On the Error Distribution in Precise Levelling Sections

Vasil Cvetkov

University of Architecture, Civil Engineering and Geodesy, Sofia 1046, Bulgaria, tzvetkov_fgs@uacg.bg;
ORCID 0000-0001-9628-6768

https://doi.org/10.29227/IM-2026-02-02-039

Submission date: *2026-05-04* | Review date: *2026-21-04*

Abstract

The assumption that measurement errors follow a Gaussian (normal) distribution is widely accepted in geodesy and related sciences. However, numerous studies over the past decades have reported observational evidence that challenges this assumption, particularly using modern measurement techniques such as Global Navigation Satellite Systems, Satellite Laser Ranging, gravimetry, and astronomical observations. Earlier investigations from the mid-20th century also indicated deviations from normality in precise and hydrostatic levelling data.This study examines the statistical properties of levelling discrepancies from several national levelling campaigns: the Second Levelling of Bulgaria (1953–1957), the Third Levelling of Bulgaria (1975–1984), the Second Levelling of Finland (1935–1955), and the Third Levelling of Finland (1978–2006). The analysis focuses on testing the normality of the discrepancies using statistical measures of skewness and excess kurtosis, as well as chi-squared goodness-of-fit tests. The results reveal significant deviations from normality across all datasets examined. The Bulgarian levelling data show platykurtic distributions with kurtosis values of 2.386 and 2.516 for the Second and Third Levelling, respectively, both exceeding the three-sigma confidence limits, while their skewness values (0.134 and −0.087) remain within the threefold standard deviation range. In contrast, the Finnish datasets exhibit leptokurtic distributions with kurtosis values of 3.467 and 4.557. Chi-squared tests reject the normality hypothesis for all datasets at significance levels greater than 99.99%. Further analysis of standardized discrepancies, obtained by scaling discrepancies by squared levelling distances, reveals even stronger deviations from normality, with kurtosis values increasing to 2.225, 2.439, 4.407, and 7.147 for the four levelling campaigns. These findings highlight that the distribution of levelling discrepancies can differ substantially from the assumed Gaussian model, underscoring the importance of accounting for real data distributions when evaluating measurement accuracy and planning geodetic observations.

Keywords: *Normal Distribution, Probability Theory, Observation Errors, Precise Levelling, Levelling Accuracy*

1. Introduction

Many theoretical approaches in geodesy are based on the assumption that observation errors follow a Gaussian distribution. Consequently, the accumulation of uncertainty is commonly described by the Gaussian error law. While this framework is convenient for defining confidence intervals and assessing a priori and a posteriori accuracy, it remains open to debate.

It is, in fact, somewhat questionable that errors arising from different types of observations, collected using various instruments, under diverse conditions, and following different methodologies, would all conform to the same distribution. A more realistic expectation is that different observation types follow different statistical distributions.

In classical geodetic practice, a given quantity is typically measured only a few times, often fewer than ten. With such limited samples, undetected gross errors are likely to occur. At the same time, valid observations may be incorrectly rejected as outliers based on the assumption that they lie outside the ±3σ limits of a normal distribution. Moreover, small sample sizes make it difficult to construct reliable histograms or to assess the underlying distribution accurately. Measures of normality, such as skewness and kurtosis, become unreliable because their standard errors can be of comparable magnitude to the estimates themselves. Likewise, goodness-of-fit tests such as the χ^2 and Kolmogorov–Smirnov tests lose effectiveness due to the low degrees of freedom.

As a result, practitioners often rely on the assumption that their observations represent a subset of a large, normally distributed population. However, empirical evidence suggests that this assumption may not always hold. Studies on GNSS data processing [1–2] indicate that non-normal distributions are not uncommon. Similar conclusions have been reported for high-precision ballistic gravity measurements [3], precise astronomical observations [4], space geodetic data [5], and precise levelling [6], with further examples discussed by Wiśniewski [7]. According to the influential work of Hampel et al. [8], outliers in engineering observations can exceed 10% of the dataset. There is little reason to assume that geodetic measurements are an exception.

Figure 1 illustrates the closing error of a test levelling loop in Sofia, with a total length of 2.99 km. The measurements were carried out by experienced Bulgarian geodesists specializing in precise levelling. The loop was observed three times using Ni007, five times with Ni002, and seven times with Ni004, yielding a total of 15 closing errors. These values represent true observation errors, ranging from −0.74 mm to 1.10 mm. As shown in Figure 1, their distribution deviates noticeably from the characteristic bell shape of the normal distribution.

