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Climate change impact on flood hazard

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Abstract Climate changes have a high impact on river discharges and therefore on floods. There are a few different methods we can use to predict discharge changes in the future. In this paper we used the complex HBV model for the Vipava River and simple correlation between discharge and precipitation data for the Soča River. The discharge prediction is based on the E-OBS precipitation data for three future time periods (2011–2040, 2041–2070 and 2071–2100). Estimated discharges for those three future periods are presented for both rivers. But a special situation occurs at the confluence where the two rivers with rather different catchments unite, and this requires an additional probability analysis.

Key words climate changes impact; E-OBS; HBV model; flood discharge

INTRODUCTION

The potential impact of climate change on floods is discussed in numerous scientific papers which have been peer-reviewed by Wilby and Keenan (2012). Most of those papers about the impact of climate change on floods are based on trend analysis from trends of the existing data. But the calculations of the impact are usually based on setting the trend analysis of the hydrological variables mean values and on consideration of the temperature increase (Walker *et al.* 2010, Wu 2010). In the analyses mentioned some hydrologic models were also used (Lotsari *et al.* 2010, Yang *et al.* 2012).

There are lots of recent papers in which the results from the global climate changes models were used to define the impact of climate changes. The results achieved this way can be recalculated for different data, different scales and different forecasting period. That is how Kollat (2012) made an analysis for the USA in which he considered changes of eight indicators at the same time (Descriptions of the eight extreme climate indicators explored in the regression analysis). In it he only used precipitation, which showed the daily amount of total rainfall. The analysis has been derived on the basis of the Monte Carlo sampling framework and correlation dependence. More advanced procedures now use hydrological models to analyse the impact in which the uncertainty analysis of maximum discharge prediction is also executed.

Booij (2005) found out that the HBV model for numerous sub basins has a big impact on the model structure which influences the simulation results of the climate change impact on floods. Much better simulation results for small basins can be achieved, but the results are still not definite (Dobler 2012). The climate change impact on floods can be also determined using the model and the predicted changes of precipitation. As a result we get the maximum discharge occurrence probability curves (Muzik 2002).

To evaluate the discharge in future we can use the predicted precipitation data. They are estimated using E-OBS which takes into account the climate change impact. E-OBS is a gridded data set of daily precipitation and temperature values from all around the Europe and is based on data which have been gathered during the European project ECA&D – European Climate Assessment & Dataset project. It was carried out by the Royal Netherlands Meteorological Institute (KNMI, 2013). The E-OBS grid shows the spatial arrangement of precipitation and temperature data for the continental part of the Europe for each day since 1950. Today the data for the E-OBS grid are contributed by 7848 meteorological stations from 61 countries. The point data are interpolated over the whole area which ensures the proper data grid to be used in any analysis (Haylock *et al.* 2008).

Our analysis is based on data from a meteorological report presented by Rakovec and Ceglar (2012). The precipitation and temperature data are taken from the raster data set based on the position of raingauge stations and used for the hydrological model. The observed data are extracted E-OBS (Haylock *et al.* 2008). They have been designed to provide the best estimate of grid box averages to enable a direct comparison with RCMs. The E-OBS dataset was defined on the same 0.25 degree grid resolution and the data collected between 1961 and 2010 were used in this study. Meteorological data from simulations of 16 different ENSEMBLES GCM-RCM model runs were used for preparation of projections. The prediction of the climate changes was prepared for three different time periods (2011–2040, 2041–2070 and 2071–2100). They have been referred to air temperature changes and to total rainfall amount with 20- and 100-year return periods. The increments of the rainfall amounts have been specified especially for every season, but the most commonly used are the data for autumn precipitation because then the expected amount is the highest (Rakovec and Ceglar 2013).

METHODS

There was no analysis of uncertainties in the report (Rakovec and Ceglar 2013). After some discussion uncertainty is estimated as 30% for a particular A1B scenario. If calculation takes into consideration other scenarios A2, B1 or B2, then uncertainty is much higher.

