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WHAT COULD WE HAVE LEARNT FROM THE PREVIOUS FLOOD DATA TO PREDICT LOSSES CAUSED BY THE 1980, 1986, AND 1998 CATASTROPHIC FLOODS IN UKRAINIAN TRANSCARPATHIAN?

Abstract. *This paper explores some aspects relating to retrospective predicting the confirmed monetary losses caused by the disastrous floods of 1980, 1986, and 1998 in the Tisza River basin within the Transcarpathian region of Ukraine. The research was based on two time series – the losses because of past floods and the maxima water discharges gauged at the hydrological station near the village of Vylok, Vynohradiv district. The main aim of the research was to make out whether it had been the possibility to predict the losses due to those floods in advance.*

In solving the task, there was revealed and modelled the dependence of the risk of losses due to the floods in Transcarpathia on the maximum water discharges of the Tisza River gauged at the "Vylok" hydrological station. Predicting was based on the hypothesis of the stationary random process for maximum water discharges, which allowed using an empirical distribution function of a random variable regarding flood water discharges assessing the risk of flood losses.

Retrospective predicting of the losses caused by the floods of 1980, 1986, and 1998 was carried out by means of a combined situational-inductive predictive modelling method (CSIPMM), being an original author's development. The method relates to predicting the behaviour of complex dynamic systems based on monitoring findings presented as time series data reflecting evolutions of a resulting (dependent) variable and an explaining (independent) variable (predictor). The method uses extrapolation-regression type models. According to this method, the prediction task is performed in two stages. The first stage realises the retrospective situational modelling task aiming to obtain a set of simple regressions (situational models) built on data of sample time series. The situational models are accepted to be adequate or relevant ones only within certain periods of time determined as situations. In the second stage, based on the generalization (on an ensemble) of the obtained retrospective situational models, inductive "levels" models are built, which reflect the behaviour of a controlled parameter of the system or process (a resulting variable) at several fixed values of a predictor in time. The inductive models are used in extrapolative predicting situational models belonging to future periods (situations).

In total, three predictions were made: (1) taking into account the annual maximum flood discharges from 1954 to 1979 (before the flood of 1980); (2) the same from

1954 to 1985 (before the flood of 1986); (3) the same from 1954 to 1997 (before the flood of 1998). The study found that there had been a possibility to predict the confirmed monetary losses inflicted by the flood of 1986 and 1998 (relative predicting errors of 7.2-8.7% and 6.0-12.8% depending on the prediction options).
Keywords: *combined situational-inductive predictive modelling method; floods; flood losses; risk of losses; maxima water discharges; prediction; time series*

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1. Introduction

Floods are considered one of the key natural risk factors for human life and activity. Each year, they challenge people because of damage to the infrastructure, resources, economy, losses of personal property and crops, and threats to human health and life. In terms of the number of catastrophic events that occurred during 1998-2017 in the world, floods outweigh any other natural disasters, including storms, earthquakes, heatwaves, landslides, droughts, forest fires, volcanoes, and more. The number of disastrous floods in the world in that period exceeded 3,000 (3,148 or 43.4% of all loss-related natural catastrophes), and the number of people affected per them in 1998-2017 was near 2.0 billion (45% of all injured through natural disasters) [1]. Overall worldwide losses caused by flood events 1980-2019 reached US$ 1,092bn, and only 12% of these losses were insured [2]. The number of worldwide deaths because of floods in 1998-2017 exceeded 142,000 (11% of all-natural disasters) [1]. According to the Red Cross for the period 1971-1995 the flood events have killed annually on average more than 12,700 people worldwide, affected 60 million others, and caused 3.2 million people to become homeless [3]. Generally, according to estimates [4], floods were responsible for about 6.8 million deaths in the 20th century. In turn, annual economic worldwide losses from floods have already reached US$ hundreds of millions [5]. Since 1990, there have been over 30 floods, in each of which either the material losses exceeded one billion USD, or the number of fatalities was greater than 1,000, or both [5].

Floods are specific natural disasters. They occur because of water overloading landscapes as a result of "the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged" [6]. However, in addition, floods happen when areas used by humans are flooded and losses occur. The problem is that, these landscapes (valleys of rivers, sea coastal areas, lakeshores, etc.) have been considered traditionally by humans as an especially priced land resource for settlement, urbanization, and using in economic activity. Properly, human settlements were formed historically on lands surrounding water bodies [7]. In total, nowadays, about 1.47 billion people, or 19% of the world population, live in flood-prone locations, whereas their area is only about 3 million km^2 [8]. Moreover, people have challenged floods too. For centuries, people have managed flood risks by using specialised infrastructures, such as dams, river dykes and levees, dunes, drainage systems, and others [9, 10], as well as applying so-called nature-based solutions mitigating floods [11]. This may be explained not only by the increase in the general deficit of land resources in the world, in particular, due to declining soil fertility in large areas of the globe, increasing soil erosion processes of various etiologies, etc. [12]. The unique combination of land and water resources gives special value to flood-prone areas. Therefore, floods are happening and intensifying through the accelerated urbanization of landscapes prone to be submerged by floods, despite people fearing floods [13], albeit accepting flood risk, doing it consciously because intending benefits of using valuable land resources.

Floods can belong to various event types; they can have various origins, causes, triggers and driving mechanisms, space-time dynamics, trends, etc. [11, 14-16]. For example, in terms of flood-prone area location, they can be broadly categorized as *coastal floods*, *inland floods*, and *compound floods* [16]. Coastal floods [16-19] arise along the coasts of oceans, seas, lakes, reservoirs, and in river deltas [20]. They are caused by (a combination of) tidal waves, storm surges, heavy rainfall, and strong onshore winds [11, 14-16]. Inland floods can be categorized into *riverine floods*, *urban floods*, and so-called *flash floods* [11, 14-16]. Riverine (river or fluvial) floods occur within fluvial (river) catchments [14, 15, 21, 22]. They can be caused by excessive rain, often from oceanic storm systems such as tropical cyclones [23], as well as because of rapid snow-melting and heavy rainfall supplemented by snowmelt. Urban (or pluvial) floods come about within urban settlements due to heavy rainfall or rapid snow melting combined with poor urban planning and the insufficient capacity of the drainage systems to control inundation [11, 16, 24-26]. Flash floods are associated with high and steep topographic relief, high magnitude and short duration precipitation and rapid concentration of streamflow in channel networks [27-31]. Finally, compound floods, according to [16], occur within coastal areas and can have attributes of different floods: coastal, riverine, urban, flash ones. They occur due to the interaction between physical drivers from multiple sources including terrain features, hydraulic, hydrological, and meteorological processes [32, 33]. Totally, anthropogenic warming and climate change, sea level rise, and increased impervious surface area due to urbanization have led to a significant increase in compound flooding over the last century, especially in major coastal cities [16, 32, 33].

Flooding origins depend on the water source and on the reasons and processes causing the water level to rise including spatial patterns and characteristics of flood seasonality (warm or cold periods etc.) [22, 34-36]. In particular, in terms of origin and drivers, riverine floods can be triggered and developed by hydrometeorological conditions through precipitation, temperature, evaporation, snow accumulating and melting processes, and high soil moisture [11, 16, 21, 22, 35, 36]; coastal floods – by high tides, combined with low atmospheric pressures and strong winds inducing a storm surging [16-19, 37]. There are also many unusual flood cases [2], including groundwater flooding caused by high seepage through permeable, river-connected alluvial aquifers [38-40], tsunamis flooding [41], floods because of dam disasters [42-44], dike and levee breaches [45, 46], floods caused by landslide dam collapses [47] and glacial lake outburst floods [48], backwater floods [49, 50], debris flows and mudflows floods [51, 52], etc.

Floods challenge often people harmfully, but flooding is regarded as a natural hazard against which precautionary measures are most effective compared with other natural hazards [2, 9-11]. The best world and European practices on flood prevention, protection and mitigation stimulated the Directive 2007/60/EC [53] being developed, which alleges: "Floods are natural phenomena which cannot be prevented. However, some human activities (such as increasing human settlements and economic assets in floodplains and the reduction of the natural water retention by land use) and climate change contribute to an increase in the likelihood and adverse impacts of flood events". It signifies that flooding hazard may be managed. Numerous data indicate the efficiency of different flood control measures [54-58].

