain gauge (WMO, 2008).

Wind-induces under measurement of precipitation increases with wind speed and decreases with increasing rainfall intensity. (ALLERUP and MADSEN, 1979)

The most important rules to follow when placing rain gauges are (WMO 2014):

- should be placed vertically so that its upper edge is 1 meter above the ground
- place them at least as far away from the landmarks as their height, thus ensuring that the precipitation can already fall from a direction of 45°

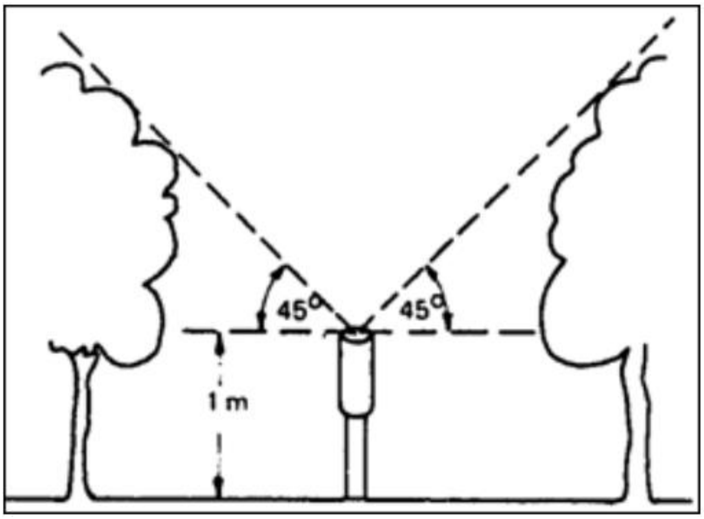

Fig.1 The Proper placement of rain gauge (Gombos 2011)

MATERIAL AND METHODS

The measurements were performed in the inner area of a village in the Great Plain (Csabacsűd). The sample area is about 1.2 km^2. Within the settlement, a high-density precipitation measuring network with 18 measuring points was established. The distance between the two closest measuring points is 150 m, while the distance between the two furthest is 1.5 km.

Fig. 2 Precipitation measurement locations in the settlement

The Hellmann rain gauge used for official measurements in Hungary. In Hungarian practice, this is the most common rain gauge. It consists of three parts, these are the receiver vessel, the collecting vessel and the holding vessel. The receiver vessel has a cross-section of 200 square centimeters and a diameter of 159.6 mm. Evaporation losses can be kept low at high temperatures because of the wall of the rain gauge which is a double aluminium cylinder. The receiver vessel narrows at the bottom, this is where the precipitate enters the collecting vessel, and then this is held by the holding vessel. (MÉSZÁROS, 2013) During the research period that was only available to me in limited numbers, so I used the most common and cost-efficient plastic rain gauges to perform the measurements.

The rain gauges were placed in the garden of family houses, at a distance at least corresponding to their height from the surrounding landmarks (trees, buildings).Particular care was taken to ensure that the rain gauges were in a horizontal position 1 meter above the ground so that the wind could not tip out of this equilibrium position, and that this position would be maintained during the repositioning after the measurements.

The main systematic error of precipitation measurements is caused by wind (WMO, 2008; CHÍVA et al., 2005), which has been kept low and unified by the targeted placement of the rain gauges (unified, wind-protected microenvironment in gardens), which is one of the most important aspects when measurements are made to explore the spatial variability of precipitation.

The first precipitation event was measured on 09.07.2018 and the last on 24.09.2018. During the research period 11 days of data were collected.

We examined the qualitative and quantitative correlations of the data with the help of the ESRI ArcGIS software, which has the following main elements:

- display data on point map
- determining station pair distances
- calculation of precipitation gradients
- use of different interpolation methods

There are 4 interpolation methods to choose from within the ArcGIS program, Among the methods, I chose the most frequently used Kriging method in the literature to show the spatial variability of precipitation.

