Acta Sci. Pol.
Formatio Circumiectus 17 (2) 2018, 145–154
ENVIRONMENTAL PROCESSES

www.formatiocircumiectus.actapol.net/pl/ ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2018.17.2.145

ORIGINAL PAPER Accepted: 28.05.2018

VERIFICATION OF EMPIRICAL FORMULAS FOR CALCULATING ANNUAL PEAK FLOWS WITH SPECIFIC RETURN PERIOD IN THE UPPER VISTULA BASIN

Dariusz Młyński[1], Andrzej Wałęga[1], Andrea Petroselli[2]

[1] Department of Sanitary Engineering and Water Management, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Kraków, ul. Mickiewicza 24/28, 30-059 Krakow Poland
[2] Department of Economics and Enterprise, University of Tuscia, Viterbo, Via S. Camillo de Lellis snc, 01100 Viterbo, Italy

ABSTRACT

The study evaluated the selected empirical formulas for calculating annual peak flows with specific return period (Q_T) in southern Poland. Data used in the calculations in the form of observation series of peak annual flows were derived from the Institute of Meteorology and Water Management in Warsaw and covered a multi-year period of 1986-2015. The data were statistically verified for their homogeneity, significance of monotonic trends, outliers, and equality of variance. Peak flows with set return period were estimated with a statistical method of Pearson Type III distribution and empirical formulas (area regression equation and Punzet formula). The analysis showed significant differences between Q_T for the investigated catchments derived from the statistical method and empirical formulas. This was evidenced by the values of mean relative errors of quantile estimation that reached 64% for the Punzet formula, and 62% for area regression equation. The obtained results indicated the need to update the empirical formulas used for calculating Q_T in the Upper Vistula region.

Keywords: annual peak flows with specific return period, empirical formulas, upper Vistula basin

INTRODUCTION

Annual peak flows are particularly important in describing hydrological regime of rivers. Determination of their values is necessary for the proper design of hydroengineering structures or delineating flood risk zones [Serinaldi and Grimaldi 2011; Li et al. 2013; Kowalik and Wałęga 2015]. Flood protection in the European Union is shaped by the provisions of the Flood Directive, under which the Member States are supposed to draw up flood risk maps [Bogdał and Ostrowski 2008; Ebrahimian et al. 2012; Kanownik et al. 2013]. Both the design of hydroengineering structures and delineation of flood risk zones require determination of annual peak flows with a set return period (Q_T) that are called design flows.

In engineering hydrology Q_T quantiles are estimated with direct, indirect, and empirical methods. In gauged catchments, Q_T is estimated using direct methods that involve determination of probability curves identified from statistical distributions, based on observation series of annual peak flows (Q_{max}) comprising at least 30 events. The following distributions are commonly used: Pearson type III (PIII), log-Pearson type III, log-normal, Generalized Extreme Value (GEV) distribution, or Weibull's distribution [Ghorbani et al. 2010; Amini et al. 2013; FLOODFREQ…2013; Teimouri and Gupta 2013;

✉e-mail: dariusz.mlynski@urk.edu.pl; andrzej.walega@urk.edu.pl; petro@unitus.it

Fan et al. 2016]. Indirect methods are used when shorter observation series of Q_{max} are available. Then Q_T quantiles are determined based on Q_{max} values for other gauges on the same river, or the gauges closing a catchment with similar hydrological regime [McCuen and Levy 2000]. When Q_T is determined for ungauged watercourses and no indirect methods may be used, so called empirical methods are employed that include, for instance, empirical formulas or rainfall-runoff models. Empirical formulas are a generalization of data on flows collected for a specific number of gauged cross-section by linking the flow amounts with climatic and physiographic factors that significantly shape the flow size [Merz and Blöschl 2005].

Currently in Poland, Q_T is established using empirical formulas, which were based on hydrometric data collected in the years 1921-1970. In analysing the pattern of physiographic and climatic changes that occur in the territory of Poland and having available longer series of hydrometric measurements, any further use of the existing empirical formulas is questioned. Hence, as the principal aim of study, we have undertaken to verify the use of empirical formulas: Punzet and area regression equation, in the calculatin of annual peak flows with specific return period in upper Vistula Basin.

