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# Variability analysis of the river flow – case study of river Gornja Dobra, Croatia

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**Abstract**: The variability of river flow depends on environmental changes that are due to either natural or human causes. Measuring river flow is an essential activity in the domain of hydrology that gives valuable information on river conditions. An appropriate understanding of the conditions of the water courses and a good anticipation of all possible situations and problems that may arise are essential. The average daily river flow time series will be analyzed on the case study of river Gornja Dobra in Croatia. Rescaled Adjusted Partial Sums (RAPS) analysis with correlation analysis will be applied to the time series provided by two available limnigraph measurement stations, Turkovići and Luke. The examples will give insight into the ability to forecast river flows in the analyzed case study and other regions in Croatia and the world. The presented methodology could be used for flood protection, determining the hydro-energy potential of the rivers, irrigation, and many other purposes.

**Keywords**: River flow, RAPS, hydrological time series, measurement station, forecast

# Analiza varijabilnosti protoka – primjer rijeke Gornje Dobre, Republika Hrvatska

**Sažetak**: Promjene protoka rijeke ovise o promjenama u okolišu, koje mogu biti prirodnog ili antropogenog porijekla. Mjerenje protoka je važna aktivnost u okviru hidrologije, koja daje vrijedne informacije o uvjetima u rijekama. Važno je odgovarajuće razumijevanje uvjeta protoka i predviđanje mogućih budućih situacija i problema koji se mogu pojaviti. Vremenski nizovi srednjih dnevnih veličina protoka analizirati će se na rijeci Gornjoj Dobri u Republici Hrvatskoj. RAPS metoda (*eng. Rescaled Adjusted Partial Sums*) i korelacijska analiza primijeniti će se na vremenski niz dobiven na dvije mjerne stanice s limnigrafom, Turkovići i Luke. Korištenjem ovih metoda dobit će se uvid u mogućnosti predviđanja protoka na analiziranom području, kao i u drugim regijama u Republici Hrvatskoj i svijetu. Predstavljena metodologija može se koristiti u okviru zaštite od poplava, utvrđivanja hidroenergetskog potencijala rijeka, navodnjavanja i mnoge druge svrhe.

**Ključne riječi**: Protok, RAPS, hidrološki vremenski nizovi, mjerna stanica, predviđanje

## 1. INTRODUCTION

The river Dobra is one of the largest sinking or losing rivers in Europe. It can be divided into three characteristic areas of flow: Gornja Dobra from spring to the town of Ogulin, the second part is from Đulin Ponor through karstic canals and caverns to the village of Gojak and the third part that flows into the river Kupa. The Đulin Ponor represents a natural drainage system for the high waters of the Gornja Dobra and its tributaries [1]. This karstic river takes various forms, i.e., it shows great variability of hydrographic, hydrologic, and hydrogeologic regimes. It also runs partly as a surface and partly as an underground river, demonstrating hydraulic interaction through many karstic forms. River Dobra is characterized by rapid and large oscillations of groundwater levels, which directly affect the hydrologic and hydrogeologic regime of open watercourses and that flowing underground karst. Water losses from the surface to the karst underground generally occur in low waters, while during high waters, the processes are generally reversed. So, depending on the hydrogeological situation, river Dobra simultaneously loses parts of the water in the karst subterranean but is also fed with water from the karst aquifers. The processes of losses and the inflow of water into/from the karst underground along the Dobra have been observed but have not yet been sufficiently studied and explained [2].

High waters on Gornja Dobra present a risk of floods in the city of Ogulin, so predicting that dangerous event is important to prevent disasters. Also, the problem is the anthropogenic impact that occurs by building dams and accumulations, over-pumping of the groundwater, and building a hydropower plant, which [2] analyses to show changes in the hydrological regime caused by human activity in their case by the operation of HPP Gojak. [3] had determined that the river Gornja Dobra has the potential to build small hydropower plants, especially kinetical.

## 2. RAPS METHOD AND CORRELATION ANALYSIS

Correlation analysis deals with the research and quantification of the connection by mixing and quantifying the connection between the observed phenomena, i.e., variables. The RAPS method can be applied in all research areas but is mostly used to analyze a river flow from a hydrological point of view [3]. This method has quite a wide range of applications, especially in hydrology [4].

That method is based on the visual determination of the values of the analyzed parameters, where the occurrence of the trends, data grouping, fluctuations, and similar appearances during the time appear. By using the average value and standard deviations of the observed time values, RAPS can be calculated through Equation (1).

$$RAPS_k = \sum_{t=1}^{k} \frac{Y_t - \overline{Y}}{S_y} \tag{1}$$

Where $Y_t$ is the value of the analyzed member (parameter) of the considered time series, $\overline{Y}$ is the average value of the considered time series, $S_y$ is the standard deviation of the considered time series, and $t$ = 1, 2,..., $k$, where $k$ is the number of members of the considered time series counter during summation [5].