The formation of flood runoff is a complex nonlinear process that cannot be easily obtained from precipitation data. For the transformation of extreme precipitation data we developed a hydrological model and then incorporated the precipitation data calculated for different projections without special analysis of uncertainty. Maximum daily precipitation data with different return periods give us the possibility for further processing and estimation of climate changes impacts on flood probability.

The climate changes impact for river flow has been estimated using the HBV-light model simulation. The HBV-light model is a conceptual hydrological model based on the HBV model (Bergström 1995). It provides the runoff simulation using the time series precipitation data, air temperature data and potential evapotranspiration data. We can say that it is a partly distributed model because we can divide the basin into more sub basins and each sub basin can be further divided on different elevation and vegetation zones (Seibert and Beven 2009). For the model calibration we need time series of measured discharge data at the point of the sub basin outflow (IHMS 1999).

The values of the predicted discharges considering climate changes can also be evaluated using correlation and regression. Correlation describes the relationship between two variables and regression gives the dependence between them. The data can be shown in a scatterplot on which we can add the regression line to show how the properties of one variable depend on the properties of another. If the regression function is linear we are talking about the linear regression. The linear dependence of two random variables is given by the covariance. Using it we can define the linear relationship measure which can be between –1 and 1. The closer the value is to 1, the better the linear relationship (Montgomery *et al.* 2012).

To use correlation and regression it is important to know the regression line equation. First, we have to calculate the mean (μ) and standard deviation (σ) from the data. Considering those two values we can calculate the correlation coefficient r and the regression lines X and Y that are used to calculate the discharge as a function of estimated precipitation values (Kirchner 2001). Because the regression line being defined based on the equations is not exact, we usually define the confidence interval. It has an upper and lower limit within which the values with certain probability are located (Brilly and Šraj 2005).

For three future time periods the flood peaks were predicted considering the estimated precipitation values. To analyse the changes in flood probability we have chosen the two parameter and asymmetrical Gumbel distribution because two points are enough to define parameters of probability function.

We calculated maximal discharges produced by maximum daily precipitation with 20- and 100-year return period using complex models or simple regression models. Maximum daily precipitation was published in the report (Rakovec and Ceglar 2013). At first we determined the probability of today discharges produced by maximum daily precipitation with 20 and 100 years return period. We accept the hypothesis saying that the probability of the discharges produced by maximum daily precipitation with 20 and 100 years return period, will be the same in future. So we have for each forecast period two data of discharges with known probability.

CASE STUDIES

The Soča watershed is generally well defined, with the exception of certain ambiguities in karst areas. The watershed of the river is rugged with the highest elevation at 2863 m a.s.l. (Triglav) and the lowest at the border with Italy at 54.6 m a.s.l. The Soča itself and the main tributaries run through the long narrow valley with steep slopes and large falls. From the confluence with Koritnica downstream the average slope of 2.9% rapidly reduces and reaches an average of 0.49% to the confluence with the Idrijca. The stream slope on the border is 0.33%.

The Soča mostly flows in a deep channel between steep slopes, so there are no large floodplains, which could lower high floods. The Soča is characterized by extremely rapid growth and rapidly diminishing flows. The speed of the peak flood flow is also very fast: 8 hours from the confluence with Koritnica to Solkan, a distance of about 72 km.

The Vipava River has a rather different regime with karst springs: it has a quick and relatively strong rise of flow. Before the regulation works in the 1960s and 1970s the Vipava frequently flooded the lower valley areas. With the implementation of some regulation works the river channel was widened and deepened; meanders in the middle river section were straightened, with some cut off from the main channel. The river channel length was thus shortened from 50 to 47 km. It has been estimated that prior to the river regulations in the case of one-in-20-years flood event, approximately 1300 ha of mainly agricultural areas would be subject to flooding whereas in the case of a one-in-100-years flood event the potential inundation might be extended up to 1600 ha. However, as a consequence of the river channel straightening flood prone areas have extended, especially in the lower river sections in the vicinity of the towns Renče and Miren. It is worth mentioning that this portion of the river is under Natura 2000 protection. The river basins present a number of gauging stations (Fig. 1).