DESCRIPTION OF STUDY AREA

The analysis included nine catchments located in southern Poland, in the water region of the upper Vistula. They belong to different physiographic units of the investigated river basin, i.e. to mountain, upland, and flatland areas. Mountain catchments included (river at gauging station): the Skawica – Skawica Dolna, the Lepietnica – Ludźmierz, the Ochotnica – Tylmanowa, the Grajcarek – Szczawnica, the Kamienica Nawojowska – Nowy Sącz, the Wołosaty – Stuposiany, the Hoczewka – Hoczew; upland catchments: the Skawinka – Radziszów; and flatland catchments: the Koprzywianka – Koprzywnica (see: Figure 1). Table 1 presents the following physiographic parameters of the investigated catchments, which are used as variables in the analysed formulas: catchment area (A), mean watercourse slope (I), mean catchment slope (Ψ), soil imperviousness index (N), and runoff coefficient (Φ).

Table 1. Values of the investigated physiographic parameters for analysed catchments [source: own study]

River	Type of catchment	A, km^2	I, ‰	Ψ, ‰	N, %	Φ, –
Skawica-Skawica Dolna	mountain	146.0	48.0	75.0	22.7	0.82
Skawinka-Radziszów	upland	316.0	10.3	18.6	34.0	0.62
Lepietnica-Ludźmierz	mountain	50.4	33.6	56.0	19.1	0.80
Ochotnica-Tylmanowa	mountain	108.0	43.8	81.8	24.0	0.82
Grajcarek-Szczawnica	mountain	85.5	33.1	84.0	15.0	0.83
Kamienica Nawojowska-Nowy Sącz	mountain	238.0	17.3	31.0	33.0	0.82
Koprzywianka-Koprzywnica	flatland	501.0	3.6	11.0	66.0	0.45
Wołosaty-Stuposiany	mountain	118.2	21.0	59.8	27.8	0.82
Hoczewka-Hoczew	mountain	180.1	21.9	45.5	27.8	0.80

