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Analysis of Differences Between Levelling Networks in the County of Hajdú-Bihar

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Abstract. The height determination of control and detail points is essential during the process of planning and manufacturing in the practice of civil engineering. Planning maps are drawn for the former, while the intended plan is set out on the ground during manufacturing, and after the manufacturing the completed installation is mapped. Using the same reference system in all three steps, both horizontally and vertically, is recommended even though in some cases it is unavoidable to change from one reference level to another.

Regardless of the fact that both refer to the mean sea level of the Baltic Sea, this can create difficulties, since the difference between the EOMA and Bendefy networks used in Hungary shows varying values depending on the geographical location. The aim of the analysis is to determine a constant difference regarding the analysed settlements based on the common points of the networks.

Keywords: Level Surface, Mean Sea Level, Baltic Sea Level, EOMA, Bendefy

Introduction

In order to be able to measure height, a point with a specified height is needed, as the measurement is always compared to that point. A control point network that refers to a given level surface is required to make the measurements homogeneous and interconnectable within a settlement, a county or a country.

Levelling networks are made out of control points, for which the main requirement is to ensure that they are as immobile as possible in height. In reality, these points are marked with bench marks placed in the walls of buildings or, outside towns, with stones. Thus, the main purpose of levelling networks is to provide control points for further altimetry.

The points of the levelling network are one-dimensional control points and therefore, they do not have horizontal coordinates. For cost efficiency, these points are classified.

The first-class network with the highest accuracy was defined first, from which the lower-class networks were derived. Further point determinations were necessary because the points of the first-class network did not meet the 1 point/4 km^{2}requirement, as the main control points of the network were only 40. The second-class network was derived from the first-class network, then the third-class from the second-class, and finally fourth-class network was created by condensing the latter. Fifth-class points, as detail points, are determined using one of the former networks in the practice of everyday civil engineering. The control points of the levelling network described are further subdivided into two groups. The first-, second- and third-class networks covering the territory of Hungary are called the upper-class or national levelling network, while the fourth-class network is called the lower-class network.

Four levelling networks have been set up in Hungary so far.

The first such network was started in 1872 by the Vienna Military Geographic Institute and its aim was to provide a uniform reference level throughout the territory of the Austro-Hungarian Empire. The surveying was led by military officers and was therefore called the first national military levelling. 7 main control points were established in the territory of Hungary at that time, the height of which was determined in comparison to the mean sea level of the Adriatic Sea. One of these points, located in the village of Nadap in the Velence Hills, falls within the territory of present-day Hungary. This main control point, which was established in 1873 and the height of which was determined in 1888, is still the starting point for the calculation of all levelling networks in the country. However, due to the rudimentary nature of the equipment, the vague establishment of the points and the long intervals between measurements, the network was subject to significant errors and could not fulfil its intended purpose.

The second national levelling network was established after the First World War, starting in 1921. One of the reasons for the creation of this network was the change of state borders and the fact that the Austrians did not provide us with the records of previous measurements. The creation of the new network is attributed to Jenő Gárdonyi and therefore it is called the Gárdonyi network. Oltay Károly created the high-precision instrument and the measuring staff, which was used for the measurement and was made in the factory of Nándor Süss. However, World War II broke out before the network could be fully established. At the time about 60% of it was destroyed, making it no longer suitable for practical tasks.

The third national levelling network was made after the Second World War, between 1948 and 1964. Its main purpose was to provide control points for the reconstruction of the country, so that every inhabited area has at least one levelling control point. The requirement of 1 point/4 km^{2}was met, i.e. to have at least one control point in every inhabited area. It can be attributed to László Bendefy, and therefore the second network is also known as the Bendefy network. During the surveying, about 23500 points were determined. However, before the network was fully established, it was ordered to switch from the Adriatic to the Baltic base sea level. The decree applied to the socialist countries of Eastern Europe, including Hungary. The Baltic mean sea level was provided by the gauge on the island of Kronstadt. However, in practice, the changeover was achieved by reducing the height of the Adriatic system's points by 0,6747 metres.

Between 1960 and 2006, the fourth levelling network, which is still in use today, the EOMA (Egységes Országos Magassági Alappont hálózat) was established as part of the modernisation of the country's geodetic foundations. The creation of the new network was also justified by the fact that the previous one (Bendefy network) had a significant point loss.