As well, special scientific studies promote to their global implementation, in particular, due to more reliable flood forecasting [59-61], hydrological and hydraulic modelling for flood management [62, 63], as well as flood emergency planning, flood mapping, and resolving flood early warning issues [64-66], because of more detail flood risk analysis and assessing [67-69], diversification of flood risk management strategies [70] and implementing integrated flood risk management [71, 72] including nature-based solutions [11, 69, 73], accounting for local socio-economic and cultural differences when designing flood risk strategies [74-78], as well as supporting decision making in flood-prone zones [79, 80] and exploring methodological approaches for strengthening the resilience of flood protection systems [81], etc. As well as, different practical tools and guidance on flood management issues have been developing. For example, promoting the concept of Integrated Flood Management (IFM) as a new approach to flood management and providing guidance and advisory materials to realise it, the World Meteorological Organization (WMO) and the Global Water Partnership (GWP) have developed Integrated Flood Management Tools Series within the Associated Programme on Flood Management [82]. We have mentioned some of the tools [64, 65, 71]. Totally, the tools [82] cover majority of flood management issues.

In addition, flood risk management programs and plans within selected river basins are being developed and kept up to date, internationally, nationally, and locally. In Europe, these are, for example, the Flood Action Programme and Flood Risk Management Plan for the Danube River Basin [83, 84], Sub-Basin Level Flood Action Plan for the Tisza River Basin [85], Internationally Coordinated Flood Risk Management Plan for the International River Basin District of the Rhine [86], Flood Risk Management in Austria [87], the Kent Local Flood Risk Management Strategy [88]. As a result, in Europe, the overall trend in losses (after adjustment for increases in values) has fallen – despite repeated severe floods, such as those in 2002 and 2013 [2, 89, 90]. There are likewise indications in North America and China that protective measures have reduced adjusted losses [2].

Ukraine also suffers from floods in a harmful way. Among natural disasters, floods are the most common in terms of frequency, area of distribution, and losses in the country [91]. The area of lands affected by floods in Ukraine is almost 165,000 km^2 (more than 27 per cent of the country's territory), and about a third of Ukraine's population lives in the flood-prone areas [92, 93]. The most threatening flood types in Ukraine are riverine floods [92]. However, increasingly, flash and urban floods occur as well, especially regionally, due to climate change, high-intensity land use, and urbanization [94, 95]. The brief characteristic of disastrous floods in the most flood-prone country's regions is shown in Table 1.

Especially often disastrous floods occur in the western regions of the country, on the Carpathian rivers [91-97]. Catastrophic floods in the Ukrainian Carpathians are an inherent element of the hydrological regime of local rivers [97]. They can cover large areas and inflict large losses. In general, the territory of the Ukrainian Carpathians (Tisza, Dniester, Prut, and Siret basins) is one of the most flood-prone regions in Europe and the world [96].

This article deals with flooding in Ukrainian Transcarpathia. In Ukraine, the Transcarpathian region seems to be characterized by the highest risk of catastrophic floods [85, 96, 97]. There have been at least 26 of them since 1779, including about 17 in the 20th century. In particular, since 1970, the most devastating floods in Transcarpathia have been marked in 1970, 1978, 1980, 1986, and 1998. In general, the flood load in the Transcarpathian region within the Upper Tisza basin is estimated to be 2-3 times higher compared to the adjacent areas of the Tisza basin belonging to neighboring countries: Romania, Hungary, and Slovakia [85].

Table 1 – The brief characteristic of disastrous floods in Ukraine [96]

Regions	River basins	Features of floods	Recurrence of floods (years)	Maximum runoff modules of 1% exceedance probability ($m^3/s \cdot km^2$)
Trans-carpathia	Tysza basin	Spring, autumn-winter thaw-rainy floods; summer rainy floods	3-7	2.0-2.5 from an area of 100-200 km^2; 1.0-2.0 from an area of 250-400 km^2
Pry-karpattia	Right bank of Dniester; Prut and Siret basins	Spring thaw-rainy floods; summer rainy floods. Summer floods exceed spring ones	3-7	2.5-3.2 from an area of 100-200 km^2; 1.0-2.2 from an area of 200-500 km^2
Polissya, Podillya	Right bank of Pripyat; Western Bug basin; left bank of Dniester	Spring thaw-rainy floods; summer rainy floods. Summer floods are near spring ones	7-14	0.2-0.6 from an area of 400-600 km^2

The aim of the article was to explore whether it had been the realistic possibility to predict confirmed monetary losses caused by the floods of 1980, 1986, and 1998 in the Transcarpathian region based on available monitoring data, in particular, regarding losses through previous floods, as well as of maxima water discharges gauged at the hydrological station (HS) near the village of Vylok, Vynohradiv district. It should be noted the proper organization of flood monitoring [98] with a comprehensive assessment of flood losses [99, 100] has been considered an important component of modern, holistic flood management strategies [11, 70-72, 75-81]. In turn, predicting possible flood losses across monitoring data is expected to contribute to effective decision-making within these strategies in order to prevent and minimise the losses in future.

2. Case study

The Tisza River Basin is the largest sub-basin in the Danube River Basin, covering 157,186 km^2 (19.5%) of the Danube Basin [85]. The drainage area of the Ukrainian part of the Tisza catchment is 9,530 km^2 [94] (about 6% of the Tisza basin). It is the upper, mostly right bank part of the Tisza basin (Fig. 1), which is totally located within one Ukrainian administrative unit – the Transcarpathia region.

The hydro-net in Transcarpathia includes 9,426 rivers and streams with a total length of 19,793 km long [85, 97]. Of these, 153 rivers have an overall length of 3,555 km, and four of them – Tisza, Borzhava, Latorica, and Uzh – are each over 100 km long [85]. The average river network density is 1.7 km/km^2, which is the highest density of rivers in Ukraine [85, 97]. About 80% of the Transcarpathia area is mountainous terrain and 20% is flatlands. The altitude of the Upper Tisza catchment ranges between 90-95 m above sea level (a.s.l.) at the outlets and 2,100 m a.s.l. in the headwaters. The percentage of area with an elevation above 600 m a.s.l. is over 70% [94]. The steepness of the mountains and the impermeability of the underlying bedrock contribute to high surface runoff rates. On contrary, in the flatter parts of the region (Transcarpathian Lowland connecting Ukraine with Hungary and Slovakia), the land is so flat that dense networks of drainage ditches are needed to drain shallow water after floods [85]. Generally, much of the Transcarpathia population of approximately 1.2 million lives in flood-prone areas, in particular, in the flatter parts of the region.

Fig. 1. Map-scheme of the Ukrainian part of the Tisza River basin (taken from [85])

The hydrological regime of the Tisza catchment is snow-melting, rainfall-driven, and combined thaw-rainy [94, 96]. Most floods occur in autumn-winter and spring (cold) seasons (in recent years the majority of floods occurred in November-December and spring months) and are generated by a combination of rapid increase in the air temperature, causing snow melt, and heavy rainy or snow-rainy precipitation events [94]. In particular, catastrophic floods in Transcarpathia – in cold periods (November-May) – occurred in 1957, 1970, 1978, 1986, and 1998. Among disastrous floods, which occurred in summer, it should be noted probably one, the unique destructive flood of 1980 (late July) [101]. Generally, it should be noted that the Carpathians are situated in the semi-humid and humid climatic zone. In Chop (102 m a.s.l.), it falls 700 mm of vertical precipitation per year, at the meteorological station Ruska Mokra (640 m a.s.l.) in Gorgan Mountains it reaches 1600 mm. To this quantity it may be also added about 200 mm of horizontal precipitation from moisture condensation of fog and hoar-frost in the forests [97]. Often heavy rainfall cover the entire region at the same time, and in just one-three days an amount of precipitation can reach 2-3 monthly norms – as much as 150-250 mm and 34 mm in just two hours [102]. Although, hydrometeorological phenomena last usually for 12-24 hours only, but due to the characters of catchment surface they may trigger floods repeating 3-8 times per year [96].