Kriging is a geostatistical interpolation technique that considers both the distance and the degree of variation between known data points when estimating values in unknown areas. A kriged estimate is a weighted linear combination of the known sample values around the point to be estimated.

Spatial variance, deviation, and CV values of precipitation were calculated using Microsoft Office Excel.

RESULTS AND DISCUSSIONS

Precipitation activities took place over 11 days during the research period and were measured at all 18 stations. Each of the surveyed precipitation events reached an average of 5 mm/day.

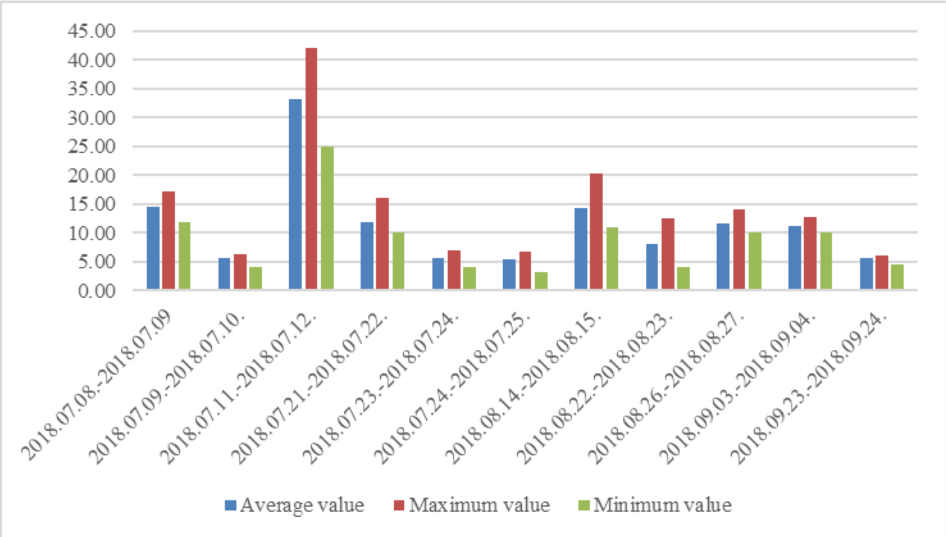

Fig.3 Average, maximum and minimum values of precipitation events in 2018 expressed in mm

The deviation which could be used to examine the spatial variability increased with the amount of precipitation. (4. Figure) This is also natural, as larger amounts of precipitation can lead to larger square differences. However the coefficient of spatial variation is, a better expression of spatial variability.

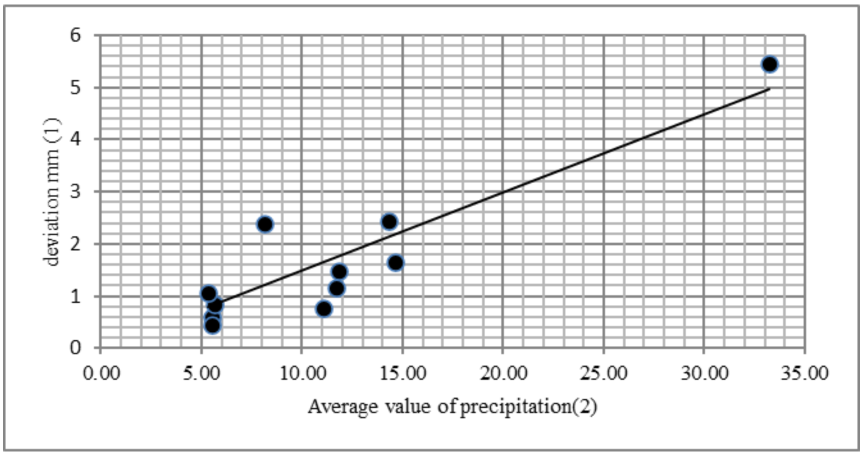

Fig.4 The value of the deviation (1) as a function of the precipitation average (2).

