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Original Research

Measuring Aquatic Environments as a Tool for Flood Risk Management in Terms of Climate Change Dynamics

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Abstract

We studied climate change dynamics in southwestern Poland. The authors based the assessment of dynamics on the results of flood risk analyses. 30-day flow maxima were selected for three 10-year periods based on hydrological data on daily flows from 1986 to 2015 from the hydrological station on the Oder River in the town of Malczyce. By utilizing the selected maxima as well as selected maximum value distributions, probabilistic models of extreme flows were constructed for the three studied periods – each divided into six-month periods of "summer" and "winter." The estimated models were used to calculate measurements of flood risks in the analyzed periods. We analyzed the studied area on the basis of the results the dynamics of flood risks.

Keywords: flood risk, flow, extreme value distributions, Gumbel distribution, climate change

Introduction

The authors analyzed the 30-day daily flow maxima in the Oder River basin in three 10-year periods – Period I, 1986-95; Period II, 1996-2005; and Period III, 2006-15 – which were in turn broken down into periods of "summer" and "winter," the aim of which was to prove the thesis that there exists a change in the flood risk dynamics during both the summer and winter periods. The thesis put forward is compatible with the Intergovernmental Panel on Climate Change (IPCC) report from February 2016 and provides an additional answer as to the direction of climate change for the studied area.

Material and Methods

The main purpose of our project was to use aquatic environments as a tool for flood risk management in terms of the climate change dynamics. The chosen paradigm and research methods are described below.

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Choice of Paradigm

The paradigm used in the following project can be defined as positivisms when based on many scientific quantitative publications created by a qualified group of scientists that have solid data from many field studies. Authors accept the theories and information from such sources to carry out of the effectiveness of aquatic environment measures as a tool to establish flood risk along with climate dynamics.

Choice of Method

In order to properly answer this topic the author decided to make quantitative research. Data collected via desk research may be from scientific research in the field of flooding, climate dynamics, and environmental management under those circumstances. The project is based on quantitative research that supplies many graphs and data reliable to the main problem.

Water Management in the Context of Sustainable Development

Water management is an activity involving the shaping, protection, and utilization of water resources in accordance with the principle of sustainable development. It is conducted according to the principle of a rational and holistic treatment of resources that surface and groundwater constitute, including their quantity and quality, taking into account the division of the country into river basin areas and water regions as well as taking into account the flood risk management systems and the role of measurements of the aquatic environment. Water management takes the principle of common interests into account and is implemented by the public administration in cooperation with water users, and representatives local communities so as to obtain the maximum social benefit. It seeks to generate maximum benefits by preventing the deterioration of ecological functions of water resources as well as the deterioration of the state of the terrestrial ecosystems and wetlands directly dependent on water resources [1].

Water management, in particular the development and protection of water resources, water use, and management of water resources in Poland (including the broadly defined drainage) is regulated by the Act of 18 July 2001 Water Law (Journal of Laws No. 115 of 11 October 2001, item 1229, as amended).

Water management is one of the sectors of the national economy strongly linked to other areas of economic life. The task of water management, understood as an economic and scientific activity, consists of rational shaping and utilization of surface water and groundwater, taking their quantity and quality into account. The key tasks of water management include:

- Improving surface and groundwater quality.
- Ensuring adequate quality and quantity of water for the population, plus industrial and agricultural needs.
- Protecting against floods and drought.
- Protecting water resources against pollution and their improper or excessive exploitation.
- Maintaining and improving the state of aquatic and water-dependent ecosystems.
- Creating conditions for the use of water resources for energy production, fishing, and transportation.
- Meeting the needs of tourism, sport, and recreation.

Joining the European Union has imposed a number of obligations arising from the adoption of the EU legal acquits on Poland [2]. In the field of water management, the Water Framework Directive (WFD) 2000/60/EC of the European Parliament and of the Council of 23 October 2000, the provisions of which were introduced to the Polish legal system, is the most important regulation establishing a framework for community actions in the field of water policy for all types of water, including flowing and standing surface water, coastal waters, transitional waters, and groundwater. The second important piece of legislation, complementary to water management, is the implementation of the Directive of the European Parliament and Council (2007/60/EC) of 26 November 2007 on the assessment and management of flood risk.