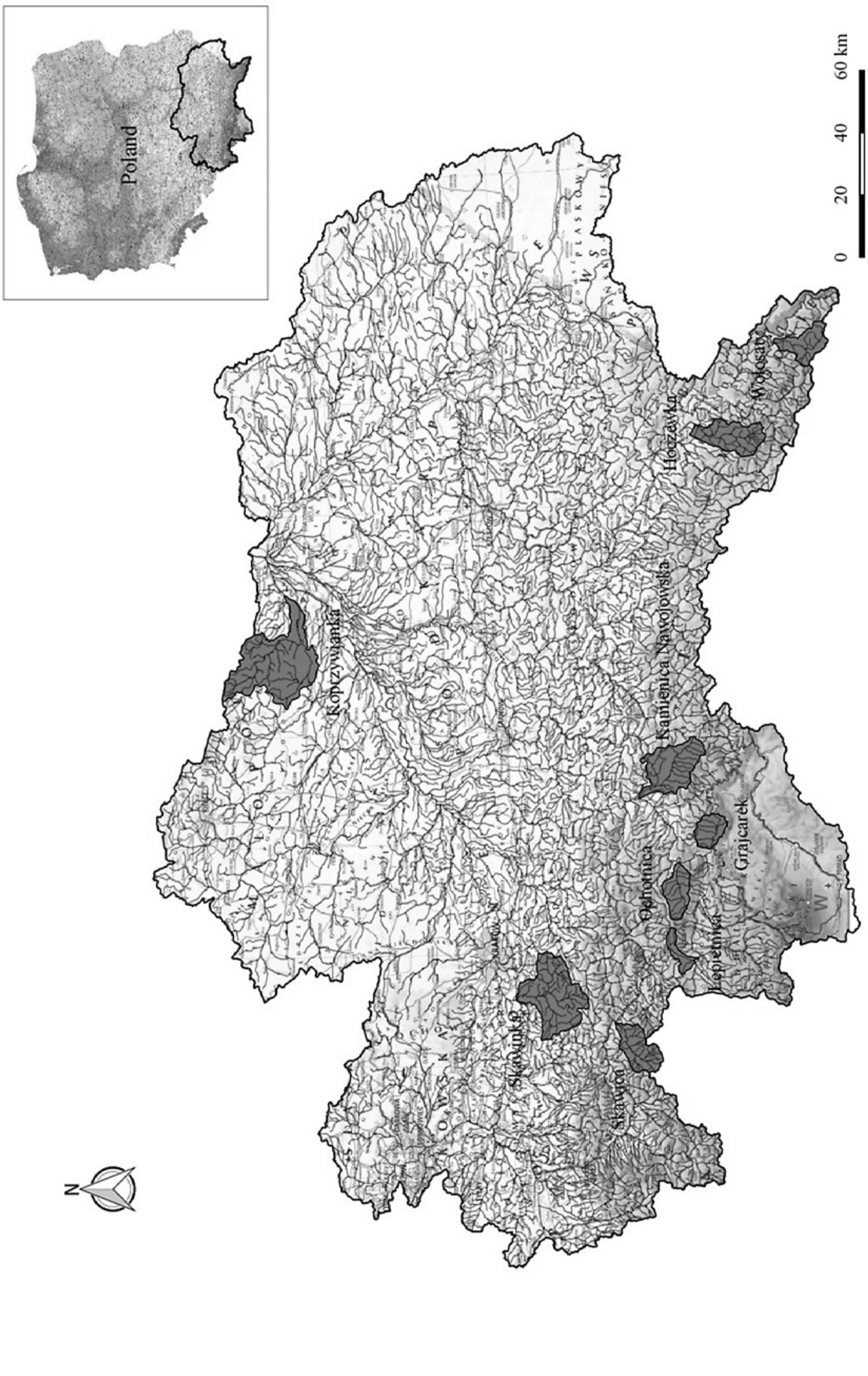

Fig. 1. Location of the investigated catchments in the upper Vistula basin. Own elaboration

MATERIAL AND METHODS

The aim of this study was to conduct an analysis based on observation series of Q_{max} for the analysed catchments. The observation series for Q_{max} covered the multi-year period of 1986-2015. Statistical verification of the hydrometric data included an analysis of homogeneity and independence based on Kruskal-Wallis test, an analysis of trend monotony by means of Mann-Kendall test, verification of outliers by Grubbs-Beck test, and an analysis of variance homogeneity carried out with non-parametric Levene test. The values of Q_T were determined using Pearson type III distribution with parameter estimation based on the maximum likelihood method and empirical formulas: Punzet formula and area regression equation.

Statistical verification of data

The verification of data homogeneity and independence was performed using Kruskal-Wallis test [Wałęga et al. 2016], with the null hypothesis (H_0) assuming that all samples are derived from the same general population (in other words, they are homogeneous). A critical region was defined by chi square statistic χ^2 with (k – 1) degrees of freedom (where k denotes the number of the compared samples). The observed series of peak annual flows were divided into two samples (1986–2000 and 2001–2015). The null hypothesis H_0 was verified for the significance level of $\alpha = 0.05$.

Trend significance for the observation series Q_{max} was verified using Mann-Kendall test [Rutkowska and Ptak 2012], with variance correction in the case of significant autocorrelation. The null hypothesis (H_0) of the test assumes there is no monotonic trend.

Verification of the observation series Q_{max} for outliers was performed with Grubbs-Beck test, with the null hypothesis (H_0) assuming no outliers in the data set. The test is based on the assumption that logarithmized (or in other way transformed) values of the original series of observation follow normal distribution [Cohn et al. 2013; Blagojević et al. 2014].

Verification of homogeneity of variance was carried out using non-parametric Levene W test, designed for checking the equality of variance of k samples ($k = 2$). Equality of variance of all samples indicates its homogeneity for the entire population [Levene 1960]. The null hypothesis (H_0) of test assumes that the population variances are equal.

Determination of peak flows with set return period

Peak flows with specific return period for the observed series of Q_{max} were determined with a statistical method using Pearson type III distribution [Młyński 2016]:

$$Q_T = \varepsilon + \frac{t(\lambda)}{\alpha} \quad \mathrm{m^3 \cdot s^{-1}} \tag{1}$$

where:

ε – lower boundary of the variable, $\mathrm{m^3 \cdot s^{-1}}$,
α – scale parameter, $\mathrm{m^{-3} \cdot s^{-1}}$,
λ – shape parameter, –,
$t(\lambda)$ – standardized variable, –.

For Q_T determined by Pearson type III distribution, the upper boundary of 84% confidence interval was calculated using the following equation:

$$Q_T^{\mu\beta} = Q_T + \mu_\beta \cdot \sigma(Q_T) \quad \mathrm{m^3 \cdot s^{-1}} \tag{2}$$

where:

Q_T – peak flows with T-year return period, $\mathrm{m^3 \cdot s^{-1}}$,
μ_β – β-quantile of the standardized normal distribution, –,
$\sigma(Q_T)$ – estimation error of Q_T, $\mathrm{m^3 \cdot s^{-1}}$.

Estimation error of Q_T was calculated using the following equation:

$$\sigma(Q_T) = \varphi(p, \lambda) \cdot \frac{1}{\alpha\sqrt{N}} \tag{3}$$

where:

$\varphi(p, \lambda)$ – value of standardized variable, –,
α – scale parameter, $\mathrm{m^{-3} \cdot s^{-1}}$,
N – sample size, –.