3. Materials and input data. Data analysis and making assumptions

When researching, the different available information on floods in the Transcarpathia region was used. First of all, those were available historical data on the relatively recent floods that occurred in the region from 1955 to 1998. It was reviewed and analysed a wide range of different facts relating to those floods, including data on their drivers and consequences (losses). The basic information on those floods was obtained from scientific publications and regulatory documents, which are presented in the references [91-97, 101, 102]. As well, it would like to apologize to authors whose works were not mentioned in the references. Useful information, after its proper verification, was obtained also due to the Internet, from relevant information and analytical notes and reviews, etc. Hydrological data concerning the maxima water discharges of the Tisza River at the hydrological (gauging) station (HS) "Vylok" were taken from the Hydrological Yearbooks of the Central Geophysical Observatory named after Boris Sreznevsky [103]. As well as, Table 2 shows the available data on confirmed monetary losses due to floods occurred in the Transcarpathian region in 1955-1998.

Table 2 – Summarised data on floods occurred in the Transcarpathian region from 1955 to 1998: *Q* is maxima water discharges of the Tisza River gauged at the HS "Vylok", and *L* is confirmed monetary losses due to floods

Years	Q (m^3/s)	L (UAH millions)	Years	Q (m^3/s)	L (UAH millions)
1955	2 742	43.7	1973	783	23.5
1957	2 410	21.3	1974	2 560	33.6
1958	2 600	9.8	1975	1 500	87.9
1965	2 070	14.2	1976	1 350	60.1
1967	1 860	10.9	1977	1 860	85.2
1968	2 930	10.4	1978	3 060	115.8
1969	1 420	34.4	1979	2 720	64.4
1970	3 650	237.0	1980	2 070	325.0
1971	1 310	35.5	1986	2 050	127.9
1972	1 790	24.0	1998	3 150	810.0

Input data regarding the monetary losses by UAH, which are shown in Table 2, were calculated in prices for 2010. The hydrological time series includes also the years 1954, 1956, 1959-1964, 1966, 1981-1985, 1987-1997, and 1999.

Fig. 2 shows the visualization of the time series presenting the monitoring data: (A) for the maxima water discharges gauged at the HS "Vylok" from 1954 to 1999; (B) for the confirmed monetary losses due to floods in the Transcarpathian region from1955 to 1998 (in logarithmic coordinates).

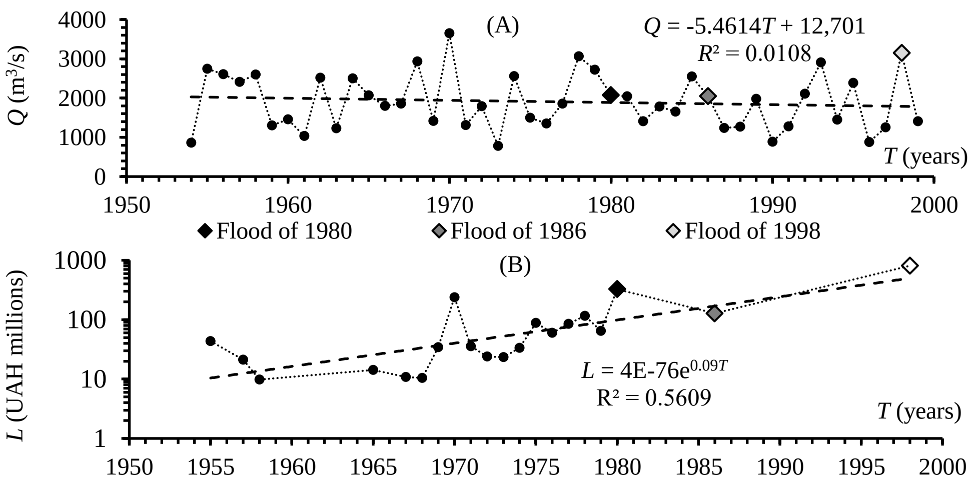

Fig. 2. Visualization of the available monitoring data as time series

Trend analysis shows the selected time series of losses due to floods (Fig. 2A) is non-stationary. It can be characterized by a growing exponential trend with the coefficient of determination $R^2 = 0.5609$. On the contrary, a trend in the selected time series of the observed maxima water discharges of the Tisza River is practically absent. This time series (Fig. 2B) can be assumed to be stationary.

Assuming the stationary of the selected time series of data regarding maxima water discharges allows applying the hypothesis of a random variable to analyse them. In particular, for a maxima water discharge value observed in the past, an empirical probability of exceedance P_{ex} may be attributed, namely, the probability (or risk) that the water discharge value could have been exceeded within a certain period of time. It can also be assumed that if the maxima water discharges of floods that caused losses in the past had appeared greater than they really observed, the losses would have been greater too.

The above-mentioned assumptions allow determining risks of losses $R(L)$ caused by past floods as products of empirical probabilities of exceedance P_{ex} of the observed maxima water discharges and confirmed losses L:

$$R(L) = P_{ex} \cdot L \,. \tag{1}$$

In this study, the probabilities P_{ex} were calculated with two formulas:
according to Chegodayev formula

$$P_1(m) = \frac{m - 0.3}{n + 0.4}, \tag{2}$$

and for Weibull formula (known also as Kritsky-Menkel's formula)

$$P_2(m) = \frac{m}{1 + n}, \tag{3}$$

where m is the ordinal number of a member ranked in descending order of variation series; n is the total number of members of the variation series.

The values of empirical probabilities of exceedance obtained with formulas (2), (3) were averaged so that $P_{ex} = (P_1 + P_2)/2$. Fig. 3 shows results of P_{ex} calculations for three time intervals of hydrological observations of the Tisza River maximum water discharges gauged at the HS "Vylok".

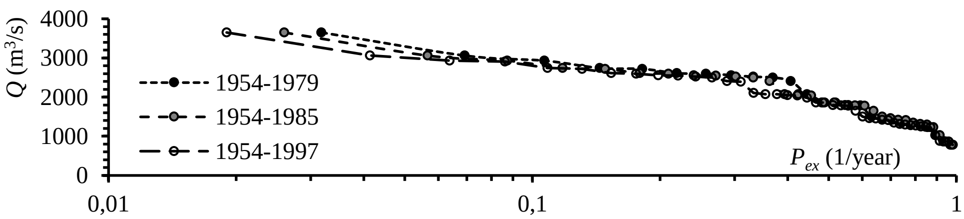

Fig. 3. Curves of empirical exceedance probabilities of the gauged maximum water discharges

Trend analysis of the time series of the calculated risks of confirmed monetary losses due to floods of 1955-1998 (See below Fig. 4) indicates this time series is non-stationary as well. However, its non-stationary appears to be weaker compared with the non-stationary of time series of the losses (Fig. 2B). In addition, some sample time series of the calculated risks of losses, for example due to the floods of 1965-1969, 1970-1974, 1970-1979, may be considered as nearly stationary ones.

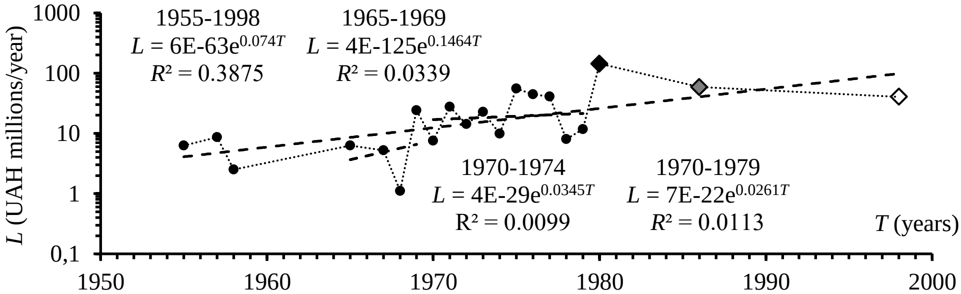

Fig. 4. Visualization of the time series of the risks of confirmed monetary losses

Comparing the results of trends analysis in the selected time series of losses (Fig. 2B) and risks of losses (Fig. 4) due to floods in Transcarpathia, it may be assumed the amounts of confirmed monetary losses are more time-dependent than the corresponding values of risks of losses. On the contrary, the values of risks of losses are more dependent on values of maxima discharges of floods than amounts of losses depend on them. Fig. 5 clearly reveals these patterns.