Hydrological model for the Vipava River basin was developed by splitting the watershed into seven sections (Fig. 2) (Kotar 2013). As input in the model data from 12 precipitation stations were used for rainfall data, and the data from three stations were used for temperature and evaporation data. Three water stations were used for model calibration and validation.

We used a model based on software LIFE – Light supported by Pestan software for calibration (Seibert and Vis 2012). Discharge data from six water stations were used for calibration and

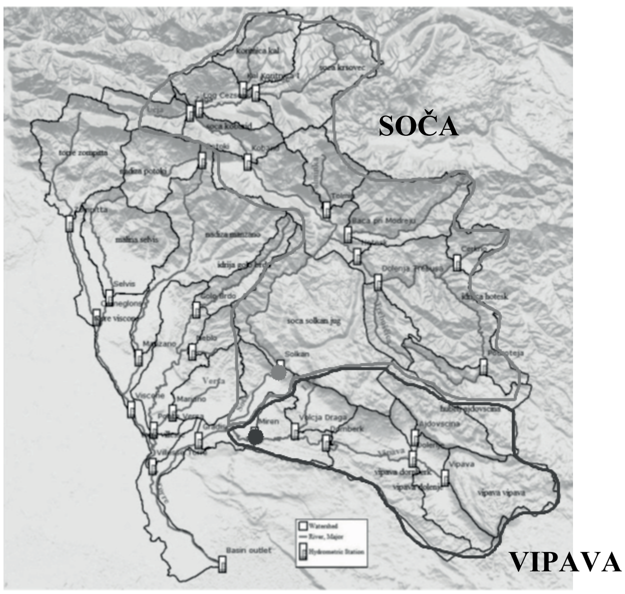

Fig. 1 River gauging stations.

Fig. 2 Sub watersheds for hydrological model and water stations used for modelling.

validation. The model was calibrated for data measured in period from 1 July 2005 to 31 December 2008 and validated for data measured in the period from 1 January 2009 to 31 December 2010. Results of calibration have coefficient R_{eff} between 0.4933 and 0.835.

The climate change impact on the Vipava River flood discharge was derived by data calculated for the whole region (Rakovec and Ceglar 2012). The rainfall data was downscaled from climate change models by E-OBS data set (Haylock *et al.* 2008). Most of the severe floods in the last year were in the autumn; E-OBS also has the highest values in autumn. The autumn rainfall data were therefore chosen as most appropriate for climate change impact analysis. Percentages of rainfall increases in different periods and different stations are between 9 and 25%. Expected temperature increases are 0.8°C for 2011–2040, 1.8°C for period 2041–2070 and 2.9°C for period 2071–2100.

Daily maximum rainfall data values and temperature increases are included in the data set of flood events in September 2010 when the most severe flood was observed. By the year 2100 the discharges with 20-years return period of rainfall will increase by 10.5% and discharges with 100-year return period of rainfall will increase by 11.95%.

Probability function of flood discharges for the Miren water station have been made by data observed in the period 1950–2011. The Gumbel probability fits the best to observed data. Discharges of E-OBS rainfall until today with 20-years return period produces flood with 8.6-years return period, and rainfall with 100-years return period produces discharges with almost 28-years return period. We can also expect that similar relation in future and because of that we can recalculate Gumbel probability functions with climate change impacts (Fig. 3).

