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ASSESSMENT OF THE IMPACT OF GEOMORPHOLOGIC AND HYDROCLIMATIC FACTORS ON THE FLOOD HAZARD IN RIVER BASINS

Abstract: A case study on the Yantra River Basin dynamics under recent climate fluctuations and economic changes is carried out to demonstrate the important role of some geographical factors for successful flood hazard assessment and risk management practices. The number of the extreme rainfalls and related flood events during the last decade grew in the river basin located in the Stara Planina Mountains in accordance with the trends observed in North Bulgaria and Central and Eastern Europe. The use of geoinformation technologies have provided tools for the assessment and mapping of the flood hazard. The settlements' exposure to flood-related hazards and vulnerable zones in the Yantra River Basin have been indicated.

Key words: flood hazard, climate change, river basins

INTRODUCTION

With the ongoing climate change, the frequency, pattern and severity of flooding are expected to change, and become more uncertain and more damaging. Results from the Expected Annual Damage modelling indicate that flood damages related to different climate change scenarios are projected to rise across much of Europe (F e y e n et al. 2006). Current dynamics of climate, land use, economy and population density in a given river basin are some of the main drivers for respective changes of flood hazard dimensions. The Yantra River basin is one of the largest river basins in Bulgaria, with diverse landscape structure and a high degree of economic development. It belongs to the international river basin of the Danube. The basin's geographical location is representative for investigation of the regional dimensions of global climate changes and the related risks.

STUDY AREA

The Yantra River basin is situated on the northern slopes of the Central Stara Planina, the Central Forebalkan and the Danubian Plain. The slopes of the Stara Planina are characterized by steep gradients which favor the formation of significant surface runoff and river flooding within relatively short time intervals. Mountain relief, with elevations from 500 to 1000 m a.s.l., is typical of 62% of the basin territory, plains and hills lands with altitudes below 500 m occupy 31%, and the high-mountain zone above 1000 m a.s.l. amounts to only 7%. The river is 285 km long and the total area of the basin is 7862 km^2. The watershed line outlining the catchment area of the Yantra River highlights the link between the development of the river-valley network and the morphotectonic structure.

In its upper, mountain part, the Yantra basin is wide, with the distance between its westernmost and easternmost points reaching 140.5 km. The basin becomes significantly narrower in the middle and lower river course. This specific form of the basin, combined with the relief features, is a prerequisite for the formation of considerable surface runoff during prolonged and intensive precipitation along the northern slopes of the Stara Planina. The runoff becomes concentrated, with extremely high power, in the middle course of the Yantra River which is characterized by the highest settlement density in the basin. According to the census in 2001, the population of the Yantra River basin amounts to 443 464 people. There are 737 settlements: 22 towns and 712 villages. The largest towns in the basin territory are Gabrovo with 67 305 inhabitants, followed by Veliko Tarnovo with 66 998 people (N e d k o v et al. 2005).

MATERIALS AND METHODS

Flood risk is a combination of the likelihood of flooding, exposure and the potential consequences of flooding. Likelihood of flooding is normally defined as the percentage probability of a flood of a given magnitude, occurring or being exceeded in any given year. The procedure for the assessment of flood risk is developed by allocating the workload into three steps. The first step refers to the task of collection and processing the necessary data in order to determine the system under risk. At this stage the identification of the system's vulnerability takes place and that is mainly the definition of the system's exposure to a potential flood hazard and the system's carrying capacity to cope with flood events. The second step involves the development of hazard scenarios, the estimation of their probability of occurrence. At each scenario the production of the respective floodplain mapping delineation is given in GIS environment so as to identify the flood-prone areas. The third step in the workflow relates to the assesses of the expected damage of the affected system and consequently it estimates the annualised flood risk in monetary units, if possible (P i s t r i k a, T s a k i r i s 2007).

Development of hazard scenarios and maps is of key importance for the whole assessment procedure; its reliability depends critically on a wide range of geographic data about the natural and socio- economic conditions in the river basin.

The basic methods of the morphometric relief analysis were applied for the estimation of the longitudinal profiles of some valleys and for izoamplitudinal map of the river basin. 1: 50 000 topographic and geomorphologic maps and digital elevation model were used in a GIS (MapInfo 7.5, Vertical Mapper 3 and ArcGIS 9.3) analysis of the hydrometric and geomorphologic features and for the identification of hazard zones in the river basin. The hydrological and meteorological data for all meteorological stations and hydrological and rain gauges in the Yantra River Basin were obtained from the publications of the National Institute of Meteorology and Hydrology (NIMH).