Water, as a factor affecting the functioning of a society, plays an important role not only from a social perspective but also an economic one, because its limited availability allows for the development of a civilized state and society [3]. Because of their value, surface water resources determine how they should be used and thus also have a strategic importance for the security of the country in terms of, among other things, flood risk management and mitigation of drought.

At this point, the high spatial and temporal volatility of water resources in Poland should be taken into account. This causes the phenomena of water excess or shortage to be relatively frequent and intense and to cause huge losses. It is also important to highlight the role of environmental measurements in environmental risk management, which enables a quick response in times of flood risk and seeks to minimize the effects of potential flooding [4-5].

Probabilistic Tools of the Extreme Values Theory Used in Flood Risk Analysis

Applications of Extreme Value Theory in Hydrology: a Literature Review

Historically, the year 1709 marks the beginning of working on the analysis of the extreme values problems. Then, Nicolas Bernouilli led reflections on the average largest distance between given n data points spread randomly on a straight line with a fixed length *t* [6].

A rich and comprehensive bibliography of the literature on the theory of extreme value distributions and their applications consists of more than 1,100 positions counting until the beginning of the 21st century. There is no way to present them all as it would require a separate multi-volume monograph devoted solely to the subject. Such a vast literature indicates great interest in this field of science as well as its wide application. Therefore, in this chapter only selected items will be presented that, in the author's opinion, had a significant impact on the development of the theory and that are closely related to the issues raised in the article. Obviously, such a rich literature in one area also has its drawbacks. The main problem is the lack of coordination between researchers in this field and the inevitable duplication (and even tripling) of the results appearing in various publications around the world.

Probably first to use the extreme values in studying floods in his article was Fuller [7]. The systematic development of a general theory of extreme values, however, is associated with the work of Bortkiewicz, which concerned the distribution range in a random sample from a normally distributed population. This work is very important, since the author introduced and clearly defined the concept of distribution of the highest value there for the first time [8].

Gumbel first drew the attention of engineers and statisticians on the possibility of using the formal theory of extreme values for certain distributions that were previously regarded as empirical. He applied the distribution of extreme value to the analysis of stream flows in the US in 1941 [9]. In subsequent works he continued his research and discussions on the estimation of extreme stream flows and flood forecasts [10-12].

In the course of his research, Teodorovic acquired the observed frequencies N(T), meaning the number of days in a period that was T days long, when the water flow in the Greenbrier river in West Virginia exceeded 17,000 feet^3. The period of his observation took 72 years, from 1896 to 1967. He then compared the observed frequency with the theoretical Poisson distributions. In the results it could be seen that the discrete observations N(T) for the studied river and for the given climate can be very well modelled with Poisson distributions [13].

In the 1970s-90s many papers were written on the subject of applying elements of the extreme value theory to solve problems associated with flooding. Pericchi and Rodriguez-Iturbe conducted research based on data on daily water flows in the Feather River in Oroville, California, USA. The data collected came from the years 1902-60, from which they selected annual flow peaks and fitted their empirical distribution t Gumbel distribution. In addition, in their work they proposed schedules such as: gamma (Person type III), gamma-log (log – Pearson type III) and log – normally for the analysis of selected peaks. In their research they also suggest the use of the distribution function for overflows and a gambling function for flood risk analysis [14]. The use of probability distributions for flood frequency estimation was also illustrated in Greis' and Wood's work [15]. Shen applied the probability distributions to forecast flood events [16]. Rossi proposed a two-component extreme value distribution to analyze the frequency of flooding [17]. The same year, Beran published a comment to this work [18]. In subsequent years, Smith, Jain, and Singh as well as Ahmad brought a discussion on the application of type I extreme value distribution to analyze the frequency of flooding [19-21]. At the end of the 20th century, after the great United States flood that caused huge losses in the Midwest, Hipel presented the use of extreme value theory in the analysis of flood events in his work. He accurately presented the analysis of emergency-level events over the span of 100 years in the context of the flood of 1993 [22].

