Articles

UDK: 368.025.66:627.512(100)"1960/2020"
DOI: 10.5937/TokOsig2303367R

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FLOOD FREQUENCY ANALYSIS IN THE WORLD

SCIENTIFIC PAPER

Abstract

The paper deals with the hypothesis that floods in the last few decades recorded an extreme increase in frequency. As analysis of the number of events is the first step in the flood risk modelling, an empirical study was conducted based on data from the natural disaster database of the *Université Catholique de Louvain* in Belgium. The Mann Kendall Trend Test is used to identify a tendency in a series (the number of floods from 1960 to 2022 in the world) by testing statistical hypotheses and a randomness check in its variations, i. e. determining whether the time series has a tendency. The test determined that the flood frequency tendency is statistically significant. Based on measures of representativeness of the tendency, standard error and mean average deviation, an exponential regression curve was chosen with a coefficient of determination of 0.8807. With a relatively high coefficient of determination value, the model gives a solid basis for predicting those events in the future, but this property could certainly be improved.

Key words: *flood insurance, catastrophic weather events, floods, flood frequency tendency*

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Paper received on: 19 September 2023
Paper accepted on: 28 September 2023

I. Introduction

Floods are certainly one of the most destructive natural catastrophic events, and due to severe economic and political consequences, they are the focus of almost all countries, as well as the most important international organizations. According to data of the UN Office for Disaster Risk Reduction, in the last twenty years, 90% of the total number of catastrophic events were related to weather events of a hydrological nature, of which 44% were floods.[5] Floods can be coastal, river, torrential and those caused by appearance of ice in the watercourse. Torrential floods are extremely destructive, since time span between the beginning of rainfall and the peak of the flood wave is short. Most often, they are result of intense local rainfall, which is why their prediction is much more difficult. Floods are the most frequent event in the past two decades, and the fact that China and India are the countries most exposed to this risk and densely populated makes them the greatest threat to property and human lives in Asia. What is even more worrying are the results of the research conducted within the UN Office for Disaster Risk Reduction, according to which in the period 2000-2019, the number of floods was two and a half times higher than in the period 1980-1999.[6]

In addition to the increase in the frequency of catastrophic weather events, an increase in the economic losses caused by them was also recorded, with a large gap between the actual damages and those covered by insurance.[7] In order for insurers to spread risk evenly and provide service to insureds, they have to be able to properly model insured risks. Floods are one of the most expensive natural disaster events, which is the case in Australia.[8] The increase in frequency and multiple negative effects are the reasons why the institutions of the EU show particular interest in this natural hazard. Namely, the European Parliament and the Council adopted the Directive 2007/60/EC on the assessment and management of flood risks that focuses on preparation of flood hazard maps and flood risk maps, with estimates of expected damages in various scenarios. In addition to extreme events, whose likelihood is small, assessments should also include events of medium likelihood (recurrence period is less than one hundred years). Events with a high likelihood may or may not be included in these assessments.

5 UNISDR, *The Human Cost of Weather-Related Disasters 1995-2015*, 2015, p. 5, *http://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf*

6 UNDRR, *The Human Cost of Disasters-an overview of the last 20 years 2000/2019,* United Nations, 2020, p. 7. *https://www.un-ilibrary.org/content/books/9789210054478/read* (15.08.2023.)

7 Jelena Doganjić, Marija Paunović, "Natural Catastrophe Risk Management", *Tokovi osigaranja* 3/2021, Dunav osiguranje, p. 54.

8 Najdana N. Spasojević, „Uticaj klimatskih promena na osiguranje (katastrofalne poplave u Brizbejnu u Australiji)", *Tokovi osigaranja* 2/2011, Dunav osiguranje, p. 26.