RESULTS AND DISCUSSION

ANALYSIS OF GEOMORPHOLOGIC FLOOD HAZARD FACTORS

The catchment area of the Yantra River is developed in three morphostructural zones of the territory of North Bulgaria: medium- and high-mountain Stara Planina, hilly and low-mountain Forebalkan, and the plain to hilly Moesian (Fig. 1.). The springs of all main tributaries of the Yantra River are in the southern part of the basin. The river-valley network is characterized by significant density and high slope of the longitudinal profiles. The river network in this part of the

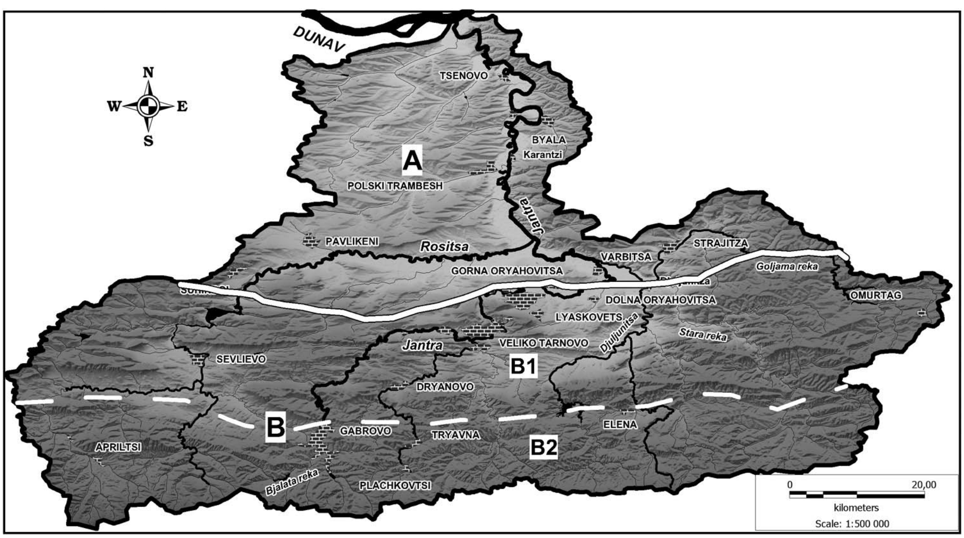

Fig. 1. Morphostructural zones in the Yantra River Basin: A — Moesian Platform; B — Balkanides; B1 — Fore Balkan; B2 — Stara Planina

basin is the most dense, from 2.5 to 3 km km^{-2}, while in the lower parts of the Forebalkan it varies from 0.5 to 1.0 km km^{-2}. Abrupt change in the longitudinal slope of these streams in the north, towards the mouth of the main river causes deposition of sediment load and formation of floodplain terraces. From the springs of the Yantra River to the mouth of the Byalata Reka tributary, the valley of the Yantra river is V-shaped with steep side slopes, of about 30° inclination, and predominant deep erosion. No terrace developed here, and only small valley extensions of the floodplain terrace are observed at some places. After the inflow of the Byalata River, the main river valley floor widens to 20 m, while the valley slopes remain relatively steep — up to 30°. The valley bottoms in the mountains are narrow, rocky and in fact restricted to channels carrying rain- and snow-melt waters. The folded structures within the range of the Forebalkan contribute to the formation of long subsequent east-west directed valley sections along the syncline axes, while within the anticline folds short gorges with steep rocky slopes are common. All rivers originating from the Stara Planina and their tributaries shaped the valleys in this manner. The antecedent gorge valleys are typical for this part of the basin. Karstic relief, developed in carbonate rocks, exerts specific impact on the flood regime in this part of the basin. The valley network is developed on the platform structure of the Danubian Plain. The water of all major tributaries of the Yantra River is collected in the northern part of the Forebalkan, almost along the border with the Moesian platform. The river gradient in this section is low (less than $1^{0}/_{00}$) and the floodplain terrace width varies from 1.5 m to 3.8 km. Numerous abandoned river meanders are typical here. The catchment is very narrow with a markedly asymmetric shape.

