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STEFAN SATORA*, ANDRZEJ WAŁĘGA*

VARIATION OF THE DISTRIBUTION OF SELECTED CONSTRUCTIONAL AND HYDROGEOLOGICAL PARAMETRES OF DRILLED WELLS

The distribution of some selected constructional and hydrogeological parametres of drilled wells located in the Małopolska province is analysed. The type of satistical distribution determined the measure of location calculation method (e.g. average value, median). In the case of normal distributions or similar (lognormal distribution), the average as a measure of location is recommended, while in the case of asymmetrical ones – the median.

Preliminary analysis indicates that if we assess the total of 112 statistical distributions of the parametres examined, 5 cases (4.5% of all) are normal distributions, and in 95.5% of the cases we deal with asymmetrical distributions. The current study aims to present empirical distribution of the elements examined and to find the method of location measurement.

1. INTRODUCTION

On the basis of hydrogeological research carried out in the area determined by morphological, administrative or geological units, we can see a need to establish the representative value of the features examined. This value allows us to take part in further scientific discussion or to use it for general description of some phenomenon or its element. In the case of normal or similar distribution (for example, log-normal), the use of average value is recommended [6], [8], while in the case of unimodal, asymmetrical distribution, the use of median value is advised.

In the present study, the attempt to establish the types of distribution and to measure their average or median values was made based on some constructional and hydrogeolgical elements of wells drilled in the Małopolska province.

* Department of Sanitary Engineering and Water Management, University of Agriculture in Kraków, al. Mickiewicza 24/28, 30-059 Kraków, Poland. Phone (012) 662 41 08, 632 57 88.

2. EXPERIMENTAL

2.1. CHARACTERISTICS OF THE AREA AND SUBJECT OF RESEARCH

The Małopolska province is located in the southern part of Poland. In borders Slovak Republic to the south, the Podkarpacie province to the east, Silesia to the west and the Świętokrzyskie province to the north. The Małopolska province covers the area of 15,188 sq. km, which makes 4.8% of the whole country area. Within the region there are the following morphological units: the Śląsk–Kraków Upland, the Miechów Upland, the Proszowice Plateau, the Oświęcim Basin, the Kraków Gate, the Sandomierz Basin, the Wieliczka Foothills, the Beskid Range, the Pieniny Klippen Belt, the Podhale Basin and the Tatra Mountains. About 80% of over 15,000 sq. km are covered by the structures of the Carpathian Arc and its foreground. Starting from the south, these structures consist of inner and outer Carpathians. In the central part of the province, the Carpathians border the Carpathian Depression to the north, and this Depression borders the Miechów Basin, the Śląsk–Kraków Monocline and a Paleozoic structure, the Upper Silesian Depression, to the north and north-west [5]. All over the Małopolska province, the Quaternary Pleistocene and Holocene beds can be found in the form of an overlayer. Below them, often within the outcrop, there are the rocky layers from the Miocene, Palaeogene, Oligocene, Cretaceous Nida and Flysh, Jurassic, Triassic, Permian, Carboniferous and Devonian geological periods.

2.2. METHODOLOGY

The archival geological data used in this study, i.e. electronic data stored in the Regional Bank of Hydrogeological Data, “Hydro” PGI, was made available by Carpathian Branch of Polish Geological Institute in Kraków. The material contains, among others, information on drilling and construction of 2033 wells drilled and utilized in the Małopolska province during the fifty four-year span from 1950 to 2004.

Statistical characteristics of hydrogeological and constructional parametres of the wells consisted in establishing the average, the median, the kurtosis and the skewness values. The skewness values allowed the distribution of the parametres analysed to be preliminarily estimated. Additionally, the attempt to match theoretical distribution with empirical data was made. The following types of distributions were tested: normal, log-normal, exponential, gamma, geralized extreme value, logistic, Rayleigh and Waibull. The hypothesis about normal distribution was verified by the Shapiro–Wilk test at $\alpha = 0.05$. In the case of other distributions, their matching with empirical data was made graphically, based on the empirical and theoretical cumulative distribution functions. In uncertain situations, mainly in the case of clear multimodality of variables, a theoretical distribution was not matched. All of the calculations were made in Statistica PL, version 8 (Licence No. JGNP805B493623AR-8), program.