Peak flows with specific return period in the investigated catchments of the upper Vistula water region were also determined using empirical formulas: Punzet formula and the area regression equation. Punzet formula is expressed as [Punzet 1981]:

$$Q_T = \varphi_T \cdot Q_2 \quad \mathrm{m^3 \cdot s^{-1}} \tag{4}$$

where:
φ_T – a function dependent on the probability, –,
Q_2 – peak flow with the return period of $T = 2$ years.

A function dependent on the probability φ_T was calculated as:

$$\varphi_T = 1 + 0.994 \cdot t_p^{1.48} \cdot c_{v\max}^{1+0.144 \cdot r_p^{0.839}} \qquad (5)$$

where:
t_p – quantile in a standardized normal distribution, –,
c_{vmax} – variation coefficient, –.

Peak flow with the return period of $T = 2$ was determined according to the following formulas:
for mountain catchments:

$$Q_2 = 0.002787 \cdot A^{0.747} \cdot P^{0.536} \cdot N^{0.603} \cdot I^{-0.075} \text{ m}^3 \cdot \text{s}^{-1} \qquad (6)$$

for upland catchments:

$$Q_2 = 0.000178 \cdot A^{0.872} \cdot P^{1.065} \cdot N^{0.07} \cdot I^{0.089} \text{ m}^3 \cdot \text{s}^{-1} \qquad (7)$$

for flatland catchments:

$$Q_2 = 0.00171 \cdot A^{0.757} \cdot P^{0.372} \cdot N^{0.561} \cdot I^{0.302} \text{ m}^3 \cdot \text{s}^{-1} \qquad (8)$$

where:
A – catchment area, km^2,
P – mean annual precipitation, mm,
N – soil imperviousness index, %,
I – river slope indicator, ‰.

Area regression equation (ARE) used for estimating Q_T is expressed by the following formula [Stachý and Fal 1987]:

$$Q_T = \lambda_T \cdot Q_{100} \text{ m}^3 \cdot \text{s}^{-1} \qquad (9)$$

where:
$\lambda_{p\%}$ – quantile established for the dimensionless curves regional peak flows;
Q_{100} – peak flow with the return period = 100 years which is determined according to the following formula:

$$Q_{100} = \alpha \cdot A^{0.92} \cdot H_1^{1.11} \cdot \Phi^{1.07} \cdot I_r^{0.10} \cdot \Psi^{0.35} \cdot (1 + JEZ)^{-2.11} \cdot (1 + B)^{-0.47} \text{ m}^3 \cdot \text{s}^{-1} \qquad (10)$$

where:
α – regional parameter, –,
A – catchment area, km^2,
H_{100} – annual maximum daily with the return period of $T = 100$ years, mm,
Φ – runoff coefficient, –,
I_r – slope of the watercourse in, ‰,
Ψ – mean slope of the catchment, ‰,
JEZ – lake index, –,
B – swamp index, –.

The values of mean relative errors of quantile estimation for Punzet formula and area regression equation were calculated as [Wałęga and Młyński 2015]:

$$\sigma = \left| \frac{Q_{T_F} - Q_{T_S}}{Q_{T_S}} \right| \cdot 100, \% \qquad (11)$$

where:
Q_{T_F} – peak flows with T-year return period calculated using the empirical formulas, m$^3 \cdot$ s^{-1},
Q_{T_S} – peak flows with T-year return period calculated using the statistical method, m$^3 \cdot$ s^{-1}.

RESULTS AND DISSCUSION

Before Q_T estimation by statistical method, the verification of hydrometric data is necessary. This necessity results from the need to meet the assumptions of simple statistical sample by observation series. The analysis was conducted for the significance level of $\alpha = 0.05$. Results are presented in Table 2.

The results of Kruskal-Wallis test revealed no significant differences in Q_{max} for the investigated periods in the analysed catchments. The outcomes indicate that the random variables originated from the same population. The p-values received from Mann-Kendall test confirmed that the trend for peak annual flows determined for the catchments of Hoczewka was significant. The main factor contributing to obtaining significant results in this catchment is probably the course of precipitation. In the investigated period, the water region of the upper Vistula is increasingly often affected by long streaks of extremely high precipitation that dramatically increase the river supply [Wałęga et al. 2016]. However, stability of the hydrological regime was confirmed for the other investigated catchments. In addition, only one outlier was noted by Grubbs-Beck test (Hoczewka). Moreover the results of Levene test indicated to homogeneity of variance in the Q_{max} observation series (excluding Ochotnica river).