A major function performed by the floodplain and wetlands is to hold excess water until it can be released slowly back into a river system or seep into the ground as a storm subsides. Floodplains have a valuable function both in attenuating or storing floodwater and through their ability to convey floodwater in a relatively controlled and safe way (The Planning System … 2009). In the western part of the basin, low floodplain terraces reach up to 3–3.5 m and the high ones 6–7 m. In the eastern part of the basin the relative heights of floodplain terraces are 1.5–2 m and 3.5–4 m for low and high floodplain terraces, respectively. The total area of the floodplain terraces in the Yantra Basin is 553.8 km^2. The thickness of the alluvial cover on the valley bottoms varies from 7 to 10 m. This thickness of the alluvium is mainly due to the enormous transportation power of the water stream during high water and flooding.

The geological and geomorphological characteristics of the basin, combined with the hydroclimatic conditions, are the prerequisite not only for flood formation but also for the activation of other natural disasters, related to the supersaturation of the ground, as rock-falls and landslides (Fig. 9).

The climate of the basin is characterized by features of four climate regions within the moderate-continental climatic zone (Tab. 1).

The growing influence of Icelandic cyclones in the moderate latitudes in Europe in spring and summer is also reflected in the observed maximum of precipitation in May and June in north Bulgaria (V e l e v 2002). Torrential rainfall and thunderstorms, often accompanied by hailstorms, are typical of the northern windward slopes of the Forebalkan and the Stara Planina during this part of the year. The synoptic circumstances for heavy precipitation, provoking floods and other disasters in Bulgaria in the warm season occur mainly during the transit of cold fronts (43%), cyclonic baric fields (20%) and Mediterranean cyclones (16%), (S i m e o n o v et al. 2007). The increase in the precipitation amounts along the northern slopes of the Stara Planina is related to its orographic effect on the moist air masses invading mainly from the northwest.

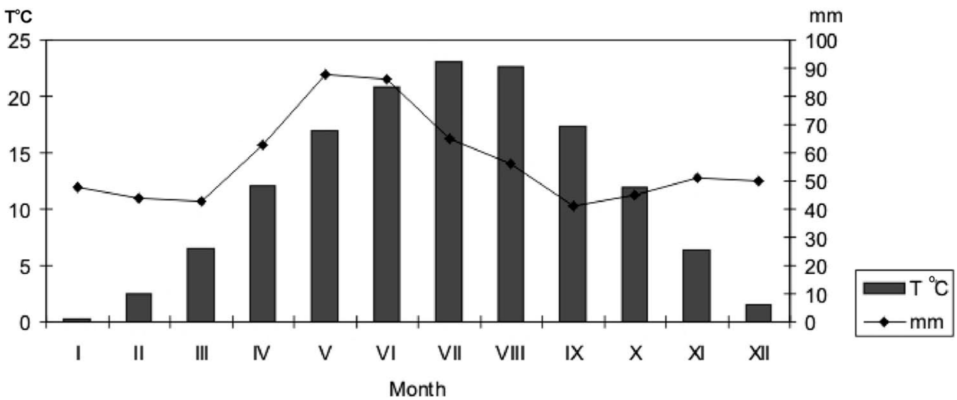

Fig. 2a. Climate chart for Veliko Tarnovo station (temperature for 1982–2010 and precipitation for 1931–1985)

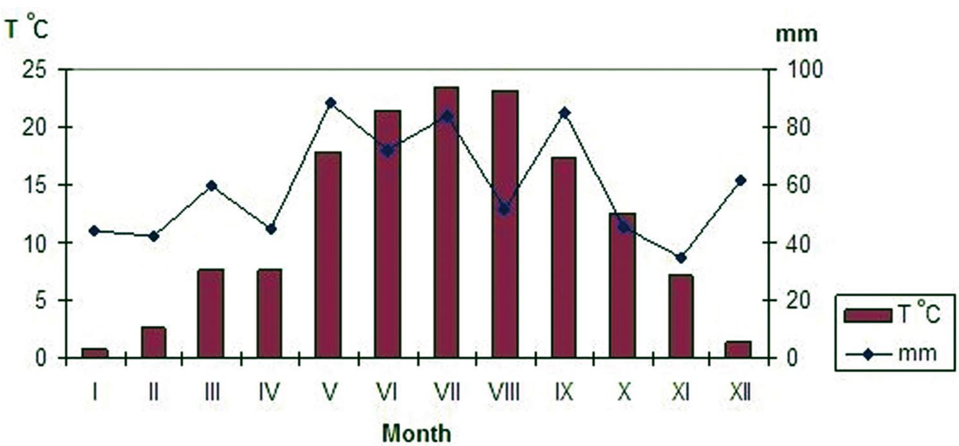

Fig. 2b. Climate chart, Veliko Tarnovo station (temperature and precipitation 2001–2010)

Table 1

Characteristics of the climatic regions, of the Yantra River basin, (V e l e v 1990).