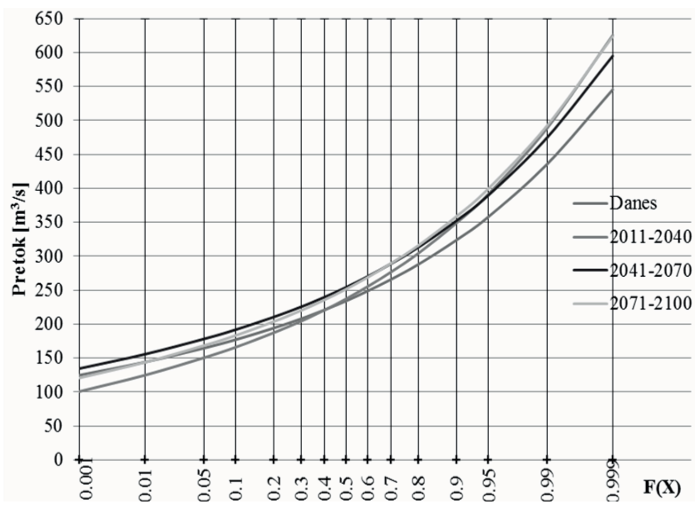

Fig. 3 Gumbel flood discharge probability functions for WS Miren including climate change.

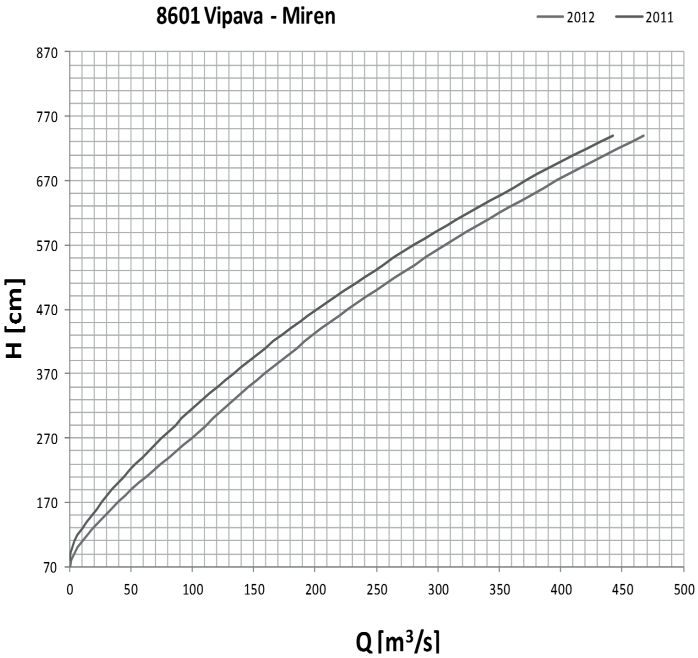

Fig. 4 WS Miren rating curve from year 2011.

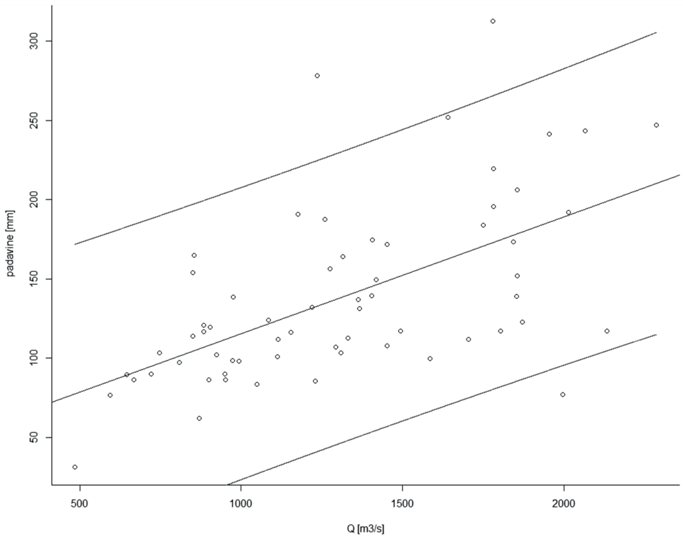

Fig. 5 Scatterplot with regression line and the 95% confidence interval for stations Solkan (discharge) and Kobarid (precipitation).

