STATISTICAL ANALYSIS OF MINERAL SOILS
IN THE ODRA VALLEY

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Abstract: The aim of this article is to present the results of statistical analyses of laboratory experiment results obtained from an ITB ZW-K2 apparatus, Kamieński tubes and grain-size distribution curves. Beside basic statistical parameters (mean, sum, minimum and maximum), correlation analysis and multivariate analysis of variance at significance levels $\alpha < 0.01$ and $\alpha < 0.05$ were taken into account, as well as calculations of LSD confidence half-intervals.

The research material was collected from the valley of the Odra river near the town of Słubice in Lubuskie province. The research involved mineral, non-rock fine-grained, non-cohesive soils lying at the depth of 0.3–1.5 m.

1. AIMS AND AREA OF THE RESEARCH

The aim of the research was to analyse variations in hydraulic conductivity (k_f) of non-cohesive soils in the area of Lubusz Odra Gorge near the town of Słubice (Lubuskie province) (Fig. 1).
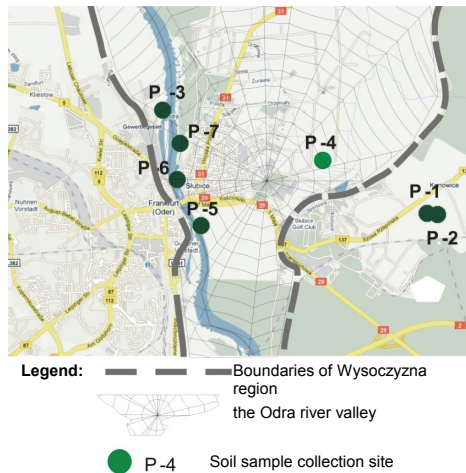

Fig. 1. Soil sample collection sites (Rojna and Błaszczyk [1])

Between August 2009 and September 2010, a number of field and laboratory measurements were performed, resulting in taking 38 samples of non-cohesive mineral soils.

Hydraulic conductivity was investigated with field methods: Maag's method and submerging absorption pits (Kamieński's method) and with laboratory methods: grain-size analysis, Kamieński's tubes and ITB ZW-K2 apparatus. A number of measurements of water table changes and discharge of water flowing through soil samples were conducted in these systems: field measurements for soils with undisturbed structure and laboratory measurements for disturbed structure (Rojna and Błaszczyk [1]).

2. RESULTS AND DISCUSSION

The input data for statistical analysis were: grain size analysis results and the results of field and laboratory hydraulic conductivity measurements of soil samples P-1–P-38.

Investigation of relationships between the obtained soil hydraulic conductivity values and various spatial factors was conducted by means of linear correlation analysis between the hydraulic conductivity of all the analysed samples (P-1–P-38) and factors which can have an influence on these values (including grain size analysis). The results of linear correlation analysis between the hydraulic conductivity of the analysed samples and percentages of particular grain size fractions in the soils under study ($d_i < 0.063$–20.0 mm) are shown in Table 1.

Table 1

Linear correlation coefficients (Pearson's r) between hydraulic conductivity of soils determined experimentally in the field at points P-1–P-38 and percentages of grain size fractions

Grain size [mm]	<0.063	0.063	0.125	0.25	0.5	1.0	2.0	20
r^*	–0.4924	–0.4971	–0.5188	–0.3878	0.3887	0.5229	0.6331	0.7170
p^{**}	0.002	0.001	0.001	0.016	0.016	0.001	0.000	0.000

*r – correlation coefficient; **p – significance level

The correlations investigated are:
Statistically significant ($\alpha \leq 0.05$ and $\alpha \leq 0.01$),
Moderate for grain size <0.063, 0.063, 0.25, 0.5 mm,
Strong for 0.125, 1.0, 2.0, 20.0 mm.
Soil grain sizes <0.063–0.25 mm show negative correlations with hydraulic conductivity. With the rise in the content of dust-clay fraction and fine sand, the values of

correlation coefficients of the samples decrease, and the strongest dependence is ob-served for 0.125 mm fraction. Coarse-grained fractions (0.5–20.0 mm) have positive linear correlations with hydraulic conductivity. As a result, the presence of coarse-grained fractions, particularly gravel with $d_i > 2.0$ mm causes a gradual rise in k_f values in the soils under investigation.

Linear correlations between the hydraulic conductivity of all the analysed samples and the equivalent grain diameters (d_i) of the soils studied are statistically significant at very low significance levels ($p = 0.000$), positive and very high (Table 2).