Climatic region	Mean annual air temperature [°C]	Meantemperature amplitude [°C]	Average annual wind velocity [$m\ s^{-1}$]	Annual precipitation sum [mm]	Days with snow cover (days per year)	Annual number of dark/clear days according to general cloudiness
Riparian Danube Lowlands	11.7	25.7	2.3	550	40	108/82
Central Danube Plain	11.3	25.1	1.8	550	42	110/80
The Forebalkan	10.3	23.0	1.4	750	44	110/80
West and Central Stara Planina	3.5	19.0	7.0	1100	120	130/55

The seasonal variability in temperature and precipitation at the Veliko Tarnovo station exhibits a well-expressed maximum of mean temperature in July and a minimum in January for the period 1982–2010 (Fig. 2a), as well as for the period 2001–2010 (Fig. 2b). However, a significant difference was observed in the monthly distribution of precipitation in the warm season during the last decade, primarily due to the higher number of events and higher amounts of maximum daily precipitation. During this short period, 34 cases of maximum daily precipitation exceeding 20 mm and 21 cases with more than 30 mm were recorded at the Veliko Tarnovo station. The maximum daily sum of precipitation for the period 2001–2010 in five monthly values exceeded the baseline monthly values during the reference period (1931–1985). It has to be pointed out that this is not only due to the years 2002 and 2005 with extremely high precipitation. Even though there was no substantial change in the seasonal sum of precipitation for the two periods, 1931–1985, (697 mm) and 2001–2010 (713.5 mm), the seasonal and annual sums of precipitation in last decade were formed by more frequent extreme precipitation.

The reported growth of extreme precipitation at the Veliko Tarnovo station during the last decade is consistent with the established trends for other areas in the whole country, with altitudes of up to 1000 m, where the number of days with precipitation above 30 mm per 24 h increased by 60% between 1991 and 2006 (S i m e o n o v et al. 2007). Between May and August, the share of rainfall with intensity 30–40 l s^{-1} ha^{-1} ranges between 18 and 35% of the monthly precipitation sum for the different parts of the Yantra River Basin. Rainfall with high intensity can be linked to river swelling and flooding.

Up to 35–40% of the precipitation sum in the high-mountain zone is formed by snowfall. In the Stara Planina, the average maximum depth of the snow cover is 180 cm with an average retention time of 190–200 days (P e t k o v a et al. 2010). Above 1400–1500 m a.s.l., all days in January are with snow cover. In comparison with the period 1921–1950, this critical altitude is over 100 m higher due to the lower winter precipitation and warmer winters (A l e x a n d r o v, P e t k o v a 2011). Rapid snow melt events caused by the foehn effect observed along the northern slopes of the Stara Planina. often result in river swelling and flooding.

The Yantra River Basin belongs entirely to the Ossam-Yantra region, a hydrological area with a moderate-continental climate impact on runoff (Y o r d a n o v a 2002). The mean annual discharge of the Yantra River near Gabrovo is 4.95 m^3 s^{-1} and 47.1 m^{-3} s^{-1} at the confluence with the Danube River, with more than 50% of the outflow being formed in the period March-June (Fig. 3).

The internal annual distribution of the maximum discharge of the Yantra River is shown in Fig. 4. It follows the distribution of the average monthly discharge during the first half of the year, but exhibits a secondary peak in October.

A well-pronounced change in the maximum discharge distribution is observed during the last decade, the values being higher for all months, with the

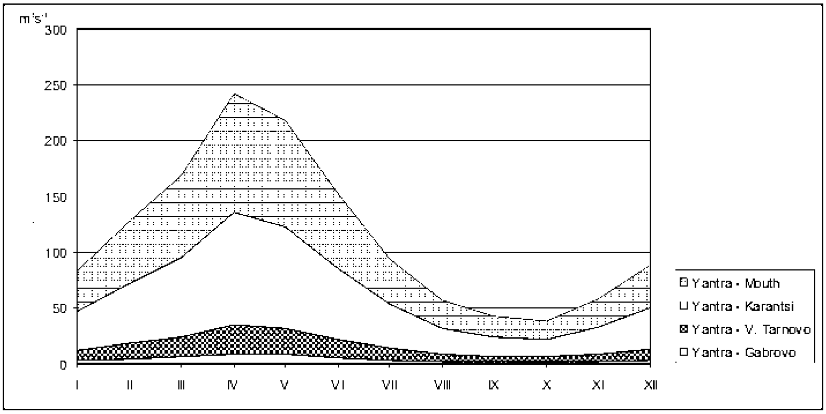

Fig. 3. Annual distribution of the average discharge of the Yantra River (1961–1998)