The concept of the EOMA was created by István Joó. 90% of the EOMA's first-class lines are identical to those of the Bendefy network, i.e. partly new lines. Thus, there are points with known heights in both the EOMA and the Bendefy networks. Both networks concern the mean sea level of the Baltic Sea, however, the height of the same control points varies. It is due to the fact that the determination of the EOMA was based on the height of the Nadap II main control point, which had been determined in the meantime, instead of Nadap I, and the control points had moved (sunk or risen) during the time elapsed (different dates for the determination of the Bendefy and EOMA networks), and different calculation methods were used to balance the two measurements. This has led to a situation where the difference in the heights of the two networks cannot be described by a constant value. The differences can be best represented on an isoline map. (Figure 1)

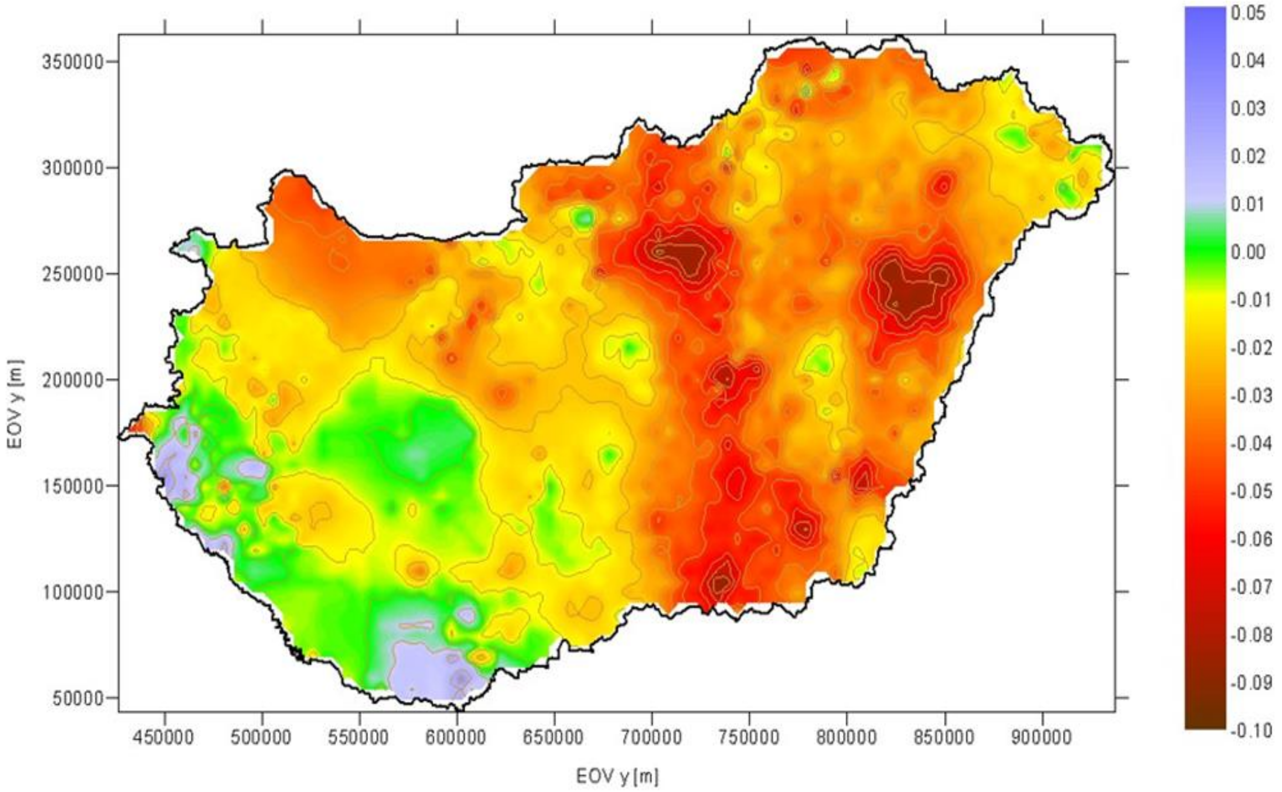

Figure 1, EOMA-Bendefy height differences [1]