In precise levelling, each height difference is typically measured twice. Therefore, the a priori accuracy is commonly estimated from the differences between the two measurements. These differences effectively represent the differences between the true errors associated with each observation of a given elevation, providing valuable insight into their statistical behaviour when their distribution is analysed.

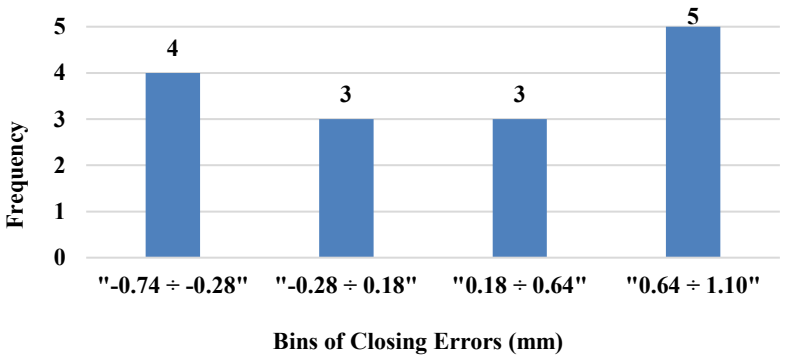

Fig. 1. Loop closing errors in testing levelling loop in Sofia (adapted from [9]).

Accordingly, the objective of this study is to examine the normality, or deviation from normality, of the section discrepancies *d* and the standardized section discrepancies $\boldsymbol{d/\sqrt{l}}$ across four levelling campaigns: the Second Levelling of Bulgaria (1953–1957), the Third Levelling of Bulgaria (1975–1984), the Second Levelling of Finland (1935–1955), and the Third Levelling of Finland (1978–2006). The study further aims to demonstrate that these discrepancies do not follow a Gaussian distribution. This issue is of critical importance for defining acceptable limits of section discrepancies, selecting appropriate weights for levelling observations, and for the planning and establishment of national and engineering levelling networks

2. Methodology and used data

In this study we used the data of the section discrepancies *d* and the standardized section discrepancies $\boldsymbol{d/\sqrt{l}}$ across four levelling campaigns: the Second Levelling of Bulgaria (1953–1957), the Third Levelling of Bulgaria (1975–1984), the Second Levelling of Finland (1935–1955), and the Third Levelling of Finland (1978–2006). The data related to the Bulgarian levelling networks can be obtained upon request from the Agency of Geodesy, Cartography and Cadastre in Sofia, Bulgaria. Data from the Second Levelling of Finland (1935–1955) and the Third Levelling of Finland (1978–2006) are published and publicly available, as referenced in [10] and [11], respectively.

To investigate the shape of the distributions of section discrepancies and standardized section discrepancies, we calculated the skewness *S*, kurtosis *K*, and excess kurtosis *E* of their samples by equations (1)-(3).

$$S = \frac{m_3}{m_2^{3/2}} \tag{1}$$

$$K = \frac{m_4}{m_2^2} \tag{2}$$

$$E = K - 3 \tag{3}$$

In equations (1) and (2), m_4 is the fourth sample moment about the mean, m_3 is the third sample moment about the mean, and m_2 is the second sample moment about the mean. They can be calculated by equation (4), where $i = \{2, 3, 4\}$, $x = \{d, \frac{d}{\sqrt{l}}\}$, and $\bar{x}$ is the mean of the *x* sample.

$$m_i = \frac{1}{n}\sum_{j=1}^{n}\left(x_j - \bar{x}\right)^i \tag{4}$$

Since our sample sizes (n) exceed 1000, we can apply simplified formulas to evaluate the standard errors of skewness and excess kurtosis, as given in equations (5) and (6), respectively.

$$\sigma_S = \sqrt{\frac{6}{n}} \tag{5}$$

$$\sigma_E = \sqrt{\frac{24}{n}} \tag{6}$$

Since the values of the skewness and excess kurtosis of the samples of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second Levelling of Bulgaria, the Third Levelling of Bulgaria, the Second Levelling of Finland, and the Third Levelling of Finland, deviate significantly from those of the normal distribution, we performed additional tests by Pearson's X^2 test [12]. The number of classes /bins/ *k* in our study was determined by Terrell-Scott's criterion (7) [13-14].

$$k = \sqrt[3]{2n} \tag{7}$$

This criterion was chosen to avoid empty bins and/or an excessive number of bins containing fewer than five values.