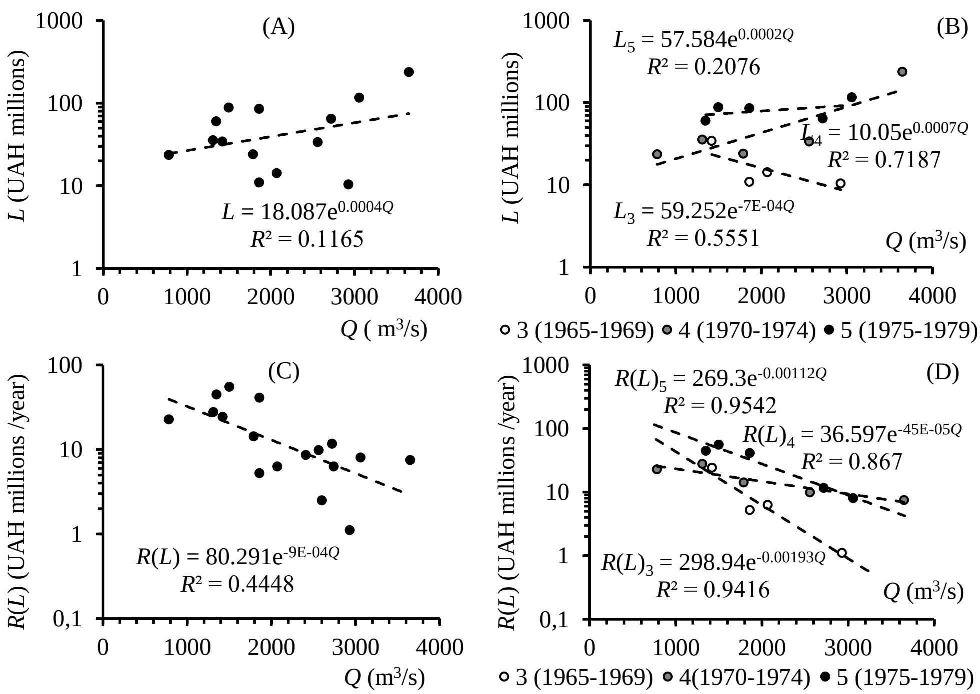

Fig. 5. Visualization of the $L = f(Q)$ and $R(L) = f(Q)$ regressions

It should be also noted the regression dependence of the risks of losses due to floods on the maxima water discharges gauged at the HS “Vylok” can be the most substantive within time intervals of 4-10 years. So, in the intervals of 1965-1969 (the index of 3), 1970-1974 (4), and 1975-1979 (5), the R^2 coefficients of determination for the regressions of $R(L) = f(Q)$ (Fig. 5D) were 0.9416, 0.867, and 0.9542, correspondingly. It may be assumed while predicting the risk of flood losses in Transcarpathia in the time intervals of 4-10 years, the time factor may not be accounted for. As predictive models at such intervals simple exponential regressions can be used, where the risk of flood losses is considered a dependent variable, and maxima water discharge of the Tisza River an independent variable.

4. The research objectives and methods

In order to figure out whether there had been the realistic possibility to predict the monetary losses caused by the destructive floods of 1980, 1986, and 1998 in Transcarpathia based on the available information and monitoring data (Table 2), the following research objectives were set: (1) to review the available information on floods in the Transcarpathian region and perform the time series analysis of available data, namely, the time series of the maxima water discharges gauged at the HS “Vylok” from 1954 to 1999, and the confirmed monetary losses, which were caused by floods in the region from1955 to 1998; (2) to make scientific assumptions on the problem and choose a basic predictive model and its variables; (3) to apply the combined situational-inductive predictive modelling method (CSIPMM) to solve the problem of predictions for the losses due to floods in the Transcarpathian region; to assess its predictive efficiency within the available data on the floods that preceded the disastrous floods of 1980, 1986, and 1998, and perform the three retrospective predictions for the losses caused by floods of 1980, 1986, and 1998, namely, taking into account data on the annual maximum flood discharges from 1954 to 1979 (before the flood of 1980), from 1954 to 1985 (before the flood of 1986), from 1954 to 1997 (before the flood of 1998); (4) to analyse the findings of the performed predictions and assess their relative errors.

Different methods within the holistic approach [103] to the problem under study were used: historical method; method of dialectical cognition and generalised scientific methods of theoretical and empirical research; heuristic methods; methods of analysis and synthesis; methods of expert evaluation and comparison; methods of formalization and modelling; as well as specific methods for time series analysis [104], intelligent data analysis [105, 106], and applied predictive modelling [107, 108] methods of modelling and decision making under risk and uncertainty [43, 109-111].

The basic research method was the combined situational-inductive predictive modelling method (CSIPMM), which is an original author’s development. The main provisions of the CSIPMM are set out in [112-114]. Moreover, in practice, this method was used in situational predictive modelling of the flood hazard in the Dniester river valley near the town of Halych [115] and prognostic modelling of piezometric levels based on seepage monitoring in an earthen dam [116].

The method of the CSIPMM is oriented to use extrapolation-regression type models to predict the behaviour of complex dynamic systems or processes under non-stationarity, data incompleteness, as well as structural and parametric uncertainty. The main idea of the CSIPMM is a purposeful decomposition of a complex prediction problem based on monitoring data presented as time series to apply relatively simple predictive models.

According to this method, the complex prediction problem is solved in two stages (Fig. 6). The first stage (A) realises the retrospective situational modelling task aiming to obtain a set of simple regression-extrapolations built on data of sample time series [112-116]. Fig. 5 shows an example of such retrospective situational modelling in the frame of the problem under study. The obtained situational models assume to be adequate or relevant ones only within certain periods of time being determined as situations. That is, the evolution of the dynamic system (process) is modelled in the context of its "movement" through a series of situations resulting from various reasons or actions. A complete description of the infinite set of all possible situations the system functioning is replaced by a certain finite set of generalized model situations that reproduce to a certain degree its possible states [117-119]. These model situations (by R. Reiter [118]) do not determine literally appropriate states of the system; they are presumed to show only the history of certain real events as completed sequences of actions in certain periods of time. Since real situations cannot be described totally, and it is possible to consider only some of their aspects, the non-monotonic output rule is used to describe the evolution of the dynamic system (process). Thereby, it is assumed (by J. McCarthy [117]) that on the basis of past facts, with which past model situations are described, and on using some general rules or assumptions, according to which actions and events within those situations take place, it is possible to predict some similar situations that will appear in the future.

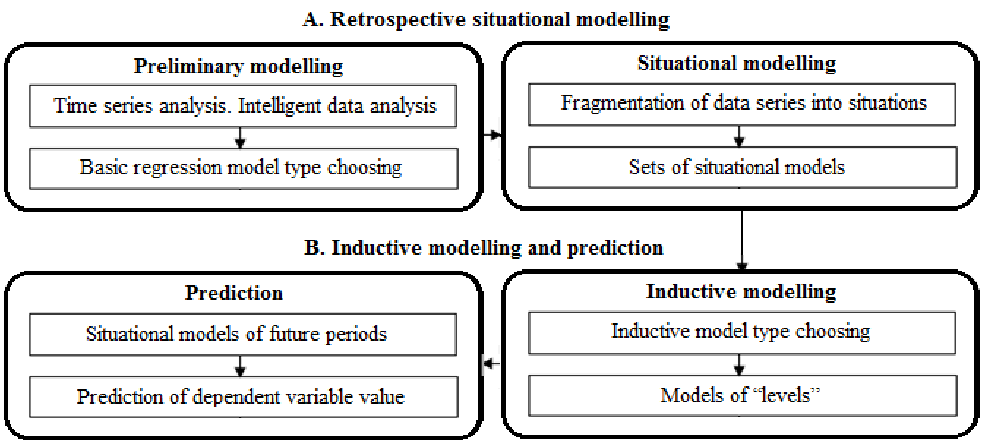

Fig. 6. Flow-chat representing the CSIPMM

It should be mentioned, situational modelling is popular today in economics, medicine, military affairs, forensics, politics, and other similar spheres, as well as in artificial intelligence, where the development of a logical approach to modelling the behaviour of complex dynamic systems and processes led to the creation of the special situational calculus theory [119].