Flood risk assessment should include:

1. maps of the river basin district at the appropriate scale including the borders of the river basins, sub-basins and, where existing, coastal areas, showing topography and land use;
2. a description of the floods which have occurred in the past, including an analysis of runoff of water and an assessment of the total damage;
3. a description of the significant floods which have occurred in the past, where significant adverse consequences of similar future events might be envisaged;
4. an assessment of the potential adverse consequences of future floods, taking into account issues such as the topography, the position of water-courses and their general hydrological and geo-morphological characteristics, including the effectiveness of existing man-made flood defence infrastructures, the position of populated areas, areas of economic activity and impacts of climate change on the occurrence of floods.[9]

Having in mind that heavy precipitation is the most common cause of river floods, the Directive stipulates that the extent of floods, water depth or water level, flow speed or water flow are mandatory elements of the analysis.[10]

Risk assessment, mapping and flood forecast are subject of various scientific disciplines and authors. The American Geophysical Union published one of the most significant studies in which, in addition to the analysis of usability and availability of various data sets, a systematic analysis of the hydrological flood forecasting models applied so far, including forecasts conditioned by climate changes was presented.[11] In 2011, the World Meteorological Organization launched the Flood Forecasting Initiative and formed an Advisory Group whose goal was to establish guidelines on the basic elements of future flood forecasting models, as well as the coordination of various bodies and initiatives. Increasing tendency of the flood frequency and intensity is the starting point in creating the French model of claim indemnity.[12] A group of authors analysed influence of various weather conditions on the frequency of floods in Italy.[13] Several authors analysed the tendency of floods in the USA, and

9 Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks, *Official Journal of the European Union*, L 288, p. 189. *http://eur-lex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN*

10 Ibid.

11 Guy J-P. Schumann, at all, *Global Flood Hazard: Applications in Modeling, Mapping, and Forecasting*, American Geophysical Union and Wiley, 2018

12 Guillier Flora, "French Insurance and Flood Risk: Assessing the Impact of Prevention Through the Rating of Action Programs for Flood Prevention", *International Journal of Disaster Risk Reduction* 8(2017), Springer, 2017

13 Alessandro Messeri, Marco Marabito Gianni Messeri, Giada Brandini, Martina Petralli, Francesca Natali et al., "Weather-Related Flood and Landslide Damage: A Risk Index for Italian Regions", *PLoS ONE* 10(12): e0144468, 2015.

Cartwright L. pointed out that the analysis of flood damage at the regional level created prerequisites for a better understanding of the tendency in the USA.[14] Serbian authors discussed assessment of the risk of floods and the damage they cause to crop and fruit.[15]

Time series analysis - the number of floods from 1960 to 2022 in the world is the key topic of this paper. Based on empirical data on the number of floods in the world from the EM-DAT database, statistical hypotheses about the existence of a tendency of their frequency will be tested – a hypothesis presented by several authors – but without its empirical confirmation. In addition to the main characteristics of the series, the tendency function will be modelled as the first step in future prediction of the number of floods, which is the goal of the concerned research. The paper will present practical instructions and insurers will use them as a basis for a more adequate understanding and modelling of flood risks.

II. Methodology of Research and Initial Assumptions

Starting with the statistical definition of risk and the model developed by Fournier d'Albe, the UN Office for Disaster Risk Reduction, in the nineties, defined the concept of natural disaster risk, which still is the reference point of all modern models. Natural disaster risk, according to the model, is determined by hazard, exposure and vulnerability and is defined:

$$R_K = (\mathrm{E})(R_S) = (\mathrm{E})(\mathrm{X.\,V}), \quad (1)$$

and for different elements at risk:

$$R_K = \sum(\mathrm{E})(R_S) = (\mathrm{E})(\mathrm{X.\,V}), \quad (2)$$

R_K – natural catastrophe risk,
(E) – element at risk,
R_S – specific risk,
X – natural hazard,
V – vulnerability.[16]

Natural hazard indicates the likelihood of occurrence of a potentially harmful natural phenomenon in a certain area in a defined period, while vulnerability reflects

[14] Lauren Cartwright, "An Examination of Flood Damage Data Trends in the United States", *Journal Of Contemporary Water Research & Education,* Issue 130, 2005.
[15] Boban Gajić, Ivan Radojković, "Risk Assessment Methodology in Crop Insurance", *Tokovi osiguranja* 2/2019, p. 49
[16] UNDRO, *Mitigating Natural Disasters (Phenomena, Effects and Options)*, United Nations, 1991, p. 91.

the potential degree of damage to one of the elements at risk and ranges from 0 to 1. Element at risk means the population, facilities, infrastructure and economic activity exposed to the natural disaster risk in a certain geographical area. Natural disaster risk is the expected value of total damages in a certain area, while the specific risk is the expected value of damages to a certain type of elements at risk.