T a b l e 2

Linear correlation coefficients, arithmetic means and standard deviations
between soil hydraulic conductivity determined experimentally
in the field at sites P-1–P-38 and d_i, $p = 0.000$

d_i	d_{10}	d_{17}	d_{20}	d_{30}	d_{40}	d_{50}	d_{60}	d_{70}	d_{80}	d_{90}
r	0.8169	0.8189	0.7983	0.7740	0.8018	0.8041	0.7843	0.7518	0.7190	0.6623
$\bar{x}$	0.26263	0.31039	0.33632	0.39803	0.46724	0.55158	0.67737	0.84974	1.24618	2.23184
s	0.09060	0.11265	0.12673	0.16536	0.23227	0.34584	0.57020	0.86163	1.63650	3.03714

The strongest correlations occur between hydraulic conductivity and equivalent grain diameters d_{10} and d_{17}. Therefore, their high correlations are $r = 0.8169$ for d_{10} and $r = 0.8189$ for d_{17}. The lowest correlation coefficient $r = 0.6623$ was observed for diameter d_{90}.

Thus, equivalent diameters d_{10} and d_{17} determine, to a large extent, the value of hydraulic conductivity, and consequently the discharge and the specific discharge. This is why previous studies of sands, including those by Hazen, Schlichter or Zauer-brey, use chiefly effective diameters d_{10} and d_{17} in defined formulas (Ishaku et al. [2], Alyamani and Şen [3]).

Figure 2 presents scatter curves of soil hydraulic conductivity for P-1–P-38 in re-lation to effective grain diameters d_{10}–d_{90}, which reflect their characteristic shapes. The plots demonstrate that hydraulic conductivity rises proportionally to the rise in effective diameter d_i.

T a b l e 3

Linear correlation coefficients (r)
between hydraulic conductivity of soils

Parameter	r	p
Depth of sample collection	–0.3936	0.015
Distance from contemporary river channel	–0.4024	0.012
Distance from former channel	0.2017	0.225