Table 3 shows Q_T values yielded by the statistical method (PIII) and the empirical formulas: Punzet and area regression equation (ARE). Figure 2 contains the values of mean relative errors for Q_T estimated using empirical formulas.

Table 2. Results of the statistical analysis conducted for the investigated catchments [source: own elaboration]

River	Kruskal-Wallis test		Mann-Kendall test		Grubbs-Beck test		Levene test	
	χ^2	p-value	Z	p-value	X_o	X_u	W	p-value
Skawica	2.35	0.12	-0.79	0.29	0	0	0.23	0.63
Skawina	1.12	0.29	1.64	0.10	0	0	0.95	0.34
Lepietnica	1.21	0.27	0.75	0.30	0	0	0.51	0.48
Ochotnica	1.60	0.21	-1.16	0.20	0	0	7.72	0.01
Grajcarek	0.11	0.74	0.71	0.31	0	0	0.82	0.37
Kamienica Nawojowska	0.36	0.55	0.61	0.33	0	0	3.38	0.07
Koprzywianka	0.04	0.84	0.87	0.27	0	0	0.23	0.63
Wołosaty	1.65	0.20	1.57	0.12	0	0	1.81	0.19
Hoczewka	1.55	0.21	2.25	0.03	0	1	4.00	0.06

χ^2 – chi square statistics, Z – Mann-Kendall statistics, X_o and X_u – number of the upper and lower border in Grubbs-Beck test crossing, W – Levene statistics, p – probability for the given statistical model

Table 3. Peak annual flows with set return period, determined using the analysed methods [source: own study]

T [year]	2	5	10	20	50	100	1000
Skawica-Skawica Dolna							
PIII(84%), $m^3 \cdot s^{-1}$	61.263	99.637	125.754	150.634	182.309	205.628	280.573
PIII, $m^3 \cdot s^{-1}$	55.061	89.589	112.194	133.359	159.978	179.410	241.256
Punzet, $m^3 \cdot s^{-1}$	56.041	114.803	167.374	219.198	285.945	334.976	491.535
ARE, $m^3 \cdot s^{-1}$	125.181	189.056	231.640	274.224	318.276	367.100	524.953
Skawinka-Radziszów							
PIII(84%), $m^3 \cdot s^{-1}$	91.401	188.399	263.605	339.615	440.765	517.622	774.033
PIII, $m^3 \cdot s^{-1}$	74.727	157.538	219.729	281.729	363.509	425.280	630.128
Punzet, $m^3 \cdot s^{-1}$	62.818	117.530	165.582	212.395	272.034	315.443	452.148
ARE, $m^3 \cdot s^{-1}$	72.005	108.746	133.240	157.735	183.073	211.157	301.955
Lepietnica-Ludźmierz							