In order for a certain natural phenomenon to be deemed a hazard, it must have a potential negative effect on society, and in the aforementioned model a natural hazard is defined as "geophysical, atmospheric and hydrological events that have the potential to cause damage to property and loss of life." Based on the previous definition of hazard, the mutual conceptual relation between a hazard and elements at risk can be observed, so that without elements at risk there is no hazard and vice versa.[17]

Modelling of catastrophic weather risks is a complex process, whose success primarily depends on availability and quality of quantitative and qualitative inputs, which best reflect the features of natural phenomena.[18] When assessing and modelling direct damages caused by catastrophic weather events, one of the real problems is the fact that damage data is mostly unavailable, especially in underdeveloped countries. In EM-DAT, currently the most complete database on direct damages caused by natural disasters, there is no data on damages in 63% of registered events, while in countries with a low GDP, data on damages is missing in 83% of registered events. In addition, we should take into account that in Oceania data is available for 51%, and in Africa for only 14% of registered events.[19]

In addition to risk assessment, catastrophe models are used for improvement of strategic weather risk management documents. Models are based on the frequency of occurrence of an event, the time and intensity of the occurrence and damages, with the aim of predicting the likelihood of occurrence of the event in future.

In the last few decades floods recorded increase in frequency, as it was pointed out in the introductory part of the paper. Analysis of the trend of such events is the first analytical step in understanding and modelling of these risks, especially concerning the lack of data on actual damages. For an empirical research, a time series was created based on the database on natural disasters of the *Université Catholique de Louvain* - the number of floods from 1960 to 2022 in the world.[20] First,

[17] Hochrainer S., *Macroeconomic Risk Management against Natural Disasters*, Deutscher Universitats-Verlag, 2006, p. 15.

[18] Patricia Grossi, Howard Kunreuther, Don Windeler, An Introduction to Catastrophe Models and Insurance, in Patricia Grossi, Howard Kunreuther, 2005, *Catastrophe modeling: a new approach to managing risk*, Springer, 2005.

[19] UNISDR, *Economic Losses, Poverty and Disasters 1998-2017*, 2017, p. 3 *https://www.unisdr.org/2016/iddr/CRED_Economic%20Losses_10oct_final.pdf* (5. 9. 2023.)

[20] EM-DAT: The CRED/OFDA International Disaster Database – *www.emdat.be* – Université Catholique de Louvain – Brussels – Belgium, File creation: Tue, 07 Feb 2023 11:16:49 CET.

the main characteristics of the time series will be analysed, after which the randomness in variations will be checked, that is, whether the time series has a tendency. The Mann-Kendall test will be used to test hypotheses about the existence of a tendency. The said non-parametric test ranks members in the time series, where data is compared as they appear in time, according to the formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \tag{3}$$

where

$$sgn(x) = \begin{cases} 1 \ ako \ x > 0 \\ 0 \ ako \ x = 0 \\ -1 \ ako \ x < 0 \end{cases} \tag{4}$$

Mathematical expectation of the test equals zero, while variance is

$$\sigma^2 = \frac{\{\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\}}{18} \tag{5}$$

Statistics *S* is approximately normally distributed and the next transformation is applicable:

$$Z = \begin{cases} \frac{S-1}{\sigma} \ ako \ je \ S > 0 \\ 0 \ ako \ je \ S = 0 \\ \frac{S+1}{\sigma} \ ako \ je \ S < 0 \end{cases}$$

where Z is standardised normally distributed.