2.3. RESULTS AND THEIR ANALYSIS

In the Małopolska province, the analysis of constructional elements and hydrogeological parametres was based on 2033 drilled wells. 863 of them access groundwater from unconfined aquifiers, 1009 – from subarthesian groundwaters and 161 – from arthesian confined groundwaters. A large number of wells (82.6%) with unconfined aquifiers access groundwaters, while the rest access deep groundwaters, most often subarthesian confined groundwaters. The drilled wells contained groundwater of different age, stratigraphically connected with the Quaternary, Miocene, Palaeogene, Oligocene, Cretaceous, Jurassic, Triassic, Permian, Carboniferous and Devonian formations dated back to the Cenozoic, Mesozoic and Palaeozoic eras.

All in all, 1101 Quaternary drilled wells, 145 Miocene wells, 245 Palaeogene wells, 19 Oligocene wells, 117 Cretaceous Nida wells, 84 Cretaceous Flysch wells, 224 Jurassic wells and 88 Triassic wells were analyzed. Because of a small sample size, a sample of 10 wells containing the groundwaters from Permian, Carboniferous and Devonian beds was not analyzed.

The depth of the Quaternary wells ranged from 5.0 to 53.0 m, with the specific discharge of a well (q_j) varying from 0.0095 to 180.0 $m^3 \cdot h^{-1} \cdot m^{-1}$; the Miocene, from 91.0 to 210.0 m with q_j from 0.01 to 26.7 $m^3 \cdot h^{-1} \cdot m^{-1}$; the Oligocene, from 22.5 to 707.1 m with q_j from 0.05 to 0.6 $m^3 \cdot h^{-1} \cdot m^{-1}$; the Cretaceous Nida, from 12.0 to 120.0 m with q_j from 0.008 to 180.0 $m^3 \cdot h^{-1} \cdot m^{-1}$; the Cretaceous Flysch, from 8.0 to 100.0 m with q_j from 0.002 to 25.9 $m^3 \cdot h^{-1} \cdot m^{-1}$; the Jurassic, form 5.2 to 300.0 m with q_j from 0.0014 to 95.9 $m^3 \cdot h^{-1} \cdot m^{-1}$, and the Triassic, from 46.0 to 430.0 m with q_j from 0.4 to 1500.0 $m^3 \cdot h^{-1} \cdot m^{-1}$ [5].

We analyzed in detail 6 main constructional parametres of drilled wells, i.e. the total depth, the well screen diameter, the length of a working part, the lengths of the parts between, above and under the well screens and 8 hydrogeological parametres such as the depths of confined piezometric surface met during drilling, the well drawdawn, the specific discharge and the yield of a well, the value of the coefficient of permeability from pumping test's results and the radius of the well dispersion cone and the aquifer thickness [1]–[4], [7].

A vast majority of the constructional and hydrogeological parametres under analysis had positively asymmetrical distribution. Most of constructional parameters (41.7%) had log-normal distribution, and the rest were as follows: gamma distribution (20.8%), general extreme distribution (14.6%), symmetrical-normal distribution (10.4%), exponential distribution (6.2%), positively asymmetrical distribution (4.2%) and logistic distribution (2.1%). 50% of them had unimodal distribution, 41.7% bi-

T a b l e

Statistics of hydrogeological and structural parameters of drilled wells in Małopolska province