The beginning of the 21st century is also rich in terms of studies of hydrological and meteorological phenomena using the extreme value theory. In their article, Katz with co-authors presented a comprehensive study using distributions of extreme values on hydrological data collected in Fort Collins, Colorado, USA [23]. Engeland, Frigessi, and Hisdal presented the analysis of flood and drought risks using the generalized extreme value distributions and Pareto. They conducted their research on data concerning stream flows on the Ha river in southwestern Norway [24]. In their work, Bordi, along with co-authors, analyzed wet and dry periods in Sicily. For this purpose they applied monthly rainfall maxima [25]. Yurtal and others compared in their work the method of maximum likelihood to weighted method of moments for estimating the parameters of hydrological data distribution probability obtained from measuring stations on the Ceyhan River in southern Turkey [26]. After a great number of floods in the Czech Republic, Holičky and Sykora used log-normal distributions and Persona III in their research to estimate the flood risk for cultural heritage [27]. Nachabe and Paynter conducted research using generalized distribution of extreme values on hydrological data from the selected lakes in southwestern Florida [28]. Chaibandit and Konyai, in their studies, analyzed hydrological data obtained on a monthly basis from 6 stations on the Yom river. The study used the distributions of extreme values, normal distribution, and log-normal distribution as well as the return period method [29]. Arns and others, in their studies, estimated the flood risk by estimating the probability of achieving a certain water level in rivers [30]. In their work, Charon along with other scientists compared a very large number of probability distributions using model wind speeds. The data came from 9 meteorological stations in The United Arab Emirates [31].

Maxima

We assume that the yiobservations are the maxima, which means that,

$$y_i = \max\{x_{i1}, ..., x_{im}\}, \qquad i = 1, ..., n, \tag{1}$$

...where x_{ij} may not be observable. In the case where x_{ij} are observable, the selection of certain maxima from certain sets with *m* number of elements is a form of selection of the upper extreme values from a data set. This method is called the block method or the Gumbel method [32].

The block maxima method requires defining the time horizon (the block) and calculating the maxima of the tested variable for the said horizon. Most commonly, blocks of one year, half a year, a quarter, a month, or of smaller size are used depending on research needs. For data in the form of hydrometric parameters blocks of the above-mentioned size are used. The block size cannot be too small to prevent the occurrence of the relationship between the maximum values of the neighbouring blocks of time. A 10-day period is considered to be the minimum limit value of the size of the time block for which the independence of neighbouring maxima can be accepted [24].

There can also be cases when, during the long-lasting floods, there may occur a risk of a dependence even between the maxima of adjacent blocks of time. In such situations, when such a relationship between the variables under consideration occurs, it is necessary to apply the cumulative distribution of extreme values for dependent random variable sequences for the analysis of the distribution of the maximum values [33]. At this point, one more fact deserves attention, namely that the observations *yi* are the embodiments of the random variable M_m defined by the formula:

$$M_m = \max\{X_1, ..., X_m\} \qquad (2)$$

Probabilistic Models of Maxima Values

According to the theorem concerning the types of extreme value distributions, the distributions of extreme values are described by one of three distribution functions from the family of extreme value distribution functions [34].

Additionally, if the random variable X has the distribution function F, then the random variable (μ + σ*X)* has the distribution function where μ and $\sigma>0$ are the parameters of position and scale, respectively [35]. Combining the above two statements results in a very broad family of distribution functions for extreme values distributions as defined by the following formulas:

Gumbel (EV0 or TYP I):

$$G_{0,\mu,\sigma}(x) = \exp\left(-e^{-(x-\mu)/\sigma}\right), \quad -\infty < x < \infty \qquad (3)$$

Frechet (EV1 or TYP II):

$$G_{1,\mu,\sigma}(x) = \exp\left(-\left(\frac{x-\mu}{\sigma}\right)^{-\alpha}\right),$$

for a certain $\alpha > 0$, $x > 0$ (4)