The previous image shows the differences between the two systems with a centimetre contour line. According to professional practice's expectation, it would be advisable to determine a constant value for each settlement. In everyday practice, if there is no such value, the change from one system to the other is achieved by selecting a control point, which has both heights, close to the settlement and using the difference of its heights. However, this value does not necessarily give a sufficiently accurate result for the whole settlement, so it is recommended to determine an average value by using several control points. [2]

Analysis of the difference between EOMA and Bendefy in the county of Hajdú-Bihar

The following data were obtained for the whole county:

	Hajdú-Bihar County
Quantity	114
Mean	-0,0801
Median	-0,0525
Variance	0,0152
Standard Deviation	0,1234
Minimum	-0,346
Maximum	-0,425
Range	0,771

Table 1. Data summary (whole county)

According to the table, the mean is -0.0801 m, which is the average difference in deviation for the whole county and therefore the average subsidence of the points is 8 cm. The reliability of the calculation is shown by the fact that the average subsidence of the former is characterised by a standard deviation of 0.1234. Since the value of the standard deviation is low, the average deviation can be considered reliable.

The line chart containing the data:

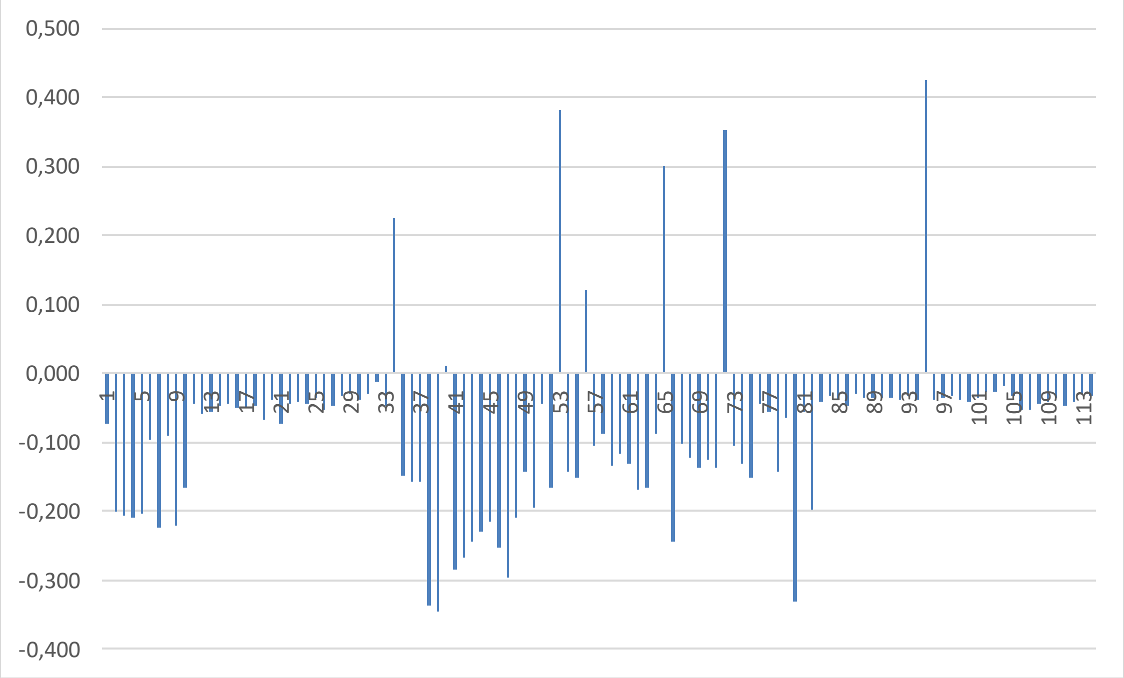

Figure 2. Line chart with the data

The line chart also confirms the subsidence of the points, as almost all are in the negative range. The positive change of the exceptions can be attributed to other causes (calculation or determination error, anthropogenic interventions, etc.) that are independent of the surface movements. [3]

Analysis of EOMA-Bendefy differences in certain settlements Hajdú-Bihar County

The EOMA-Bendefy differences were analysed in certain settlements (Balmazújváros, Berettyóújfalu, Debrecen, Hajdúböszörmény, Nyíradony) of Hajdú-Bihar County. Based on the available data, the average hight differences were the highest in the area of Balmazújváros and the lowest in the area of Nyíradony.