Statistics	Hydrogeological parameters								Structural parameters of wells						Range of oscillations
	H_n (m)	H_u (m)	S (m)	q_j ($m^3 \cdot h^{-1} \cdot m^{-1}$)	q_{wl} ($m^3 \cdot h^{-1} \cdot m^{-1} \cdot m^{-2}$)	k ($m \cdot s^{-1}$)	m (m)	R (m)	H_c (m)	∅ (mm)	L_n (m)	L_c (m)	L_m (m)	L_p (m)	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Quaternary															
Mean	6.1	4.9	7.7	8.4	3.9	2.3	7.7	114.4	16.2	291.6	9.5	3.1	3.8	2.6	–
Median	4.4	3.5	6.7	6.0	2.3	1.0	6.7	97.0	14.0	280.0	7.5	3.0	2.0	3.0	–
Kurtosis	5.3	2.6	26.4	65.2	41.3	33.9	26.4	49.9	2.2	21.4	1.4	14.2	7.0	114.0	1.4–114.0
Skewness	6.5	1.6	3.6	6.3	5.5	5.1	3.6	4.8	1.4	4.1	1.3	2.6	2.5	6.5	1.3–6.5
Miocene															
Mean	31.8	9.3	14.8	1.8	0.4	0.4	23.7	201.4	61.8	245.7	39.9	9.8	17.1	6.5	–
Median	24.2	6.8	12.0	1.0	0.2	0.1	14.7	170.0	42.3	246.0	31.7	7.4	6.5	3.8	–
Kurtosis	2.8	1.9	3.2	44.8	44.0	43.0	3.9	1.2	1.8	–0.4	1.7	6.8	1.2	46.0	–0.4–44.8
Skewness	1.7	1.5	1.7	5.9	5.9	6.1	1.9	1.1	1.6	0.2	1.5	2.3	1.6	6.3	0.2–6.3
Palaeogene															
Mean	19.9	7.9	12.9	0.5	0.2	0.1	18.8	86.7	38.4	215.8	26.7	8.1	5.8	3.1	–
Median	20.0	5.2	12.0	0.2	0.04	0.01	15.0	70.0	30.2	225.0	22.2	6.0	4.0	3.0	–
Kurtosis	6.4	34.1	10.6	32.5	29.8	29.6	4.7	8.4	6.5	0.3	5.5	26.1	6.1	13.2	0.3–34.1
Skewness	1.8	4.6	2.4	5.1	5.2	5.2	2.1	2.2	1.8	–0.5	1.8	3.9	2.5	3.0	–0.5–5.2
Podhalan Oligocene															
Mean	112.1	25.8	23.3	0.3	0.06	0.03	44.9	126.2	56.0	220.6	54.9	11.8	12.4	3.5	–
Median	28.0	13.0	14.0	0.3	0.04	0.02	24.0	101.0	45.5	225.0	32.4	6.5	9.9	3.0	–
Kurtosis	3.6	2.3	3.9	–1.0	0.9	7.4	11.3	2.2	–1.1	–0.4	10.0	1.3	0.6	–1.3	–1.3–11.3
Skewness	2.2	1.7	2.1	0.3	1.1	2.5	3.2	1.7	0.7	–0.3	2.9	1.6	1.1	0.2	–0.3–3.2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cretaceous Nida															
Mean	25.8	18.8	9.3	11.8	2.4	0.8	21.7	168.6	48.5	268.0	36.9	8.3	6.0	3.0	–
Median	20.0	13.3	6.0	3.7	0.7	0.2	18.6	116.0	40.0	273.0	31.5	6.4	4.9	3.0	–
Kurtosis	1.3	1.6	6.3	24.1	47.6	25.1	2.1	3.8	0.2	5.5	0.6	2.4	3.8	24.9	0.2–47.6
Skewness	1.3	1.4	2.2	4.4	6.2	4.6	1.4	1.7	0.8	–0.8	1.0	1.4	1.8	3.9	–0.8–6.2
Cretaceous Flysch															
Mean	17.7	8.4	12.5	1.7	0.4	0.16	20.2	87.1	40.5	225.1	27.1	8.6	6.5	3.3	–
Median	16.3	6.0	11.2	0.2	0.06	0.01	16.5	62.0	38.0	225.0	24.0	6.2	5.0	3.0	–
Kurtosis	4.3	1.6	3.6	15.4	14.02	61.7	2.3	6.8	0.97	1.5	1.03	2.9	5.3	7.2	1.03–61.7
Skewness	1.5	1.3	1.6	3.8	3.7	7.7	1.4	2.2	1.1	–0.8	1.1	1.6	1.9	2.2	–0.8–7.7
Jurassic															
Mean	40.3	26.8	17.8	4.6	0.9	0.8	40.4	179.6	82.3	258.1	60.8	13.4	14.1	5.1	–
Median	35.3	18.3	13.0	0.9	0.1	0.04	33.0	119.0	80.0	246.0	56.0	10.7	8.0	4.5	–
Kurtosis	8.7	8.7	3.0	35.1	77.8	208.8	1.3	3.3	4.3	2.6	3.6	4.3	1.3	13.5	1.3–208.8
Skewness	2.2	2.0	1.6	5.4	7.7	14.3	1.3	1.9	1.4	0.2	1.4	1.7	1.5	3.1	0.2–14.3
Triassic															
Mean	71.8	32.8	11.3	109.1	4.9	2.0	56.1	265.0	132.7	306.5	97.1	26.5	7.5	10.2	–
Median	51.7	29.7	5.6	16.1	0.6	0.4	51.05	182.0	102.9	299.0	74.7	23.5	7.2	5.7	–
Kurtosis	6.6	–0.1	0.5	16.7	11.1	35.6	5.4	14.7	4.2	5.7	4.1	0.3	2.9	16.7	–0.1–35.6
Skewness	2.6	0.7	1.3	4.0	3.2	5.8	1.8	3.2	2.0	1.6	2.1	0.9	1.3	3.9	0.7–5.8