The highest CV value was 29%, the precipitation event was measured on 2018.08.23. The average value of precipitation was 8 mm on this day in the settlement. The minimum and maximum value of precipitation measured between two stations was 4 mm and 12,5 mm. Figure 5. illustrates that the minimum of precipitation was in the south-central part of the settlement, and an increase in precipitation was observed in the east-west direction.

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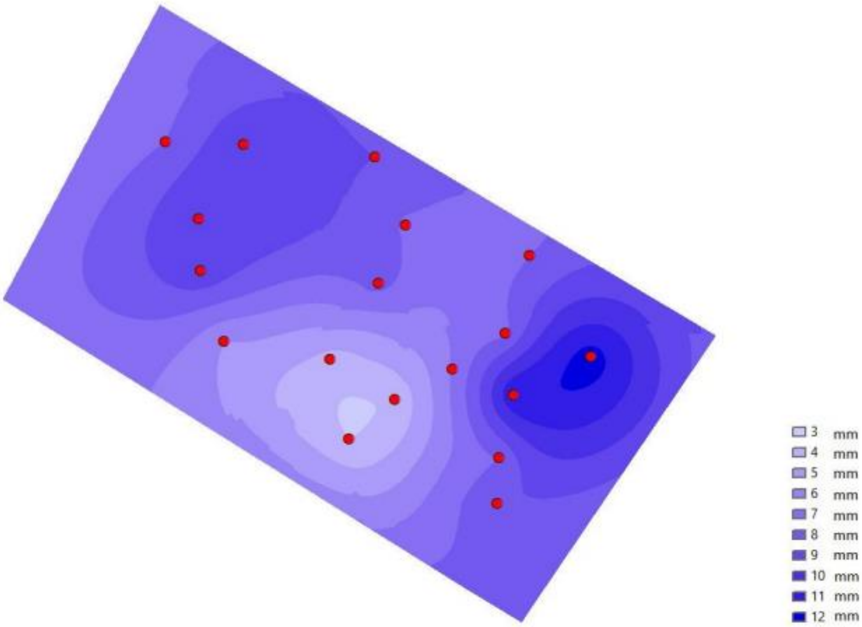

Fig.5 Spatial variability of precipitation in Csabacsűd 2018.08.23.

Of the CV values, only the fourth largest data is measured on 2018.07.12 with 16%, but with a daily average of 33 mm it stands out from other precipitation events. The measured minimum value was 25 mm and the maximum is 42 mm. On this day the difference between two measure station reached 17 mm, the distance between the two station was 1,4 km, this data is equivalent to 12,2 mm/km horizontal gradient. Shown well in the 6. figure that the precipitation maximum was in the western part of the settlement, then a steady decline to the east can be observed. That is worth noting that on this day the automatic rain gauge of the Szent István University only measured 7 mm rainfall on the neighboring settlement Szarvas.