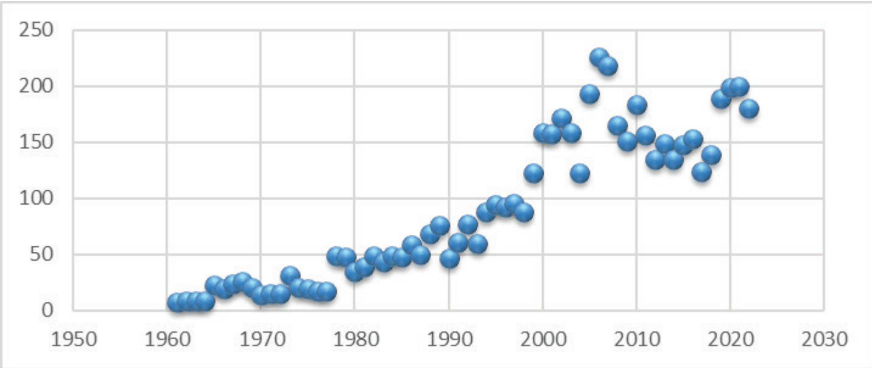
Based on measures of representativeness of the tendency, standard error and mean average deviation, the appropriate model will be selected, after which the model parameters will be evaluated.[21]

III. Results and Discussion

Chart 1 shows the overview, while Table 1 presents the basic statistics of the time series.

[21] Programmes XLSTAT and SPSS will be used for calculation.

Chart 1 Number of floods from 1960 to 2022 in the world



Source: EM-DAT database (2023)

As can be seen in Chart 1, the number of floods has an increasing tendency, which is particularly prominent in period from 1999 to 2010 when it doubled. The highest number of floods was recorded in 2006. In 2006, floods were recorded in all parts of the world, and devastating ones hit North America, the Philippines, and Central and Eastern Europe.

Table 1 Basic statistics of the time series

Statistics	No. of floods
No. of observations	62
Minimum	7,000
Maximum	226,000
1. Quartile	27,250
Median	72,000
3. Quartile	150,500
Mean value	89,177
Variance (n-1)	4366,476
Standard deviation (n-1)	66,079

Source: EM-DAT database (2023)

We will define the null and the alternative hypothesis:

Ho: Tendency of floods does not exist, that is, manifested variations of the time series are random

Ha: Tendency of floods is statistically significant, that is, manifested variations of the time series are not random

Mann-Kendall test gives the next results:

Table 2 Mann-Kendall test results

Kendall's tail	0,776
S	1463
Var(S)	27091,667
p-value (double)	**<0,0001**
alpha	0,05

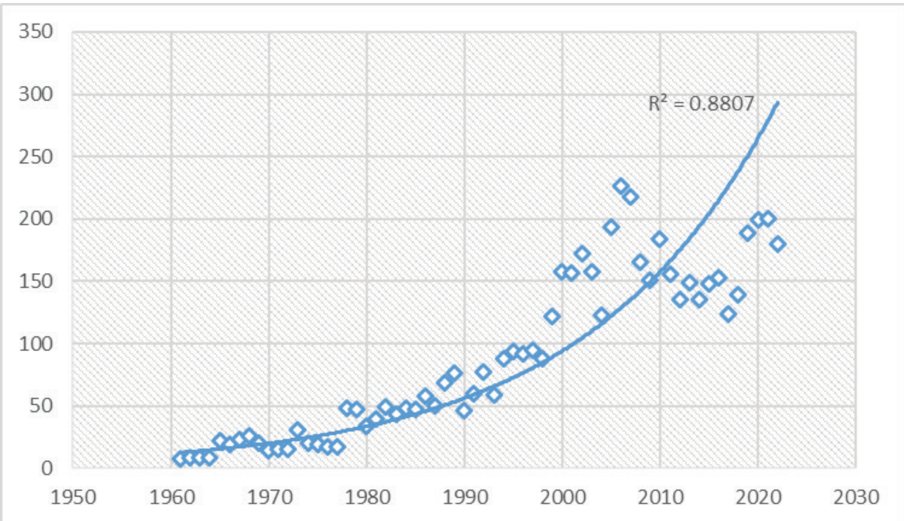
Source: EM-DAT database (2023)

Calculated p-value is less than the alpha significance level, we reject the null hypothesis and accept the alternative hypothesis, i.e. the flood tendency is statistically significant and manifested time series variations are not random.