Table 3. cont

T [year]	2	5	10	20	50	100	1000
PIII(84%), $m^3 \cdot s^{-1}$	25.920	52.177	72.326	92.606	119.513	139.918	207.839
PIII, $m^3 \cdot s^{-1}$	21.538	44.066	60.795	77.392	99.209	115.649	170.018
Punzet, $m^3 \cdot s^{-1}$	20.856	45.858	68.525	91.059	120.307	141.934	211.672
ARE, $m^3 \cdot s^{-1}$	38.163	57.636	70.618	83.600	97.030	111.914	160.037
Ochotnica-Tylmanowa							
PIII(84%), $m^3 \cdot s^{-1}$	21.773	38.586	51.260	63.922	80.634	93.261	135.123
PIII, $m^3 \cdot s^{-1}$	19.111	33.661	44.258	54.683	68.303	78.523	112.155
Punzet, $m^3 \cdot s^{-1}$	36.076	77.426	114.749	151.747	199.646	234.985	348.568
ARE, $m^3 \cdot s^{-1}$	66.187	99.960	122.475	144.990	168.281	194.096	277.557
Grajcarek-Szczawnica							
PIII(84%), $m^3 \cdot s^{-1}$	19.762	38.264	52.330	66.432	85.093	99.217	146.134
PIII, $m^3 \cdot s^{-1}$	16.758	32.703	44.425	56.003	71.173	82.579	120.205
Punzet, $m^3 \cdot s^{-1}$	38.165	80.068	117.729	154.961	203.043	238.443	351.863
ARE, $m^3 \cdot s^{-1}$	52.058	78.621	96.330	114.039	132.358	152.662	218.307
Kamienica Nawojowska-Nowy Sącz							
PIII(84%), $m^3 \cdot s^{-1}$	141.194	257.174	342.433	426.710	537.094	620.064	893.450
PIII, $m^3 \cdot s^{-1}$	124.217	225.751	297.759	367.771	458.432	526.042	746.926
Punzet, $m^3 \cdot s^{-1}$	73.151	142.309	203.548	263.521	340.297	396.407	574.201
ARE, $m^3 \cdot s^{-1}$	134.817	203.609	249.470	295.332	342.775	395.357	565.361
Koprzywianka-Koprzywnica							
PIII(84%), $m^3 \cdot s^{-1}$	27.511	54.628	74.696	94.589	120.700	140.354	205.222
PIII, $m^3 \cdot s^{-1}$	23.456	47.123	64.026	80.512	101.912	117.897	170.226
Punzet, $m^3 \cdot s^{-1}$	14.581	24.704	33.393	41.736	52.221	59.766	83.121
ARE, $m^3 \cdot s^{-1}$	48.871	73.809	90.433	107.058	124.256	143.318	204.944
Wołosaty-Stuposiany							
PIII(84%), $m^3 \cdot s^{-1}$	75.129	118.968	150.626	181.663	222.070	252.303	351.427
PIII, $m^3 \cdot s^{-1}$	68.610	107.244	134.139	160.068	193.430	218.196	298.668
Punzet, $m^3 \cdot s^{-1}$	40.314	83.422	122.064	160.204	209.382	245.542	361.171
ARE, $m^3 \cdot s^{-1}$	60.687	91.653	112.297	132.941	154.297	177.966	254.492
Hoczewka-Hoczew							
PIII(84%), $m^3 \cdot s^{-1}$	62.898	108.998	143.816	178.628	224.603	259.355	374.619
PIII, $m^3 \cdot s^{-1}$	55.558	95.413	124.501	153.147	190.594	218.706	311.271
Punzet, $m^3 \cdot s^{-1}$	61.913	124.022	179.345	233.728	303.590	354.798	517.774
ARE, $m^3 \cdot s^{-1}$	79.213	119.633	146.579	173.526	201.401	232.297	332.185

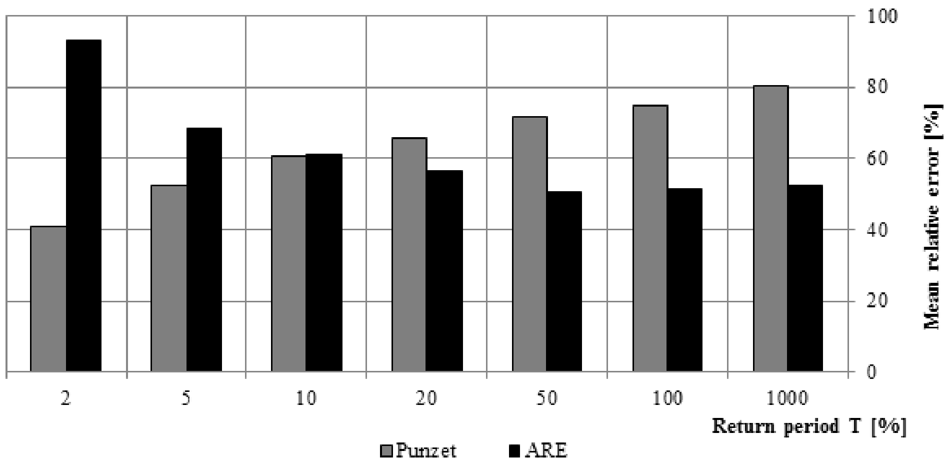

Fig. 2. Mean relative errors in Q_T values yielded for empirical formulas.

Own study

The study results indicated the smallest differences in Q_T determined using the statistical method and the empirical formulas for the Wołosaty-Stuposiany catchments, and the greatest, for the Ochotnica-Tylmanowa. For the Wołosaty-Stuposiany, the values of Q_T determined from the empirical formulas were underestimated as compared with Pearson type III distribution. Mean relative error of the resulting Q_T for Punzet formula and ARE was about 16%. The values of Q_T determined from the empirical formulas for the Ochotnica-Tylmanowa were overestimated as compared with the results from the statistical method. Mean relative error of Q_T for Punzet formula and ARE was 40%, whereas for ARE, it was 79%. With regard to the entire Upper Vistula basin, the mean relative error of Q_T quantile estimation for Punzet formula was 64%, and for ARE, it was 62%. In addition, it should be emphasized that in the case of the Punzet formula, the value of the mean relative quantile estimation error decreases along with the increase of the exceedance probability. However, for ARE, this value increases, as the probability of exceedance also increases.