In many applied studies relating to natural and man-made systems and processes situational models being built on sample data and adapted to limited time periods may be presented as simple (single-factor) regression models [112-116]. To realise this, unknown and uncontrollable factors being capable affecting the structure and parameters of a situational model are considered a peculiar relatively unchangeable predictive background. Thereby, in fact, the predictive background reflects certain stable conditions in which the system (process) develops in a certain period of time, and, accordingly, determines the only specific situation and the only specific situational model [112-116].

The second stage (Fig. 6) realises the inductive modelling and prediction tasks. The inductive modelling task is reduced to generalization of the findings of retrospective situational modelling in the form of an inductive model of "levels" corresponding to some fixed predictor values (Fig. 7A). The inductive model of "levels" (Fig. 7A) is further considered as a tool for performing an extrapolation prediction of a future situation (or a set of situations), thereby predicting possible situational models of future periods. Actually, the main task of predicting based on monitoring data according to the CSIPMM is to solve the problem of extrapolation, which consists in establishing the most probable situational model matching up with a certain expected situation in the future (Fig. 7B).

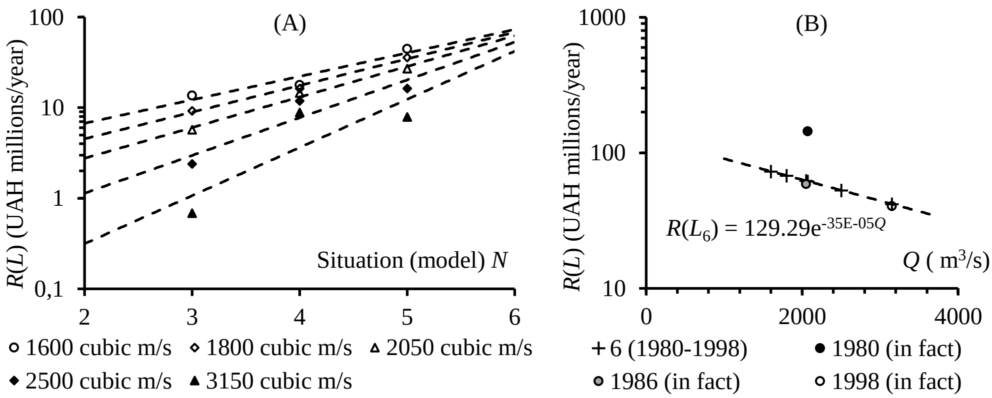

Fig. 7. Results of inductive modelling and establishing the prospective situational model $R(L_6)$

Ultimately, the obtained prospective situational model is used to predict the values of the resulting variable.

5. Results

In total, three options for the prediction were made: (1) taking into account the annual maximum flood discharges from 1954 to 1979 (before the flood of 1980); (2) the same from 1954 to 1985 (before the flood of 1986); (3) the same from 1954 to 1997 (before the flood of 1998). It should be noted the exceedance probability empirical estimates of the discharges vary with the duration of hydrological observations (See Fig. 3). Therefore, it can be expected that the obtained results can differ depending on the selected predicting options.

In order to assess the predictive (forecast) skill of the retrospective situational models (3), (4), (5), and the prospective situational model (6) taking into account the choice of the dependent (risk of losses) and independent (maximum water discharge) variables, as well as the structure of the situational model (one-factor regression) and the regression type (exponential function) the Nash-Sutcliffe model efficiency coefficient (NSE) was used [120]. It is widely applied for assessing the goodness-of-fit and predictive power of hydrological models [121].

The NSE coefficient value was calculated as:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (L_{o,i} - L_{p,i})^2}{\sum_{i=1}^{n} (L_{o,i} - \overline{L}_o)^2}, \tag{4}$$

where $L_{o,i}$, $L_{p,i}$ are observed and predicted values of losses because of a flood i, $i = \overline{1,n}$; n is the number of floods being analysed to predict losses; $\overline{L}_o$ is the mean of the observed losses $L_{o,i}$.

Predicted values of losses were calculated with the formula

$$L_{p,i} = \frac{R(L_{p,i})}{P_{ex,i}}, \tag{5}$$

where $R(L_{p,i})$ is the predicted value of the risk of losses because of a flood i and $P_{ex,i}$ is the empirical probability of exceedance of an observed (gauged) maxima water discharge Q_i of the flood i causing the losses $L_{o,i}$.

It is thought [120] that values of the NSE nearer to 1 suggest a model with more predictive skill. An application of the NSE coefficient in regression procedures (NSE_R) was also used, which was equivalent to the coefficient of determination R^2 of the simple linear regression $L_p = f(L_o)$.

5.1. The results of predicting taking into account the annual maximum flood discharges from 1954 to 1979 (Prediction 1, before the flood of 1980)

The retrospective situational models of the risks of monetary losses caused by the floods of 1965-1969 (situation 3), 1970-1974 (situation 4), and 1975-1979 (situation 5) taking into account the annual maximum water discharges from 1954 to 1979 (before the flood of 1980) are shown in Fig. 5D. In turn, Fig. 7 shows the results of inductive modelling carried out to establish the prospective situational model (situation 6), which was used to predict the risks of monetary losses caused by the floods of 1980, 1986, and 1998. Inductive modelling was performed for “levels” that corresponded to the fixed values of maximum water discharges amounting to 1600, 1800, 2050, 2070, 2500, and 3150 m^3/s. Note, that the discharges of 2070, 2050, and 3150 m^3/s included in the ensemble of “levels” were observed in 1980, 1986, and 1998, respectively.

Below, Table 3 comprises the numerical results of the retrospective prediction of the monetary losses due to the floods that occurred from 1965 to 1979. In particular, they were used to assess the quality, and predictive skill of the retrospective situational models (3), (4), and (5).

Table 3 – The numerical results of retrospective predicting the monetary losses due to the floods of 1965-1979

Years	Q (m^3/s)	P_{ex} (1/year)	$R(L_p)$ (UAH millions/year)	L_p (UAH millions)	L_o (UAH millions)
1965	2 070	0.44	5.50	12.4	14.2
1967	1 860	0.48	8.25	17.1	10.9
1968	2 930	0.11	1.05	9.8	10.4
1969	1 420	0.71	19.29	27.3	34.4
1970	3 650	0.03	7.08	222.9	237.0
1971	1 310	0.78	20.30	26.0	35.5
1972	1 790	0.59	16.35	27.5	24.0
1973	783	0.97	25.73	26.6	23.5
1974	2 560	0.29	11.56	39.3	33.6
1975	1 500	0.63	50.19	79.5	87.9
1976	1 350	0.74	59.37	79.9	60.1
1977	1 860	0.48	33.54	69.7	85.2
1978	3 060	0.07	8.75	126.3	115.8
1979	2 720	0.18	12.80	70.5	64.4

The check revealed the NSE coefficient to be 0.973. The NSE_R coefficient (See below Fig. 9A) is 0.974. So, the predictive skill of the retrospective situational models (3), (4), and (5) shown in Fig. 5D is quite good.

Table 4 comprises the modelled (predicted) values of the risks of monetary losses caused by the floods of 1965-1969 (situation 3), 1970-1974 (situation 4), and 1975-1979 (situation 5). They were computed on the set presenting six “levels” of the fixed values of maximum water discharges amounting to 1600, 1800, 2050, 2070, 2500, and 3150 m^3/s by means of the situational models shown in Fig. 5D. Further, these modelled values of the retrospective situational risks were used to build the inductive model of “levels” with extrapolation one step forward (to the next situation 6) (Fig. 7A) to get the prospective situational model 6 (Fig. 7B).