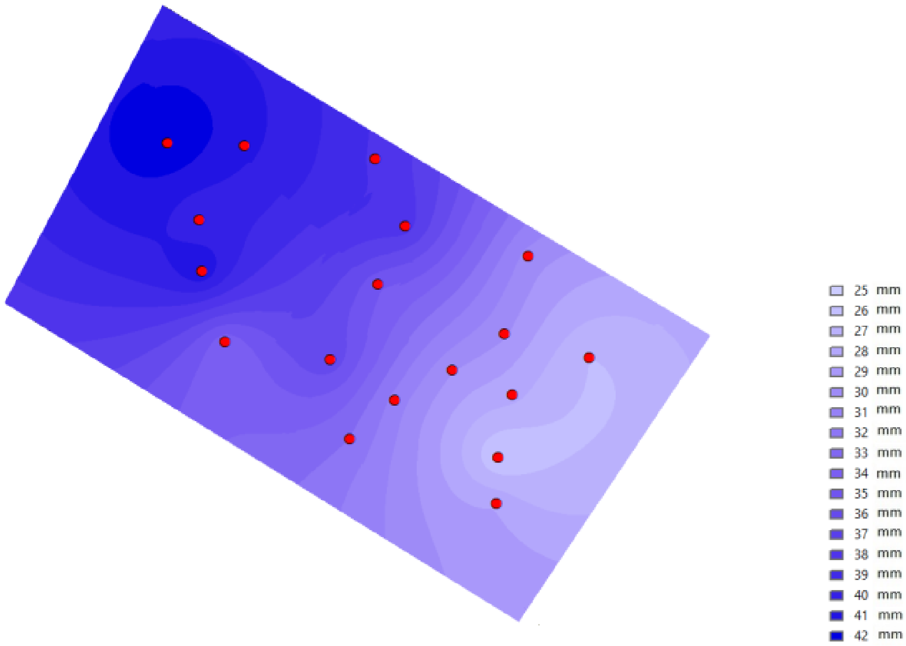

Fig.6 Spatial variability of precipitation in Csabacsűd 2018.07.12.

The difference between the highest and lowest precipitation measured in the settlement on each day is a good illustration of the spatial variability: there were 5 days during the research period when the difference reached 5 mm. The average CV value was 14% for the 11 measurement days.

During the research period, there were much more spectacular, nearly double gradients between the measuring points closer to each other so 3,6 mm per 100m.

Using the ArcGIS program, I determined Using the ArcGIS program, I determined the distance between the station pairs, followed by the calculation of the difference in precipitation between the two stations, and the last step was to determine the precipitation gradient in mm / 100 m.

Table 1

The highest precipitation gradient values measured in the settlement

Date	Distance between measuring point	Precipitation difference	Precipitation gradient
2018.07.11	370 m	8,2 mm	2,2 mm/100m
	240 m	3,8 mm	1,6 mm/100m
	225 m	5,2 mm	2,3 mm/100m
	350 m	5,6 mm	1,6 mm/100m
2018.07.22	150 m	2,8 mm	1,9 mm/100m
2018.08.15	150 m	5,4 mm	3,6 mm/100m
	240 m	4,9 mm	2,0 mm/100m
2018.08.23	170 m	4,2 mm	2,5 mm/100m
	230 m	4,9 mm	2,1 mm/100m
	360 m	7,8 mm	2,2 mm/100m

The table shows the precipitation events with the largest difference between the maximum and the minimum among the measuring stations.

- On 2018.07.11 there was an average precipitation of 33 mm in the settlement, on this day there was the most significant difference between the measuring stations, when the value of the difference between the highest and lowest precipitation was 17 mm. The most significant precipitation gradient was 2.3 mm / 100 m, during which was a difference of 5.2 mm in the amount of precipitation between the measuring stations located 225 m apart.
- The second largest difference occurred on 2018.08.15., the average precipitation was 14 mm and the difference between measuring stations was 9.4 mm. This precipitation event also showed the highest precipitation gradient value in the research period, which was 3.6 mm / 100 m.
- The third most spectacular precipitation event was on 2018.08.23., the difference between two measuring station was 8.5 mm and the average was 8 mm on this day. There was a difference of 4.2 mm between two stations 170 m apart, which is 2.5 mm / 100 m in terms of precipitation gradient.
- On 2018.07.22., the average precipitation was 12 mm and the difference between two rain gauges reached 6 mm. Within 150 m, a difference of 2.8 mm was detected between two measuring points, corresponding to a precipitation gradient of 1.9 mm / 100 m.