Table 3 presents results of linear correlation analysis between hydraulic conductivity for all the samples analysed (P-1–P-38) and three spatial parameters defining the location of measurement sites, i.e., their distance from the contemporary Odra river channel, distance from the old channel dating back to the 13th century (Brose [4]) and the depth of sample collection in relation to terrain datum. The calculated correlations are negative and moderate, they are significant ($p < 0.05$) only for the relationship between hydraulic conductivity and distances from particular river channels. Hydraulic conductivity decreases with the increase in the depth of soil and the distance from the Odra channel but the dependence on the distance from the river is slightly stronger. The values of hydraulic conductivity rise with the growth in the distance from the former Odra river channel, as compared to the contemporary one, but this relation is weak and statistically insignificant.
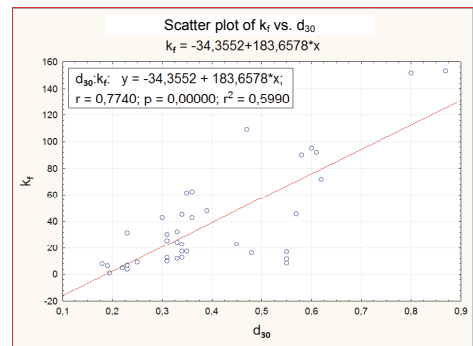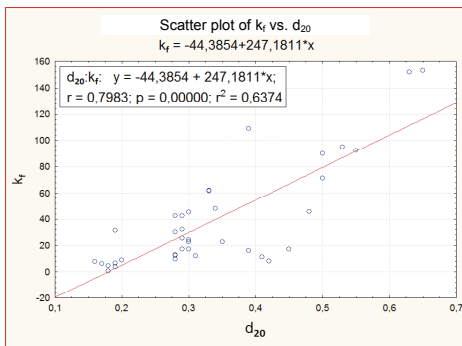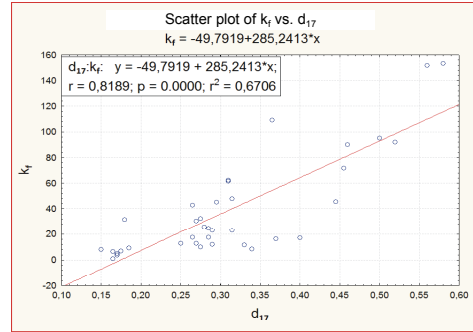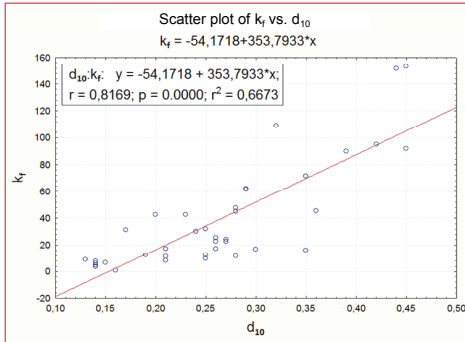
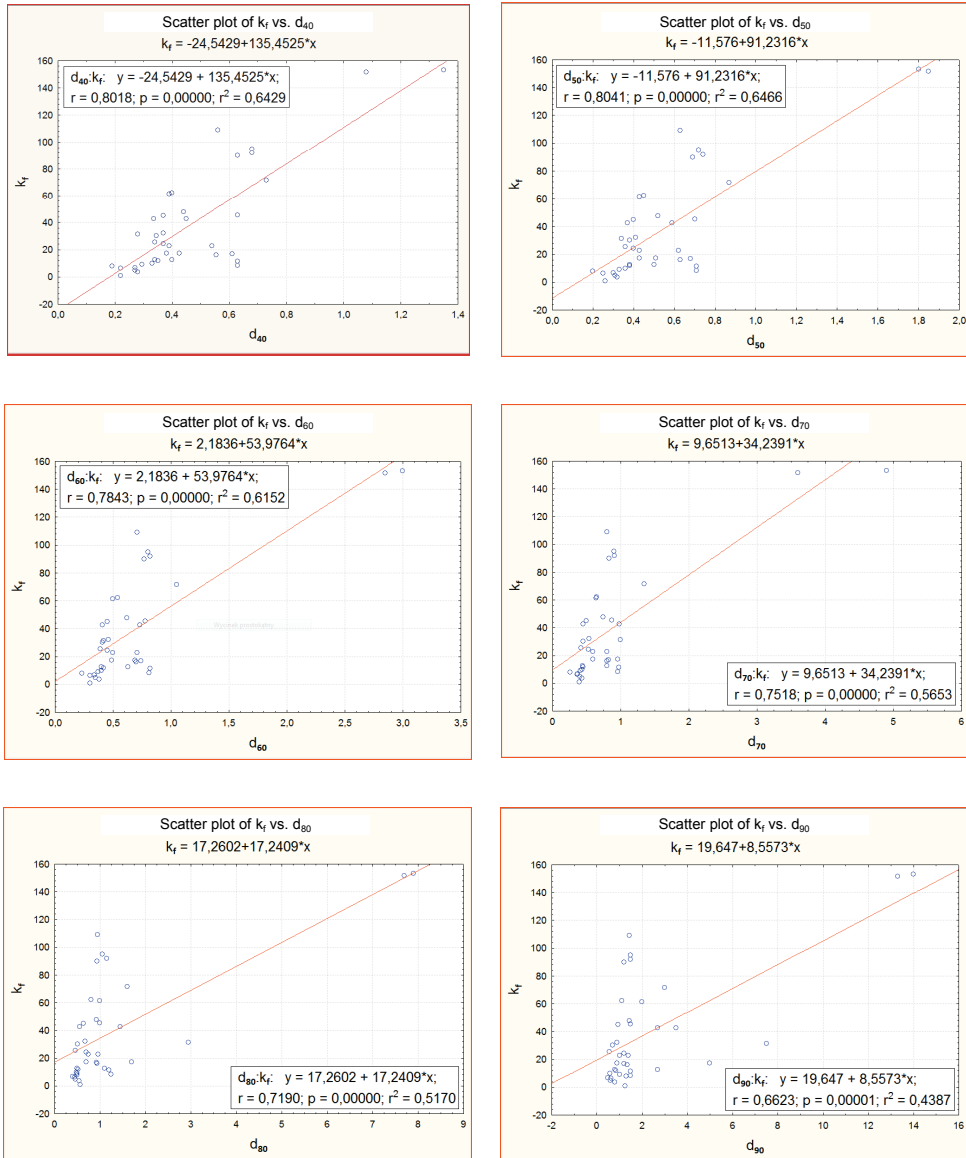Fig. 2. Scatter plots of hydraulic conductivity k_f vs. d_{10}–d_{90}

In order to define the parameter which has the strongest influence on hydraulic conductivity, multiple regression analysis was performed (Table 4). The independent variables were spatial parameters most correlated with hydraulic conductivity (depth of the analysed soil samples and their distance from the contemporary river channel)

and the grain-size factor; diameter d_{17} was chosen from among the grain-size parameters under study in view of its highest correlation coefficient with hydraulic conductivity. The results of correlations between hydraulic conductivity values and the chosen parameters are shown in Table 4.