H_n – depth of water-table met during drilling, H_u – depth of water-table stabilised, S – depression, q_j – unitary yield, q_{wl} – specific yield, k – filtration coefficient, R – depression cone, m – aquifer thickness, H_c – depth of well, ∅ – diameter of well screen, L_n – length of a working part, L_c – length of part between screens, L_m – length of part above well screen, L_p – length of part under well screen.

modal distribution, 6.2% trimodal distribution, and 2.1% quadrimodal distribution. The majority of the hydrogeological parametres had gamma distribution (31.3%), general extreme distribution (29.6%), exponential distribution (17.2%), log-normal distribution (9.4%), positively asymmetrical distribution (6.3%), the Rayleigh distribution (4.7%) and the Weibull distribution (1.5%). In 59.4%, the distribution was unimodal, in 31.2% was bimodal, in 7.8% trimodal and in 1.6% it was quadrimodal. In the case of both constructional and hydrogeological parametres, the distributions had one dominant modal value, the rest of modal values were many times smaller.

In most cases, the average values of the analyzed constructional and hydrogeological parametres were larger than that of the median, being indicative of the positive asymmetry. We also dealt with an opposite situation, indicative of a negative asymmetry, when the median value was larger than the average. It arose in 6 (5.4% of all) cases and most often (3.6% of all and 66% of exeptions) it concerned the diameter of the screen installed in the wells that get water from the Miocene, Palaeogene, Oligocene and Cretaceous Nida formations, in one case it concerned the length under the well screen in the Quaternary beds and in another one, the water table met during drilling in the Palaeogene beds.

The kurtosis value at the parameters connected with aquifers of differential age varied from –1.3 to 208.8. The highest kurtosis value was obtained for the distribution of the permeability *k* of the Jurassic rocks, a slightly lower value, i.e. 11.0, for the length under well screen in the Quaternary rocks, the lowest value was reached for the length under well screen in the Oligocene Flysch rocks, and a slightly higher, i.e. 0.4, for the diameter of well screen in the Miocene rocks. The negative values of kurtosis that were found for the Oligocene rocks and concerned the well depth, the length, the diameter of the well screen, the specific discharge of the well on the level of the Oligocene rocks and for the water table enocountered during the drilling on the Triassic level were indicative of the distributions steeper than a normal one. In other cases with postive values, they were indicative of the distributions that are flatter than normal one [6].

The skewness values of the constructional and hydrogeologicl parametres vary from –0.8 to 14.3. The smallest value representing the diameter of the well screen installed in the Cretaceous Nida and the Cretaceous Flysch rocks was found twice, while smaller values concerned the diameter of the well screen in the Palaeogene and the Oligocene rocks, which was indicative of negatively asymmetrical distributions. In other cases, the positive values of the skewness, higher than 0.3, were connected with positively asymmetrical distributions. The skewness value higher than 0.3 indicates the normal distributions and the like. This type of the distribution can be found for the screen diameters in the Miocene, Oligocene and Jurassic rocks and probably in the Palaeogene, Cretaceous Nida and Flysch rocks (the skewness value range of 0.5–0.8), in the case of the length under well screen in the Oligocene rocks and in the case of the depths of wells located in the Oligocene and the Cretaceous Nida rocks (the skewness value of 0.7–0.8) (the table).

3. SUMMARY

The detailed analysis of the distribution types related to 6 main constructional parametres of drilled wells such as the total depth, the well screen diameter, the lenght of a working part, the lengths of the parts between, above and under the well screens and to 8 hydrogeological parameters: the depths of confined piezometric surface met during drilling, the well drawdawn, specific discharge and the yield of a well, the value of the coefficient of permeability from pumping test's results and the radius of the well dispersion cone and the aquifier thickness proved that in most cases the distribution was positively asymmetrical. Constructional parametres most frequently had the log-normal and gamma distributions, while hydrogeological ones – the gamma and the general extreme distributions. The symmetrical, normal distribution of the constructional parametres was found in 5 cases only and most frequently it concerned the diameter of the well screen installed in the Miocene, Palaeogene, Cretaceous Nida and Jurassic rocks and of the pipe between the screens in the Triassic rocks. In most cases, the distributions are unimodal (55.4% of all) and, to a lesser extent (35.7% of all), bimodal. The analysis of both distribution types and interval characteristics (kurtosis and skewness) indicates that when subject parameters discussed are treated as representative (for example, to represent a well's construction typical of a certain aquifier of a known age), the median, i.e. a middle value of a sample or a population, not the average value, should be used.

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