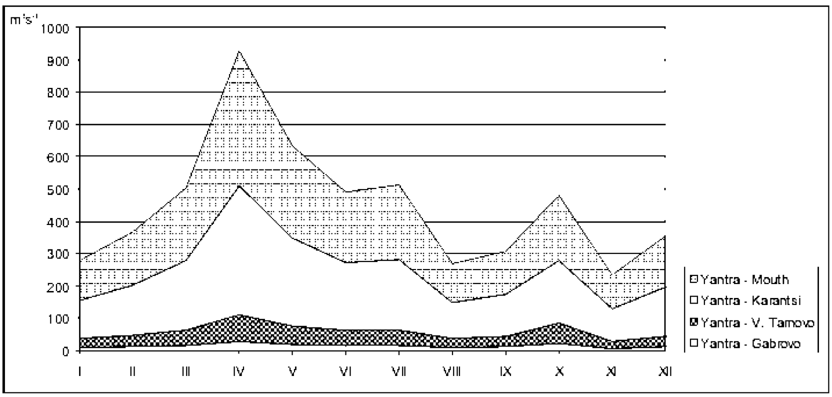

Fig. 4. Annual distribution of the maximum discharge of the Yantra River (1961–1988)

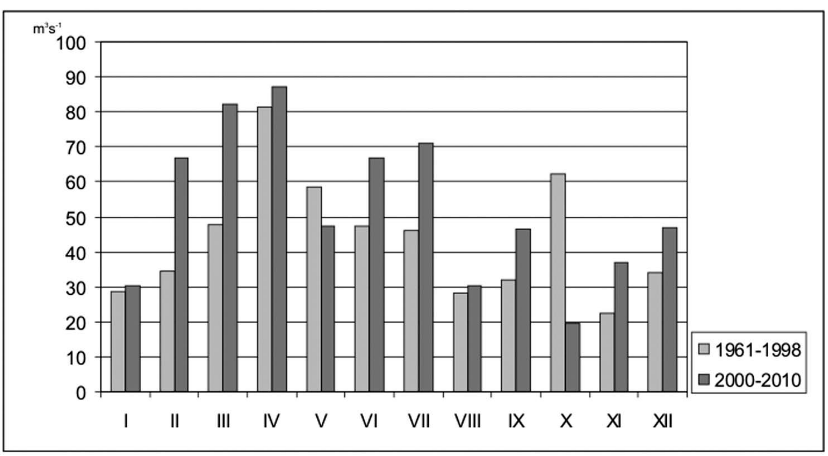

Fig. 5. Maximum discharge of the Yantra River at the Veliko Tarnovo station

exception of May and October (Fig. 5). In total, 19 cases with extreme discharge exceeding 100 m^3 s^{-1} were recorded for the period 2000–2010 at the Veliko Tarnovo station.

With respect to the torrentiality degree, the Yantra, Rositsa and Vidima rivers belong to the most torrential rivers in Bulgaria, with up to 95–100% relative deviation of the maximum runoff from the annual average (Z y a p k o v 1997).

ANALYSIS OF THE FLOOD HAZARD IN THE YANTRA RIVER BASIN

Analysis of data for past flood events and the evaluation of the probability of their future occurrence represents a key aspect of flood risk analysis. Historical evidence and data for major floods in the past provide very important initial information for flood hazard analysis. Historical data are available for catastrophic floods and damages in the Yantra River Basin for the years 1858, 1873, 1879, 1897, 1924 and 1939 (G e n e v, R a j k o v a 2003). Large floods of the Yantra River, caused by rain- and snow-rain water (both in the form of snow melt and rain-on-snow floods) ocurred also in 1940, 1941, 1944, 1955, 1957, 1960, 1965, 1966, 1972, 1973, 1991, 1997, 2002 and 2005.

Catastrophic floods were recorded e.g. on 14.07.1944 (1310 m^3 s^{-1}) and 28.06.1957 (1580 m^3 s^{-1}) at Veliko Tarnovo, as well as on 02.07.2005 (1593 m^3 s^{-1}) at the Karantsi station. An extreme discharge peak was measured for the Rositsa River near Sevlievo (28.06.1939) — 2780 m^3 s^{-1}. The specific runoff in this case is 2560 dm^3 s^{-1} km^{-2}, reaching 9780 dm^3 s^{-1} km^{-2} for the same wave at the higher an upstream station near Batoshevo village, and representing the absolute maximum specific runoff measured in Bulgaria (P e n c h e v 1982).