Weibull (EV2 or Type III):

$$G_{2,\mu,\sigma}(x) = \exp\left(-\left(-\left(\frac{x-\mu}{\sigma}\right)\right)^{\alpha}\right),$$

for a certin $\alpha>0$, $x\leq 0$

(5)

The family of the distribution functions of the maximal values distribution, presented with formulas (3-5), consists of 3 separate formulas. By parameterisation of $\gamma = 1/\alpha$ of the distribution functions of maximal $G_{i,\alpha}$ (i = 0, 1, 2) according to von Misses [36] and by introducing the location and scale parameters we receive a continuous, unified model described by the formula:

$$G_{\gamma,\mu,\sigma}(x) = \begin{cases} \exp\left\{-\left[1+\gamma\left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\gamma}}\right\} & if \quad \gamma \neq 0 \\ \exp\left\{-\exp\left(\frac{x-\mu}{\sigma}\right)\right\} & if \quad \gamma = 0 \end{cases} \qquad (6)$$

[24, 37]

In this imaging, the distribution function of the Gumbel distribution, again, has the parameter $\gamma = 0$. Standard versions that do not take the parameters of position μ and scale σ in γ - parametrization are defined in this way, that

$$G_\gamma(x) \to G_0(x), \qquad \gamma \to 0 \qquad (7)$$

[38]. By extending the standard version of the model with γ - parametrization through the introduction of the location and scale parameters we get a model expressed with the formula (6).

For the purpose of this article, in the research that was conducted a tool in the form of an empirical distribution function was used to visualise empirical distributions of the maximal values of specific hydrological characteristics in the context of chosen theoretical distributions [38].

Estimation Methods and Tests of Significance

One of the more well-known and widely used methods for estimating the parameters of statistical models, namely the maximum likelihood method, gives effective results when used to estimate the parameters of the distribution functions of the extreme distributions described with Formulas (3-5). In the case of the Gumbel distribution it is also possible to apply the method of moments.

In the case of a unified, or in other words, generalised, version of the model of extreme values presented with Formula (6), three procedures can be used to estimate its parameters.

The first of them is the maximum likelihood method, which has to be numerically evaluated as a solution to the equations of likelihood for this model. This method determines the local maximum of a likely function when the iterated values of the estimated parameter γ remain in the area $\gamma > -1$. If the value of γ reaches below -1, neither the global nor local maximum of the likelihood function exist [39].

The second method applicable in the case of this model is the minimum distance method. If d is set to mean the distance between the empirical and theoretical distribution functions for the family of distribution functions, then (γ_n, μ_n, σ_n) is the minimum distance estimator, *if*

$$d\left(\hat{F}_n, G_{\gamma_n,\mu_n,\sigma_n}\right) = \inf_{\gamma,\mu,\sigma}(\hat{F}_n, G_{\gamma,\mu,\sigma}) \tag{8}$$

…where is the distribution function of the empirical distribution of the sample containing n elements.

The third method is a method wherein to estimate the parameter γ of a generalized distribution of extreme values a class of estimators is used, which are LRSE, or linear combinations of ratios of spacings:

$$\hat{r} = \frac{x_{[nq_2]:n} - x_{[nq_1]:n}}{x_{[nq_1]:n} - x_{[nq_0]:n}} \tag{9}$$

…where the percentile $q_i = i / (n+1)$ i $q_0<q_1<q_2$. It should be noted here that this statistic is independent of the position and scale parameters in the distribution. In other words, is constant in accordance with the affine transformations of data [40].

Because $\hat{F}_n^{-1}(q_i) = x_{i:n}$, the relation:

$$x_{i:n} = \hat{F}_n^{-1}\left(\frac{i}{n+1}\right) \approx F^{-1}\left(\frac{i}{n+1}\right) \tag{10}$$

…between the sample quantile function and the theoretical function gives the relation:

$$\hat{F}_n^{-1}(q_i) \approx\sim F_{\mu,\sigma}^{-1}(q_i) = \mu + \sigma F^{-1}(q_i) \tag{11}$$

As a consequence of (10)

$$\hat{r} = \frac{G_\gamma^{-1}(q_2) - G_\gamma^{-1}(q_1)}{G_\gamma^{-1}(q_1) - G_\gamma^{-1}(q_0)} = \left(\frac{-\log q_2}{-\log q_0}\right)^{-\gamma/2} \tag{12}$$

…if q_0, q_1, q_2 satisfies the equation. In this way, a parameter estimator γ is obtained:

$$\gamma_n = 2\log(\hat{r}) / \log\left(\log(q_0)/\log(q_1)\right) \tag{13}$$

[38]

The location parameter μ and scale parameter σ for the generalized model G $_{\gamma,\mu,\sigma}$ can be estimated using a well-known method of least squares.