3. Results

Table 1 presents the basic statistics describing the central tendency and shape parameters of the distributions of the differences *d* and the standardized differences $\boldsymbol{d/\sqrt{l}}$ for sections from the Second Levelling of Bulgaria (1953–1957), the Third Levelling of Bulgaria (1975–1984), the Second Levelling of Finland (1935–1955), and the Third Levelling of Finland (1978–2006). Tables 2–5 provide the bin ranges, along with the observed and theoretical frequencies of the differences *d* for the aforementioned levelling campaigns. Tables 6–9 present the corresponding bin ranges and the observed and theoretical frequencies for the standardized differences $\boldsymbol{d/\sqrt{l}}$ in these campaigns.

Tab. 1. Characteristics of samples of the analysed levelling networks.

Network	Statistic	Count	Average	Skewness (S)	Skewness Standard Deviation (σ_S)	Kurtosis (K)	Excess Kurtosis (E)	Excess Kurtosis Standard Deviation (σ_E)
BG II	d	2311	-0.193	0.134	0.051	2.386	-0.614	0.102
	$d/\sqrt{l}$	2311	-0.166	0.115	0.051	2.225	-0.775	0.102
BG III	d	4573	0.178	-0.087	0.036	2.561	-0.439	0.072
	$d/\sqrt{l}$	4573	0.165	-0.086	0.036	2.439	-0.561	0.072
FIN II	d	3365	0.033	-0.062	0.042	3.467	0.467	0.084
	$d/\sqrt{l}$	3361	0.026	-0.245	0.042	4.407	1.407	0.084
FIN III	d	6701	0.129	0.142	0.030	4.541	1.541	0.060
	$d/\sqrt{l}$	6701	0.101	0.133	0.030	7.144	4.144	0.060

Tab. 2. Terrell-Scott's bins regarding the section discrepancies d in the Second Levelling of Bulgaria /1953-1957/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-5.27	-4.72	1	4.56	2.78
2	-4.72	-4.17	1	11.26	9.34
3	-4.17	-3.63	12	24.91	6.69
4	-3.63	-3.08	49	49.43	0.00
5	-3.08	-2.53	110	87.91	5.55
6	-2.53	-1.98	180	140.18	11.31
7	-1.98	-1.44	226	200.39	3.27
8	-1.44	-0.89	248	256.80	0.30
9	-0.89	-0.34	295	295.04	0.00
10	-0.34	0.21	265	303.88	4.98
11	0.21	0.75	262	280.59	1.23
12	0.75	1.30	194	232.27	6.30
13	1.30	1.85	161	172.37	0.75
14	1.85	2.40	145	114.67	8.02
15	2.40	2.94	94	68.39	9.59
16	2.94	3.49	50	36.57	4.93
17	3.49	4.04	18	17.53	0.01

Tab. 3. Terrell-Scott's bins regarding the section discrepancies d in the Third Levelling of Bulgaria /1975-1984/.

Bin	From (mm)	To (mm)	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-2.57	-2.28	4	7.25	1.46
2	-2.28	-1.99	7	18.57	7.21
3	-1.99	-1.69	35	42.52	1.33
4	-1.69	-1.40	111	87.06	6.58
5	-1.40	-1.11	209	159.35	15.47
6	-1.11	-0.82	303	260.78	6.84
7	-0.82	-0.52	378	381.54	0.03
8	-0.52	-0.23	444	499.06	6.08
9	-0.23	0.06	535	583.63	4.05
10	0.06	0.35	510	610.20	16.45
11	0.35	0.65	552	570.38	0.59
12	0.65	0.94	512	476.67	2.62
13	0.94	1.23	459	356.15	29.70
14	1.23	1.52	303	237.90	17.81
15	1.52	1.82	136	142.08	0.26
16	1.82	2.11	49	75.86	9.51
17	2.11	2.40	13	36.21	14.88
18	2.40	2.69	6	15.45	5.78
19	2.69	2.99	2	5.90	2.57
20	2.99	3.28	2	2.01	0.00
21	3.28	3.57	3	0.61	9.29