The 100-year return period floods will increase by 13% and 400-year return flood will be 100-year return period flood up to year 2100. In this time climate change impact will increase flood water level of 100-year return period of flood by 60 cm (Fig. 4).

Only correlation was used to analyse discharge increase because of the climate changes impact on the Soča River. The E-OBS data for precipitation were gathered for the two nearest precipitation stations Kobarid and Kneške ravne. Only the data from the first one (Kobarid) were used because correlation coefficient between those two data sets was better (Fig. 5).

Using the equation of regression line (Fig. 5) we calculated the discharge data until year 2010 according to E-OBS precipitation values. For three future time periods we evaluate the discharge using the equation of linear transformation.

On the water gauging station Solkan we can expect the 20-year return period discharge to increase in comparison with today's by 12% in 30 years, by almost 20% in 60 years and by 26% in 90 years. That means that in 2100 the discharge with 20-year return period will be higher by 768

m^3/s. The 100-year return period discharge in comparison with today's is in 30 years expected to be 12% higher, in 60 years 19% higher and in 90 years 24% higher. Again it means the discharge with 100-years return period will be higher by 870 m^3/s.

The same discharges with today's 100-year return period will present only the 30-year return period discharge until year 2040, until 2070 they will have a return period of 20 years and in year 2100 their return period will be just 12.5 years. Even bigger changes will occur with today's 1000-year return period discharge; until 2040 its return period will fall in 170 years, until 2070 in 115 years and in year 2100 it will be equal to 50 years (Fig. 6).

The outflow of the Vipava River is under strong impact of the water level of the Soča River. The flood peaks on the confluence have a small time lag. Probability of flood at the confluence is a function of discharges in both rivers and their coincidence. The backwater influence is significant a few kilometres upstream of the confluence.

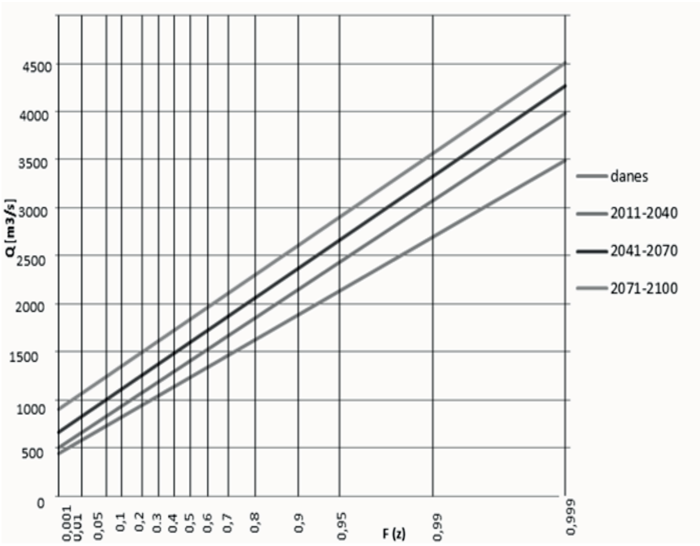

Fig. 6 Dependence between the discharge and the distribution function for the water gauging station Solkan.

CONCLUSIONS

We can define the climate change impact using more complex hydrological models or simple correlation between discharge and precipitation data for smaller basins with quite high, and at the moment unknown, uncertainty.

In mountain areas the climate changes have quite high impact and can also have an extreme influence on discharges in the lowlands. The impact of climate changes on rivers that collect water from hilly karst landscapes is much smaller but still present and can be noticed.

The confluences which are influenced by both water regimes are a specific problem. The water in one river can come from the mountains and because of that we can expect a high increase of discharge in the future, but the other river can be from karst, which means a smaller increase of water. Such cases should be treated differently using an additional probability analysis of coincidence of high water peaks.

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