To verify the hypothesis concerning the compliance of the studied empirical distributions with the selected distributions of maximal values from the family expressed with Formula (6), the following compliance tests were applied: Kolmogorov-Smirnov test and Anderson-Darling test [41].

At the end of this section one other important fact should be pointed out. In studies conducted on the extreme values a situation can occur in which the best-fitting distribution describing the studied extreme random variable is a commonly known normal distribution. Therefore, it should not be ignored in the distribution-matching procedure.

Measurements of the Flood Risk Dynamics

Hydrometric Data

Hydrological studies on rivers use two of the most well-known hydrometric parameters: water level *(H)* and flow rate *(Q)*. The first parameter is defined as the water table rise for a given river profile above an agreed-upon reference level, which is the value of zero on a stream gauge, which is used for conducting the observations of this parameter, and it is expressed in cm. The second parameter is defined as the volume of water flowing through a certain cross-section of the riverbed in a given unit of time expressed in m^3/s [42]. Functional association linking both parameters *Q = f(H)* is defined as the curve of flow rate or rating curve and it is used to determine flow rates corresponding to the observed water levels.

For the purposes of this article we used flow rates for the Oder River gathered by Malczyce hydrological station at 300 km. The data gathered contain daily flow rates in the period from 01.01.1985 to 31.12.2015, which gives a sample size of n = 16,425. The time horizon, where the observations were performed for the purpose of the research, was divided into three equal lengths of 10 years each: period I spans 1986 to 1995, period II spans 1996 to 2005, and period III spans 2006 to 2015.

Due to the fact that in the studies on hydrological flood events the calendar year is divided into so-called "summer" and "winter" periods, each of the three periods was also additionally divided accordingly. The "summer" period consists of the months from April to September, while the "winter" period consists of January to March and from October to December.

Table 1. The values of the parameter estimates of the theoretical distributions suited to the empirical distributions of the 30-day maxima of the water flows for the three studied periods in the "summer" and "winter" periods.

Periods	Model and the estimator values
1986-95 "summer"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.549$ $\hat{\mu}=157$ $\hat{\sigma}=86.29$
1986-95 "winter"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.679$ $\hat{\mu}=126.9$ $\hat{\sigma}=44.2$
1996-2005 "summer"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.548$ $\hat{\mu}=191.1$ $\hat{\sigma}=92.9$
1996-2005 "winter"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.409$ $\hat{\mu}=154$ $\hat{\sigma}=78.6$
2006-15 "summer"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.475$ $\hat{\mu}=211.1$ $\hat{\sigma}=133.2$
2006-15 "winter"	$G_{\gamma,\mu,\sigma}$ $\hat{\gamma}=0.293$ $\hat{\mu}=176.4$ $\hat{\sigma}=81.4$

Source: own materials

Using the block method, which was described in the previous section, monthly maxima of daily flows were selected for the months of the "summer" and "winter" periods in all three studied periods.

Since calendar months have different lengths (28, 29, 30, and 31 days) for simplification purposes, a period of 30 days was adopted in the study for all months. The differences arising from the simplification introduced into the probabilistic analyses are statistically insignificant.