Tab. 4. Terrell-Scott's bins regarding the section discrepancies d in the Second Levelling of Finland /1935-1955/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-4.77	-2.90	7	3.24	4.38
2	-2.90	-2.43	15	12.15	0.67
3	-2.43	-1.96	46	43.04	0.20
4	-1.96	-1.49	124	119.93	0.14
5	-1.49	-1.03	238	262.76	2.33
6	-1.03	-0.56	398	452.71	6.61
7	-0.56	-0.09	586	613.38	1.22
8	-0.09	0.38	839	653.61	52.58
9	0.38	0.84	488	547.76	6.52
10	0.84	1.31	299	361.01	10.65
11	1.31	1.78	212	187.12	3.31
12	1.78	2.25	80	76.26	0.18
13	2.25	2.72	29	24.44	0.85
14	2.72	4.12	5	7.57	0.87

Tab. 5. Terrell-Scott's bins regarding the section discrepancies d in the Third Levelling of Finland /1978-2006/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-5.65	-3.59	6	1.30	16.91
2	-3.59	-3.08	17	6.20	18.84
3	-3.08	-2.56	38	26.97	4.51
4	-2.56	-2.05	98	92.70	0.30
5	-2.05	-1.53	202	251.56	9.76
6	-1.53	-1.02	425	539.09	24.15
7	-1.02	-0.50	777	912.38	20.09
8	-0.50	0.01	1562	1219.54	96.17
9	0.01	0.53	1520	1287.49	41.99
10	0.53	1.04	928	1073.54	19.73
11	1.04	1.55	550	706.99	34.86
12	1.55	2.07	317	367.71	6.99
13	2.07	2.58	155	151.03	0.10
14	2.58	3.10	58	48.98	1.66
15	3.10	3.61	30	12.54	24.30
16	3.61	4.13	8	2.54	11.78
17	4.13	6.70	10	0.46	197.39

Tab. 6. Terrell-Scott's bins regarding the reduced section discrepancies $\boldsymbol{d/\sqrt{t}}$ in the Second Levelling of Bulgaria /1953-1957/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-4.68	-4.21	1	2.69	1.06
2	-4.21	-3.74	0	7.22	7.22
3	-3.74	-3.27	0	17.29	17.29
4	-3.27	-2.80	27	36.92	2.67
5	-2.80	-2.33	84	70.27	2.68
6	-2.33	-1.86	165	119.19	17.60
7	-1.86	-1.39	221	180.22	9.23
8	-1.39	-0.92	252	242.90	0.34
9	-0.92	-0.45	280	291.81	0.48
10	-0.45	0.02	265	312.48	7.22
11	0.02	0.49	266	298.27	3.49
12	0.49	0.96	210	253.78	7.55
13	0.96	1.44	193	192.47	0.00
14	1.44	1.91	154	130.11	4.39
15	1.91	2.38	124	78.40	26.52
16	2.38	2.85	62	42.11	9.39
17	2.85	3.32	7	20.16	8.59

Tab. 7. Terrell-Scott's bins regarding the reduced section discrepancies $d/\sqrt{l}$ in the Third Levelling of Bulgaria /1975-1984/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-2.43	-2.15	3	5.47	1.12
2	-2.15	-1.86	3	15.48	10.06
3	-1.86	-1.58	13	38.54	16.93
4	-1.58	-1.30	109	84.50	7.11
5	-1.30	-1.01	225	163.08	23.51
6	-1.01	-0.73	326	277.11	8.63
7	-0.73	-0.45	451	414.56	3.20
8	-0.45	-0.16	488	546.01	6.16
9	-0.16	0.12	514	633.14	22.42
10	0.12	0.40	540	646.38	17.51
11	0.40	0.69	582	580.98	0.00
12	0.69	0.97	524	459.75	8.98
13	0.97	1.25	421	320.31	31.65
14	1.25	1.54	287	196.47	41.71
15	1.54	1.82	54	106.10	25.58
16	1.82	2.10	21	50.44	17.19
17	2.10	2.39	3	21.11	15.54
18	2.39	2.67	4	7.78	1.84
19	2.67	2.95	3	2.52	0.09
20	2.95	3.24	1	0.72	0.11
21	3.24	3.52	1	0.18	3.70