The year 2005 was hydrologically exceptional, with immensely high flood waves along almost all rivers in Bulgaria occurring throughout the year due to extremely heavy and prolonged precipitation, intensive snow-melt, strong supersaturation of the soil and water releases from dam reservoirs. The total annual river discharge exceeded twice the annual norm, and 38% of the runoff volume was formed in the period June–September. The river stage, according to the hydrograph for the Yantra River at Karantsi, rose by 940 cm during the event on 4–6 July, 2005. The damages caused by the floods in the country, and in the Yantra River Basin in particular, were also unprecedented (Tab. 2).

Considerable increase in the discharge of the Yantra River is associated with the increase in runoff from its tributary catchments (Tab. 2). The most important factors for the maximum discharge formation were the continuous precipitation with over-average amounts throughout the year, the supersaturated soil, as well as the significant amounts of the measured daily precipitation, which was 79 mm per 24 h at the Veliko Tarnovo station on 04.07.2005, reaching 102 mm per 24 h during the following flood on 15 September 2005 (Tab. 2).

The analysis of the flood data for the events for the period 1991–1998 and for 2005 shows that considerable flood damages are recorded almost without

Table 2

Floods in the Yantra River Basin in 2005.

Date	River, point	Discharge [Q $m^3 s^{-1}$]	Change in stage [H cm]	Damages
15–16 February	Yantra–Gabrovo	47.7	96	In Gorna Oryahovitsa municipality crops were destroyed on 500 dka of arable land; damages to 60 houses, retention walls, the Varbitsa-Bregovitsa road; 18 micro-dams in Gabrovo district overflowed; disruptions in electric power and water supply and communications.
	Yantra–Veliko Tarnovo	198.3	205	
	Yantra–Karantsi	766.7	430	
	Dzhulyunitsa – Dzhulyunitsa	188	—	
02–04 July	Yantra–Gabrovo	150	244	In the Veliko Tarnovo district: 1 fatality, and totally 293 272 people and 2% of the agricultural land were affected by the disaster. The historic-cultural heritage suffered significant damages, incl. the Holy Forty Martyrs church. In Gabrovo district 12 201 people, 38% of the agricultural lands and 0.05% of the forest areas were affected by the disaster. There were significant damages in 14 municipalities along the main river and its tributaries.
	Yantra–Veliko Tarnovo	571.6	800	
	Yantra–Karantsi	1593	940	
	Rositsa–Sevlievo	394	346	
	Dzhulyunitsa – Dzhulyunitsa	453	726	
12–15 July	Yantra–Gabrovo	165	260	
	Yantra–Veliko Tarnovo	332	520	
	Yantra–Karantsi	597	527	
19–24 September	Rositsa–Sevlievo	371	221	
	Dzhulyunitsa – Dzhulyunitsa	114	210	
	Golyama Reka – Strazhitsa	60	215	

Sources: Civil Defense Agency, NIMH and Bulgarian Ministry of Emergency Situations.

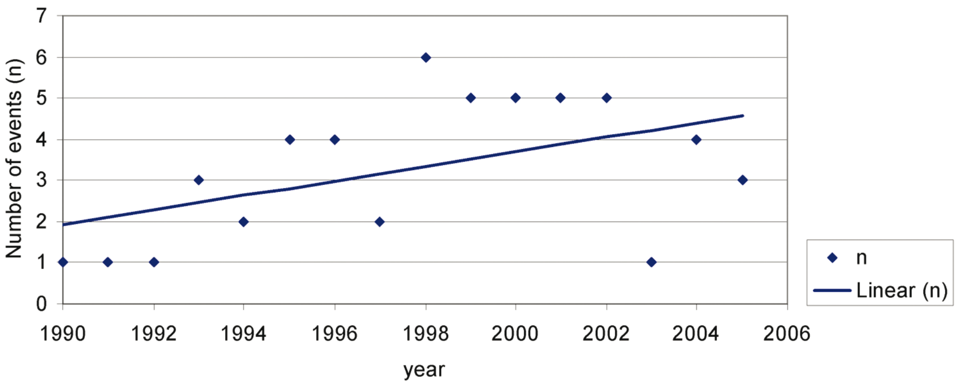

Fig. 6. Number of floods in the Yantra catchment (1990–2005). Source GA "Civil Defense"

exception at Veliko Tarnovo when discharge of the Yantra River exceeds 100 m^3 s^{-1}. We assume that this is the critical discharge value for the town and its surroundings, above which flood hazard occurs. Flooding causes predominantly river bank erosion, accompanied by vertical changes in river beds, activation of landslides, rock-falls, and deposition of large amounts of sediments. Although the data of the Civil Protection State Agency show that during the last two decades a clear trend is observed towards an increased number of flood events in the studied river basin (Fig. 6) (N e d k o v, N i k o l o v a 2006), the number of high flood waves with discharge exceeding 100 m^3 s^{-1} for the Yantra River at Veliko Tarnovo does not exhibit an upward trend in a multiannual plan (Fig. 7).