As evidenced by the study results summarized in Table 2 and in Figure 2, peak annual flows with a set return period determined using the empirical formulas differed considerably from those calculated using the statistical method. It should be emphasized that these formulas were developed in the 1980s, based on hydrometric data from the years 1921–1970. Considering the subsequent changes in the climatic conditions and land use [Cebulska et al. 2007; Szuba 2012], applicability of the current empirical formulas for estimating Q_T may raise reasonable doubts. Empirical formulas should be regularly revised due to lengthening of the observation series, and to changes in the flow regime caused by possible anthropogenic transformations; also, climate change should be taken into account. Moreover, the empirical formulas should follow the most current methodology. Area regression equation and Punzet formula are multiple regression models. A reliable model should include variables strongly correlated with the dependent variable and correlated with each other as little as possible [Vogel et al. 1999]. A careful analysis of the ARE and Punzet formulas demonstrated that this condition was not met. Furthermore, the number of describing variables in the empirical formulas should be optimal. This requirement is explained by the fact that each describing variable, in addition to carrying information about the described variable, brings about uncertainty that is connected with a series of observations of this variable [Węglarczyk 2015]. With this in mind, it is necessary to understand that the results yielded by the current empirical formulas used for calculating Q_T may differ significantly from those derived using direct methods, and this may explain the disparity in the study outcomes.

CONCLUSION

The study evaluated the empirical formulas for calculating annual peak flows with specific return period in selected catchments of the Upper Vistula basin. The discussion concerning empirical formulas currently used to calculate Q_T in ungauged catchments in Poland clearly demonstrated their shortcomings and doubts as to their credibility. Therefore, a constant and research-based monitoring of calculation of Q_T in ungauged catchments is necessary. This will facilitate the application of the empirical formulas, thus ensuring correct and accurate hydrological calculations necessary for proper dimensioning of hydroengineering structures, as well as zoning of flood hazard areas and flood risk mapping. Considering the obtained results, the empirical formulas yielded high value of mean relative quantile estimation error. Additionally, the empirical formulas currently used for Q_T calculation in the catchments of southern Poland should be carefully verified and updated due to considerable differences compared to the results yielded using the statistical method.

REFERENCES

Amini, M., MirMostafaee, S., Ahmadi, J. (2014). Log-gamma generated families of distribution. Statistics, 48, 1–20.

Blagojević, B., Mihailović, V., Plavsić, J. (2014). Outlier treatment in the flood flow statistical analysis. J. Facult. Civil Engineer., 25, 603–609.

Bogdał, A., Ostrowski, K. 2008. Water outflows from small agricultural catchment in Wilamowickie Foorhills. Acta Sci. Pol., Formatio Circumiectus, 7, 13-21.

Cebulska, M., Twardosz, R., Cichocki, J. (2007). Zmiany rocznych sum opadów atmosferycznych w dorzeczu górnej Wisły w latach 1881–2030. [In:] K. Piotrowicz, R. Twardosz (ed.). Wahania klimatu w różnych skalach przestrzennych i czasowych. Instytut Geografii i Gospodarki Przestrzennej UJ, Kraków, 383–390.

Cohn, T.A., England, J.F., Barenbrock, C.E., Mason, R.R., Stedinger, J.R., Lamontagne, J.R. (2013). A generalized Grubbs-Beck test statistic for detecting multiple potentially influential low outliers in flood series. Water Resour. Res., 48, 5047–5058.

Ebrahimian, M., Nuruddin A., Soom M., Sood A., Neng L. (2012). Runoff estimation in steep slope watershed with standard and slope-adjustment Curve Number Method. Polish J. Environ. Stud., 21, 1191–1202.

Fan, Y., Huang, W., Huang, G., Li, Y., Huang, K., Li, Z. (2016). Hydrologic risk analysis in the Yangtze River basin through coupling Gaussian mixtures into copulas. Advan. Water Resour., 88, 170-185.

FLOODFREQ COST Action ES0901. Review of Applied – Statistical methods for flood-frequency analysis in Europe. Center for Ecology and Hydrology, 2013.

Ghorbani, M.A., Ruskeepaa, H., Singh, V., Sivakumar, B. (2010). Flood frequency analysis using Mathematica. Turkish J. Engineer. & Environm. Sci., 34, 171–178.

Kanownik, W., Kowalik, T., Bogdał, A., Ostrowski, K. (2013). Quality categories of stream water included in a Small Retention Program. Polish J. Environ. Stud., 22, 159–165.