Table 4 – The modelled values of the retrospective situational risks of monetary losses $R(L_p)$ depending on the fixed values of water discharges Q

Situations (situational models) N = 3, 4, 5 (years)	$R(L_p)$ (UAH millions/year) computed for Q (m^3/s)					
	1 600	1 800	2 050	2 070	2 500	3 150
3 (1965-1969)	13.63	9.26	5.72	5.50	2.40	0.68
4 (1970-1974)	17.81	16.28	14.55	14.42	11.88	8.87
5 (1975-1979)	44.87	35.87	27.11	26.51	16.38	7.91

The numerical results of inductive modelling to get the prospective situational model 6 (Fig. 7B) are given in Table 5. The prediction results of the monetary flood losses caused by the floods of 1980, 1986, and 1998 taking into account the annual maximum flood discharges from 1954 to 1979 with the comparison with their observed (confirmed) values are given below in Table 6 and Fig. 8. The predicted values of the losses were calculated with the formula (5).

Table 5 – The numerical results of inductive modelling to get the prospective situational model 6 (for the situation with the number $N = 6$)

"Levels" of Q (m^3/s)	Equations for the chosen "levels" of the inductive model depending on a situation with the number N	Coefficients of determination R^2	$R(L_p)$ (UAH millions/year), $N = 6$
1 600	$R(L) = 2{,}0452e^{0{,}5958N}$	0.908	72.99
1 800	$R(L) = 1{,}1714e^{0{,}6768N}$	0.991	67.97
2 050	$R(L) = 0{,}5836e^{0{,}778N}$	0.987	62.14
2 070	$R(L) = 0{,}552e^{0{,}7861N}$	0.983	61.71
2 500	$R(L) = 0{,}1665e^{0{,}9603N}$	0.871	52.93
3 150	$R(L) = 0{,}0272e^{1{,}2235N}$	0.715	41.95

The check of the predictive power of the combined situational-inductive predictive modelling method (CSIPMM) for modelling and predicting the losses caused by floods in the time interval from 1965 to 1998 revealed the NSE coefficient to be 0.939. The NSE_R coefficient (in regression procedure, see below Fig. 9B) is 0.943. The NSE and NSE_R coefficient values confirm the quite high predictive efficiency of the CSIPMM to solve the presented problem.

Table 6 – The observed and predicted losses due to the floods of 1980, 1986, 1998

Years	Q (m^3/s)	P_{ex} (1/year)	L_o (UAH millions)	$R(L)$ (UAH millions/year)		L_p (UAH millions)	E_r (%)
				Actual	Predicted		
1980	2 070	0.44	325.0	144.24	62.65	141.2	56.6
1986	2 050	0.46	127.9	58.83	63.09	137.2	7.2
1998	3 150	0.05	810.0	40.50	42.93	858.6	6.0

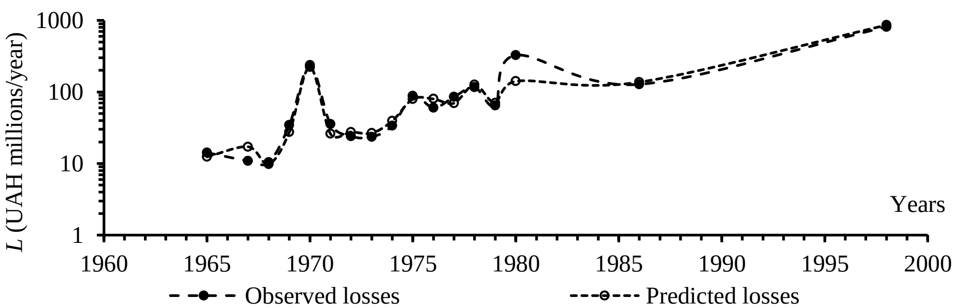

Fig. 8. Visual comparison of time series of the observed (confirmed) and predicted values of monetary losses because of the floods from 1965 to 1998

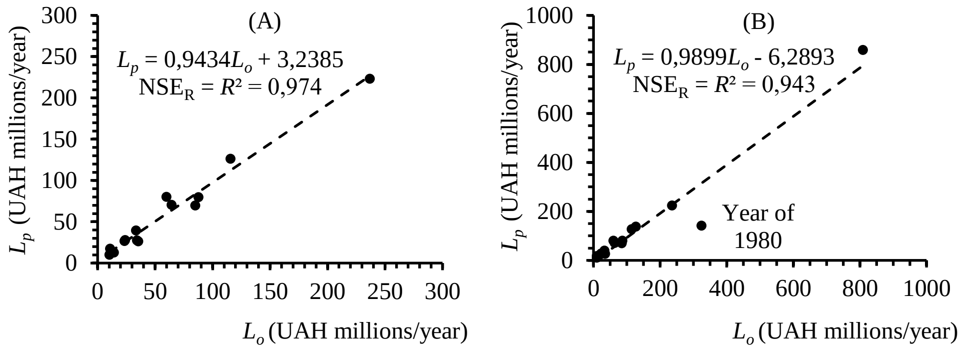

Fig. 9. Visual illustration of the CSIPMM goodness-of-fit check to predict losses using the Nash-Sutcliffe efficiency coefficient in regression procedure (NSE_R)

The relative prediction errors E_r (%) were calculated with the formula

$$E_r = \frac{|L_o - L_p|}{L_o} \cdot 100\%, \quad (6)$$

where L_o is the observed (conformed) and L_p is the predicted values of losses.

The results of predicting the monetary losses caused by the floods of 1980, 1986, and 1998 in the Transcarpathian region according to the time series of the losses due to floods of 1965-1979 and the maximum water discharges gauged at the HS "Vylok" from 1954 to 1979 indicate that there was the possibility to predict the losses because of the flood of 1986 (a relative error of the prediction E_r = 7.2%) and the flood of 1998 (E_r = 6.0%) with good accuracy. With regard to the losses due to the flood of 1980 (E_r = 56.6%), it should be noted that the prediction in total (L_p = UAH 141.2 million, in the maximum water discharge Q = 2,070 m^3/s) indicates that they would have exceeded eventually the losses due to the flood of 1978 (L_o = UAH 115.8 million, Q = 3,060 m^3/s). The main factor most likely affected the prediction accuracy was that the flood of 1980 occurred in the warm season (summer), which is a rather atypical phenomenon in Transcarpathia [101]. It can be assumed that the predicted value of the losses caused by the flood of 1980 corresponds more to the hypothetical situation of the cold period flood.

5.2. The results of predicting taking into account the annual maximum flood discharges from 1954 to 1985 (Prediction 2, before the flood of 1986) and from 1954 to 1997 (Prediction 3, before the flood of 1998)

Below, Fig. 10 summarises the results relating to Prediction 2 and Prediction 3 in graphical form. These predictions were also performed on the basis of the time series of the confirmed monetary losses due to the floods that happened in the interval from 1965 to 1979. There were considered the same situational time intervals 1965-1969 (situation 3), 1970-1974 (situation 4), and 1975-1979 (situation 5), and similar situational-inductive models by type and structure.