In total, 142 high floods with peak discharge exceeding 100 m^3 s^{-1} were recorded on the Yantra River at Veliko Tarnovo during the entire observation pe-

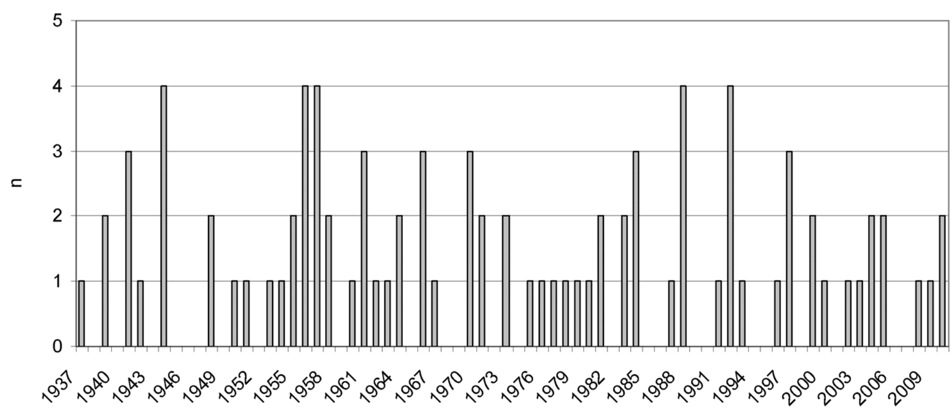

Fig. 7. Number of cases (n) with discharge exceeding 100 m^3 s^{-1} for the Yantra River, at Veliko. Tarnovo (1937–2010)

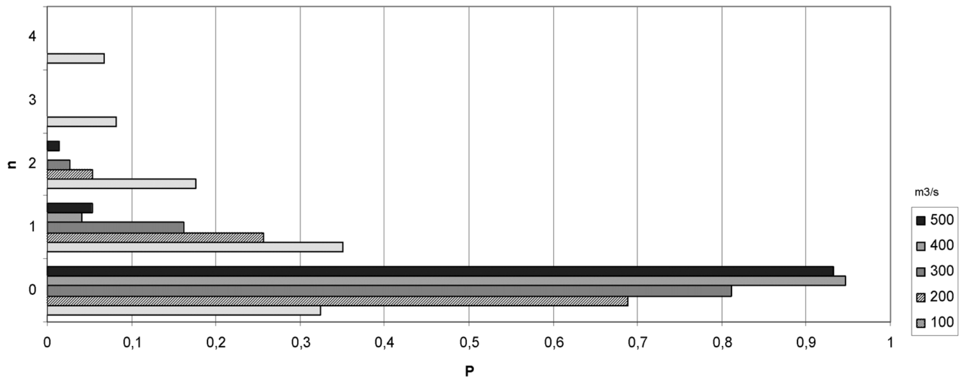

Fig. 8. Probability (P) for 0, 1, 2, 3 or 4 cases (n) with high waves per year with peak discharge exceeding 100, 200, 300, 400 and 500 $m^3\ s^{-1}$ for the Yantra River at Veliko Tarnovo

riod of 74 years (or 1.9 cases per year on average). The probability for expecting one, two or more events with a peak discharge that might provoke flooding of the Yantra River at Veliko Tarnovo is presented in Fig. 8.