Formula (1) for all the periods adopted in the study and both parts of the year takes the form:

$$y_i = \max\{x_{i1}, ..., x_{i30}\}, \qquad i = 1, ..., 60, \tag{14}$$

…which gives 6 maxima sets consisting of 60 observations each. All selected maxima sets are the

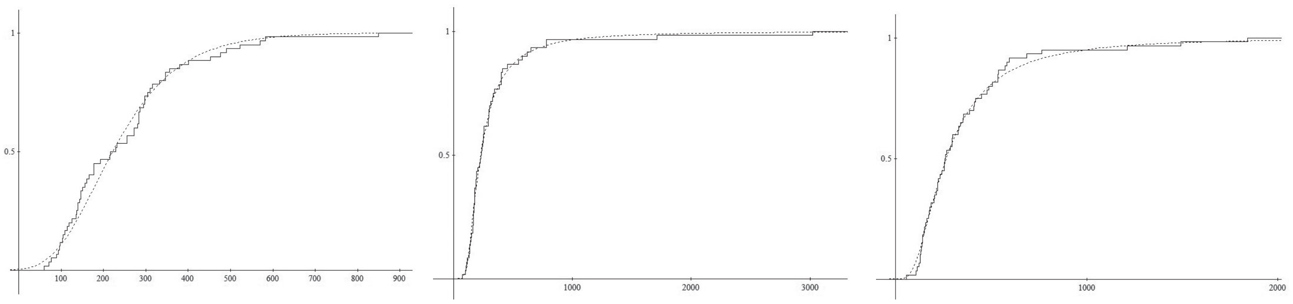

Fig. 1. The empirical distribution functions of the maxima distributions for the summer months (solid line) and the distribution functions matched to the theoretical distributions (dotted line) for period I (the graph at left), period II (middle), and period III (right); *X*-axis are the values of the 30-day flow maxima, *Y-axis* are the values of the distribution functions of the empirical and theoretical distributions.
Source: own materials

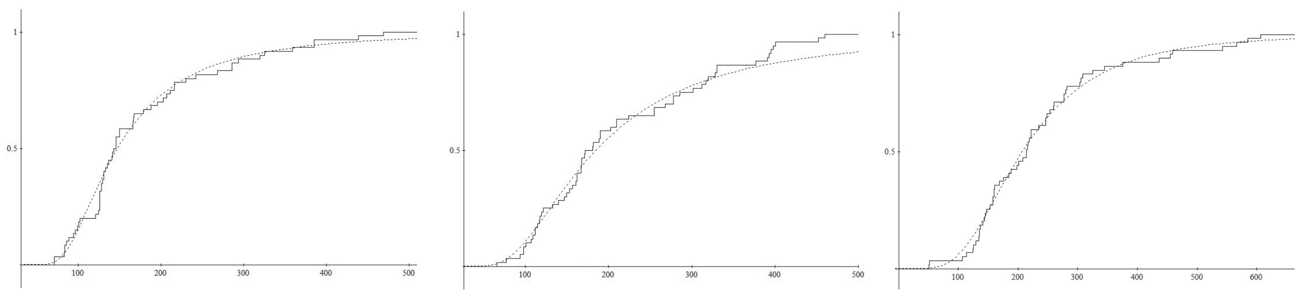

Fig. 2. The empirical distribution functions of the maxima distributions for the winter months (solid line) and the distribution functions matched to the theoretical distributions (dotted line) for period I (the graph at left), period II (middle), and period III (right); *X*-axis are the values of the 30-day flow maxima, *Y-axis* are the values of the distribution functions of the empirical and theoretical distributions.
Source: own materials

Table 2. *P-values* in the Kolmogorov-Smirnov and Anderson-Darling tests.

Periods	K-S Test	A-D Test
1986-95 summer	$p_v = 0.336$	$p_v = 0.701$
1986-95 winter	$p_v = 0.423$	$p_v = 0.756$
1996-2005 summer	$p_v = 0.976$	$p_v = 0.985$
1996-2005 winter	$p_v = 0.666$	$p_v = 0.595$
2006-15 summer	$p_v = 0.997$	$p_v = 0.980$
2006-15 winter	$p_v = 0.901$	$p_v = 0.811$

Source: own materials

realisations of a variable expressed with Formula (2), wherein $m = 30$.

Theoretical and Empirical Probabilistic Maxima Models

Using the selected maxima sets as well as the estimation methods discussed in the previous section, the parameters of theoretical distributions optimally suited to the empirical distributions for the 30-day maxima were estimated. The values of the parameter estimates are presented in Table 1.