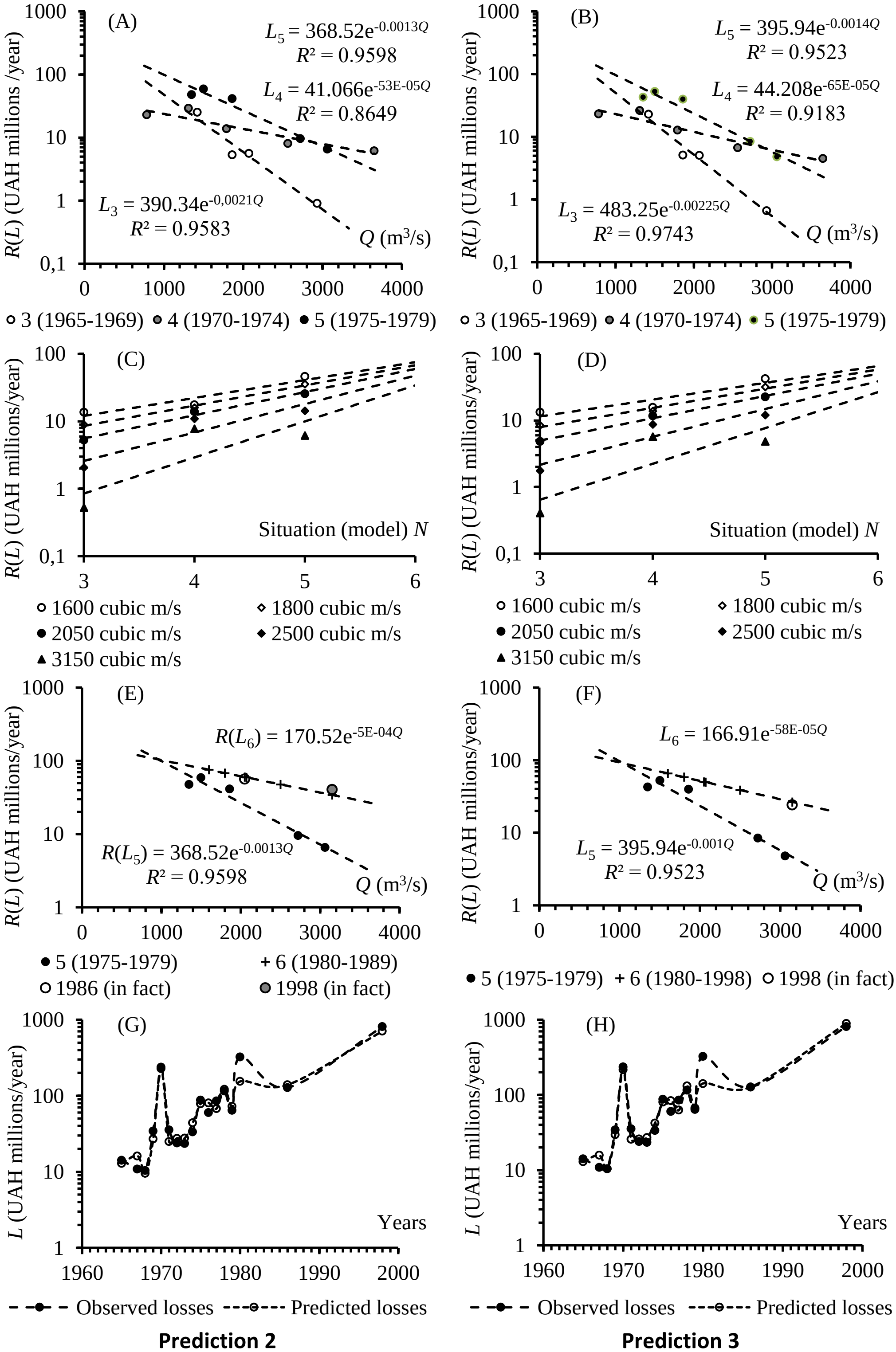

Fig. 10. Visual presentation of predicting monetary losses according to Prediction 2 and Prediction 3

Compared with the previous Prediction 1 (See its results in the section 5.1 of the article), only the parameters (coefficients) of the accepted situational and inductive models were subject to clarification taking into account the new values of the empirical exceedance probabilities (See Fig. 3) determined for the extended time series of the maximum water discharges: from 1954 to 1985 (Prediction 2), from 1954 to 1997 (Prediction 3).

In particular, in Fig. 10, there are the retrospective situational models of the risks of monetary losses caused by the floods of 1965-1969 (situation 3), 1970-1974 (situation 4), and 1975-1979 (situation 5), where (A) refers to Prediction 2, and (B) – Prediction 3. Next, there are the results of inductive modelling carried out to establish the prospective situational model 6 (for the situation with the number 6) to predict the risks of losses due to the floods of 1986, and 1998, shown as (C) and (D), (E) and (F), correspondingly. Finally, there are presented visual comparisons of time series relating to the predicted and observed (confirmed) values of monetary losses because of the floods from 1965 to 1998 according to results of Prediction 2 (Fig. 10G), and Prediction 3 (Fig. 10H).

The check of the predictive power of the developed models revealed the Nash-Sutcliffe model efficiency coefficient (NSE) value in the case of Prediction 2 varied from 0.972 (retrospective situational modelling) to 0.932 (including prospective modelling); the NSE_R coefficient value – from 0.972 to 0.958, correspondingly. In the case of Prediction 3, the NSE coefficient value varied from 0.957 (retrospective situational modelling) to 0.93 (including prospective modelling); the NSE_R coefficient value – from 0.959 to 0.94, correspondingly. Totally, the obtained NSE and NSE_R coefficient values confirm the good predictive efficiency of the CSIPMM to solve the considered problem.

Table 7 summarises the numerical data for the comparison the observed (confirmed) and predicted values of the monetary losses due to the floods of 1980, 1986, and 1998 according to the accepted prediction options.

Table 7 – Comparison the observed and predicted values of the monetary losses due to the floods of 1980, 1986, and 1998 according to the accepted prediction options

Years	Q (m^3/s)	P_{ex} (1/year)	L_o (UAH millions)	$R(L)$ (UAH millions/year)		L_p (UAH millions)	E_r, %
				Actual	Predicted		
Prediction 1 taking into account the annual maximum flood discharges from 1954 to 1979 (before the flood of 1980)							
1980	2 070	0.44	325.0	144.24	62.65	141.2	56.6
1986	2 050	0.46	127.9	58.83	63.09	137.2	7.2
1998	3 150	0.05	810.0	40.50	42.93	858.6	6.0
Prediction 2 taking into account the annual maximum flood discharges from 1954 to 1985 (before the flood of 1986)							
1986	2 050	0.44	127.9	56.8	61.18	139.0	8.7
1998	3 150	0.05	810.0	40.50	35.30	706.0	12.8
Prediction 3 taking into account the annual maximum flood discharges from 1954 to 1997 (before the flood of 1998)							
1998	3 150	0.03	810.0	24.30	26.86	895.2	10.5

Analysing the findings given in Table 7, it can be concluded that all three predictions, which were based on the different duration of hydrological observations, showed fairly good reliability in predicting the monetary losses caused by the 1986 and 1998 floods. Moreover, there had been a good chance to predict the losses related to those floods or other similar floods in 1980-1998 by the results of the first Prediction 1 considering the losses caused by the previous floods that occurred from 1965 to 1979.

6. Discussion

Is it possible to predict the flood losses in the Tisza River basin in the Ukrainian Transcarpathia based on the long-term time series data presenting the flood losses and the gauged maximum flood water discharges at HS "Vylok"? Provided that proper monitoring is implemented? This research showed such a possibility existed at least regarding the disastrous 1986 and 1998 floods.

In order to answer these questions, in the study, the original method of prediction was used, which is an original author's development. The method was called as the combined situational-inductive predictive modelling method (CSIPMM). It was shown the CSIPMM allows implementing the main ideas of the adaptive approach to predictive modelling according to flood monitoring data, in particular to ensure effective adjustment of applied predictive models as new monitoring data become available.

Regarding the problem under study, it is wanted to assume the CSIPMM allows performing different types of predictions of the monetary losses caused by future floods. These can be long-term predictions, for example, in the form of perspective situational models (models of future situations), or operational predictions – within defined situations, with using temporary situational models. The CSIPMM can be also used to retrospectively predict losses that may have occurred in the past (within the procedure of restoring lost data in time series), which have not been confirmed or have been avoided due to flood control measures. To illustrate it, Fig. 11 shows some results of retrospectively predicting monetary losses that might have come due to the 1960-1964, and 1966 floods, for which data regarding credible losses are missing (See Table 2, Fig. 2B).

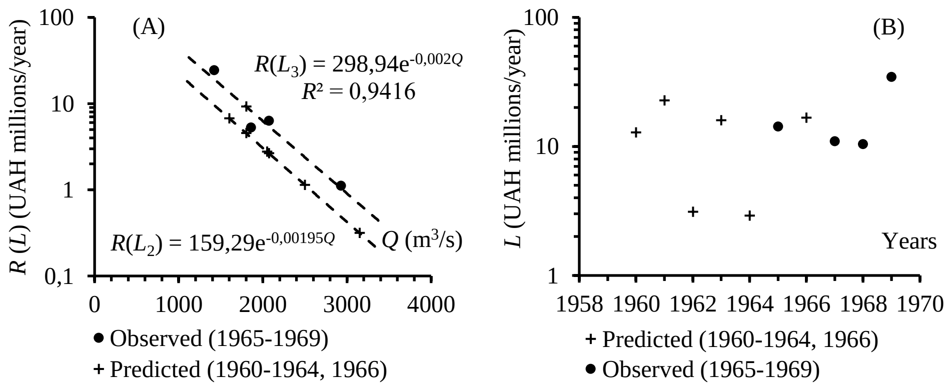

Fig. 11 – Visual illustration of the CSIPMM applying to retrospectively predict flood losses within the procedure of restoring lost data in time series

In particular, Fig. 11A shows the retrospective situational model 2 to predict the possible (unconfirmed) risks of losses caused by the floods of 1960-1964, for which data regarding credible losses are missing. These risks may be obtained due to the results of inductive modelling (See the inductive models of "levels" in Fig. 7A and the corresponding equations in Table 5) with extrapolation one step back (to situation 2 preceding assumingly the situations 3, 4, 5). In turn, the "missed" value of the risk of losses due to the flood of 1966 (Fig. 11A) may be restored by the retrospective model 3. The "missed" losses that might have been caused by the floods of 1960-1964 and 1966 are shown visually in Fig. 11B.