The recurrence interval of large floods exceeding 100 $m^3\ s^{-1}$ and 200 $m^3\ s^{-1}$ is, respectively, once in two and in three years. Flood waves of over 300 $m^3\ s^{-1}$

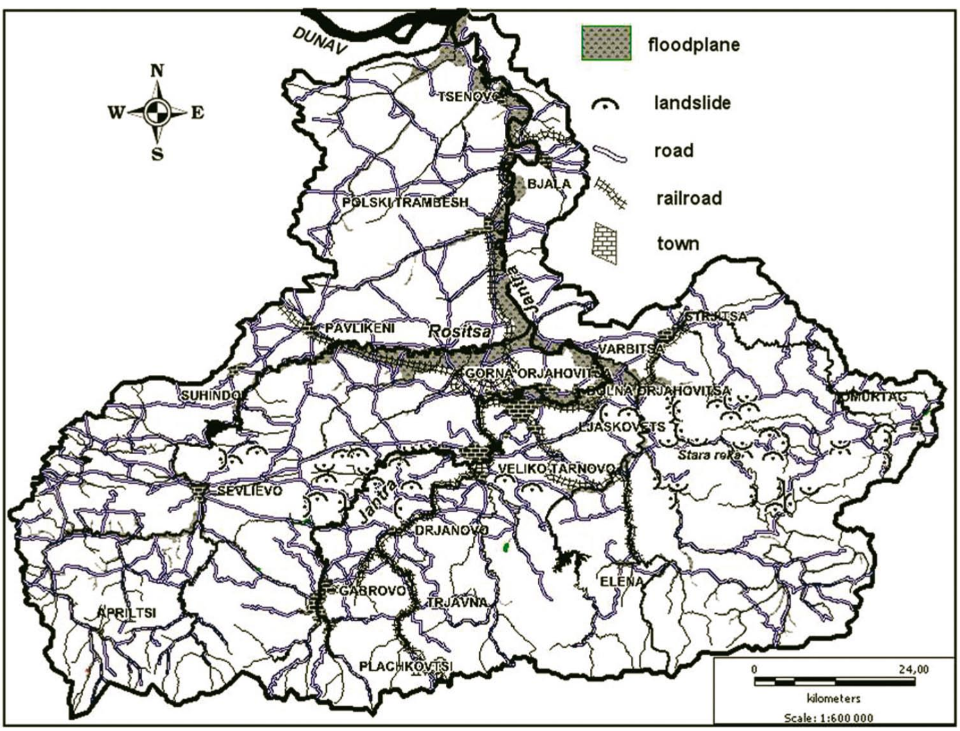

Fig. 9. Map of vulnerable zones to flood related hazards in the Yantra River Basin

may be expected once in five years, and above 400 $m^3 s^{-1}$ – once in 25 years. Extreme events with a peak discharge exceeding 500 $m^3 s^{-1}$ may happen once in 50 years.

The results from a flood hazards modelling, using SWAT for five flood events at Veliko Tarnovo, illustrate the potential of the land use management for flood hazard reduction. Simulations of a scenario for the increase of the forest areas at the expense of arable land and transitional woodland-scrub in the basin show reduction of the discharge for three of the five investigated floods below the hazardous threshold of 100 $m^3 s^{-1}$ and 17% reduction of the floods hazard for that area (N i k o l o v a et al. 2008).

The vulnerability to flood risk of an area depends on whether it is inhabited, the population density and distribution of the settlement network, and the degree of economic development. Geoinformation technologies were used for geomorphologic mapping of the region, delineating river floodplain terraces and identification of the hazardous zones in the Yantra River Basin. The special databases for settlement areas were affiliated with the digital relief model, to establish the extent of the vulnerable zones in the settlements located on the floodplain terraces (Fig. 9).

The number of the flood-prone settlements in the basin of the Yantra River is 77, and the total area of the vulnerable zone amounts to 61.34 km^2, that is 32.5% of the floodplain terrace area of the rivers in the basin. The greatest share of potentially threatened terrain is in the floodplain terrace of the Yantra River. The most endangered settlements are Gorna Oryahovitsa, Gabrovo, Polski Trambesh and the Draganovo, Seshevo, Dolna Studena, Radanovo and Ledenik villages.

CONCLUSIONS

The environmental conditions in the Yantra River Basin, in particular morphographic and hydroclimatic characteristics, are determinant for distinguishing hazard zones, especially endangered by flooding. Areas of floodplain and wetlands should be recognised and preserved to the extent possible as natural defences against flood risk. This is an important element of the now internationally accepted philosophy of “leaving space for water”.

The simulation of river runoff behaviour for different scenarios of the expected climate changes and the possible changes in land use and regional management, aimed at mitigating the consequences of natural disasters, is considered to be of major importance for ensuring adequate management of the flood risk in the river basin.

The geographic characteristics of the territory and the complex geographic approach to the hazard and vulnerability assessment ensure high accuracy and reliability of the information on the spatial aspects and dynamics of hazardous phenomena and should be used to optimize the activities for management of flood risk and other natural hazards in the river basins.

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