The CV values and the spatial variability of precipitation showed extremely varied differences in 2018 after one rain shower precipitation event on the other hand for a longer period of time, precipitation amounts show an equalization. In the 2018 research year, based on data from 18 precipitation measuring stations, the average data over 3 months was 126.9 mm. It was also clear from the CV values and the precipitation gradient that there can be a really varied spatial distribution in the summer semester. In Figure 7, however, these differences are less apparent. The most precipitation was at the western part of the settlement, with a value of 132.9 mm, and the least precipitation was from 140 m away from that measuring station, with a value of 118,6 mm, with a difference of only 14,3 mm.

The value of the deviation was 4.48 mm, the coefficient of spatial variation that can best describe the spatial variability of precipitation is only 3.53%. This also shows that there are larger differences, as in the case of 2018.08.23., where the value of CV was 29%, but in the long run there is a kind of equalization.

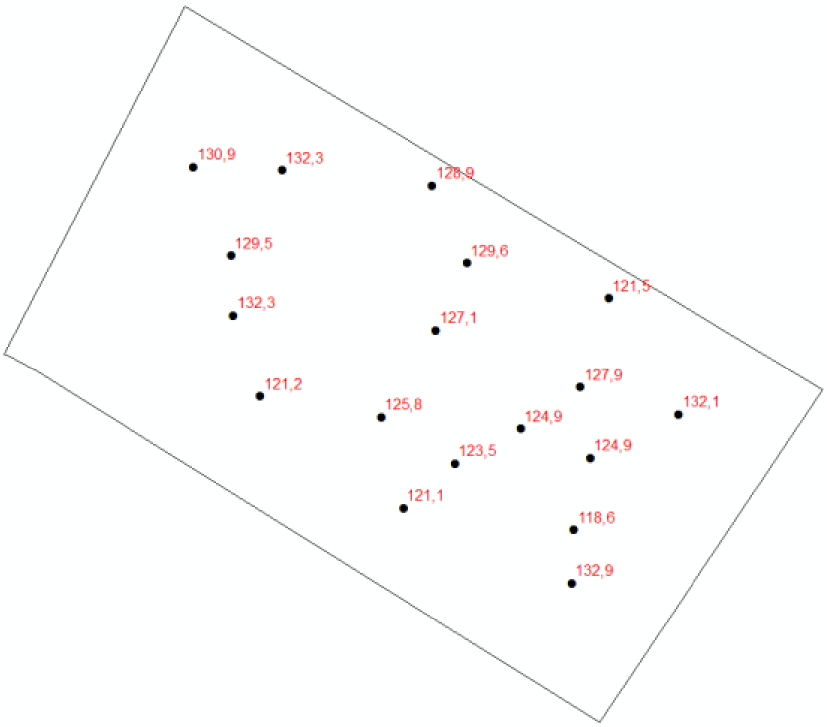

Fig.7 Aggregation of precipitation events in 2018.

CONCLUSIONS

Based on the results of the 4-month measurement program launched in 2018, it can be stated that even within a small settlement, significant differences in daily rainfall can occur. In almost half of the cases during the summer rain showers we could see a difference of at least 5 mm within 200-300 meters, and a horizontal gradient exceeding 2 mm / 100 meters. Spatial deviation and absolute variations also increase with higher daily precipitation, while the coefficient of variation shows the opposite trend.

A good example of this is the precipitation event measured on 2018.07.12., when I measured a daily average of 33 mm in the settlement, and the meteorological station of the OMSZ in Szarvas was only measured 7 mm.

Outside the growing season, the amount of precipitation over a longer period counts, at which the standard deviation may be much lower, in which case it may be sufficient to use a precipitation measuring instrument that provides reliable data and underestimation by wind is no longer significant. In this case, the data of a measuring point located up to 5-10 km may be sufficient.

On the other hand we need to pay attention to the following steps, because these are essential in order not to lose the advantages of the on-site measurements.

- should be placed vertically so that its upper edge is 1 meter above the ground
- place them at least as far away from the landmarks as their height, thus ensuring that the precipitation can already fall from a direction of 45°
- reading within short time after the precipitation event in order to minimalize evaporative loss

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