It should be noted that flood losses are almost inevitable. Eventually, the worldwide practice shows that only 12% of these losses were insured [2]. Often, even obvious losses are neglected. In any case, predicting adequately the probable flood losses that have been avoided can be seen as a powerful tool to justify spending on flood-suppressing measures. Thereby, solving the problems of perspective and retrospective predicting of flood losses will allow us to more adequately justify the measures aimed at flood management in order to minimize the negative consequences associated with floods.

A challenge probably is the flood of 1980. However, in this case, the main factor most likely complicated predicting was that the flood of 1980 occurred in the warm season (summer), which is an atypical phenomenon in Transcarpathia [101]. Herein, this is an outlier case, something like a "black swan" according to Nassim Taleb. The possibility of such "outlier" data on floods being has been mentioned earlier in the example of the Dniester River near the town of Halych [115].

Conclusions

1. The main aspects of flood hazards in the world and in Ukraine were analysed. It was noted that proper organization of flood monitoring with a comprehensive assessment of flood losses could be an important component of modern, holistic flood management strategies internationally, nationally, and locally. Purposeful monitoring creating the reliable groundwork for predicting losses can contribute to effective decision-making within different flood management strategies in order to prevent and minimise flood risks.

2. In order to emphasize the importance of targeted monitoring of flood losses in conjunction with the usual hydrological monitoring of river runoff, there was performed a retrospective prediction of the confirmed monetary losses due to destructive floods that occurred in the Tisza River basin in the Transcarpathian region of Ukraine in 1980, 1986, and 1990 using available monitoring data on the floods in the region from 1955 to 1998. The main aim of the research was to reveal whether the confirmed monetary losses caused by the floods of 1980, 1986, and 1990 could have been predicted in advance.

3. Input data comprised the time series on maxima water discharges gauged at the hydrological station (HS) "Vylok" from 1954 to 1999 and confirmed losses due to floods in the Transcarpathian region from1955 to 1998. While solving the problem, there was revealed and modelled the dependence of risks of flood losses on the maximum water discharges of the Tisza River gauged at the HS "Vylok". Predicting was based on the hypothesis of the stationary random process for maximum water discharges, which allowed using an empirical distribution function of a random

variable regarding observed flood water discharges for numerical computing of the risks of flood losses.

4. Predicting was carried out by means of the combined situational-inductive predictive modelling method (CSIPMM) of an original author's development. The method is based on the use of extrapolation-regression type models. According to this method, the prediction task was performed in two stages. The first stage realised the retrospective situational modelling task aiming to obtain a set of simple regressions (situational models) built on data of sample time series. Those situational models assumed to be adequate and relevant ones within certain periods of time determined as situations. In the second stage, based on the generalization (on ensemble) of the obtained retrospective situational models, inductive "levels" models were built to reflect the behaviour of risks of losses as a resulting variable at fixed values of the predictor in time. Next, the inductive models were used in extrapolative predicting situational models belonging to future periods (situations).

5. In total, three prediction options were made: (1) taking into account the annual maximum flood discharges from 1954 to 1979 (before the flood of 1980); (2) the same from 1954 to 1985 (before the flood of 1986); (3) the same from 1954 to 1997 (before the flood of 1998). In order to assess the predictive skill of developed predictive models the Nash-Sutcliffe model efficiency coefficient (NSE) and its application in regression procedures (NSE_R) were used. The check revealed that the NSE coefficient value for all three prediction options was over 0.93, and the NSE_R coefficient value – 0.94. It confirmed the good predictive skill of the used predictive models and the CSIPMM as a predictive modelling method. The study found that there had been a realistic possibility to predict the confirmed monetary losses caused by the flood of 1986 and 1998 (relative predicting errors of 7.2-8.7% and 6.0-12.8% depending on the prediction options).

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ПРО ЩО МИ МОГЛИ ДІЗНАТИСЯ З ПОПЕРЕДНІХ ДАНИХ ПРО ПОВЕНІ, ЩОБ ПЕРЕДБАЧИТИ ЗБИТКИ, ЗАВДАНІ КАТАСТРОФІЧНИМИ ПОВЕНЯМИ 1980, 1986 ТА 1998 РОКІВ В УКРАЇНСЬКОМУ ЗАКАРПАТТІ?

Анотація. У цій статті досліджуються деякі аспекти, пов’язані з ретроспективним прогнозуванням підтверджених грошових втрат (збитків) від паводків, спричинених катастрофічними повенями 1980, 1986 та 1998 років у басейні річки Тиса в Закарпатській області України. Дослідження проводилося на основі двох часових рядів – збитків від минулих паводків та максимальних скидів, зафіксованих на гідрологічній станції поблизу села Вилок Виноградівського району. Основною метою дослідження було з'ясувати, чи була реальна можливість заздалегідь передбачити збитки від цих повеней.

При вирішенні поставленого завдання було виявлено та змодельовано залежність ризику втрат внаслідок паводків на Закарпатті від максимальних витрат води р. Тиса, заміряних на гідрологічній станції «Вилок». Прогнозування ґрунтувалося на гіпотезі стаціонарного випадкового процесу для максимальних витрат води, що дозволило використовувати емпіричну функцію розподілу випадкової величини щодо витрат води для оцінки ризику втрат від паводків.

Ретроспективне прогнозування втрат від повеней 1980, 1986, 1998 рр. здійснювалося за допомогою комбінованого ситуаційно-індуктивного методу прогнозного моделювання, який є оригінальною авторською розробкою. Метод стосується прогнозування поведінки складних динамічних систем на основі результатів моніторингу, представлених у вигляді часових рядів, дані яких відображають еволюцію результуючої (залежної) змінної та пояснюючої (незалежної) змінної (провісника). Метод використовує моделі екстраполяційно-регресійного типу. Згідно з цим методом завдання прогнозування виконується в два етапи. На першому етапі реалізується завдання ретроспективного ситуаційного моделювання з метою отримання набору простих регресій (ситуаційних моделей), побудованих за даними вибіркових часових рядів. Ситуаційні моделі визнаються адекватними або релевантними лише в межах певних проміжків часу, визначених як ситуації. На другому етапі на основі узагальнення (за деяким ансамблем) отриманих ретроспективних ситуаційних моделей будуються індуктивні моделі «рівнів», які відображають поведінку контрольованого параметра системи або процесу (результуючої змінної) при кількох фіксованих значеннях провісника в залежності від часу. Індуктивні моделі використовуються для екстраполяційного прогнозування ситуаційних моделей майбутніх періодів (ситуацій).

Всього було виконано три варіанти прогнозування: (1) з урахуванням даних щодо щорічних максимальних витрат води паводків з 1954 по 1979 рр. (до повені 1980 р.); (2) те саме з 1954 по 1985 рік (до повені 1986 року); (3) те саме з 1954 по 1997 рік (до повені 1998 року). Дослідження показало, що була реальна можливість передбачити підтверджені грошові втрати, завдані повенями 1986 та 1998 років (відносні похибки прогнозів 7,2-8,7% і 6,0-12,8% залежно від варіантів).

Ключові слова: комбінований ситуаційно-індуктивний метод прогнозного моделювання; повені; збитки від повені; ризик збитків; максимальні скиди води; прогнозування; часові ряди

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