To describe the empirical distribution of the maxima for each of the 6 selected sets we used a probabilistic model of extreme values represented by Formula (6).

To illustrate the empirical distribution of the maxima of the studied hydrological characteristics for all selected sets we used a widely known tool in the form of an empirical distribution function. In addition, the graph for each of the 6 empirical distribution functions contains a chart of the distribution function matched to the theoretical distribution, the parameter estimates of which are included in Table 1. All the charts referred to are presented in Figs 1 and 2.

A visual inspection of the charts of the empirical and theoretical distribution functions indicates a very good fit of the theoretical distributions with the empirical distributions for all the examined cases. In order to confirm the goodness of fit resulting from the visual evaluation the following statistical tests of conformity were performed: Anderson-Darling test and Kolmogorov-Smirnov test. The results of both tests for all six cases in the form of *p-value* are shown in Table 2.

The results of both of these tests confirm a very high goodness of fit of the proposed theoretical distributions with the empirical distributions of the maxima in each case in the three analyzed periods. Therefore, the proposed probabilistic models can be used in the next chapter for estimating flood risk in the studied area.

Probabilistic Analysis of the Flood Risk Dynamics on the Oder River Taking Seasonality into Account

Defining the concept of risk proves to be a difficult task every time. Providing a precise definition is impossible. Risk is defined on the basis of various branches of knowledge and theories, including economics, behavioural sciences, legal sciences, psychology, statistics, insurance, probability theory, and more.

According to the authors, the following two definitions of risk are most suitable to determine flood risk. The first one treats risk as the possibility or likelihood of loss, e.g., due to flooding [43-44]. The second definition assumes risk to be the probability of a system failure or the failure of its p_f element, which, in particular cases, may be equated with flooding [45].

In this paper, based on the aforementioned two definitions, the probability of exceeding a certain level of water flow *(q)* by the maximal daily water flow from the time horizon is assumed in the study. The time horizon of 30 days was chosen for the purpose of this study.

The probabilities of exceeding the assumed level of the flow rates, which constitute the measures of flood risk in this study, will be calculated using the theoretical distribution functions of the maximum flow distributions. The estimated parameters of the theoretical distribution functions based on the empirical flow maxima that were used to calculate the risk measures are presented in Table 1.

The level of flow rate *(q),* used to calculate the flood risk measures, can take any value determined arbitrarily by the researchers based on their substantive knowledge related to the flood risk in the studied area.

To calculate the flood risk measures in this article, the greatest levels of flow rates recorded during two historic floods that took place in Lower Silesia in July 1997 and June 2010 were adopted. These levels were: $q_{1997} = 3,020\ m^3/s$ and $q_{2010} = 1,840\ m^3/s$, respectively.

Table 3. Measures of flood risk and its dynamics for "summer" months.

Periods	$P(M_{30}>q_{1997})$	Indexes It/t-1	% change	$P(M_{30}>q_{2010})$	Indexes It/t-1	% change
1986-95	0.0046	-	-	0.0113	-	-
1996-2005	0.0053	1.152	15.2	0.0131	1.159	15.9
2006-15	0.0064	1.207	20.7	0.0175	1.336	33.6

Source: own materials

Table 4. Measures of flood risk and its dynamics for "winter" months.

Periods	$P(M_{30}>q_{1997})$	Indexes It/t-1	% change	$P(M_{30}>q_{2010})$	Indexes It/t-1	% change
1986-95	0.0036	-	-	0.0076	-	-
1996-2005	0.0012	0.333	- 66.7	0.0038	0.5	- 50
2006-15	0.00025	0.208	- 79.2	0.0013	0.342	- 65.8

M30 – random variable
Q1997 – level of flow rate recorded in 1997
Q2010 – level of flow rate recorded in 2010
Source: own materials

In accord to Formula (2) and the above denotations, the possibility of exceeding the values of q_{1997} and q_{2010} by a random variable M_{30} calculated for each of the three test periods taking into account the seasonal factor will constitute the measures of flood risk. Taking into account all the variants together, 12 measures of risk which are included in Tables 3 and 4 were obtained in the study.