<div align="right">T a b l e 4</div>

Results of multiple regression analysis of relationships between hydraulic conductivity, spatial parameters and grain size factor

		Value	Standard error	p
Parameter	b_0	−28.93	18.29	0.1228
d_{17}	b_1	259.9	37.27	$4.8 \cdot 10^{-8}$
	b_1*	0.7463	0.1070	
Depth of sample collection	b_2	−10.52	19.69	0.5968
	b_2*	−0.0554	0.1037	
Distance from contemporary channel	b_3	−0.0052	0.0032	0.1132
	b_3*	−0.1616	0.0994	
Statistical coefficients				
R	R^2	R^2 corrected	p	S
0.8354	0.6979	0.6713	$5.84 \cdot 10^{-9}$	22.498

The values of standardized coefficients $b*$ demonstrate that the correlations between hydraulic conductivity, depth of soil sample collection and the distance of measurement sites from the Odra are very weak (statistically insignificant) and the values of hydraulic conductivity decrease with their rise. In contrast, the influence of diameter d_{17} on hydraulic conductivity is dominant – hydraulic conductivity values increase with the rise in diameter d_{17}, and this dependence has been defined with very high probability ($p = 4.8 \cdot 10^{-8}$). The values of determination coefficient R^2 and the corrected R^2 indicate that the dependence described with the multiple regression equation (Table 4) accounts for almost 70 % of variations in hydraulic conductivity of the soils studied and the grain-size factor (d_{17}) is dominant here. The remaining factors influencing hydraulic conductivity of the soils being studied in the Odra valley account for hardly 30% of its variations.

The multiple regression equation obtained assumes the following form

$$k_f = b_0 + b_1 \cdot (d_{17}) + b_2 \cdot (\text{depth of sample collection}) + b_3$$
$$(\text{distance from contemporary channel}).$$

Table 5 contains results of linear correlation between hydraulic conductivity values obtained with laboratory methods, i.e., on ITB ZW-K2 apparatus and Kamieński tubes and soil gradation analysis.

T a b l e 5

Linear correlation coefficients between hydraulic conductivity of soils,
determined experimentally on ITB ZWk-2 apparatus at sites P-1–P-38,
and percentages of grain size fractions

Grain size [mm]	<0.063	0.063	0.125	0.25	0.5	1.0	2.0	20
r*	–0.4034	–0.3801	–0.3956	–0.2133	0.5400	0.2918	–0.0238	0.0167
p**	0.012	0.019	0.014	0.199	0.001	0.075	0.887	0.921

*r – correlation coefficient, **p – significance level

The statistical analyses performed have revealed that correlations are statistically significant ($\alpha \leq 0.05$ and $\alpha \leq 0.01$) and moderate for grain sizes <0.063–0.25 mm, and high for $d_i = 0.5$ mm. This dependence shows directly that only soil fractions of 0.5–1.0 mm correlate positively with the hydraulic conductivity values obtained. A rise in the content of sand fraction results in a relative rise in the hydraulic conductivity of the analysed samples. However, the strongest correlation, with a statistically significant level $p = 0.001$, is observed for 0.5 mm fraction. Coarse-grained gravel fractions (2.0–20.0 mm) display relatively weak linear correlations with hydraulic conductivity.

T a b l e 6

Linear correlation coefficients between hydraulic conductivity of soils,
determined experimentally in Kamienski tubes at sites P-1–P-38,
and percentages of particular grain-size fractions

Grain size [mm]	<0.063	0.063	0.125	0.25	0.5	1.0	2.0	20
r*	–0.3917	–0.3863	–0.4323	–0.1192	0.4460	0.1941	0.0567	0.1867
p**	0.015	0.017	0.007	0.476	0.005	0.243	0.735	0.262

*r – correlation coefficient; **p – significance level

The calculated correlations are statistically significant ($\alpha \leq 0.05$) or moderate for grain sizes of <0.063–0.125, 0.5 mm. Dust-clay and sand fractions up to 0.25 mm determine negative values of hydraulic conductivity – soil permeability will decrease with the rise in the percentage of particular fractions. The correlation between k_f value and 0.5 mm fraction (with significance level $p = 0.005$) is clearly distinct from the remaining hydraulic conductivity values, as the rise in the content of this fraction will lead to the rise in hydraulic conductivity.

3. CONCLUSIONS

The results obtained from the analyses performed enabled the following conclusions to be drawn:

Correlations between the hydraulic conductivity of soils labelled as P-1–P-38 and the effective diameters d_{10} and d_{17} ($r = 0.8169$ and $r = 0.8189$, respectively) are highly significant with a relatively high significance level $p = 0.0000$.

Dependences between soil hydraulic conductivity determined with field and laboratory methods and the percentage of d_i fraction (<0.063–0.25 mm) show negative correlations, so they will reduce permeability values.

Analyses conducted with ITB ZW-K2 apparatus and Kamieński tubes demonstrated that the presence of 0.5 mm fraction will cause a rise in k_f value at significance levels $p = 0.005$ and $p = 0.001$.

It was ascertained, as a result of multiple regression analysis, that the growth in the distance from the former Odra river channel towards its contemporary course will cause a slight rise in the hydraulic conductivity of non-cohesive soils.

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