Based on the value of the coefficient of determination and the standard error of tendency, the mean absolute deviation was calculated, which has the smallest value in case of an exponential function. Based on the estimate of the parameters, we obtain the tendency function of the number of floods:

$$Y=11{,}883e^{0{,}0517x} \quad (6)$$

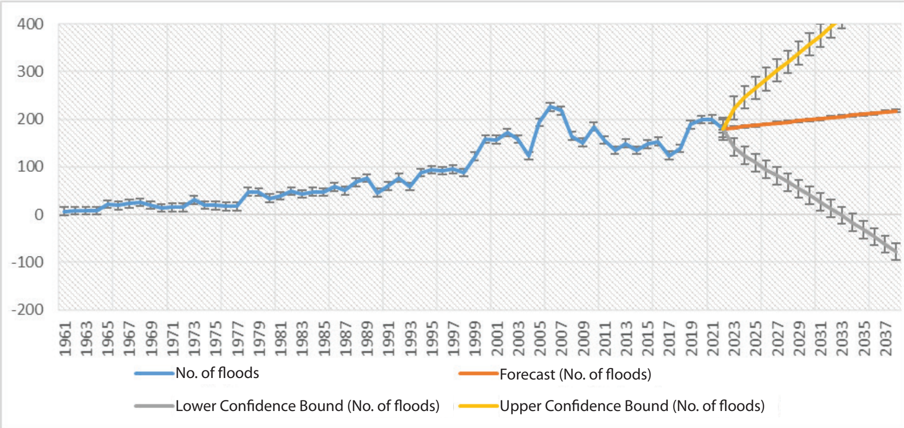
Chart 2 Tendency function of the number of floods in the world



Source: EM-DAT database (2023)

Based on the calculated regression curve, it is possible to predict the number of floods in future. Prediction was done by using the SPSS Forecasting tool with Expert Modeler and Exponential smoothing. The results are shown in Chart 3 and Table 3.

Chart 3 Prediction of the number of floods until 2032



Source: own calculation

Table 3 Prediction of the number of floods until 2032

Model		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
floodsModel_1	Estimate	185	186	186	187	188	188	189	189	190	191
	UCL	243	260	274	287	299	309	320	330	339	348
	LCL	133	121	112	104	97	91	86	81	76	72

Source: own calculation

It can be said that the significance level of 0.003 for the proposed model is acceptable, however, as it is less than 0.05 it can be concluded that there is room for improvement in the model itself.

IV. Conclusion

In the last two decades, of total number of catastrophic events, the largest number of related to weather events of a hydrological nature, caused by appearance, movement and surges of surface and subsurface fresh and salt water. As there is no universal and generally accepted methodological framework for measuring all effects of floods, most countries do not quantify them in a systematic and consistent manner, which significantly complicates their modelling and forecasting. In addition to characteristics of the risk of floods, the paper conducted research on the main characteristics of this phenomenon on the basis of empirical data.

First, based on data collected from EM-DAT database of the Centre for Research on the Epidemiology of Disasters of the *Université Catholique de Louvain*, data on mean values, minimum, maximum, mode and median number of floods in the world in the period from 1960 to 2022 were analysed. Maximum value of 226 floods was recorded in 2006, and the number of floods in that decade was more than twice as high as in the previous decade. The fact that the lowest number of floods was recorded in the first years of measurement indicates deficiencies in their recording and analysis of their effects. Lack of data is one of the main obstacles for adequate modelling of catastrophic weather events, including floods. EM-DAT database, currently the most complete database on direct damages caused by natural disasters, does not have data on damages in 63% of registered events, while in countries with a low GDP, data on damages is missing in 83% of registered events.

Based on the formed time series, the Mann-Kendall test confirmed the presence of a tendency in the number of floods. With a coefficient of determination of 0.8807 for modelling of the regression line, an exponential function was chosen. The model gives a solid basis for forecasting, but since the significance level of 0.003 is lower than 0.05, the model itself can be further improved.

Translated by
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