The mean, median, variance, standard deviation, minimum, maximum, and range for each settlement are shown in the table below:

Settlements	**Balmazújváros**	**Berettyóújfalu**	**Debrecen**	**Hajdúböszörmény**	**Nyíradony**
Quantity	13	20	42	25	14
Mean	-0,1422	-0,0428	-0,1149	-0,04332	-0,03714
Median	-0,166	-0,0435	-0,1415	-0,038	-0,0355
Variance	0,005221	0,000185	0,02754	0,01405	0,000104
Standard Deviation	0,07226	0,013606	0,1660	0,1185	0,01017
Minimum	-0,224	-0,074	-0,346	-0,331	-0,053
Maximum	-0,044	-0,011	0,382	0,425	-0,019
Range	0,18	0,063	0,728	0,756	0,034

Table 2. Summary of data by settlement

With the data shown on a boxplot, we get the following diagram (from left to right the figures of Balmazújváros, Berettyóújfalu, Debrecen, Hajdúböszörmény, Nyíradony can be seen).

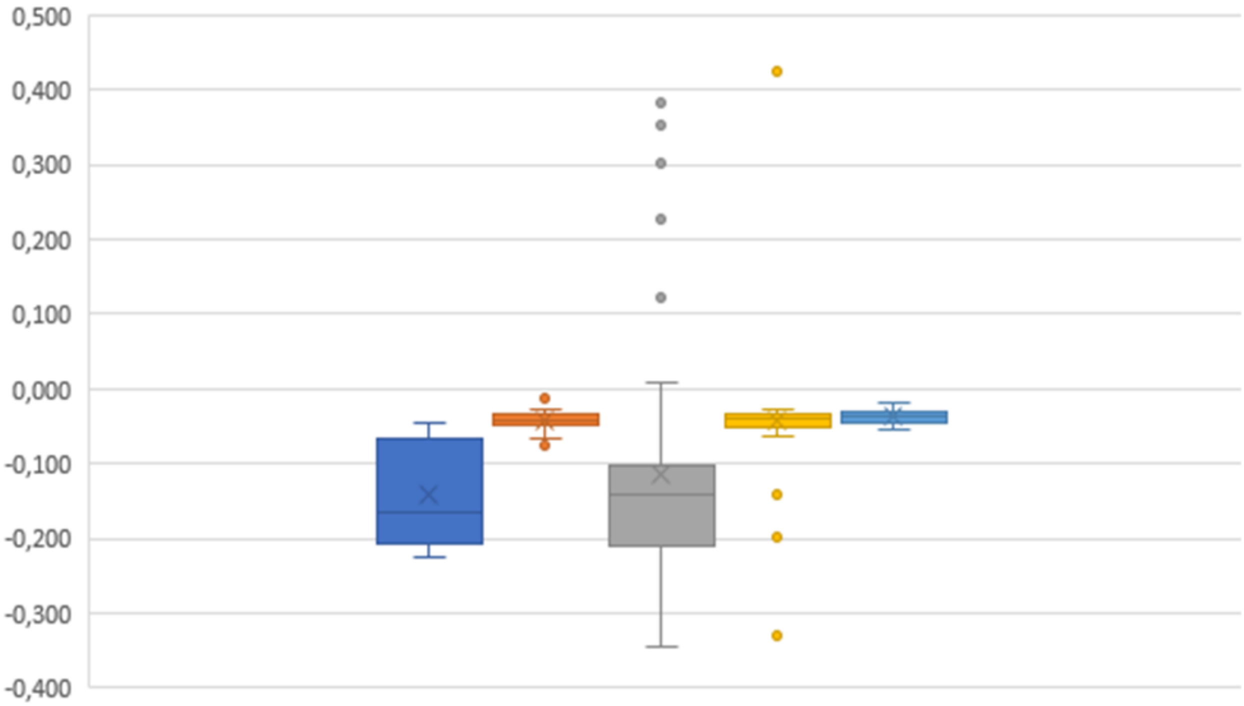

Figure 3. Boxplots of each settlement

Analysis of variance shows the average deviation values for each settlement are not the same, as the calculated value of corresponding F test is 3.35, while the critical value is 2.455, which means that the calculated value is lower than the critical value, i.e. there is a significant difference in the height difference values for each settlement at the 95% confidence level:

Factors	**SS**	**df**	**MS**	**F**	**p-value**	**F critic**
Between groups	0,1885	4	0,04713	3,3492	0,01257	2,455
Within groups	1,534	109	0,01407			
In total	1,7226	113				

Table 3. Analysis of variance

Differences in height by settlement over the years

In the following, a formula is given for the variation of height differences by year for each settlement. This is necessary, especially if several years, or even decades, have passed between the measurement of points in one system and the other. The vertical movement of each point needs to be taken into account, since this movement distorts the height differences. When several measurements are available in a given year, their mean is used. In the case of Balmazújváros, the following figure and regression model are obtained:

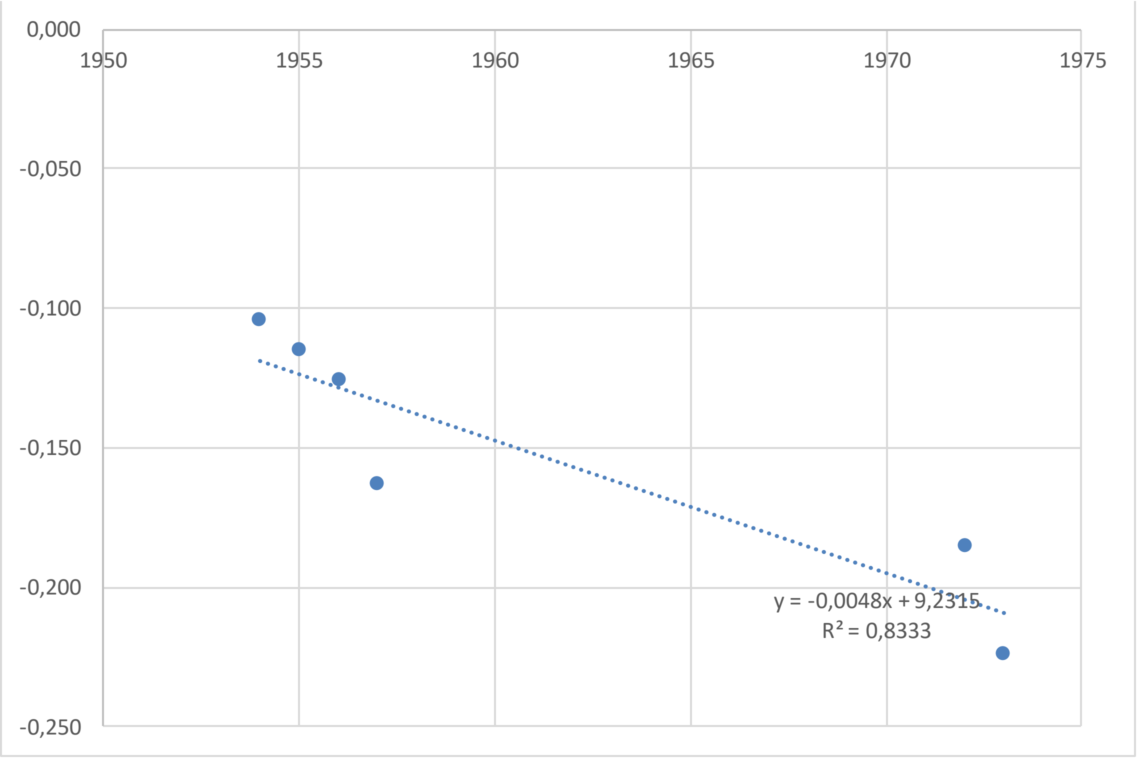

Figure 4. Height differences over the years (Balmazújváros)

In the case of Berettyóújfalu, the following figure and regression model are obtained:

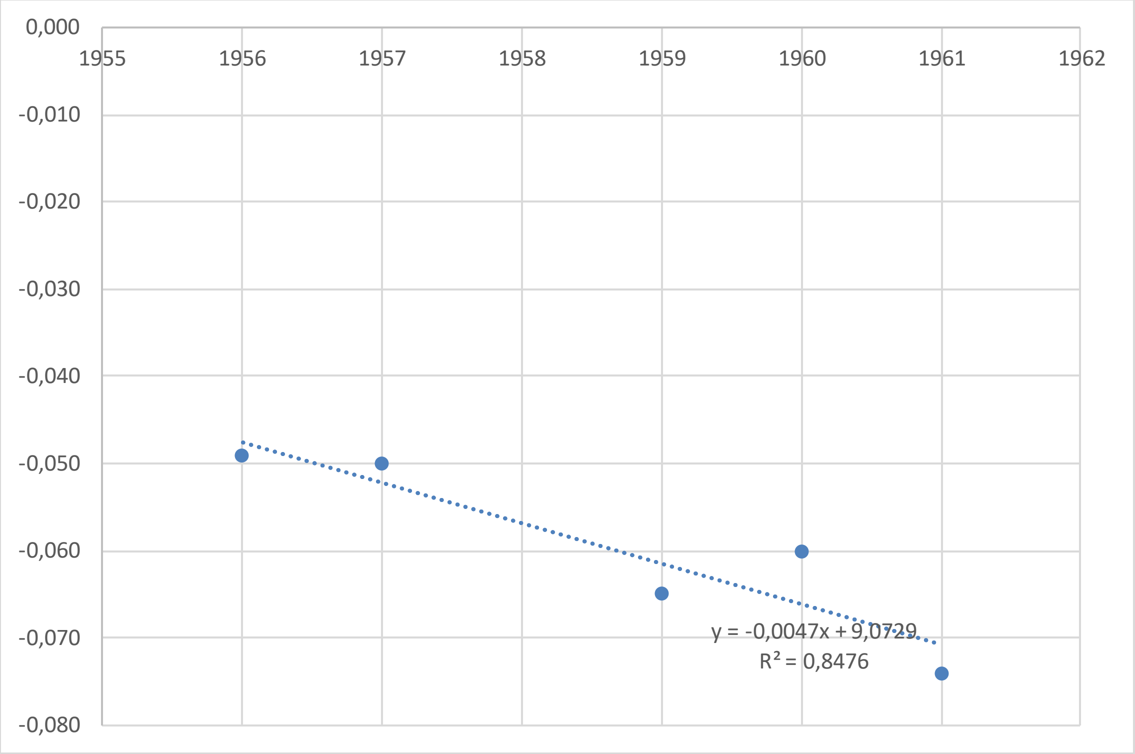

Figure 5. Height differences over the years (Berettyóújfalu)

In the case of Debrecen, the following figure and regression model are obtained:

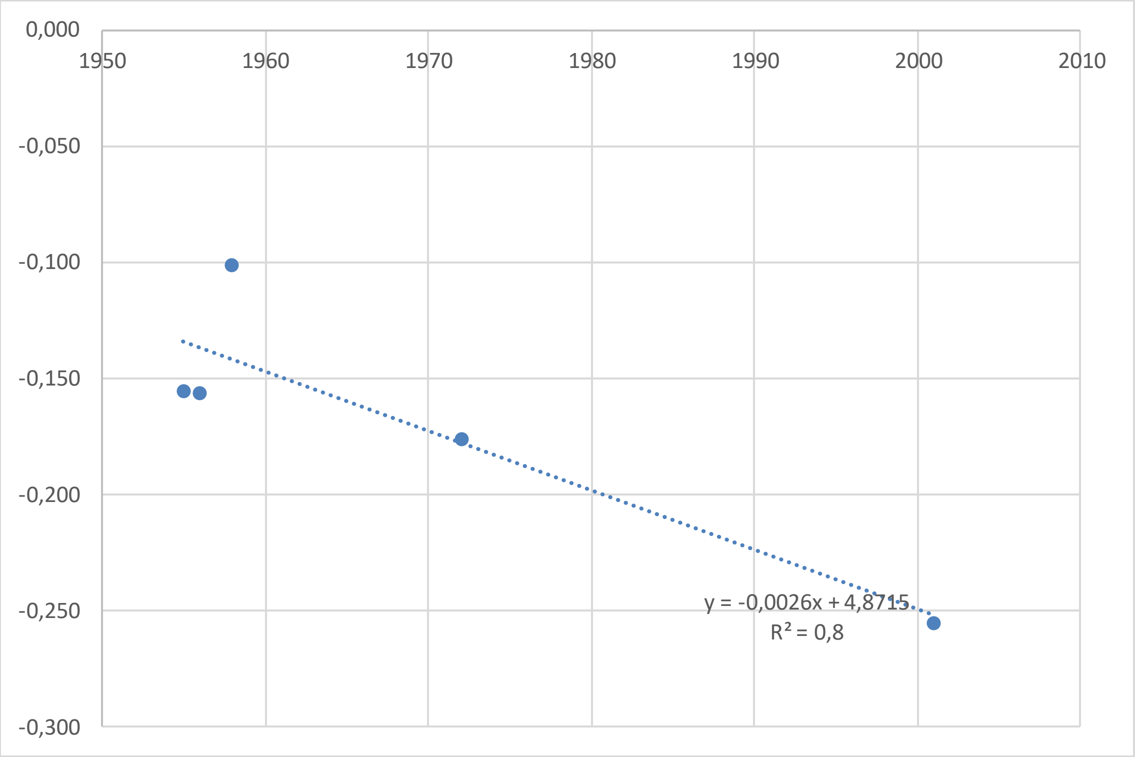

Figure 6. Hight differences over the years (Debrecen)

In the case of Hajdúböszörmény, the following figure and regression model are obtained:

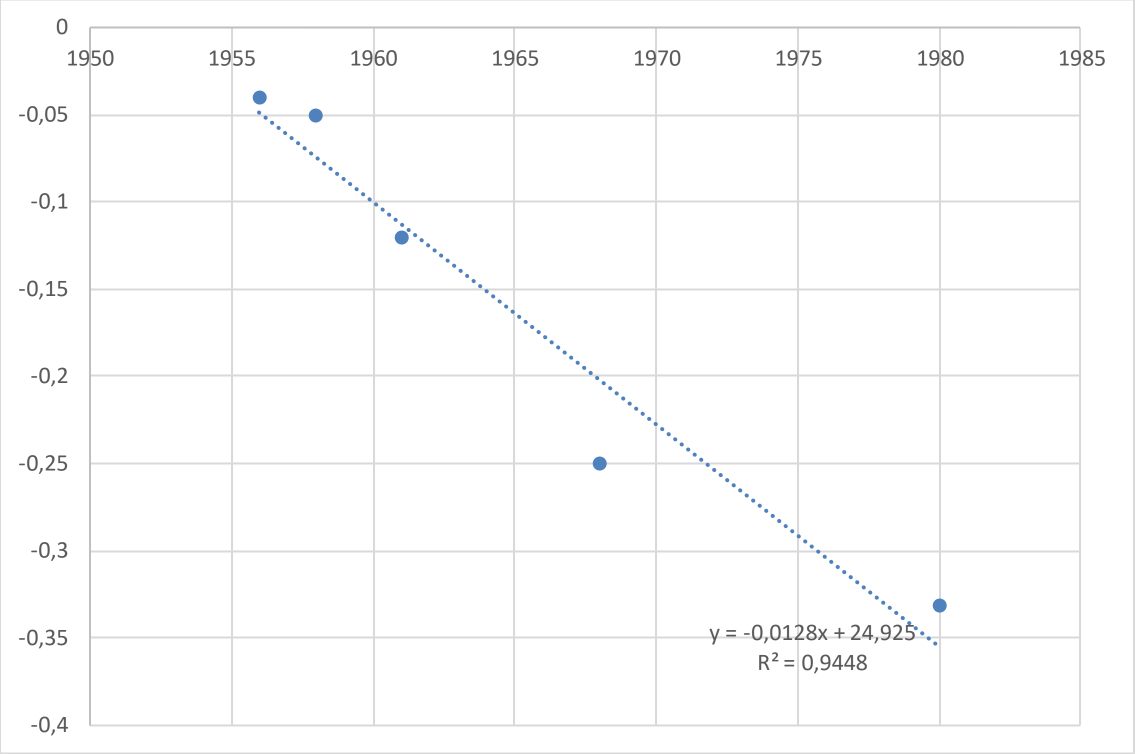

Figure 7. Height differences over the years (Hajdúböszörmény)

In the case of Nyíradony, it is not possible to construct a similar model to the previous ones due to the uneven distribution of available data over time.

Summary

In conclusion, analyse of variance shows that at the 95% confidence level, there is a significant difference in the height differences between the various settlements in Hajdú-Bihar County. The highest average difference was found in Balmazújváros, the lowest in Nyíradony. [4]

The differences of height by settlement over the years was analysed on the basis of the available data. This can be used to provide estimates for years when no specific measurement has been done, and also to predict future values.

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