Tab. 8. Terrell-Scott's bins regarding the reduced section discrepancies $d/\sqrt{l}$ in the Second Levelling of Finland /1935-1955/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-5.83	-2.27	7	2.15	10.92
2	-2.27	-1.83	7	13.65	3.24
3	-1.83	-1.38	65	65.56	0.00
4	-1.38	-0.94	214	215.90	0.02
5	-0.94	-0.49	466	487.81	0.97
6	-0.49	-0.05	744	756.49	0.21
7	-0.05	0.40	894	805.39	9.75
8	0.40	0.84	517	588.66	8.72
9	0.84	1.29	320	295.34	2.06
10	1.29	1.73	112	101.68	1.05
11	1.73	2.62	15	27.90	5.96

Tab. 9. Terrell-Scott's bins regarding the reduced section discrepancies $d/\sqrt{l}$ in the Third Levelling of Finland /1978-2006/.

Bin	From	To	Observed (O)	Theoretical (T)	$(O-T)^2/T$
1	-6.66	-4.08	6	0.01	4783.66
2	-4.08	-2.78	5	3.64	0.51
3	-2.78	-2.14	27	34.09	1.47
4	-2.14	-1.49	197	201.76	0.11
5	-1.49	-0.84	611	713.51	14.73
6	-0.84	-0.20	1478	1509.81	0.67
7	-0.20	0.45	2195	1913.35	41.46
8	0.45	1.10	1371	1452.59	4.58
9	1.10	1.74	609	660.41	4.00
10	1.74	2.39	155	179.64	3.38
11	2.39	3.04	34	29.19	0.79
12	3.04	3.68	7	2.83	6.15
13	3.68	8.85	6	0.17	201.22

Tab. 10. Values of $X^2(\alpha=0.0001, df)$ considering the analysed levelling networks.

Network	Statistic	X^2	Degree of freedom df	$X^2(0.0001, df)$
BG II	d	75.07	14	42.58
	$\boldsymbol{d/\sqrt{l}}$	125.72	14	42.58
BG III	d	158.51	18	49.19
	$\boldsymbol{d/\sqrt{l}}$	263.02	18	49.19
FIN II	d	90.53	11	37.37
	$\boldsymbol{d/\sqrt{l}}$	42.91	8	31.83
FIN III	d	529.53	14	42.58
	$\boldsymbol{d/\sqrt{l}}$	5062.74	10	35.56

As shown in Table 10, none of the section data samples from the analysed levelling networks follow a normal distribution at the significance level $\alpha = 0.0001$. Therefore, at a 99.99% confidence level, it can be concluded that the discrepancies *d* and the standardized discrepancies $\boldsymbol{d/\sqrt{l}}$ do not conform to the Gaussian law.

4. Discussion

According to the results given in Table 1, the following facts must be drawn:

- Skewness of the distributions of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second Levelling of Bulgaria, the Third Levelling of Bulgaria are in the range $0\pm3\sigma_S$. Thus, we can claim that these distributions are symmetric. We have a similar situation to the skewness of the section differences d in the Second Levelling of Finland.
- Skewness of the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second and the Third Levelling of Finland are out of the range $0\pm3\sigma_S$. Therefore, the distribution of their samples cannot be related to the normal distribution. The same is true for the section discrepancies *d* in the Third Levelling of Finland.
- The distributions of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in both Bulgarian levelling networks are platykurtic with significant declination from normal distribution. The corresponding distributions in both Finnish levelling networks are leptokurtic. Their declination from bell shape is also significant, especially in the case of the Third Finnish Levelling. All estimated excess kurtosis values are out of the range $0\pm3\sigma_E$.
- Thus, one can conclude that the probability density functions of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second and the Third Levelling of Bulgaria can be given by Pearson's curve type I. Contrary to the Bulgarian case, the probability density functions of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second and the Third Levelling of Finland can be given by Pearson's curve type IV [7].

Analysing Tables 2-9, one can see a huge deviation between the observed and expected theoretical frequencies of the statistics *d* and $\boldsymbol{d/\sqrt{l}}$ for all analysed levelling networks. Based on the estimated critical values in Table 10, it is obvious that at the significance level $\alpha=0.0001$ the distributions of of the section differences *d* and the standardized section differences $\boldsymbol{d/\sqrt{l}}$ in the Second and the Third Levelling of Bulgaria, and the Second and the Third Levelling of Finland, we cannot accept the hypothesis that these statistics are normally distributed.