Analyzing the results from Table 3 for the summer months, meaning the period in which there are flood events in the Polish climate zone, an upward trend of flood risks in the examined period is clearly visible. For the assumedlevel of flowq_{1997} the risk during period II in comparison to period I is about 15.2% higher, while in period III compared to period II it is even 20.7% higher. This trend is also observed for flow rateq_{2010}. Here, in period II compared to period I the risk is 15.9% higher while in period III compared to period II it is as much as 33.6% higher.

In the case of the results in Table 4 for the winter months that do not belong to the period in which there are floods in Poland, the opposite situation in relation to the results from the summer months can be clearly seen. The flood risk has a downward trend. Assuming a flow rate of q_{1997} for the calculation the risk obtained during period II in comparison to period I is about 66.7% lower and in period III compared to period II it is 79.2% lower. A descending tendency for risk was also obtained by adopting the calculation for the level of q_{2010}. In period II in comparison to period I the risk is 50% lower while in period III compared to period II the risk is even 65.8% lower.

Result

In the first part of the chapter devoted to the conducted research using the models of distribution functions of the maxima distributions with estimated parameters from Table 1, the flood risk in each of the three studied periods will be calculated, taking the seasonal factor into account. In the second part, by using the obtained flood risk measures results, an analysis of the dynamics of the flood risk during the studied period was carried out, taking into account the seasonal nature of flood events.

The results presented for the summer period, which is the time when floods can occur in Poland, show quite a disturbing phenomenon in the form of an upward trend of flood risk. In the months belonging to the winter period the situation is reversed.

Discussion and Conclusions

The phenomena of climate change are discussed across many academic fields. These fields include the protection of the atmosphere, animate and inanimate natural resources, and water management. It is important to be able to parameterize these changes in order to build forecasts and to seek environmental and technical solutions that counter these phenomena.

Water resources in Poland are relatively low in comparison to Europe. Additionally, they have an uneven temporal and spatial distribution. Climate change is contributing more and more to the occurrence of high flows in the rivers and, consequently, to water levels. The impact of these changes has a direct impact on increasing flood risk.

Sustainable water management should be implemented through the integration of social, environmental, and economic objectives [46]. Activities aimed at flood protection should consist primarily of the least invasive, ecologically sensitive solutions such as flood risk assessment and management, as well as the appropriate designation of floodplains and development.

Flood risk management is the basis for rational planning in the water management area. In this process, models that serve to measure and assess flood risk are important. Of the many models used for flood risk measurement, in the authors' opinion probabilistic models of maximum values of hydrological characteristics are most effective.

Extreme value models were in the 20th century and still are in the 21st century, widely used for flood risk measurement and evaluation [7, 13, 23, 27, 30].

In the study authors used probabilistic models of extreme values of flows for the studied area in three equal periods of 10 years, divided into winter and summer parts. Utilizing data on maximum daily flows from 30-day time horizons for all periods, probabilistic flood risk measurement models were constructed.

The research results show clear changes in the flood risk for the studied area, which were different for the summer and winter months.

In the months belonging to the summer period, the risk and its dynamics are clearly on the rise. However, in the months of the winter period the risk is characterized by a decreasing trend and the dynamics of this decline are also increasing.

Due to the above, during the summer period special attention should be given to the proper maintenance of riverbeds and embankment areas, which in cases of potential flood events will improve the conditions of big waters.

The area of the Oder River basin during the winter period is often under the influence of marine and continental climates, which causes frequent temperature changes as a result of which embolic and snowmelt flooding may occur.

Despite the decreasing trend of flood risk during the winter period, one should not forget about the soft and hard technical activities. Directive 2000/60/EC and Directive 2007/60/EC, clearly marks these actions as being implemented in the European Union.

The probabilistic models for flood risk assessment and measurement presented in this paper provide a precise tool complementary to global analysis and support for broadly understood flood protection measures.

Measuring flood risk dynamics using the models described above allows for precise updating of formal requirements for implementation and derogation in time (Directive 2007/60/EC).

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