Kowalik, T., Wałęga, A. (2015). Estimation of CN parameter for small agricultural watersheds using asymptotic functions. Water, 7, 939–955.

Levene, H. (1960). Robust tests for equality of variances. [In:] Contributions to Probability and Statistics: Essays in Honor of Harold Hotelling. Eds. I. Olkin, H. Hotteling. Stanford University Press, Redwood City, 278–292.

Li, T., Guo, S., Chen, L., Guo, J. (2013). Bivariate flood frequency analysis with historical information based on copula. J. Hydrol. Engineer., 18, 1018-1030.

McCuen, R.H., Levy, B.S. (2000). Evaluation of Peak Discharge Transposition. J. Hydrol. Engineer., 5(3), 278–289.

Merz B., Blöschl, G. (2005). Flood frequency regionalization-spatial proximity vs. catchment attributes. J. Hydrol., 302, 283–306.

Młyński, D. (2016). Analiza postaci rozkładów prawdopodobieństwa do obliczania przepływów maksymalnych o określonym prawdopodobieństwie przewyższenia na przykładzie rzeki górskiej. Episteme, 30, 399–412.

Punzet, J. (1981). Empiryczny system ocen charakterystycznych przepływów rzek i potoków w karpackiej części Dorzecza Wisły. Wiadomości IMGW, 1–2, 31–39.

Rutkowska, A., Ptak, M. (2012). On certain stationary tests for hydrological series. Stud. Geotech. Mech., 34, 51–63.

Serinaldi, F., Grimaldi, S. (2011). Synthetic design hydrographs based on distribution functions with finite support. J. Hydrol. Engineer., 16, 434–446.

Stachý, J., Fal, B. (1987). Zasady obliczania maksymalnych przepływów prawdopodobnych. Obszarowe równanie regresji. Gospodarka Wodna, 1, 8–13.

Szuba, K. (2012). Przemiany stosunków wodnych w zlewni i dolinie Dunajca w kontekście poszukiwania środków ograniczenia zagrożenia powodziowego. Czasopismo Techniczne. Środowisko, 2, 237–251.

Teimouri, M., Gupta, A.K. (2013). On the three-parameter weibull distributionshape parameter estimation. J. Data Sci., 11, 403-414.

Wałęga, A., Młyński, D., Bogdał, A., Kowalik, T. Analysis of the course and frequency of high water Stages in selected catchments of the upper Vistula basin in the south of Poland. Water, 8, 394–409.

Węglarczyk, S. (2015). Osiem powodów konieczności rewizji stosowanych w Polsce wzorów na maksymalne roczne przepływy o zadanym prawdopodobieństwie przewyższenia. Gospodarka Wodna, 11, 323–328.

Vogel, R.M., Wilson, I., Daly, C. (1999). Regional regression models of annual streamflow for the United States. J. Irrigat. Drain. Engineer., 125, 148–157.

WERYFIKACJA WYBRANYCH WZORÓW EMPIRYCZNYCH DO OBLICZANIA PRZEPŁYWÓW MAKSYMALNYCH ROCZNYCH O OKREŚLONYM PRAWDOPODOBIEŃSTWIE PRZEWYŻSZENIA W ZLEWNIACH REGIONU WODNEGO GÓRNEJ WISŁY

ABSTRAKT

W pracy dokonano weryfikacji wybranych wzorów empirycznych do szacowania kwantyli przepływów maksymalnych rocznych o określonym prawdopodobieństwie przewyższenia, w zlewniach południowej Polski. Dane do analizy, obejmujące wielolecie 1986-2015, pozyskano z Instytutu Meteorologii i Gospodarki Wodnej w Warszawie. Dane poddano statystycznej weryfikacji na jednorodność i niezależność, istotność trendu, występowanie elementów odstających oraz równości wariancji. Kwantyle przepływów maksymalnych rocznych o określonym prawdopodobieństwie przewyższenia oszacowano za pomocą rozkładu Pearsona typu III oraz wzorów empirycznych: Punzeta i obszarowego równania regresji. Weryfikacja formuł empirycznych wykazała znaczne różnice pomiędzy rezultatami uzyskanymi za pomocą analizowanych wzorów oraz metody statystycznej. Świadczą o tym średnie wartości błędów względnych oszacowania kwantyli przepływów maksymalnych rocznych, które dla wzoru Punzeta wynosiły 64% natomiast dla obszarowego równania regresji 62%.

Słowa kluczowe: przepływy maksymalne roczne o określonym prawdopodobieństwie przekroczenia, wzory empiryczne, region wodnych Górnej Wisły