5. Conclusion

The results of this study provide strong empirical evidence that the assumption of normally distributed measurement errors is not valid for the analysed levelling datasets. Across all four national levelling campaigns, both the raw and standardized discrepancies exhibit statistically significant deviations from the Gaussian model, as confirmed by skewness, kurtosis, and chi-squared tests at confidence levels exceeding 99.99%.

The observed presence of both platykurtic and leptokurtic distributions indicates that levelling errors are more complex than traditionally assumed and may vary depending on the measurement conditions and methodologies. The even stronger non-normality observed in standardized discrepancies further emphasizes the limitations of conventional error models.

These findings have important implications for geodetic practice, particularly in assessing measurement accuracy, defining acceptable discrepancy limits, and selecting appropriate stochastic models. They suggest that reliance on the Gaussian assumption may lead to misleading conclusions and that more robust or alternative statistical approaches should be considered to better reflect the true nature of observational data.

Acknowledgments

The author expresses gratitude to the Centre for Scientific Research and Design at the UACEG for funding and support for the completed research project under contract No BN340/2026 on the "Analysis of the suitability of existing and new robust estimators and methods in the mathematical processing of geodetic measurements".

References

1. Dvulit, P., Savchuk, S., and Sosonka, I. Accuracy estimation of site coordinates derived from GNSS observations by non-classical error theory of measurements. Geodesy and Geodynamics, 12(5), (2021), 347–355, https://doi.org/10.1016/j.geog.2021.07.005
2. Dvulit, P., Savchuk, S., and Sosonka, I. The processing of GNSS observation by non-classical error theory of measurements. JGD, 28(1), (2020), 19–28. https://doi.org/10.23939/jgd2020.01.019
3. Dvulit, P., and Dzhun, J. Diagnostics of the high-precise ballistic measured gravity acceleration by methods of non-classical errors theory. Geodynamics, 1(26), (2019), 5–16. https://doi.org/10.23939/jgd2019.01.005
4. Dzhun, I. V. What should be the observation–calculation residuals in modern astrometric experiments. Kinematics and Physics of Celestial Bodies, 28, (2012), 72–80.

References

5. Hu, X., Huang, C., and Liao, X. A New Solution Assessment Approach and Its Application to Space Geodesy Data Analysis. Celestial Mechanics and Dynamical Astronomy 81, 265–278, (2001). https://doi.org/10.1023/A:1013204418865
6. Wassef, A. M. Note on the application of mathematical statistics to the analysis of levelling errors. Bulletin Géodésique, 52, (1959), 19–26.
7. Wiśniewski, Z. M-estimation with probabilistic models of geodetic observations. Journal of Geodesy, 88, (2014), 941–957. https://doi.org/10.1007/s00190-014-0735-7
8. Hampel, F. R., Ronchetti, E. M., Rousseeuw, P. J., and Stahel, W. A. Robust statistics: The approach based on influence functions. New York, NY: Wiley. (1986).
9. Burilkov, T. First results from measurements with the new compensator level Ni 002. Izvestiya na GUGK, (3), (1974), 10–19, (in Bulgarian).
10. Kääriäinen, E. The Second Levelling of Finland in 1935–1955, Publications of the Finnish Geodetic Institute No. 61, Helsinki, (1966), http://hdl.handle.net/10138/347072
11. Saaranen, V, Lehmuskoski, P., Takalo, M. and Rouhiainen, P. The Third Precise Levelling of Finland, FGI Publications No. 161, Kirkkonummi, (2021), https://helda.helsinki.fi/items/921bf91e-e93d-4ccd-9f83-aac063ee014f
12. Pearson, K. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. Philosophical Magazine. Series 5. 50 (302), (1900), 157–175. https://doi.org/10.1080/14786440009463897 .
13. Ilieva, T., and Pavlov, P. Significance of interval number and limits in the analysis of geodetic data for testing the hypothesis of normal error distribution by Pearson's criterion, Annual of the University of architecture, civil engineering and geodesy, Sofia, 57(2), (2024), 371-378. (in Bulgarian)
14. Doğan, N. and Doğan, I. Determination of the number of bins/classes used in histograms and frequency tables: a short bibliography. TurkStat, Journal of Statistical Research, 7(2), 77-86, (2010), https://dergipark.org.tr/tr/download/article-file/2579010 .