The correlation coefficient describes the correlation of variables that presents the direction and strength of the correlation of variables in a linear relationship. The correlation coefficient values are expressed from -1 to +1, where -1 indicates the complete negative correlation between the two variables, +1 fills the positive correlation between the two variables, and 0 indicates the absence of correlation between the observed variables [6].

## 3. RESULTS OF THE STUDY CASE ANALYSIS

Variability analysis of the river flow will be given through RAPS analysis of data from measurement stations Luke and Turkovići, which are shown alongside the location of river Gornja Dobra in Figure 1. Data from the mentioned stations are given for an examined period of 20 years, from the beginning of 2000 to the end of 2019 [7].

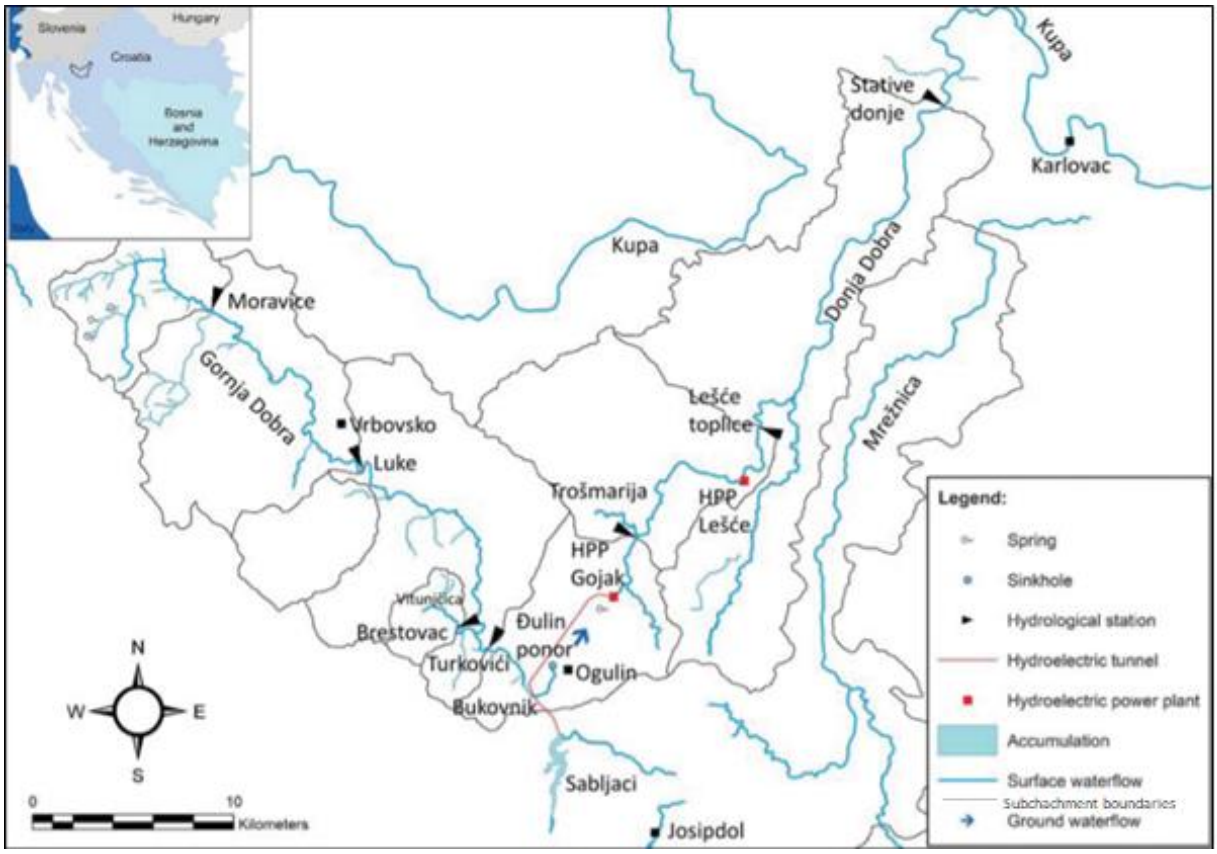


Figure 1. River Gornja Dobra with the location of measurement stations Luke and Turkovići, modified from [1]

Figures 2 and 3 show the view of the river Gornja Dobra at Luke and Turkovići measuring station. Figures 4 and 5 show the average daily flow from Turkovići station.

Figure 2. River Gornja Dobra at Luke measuring station

Figure 3. River Gornja Dobra at Turkovići measuring station

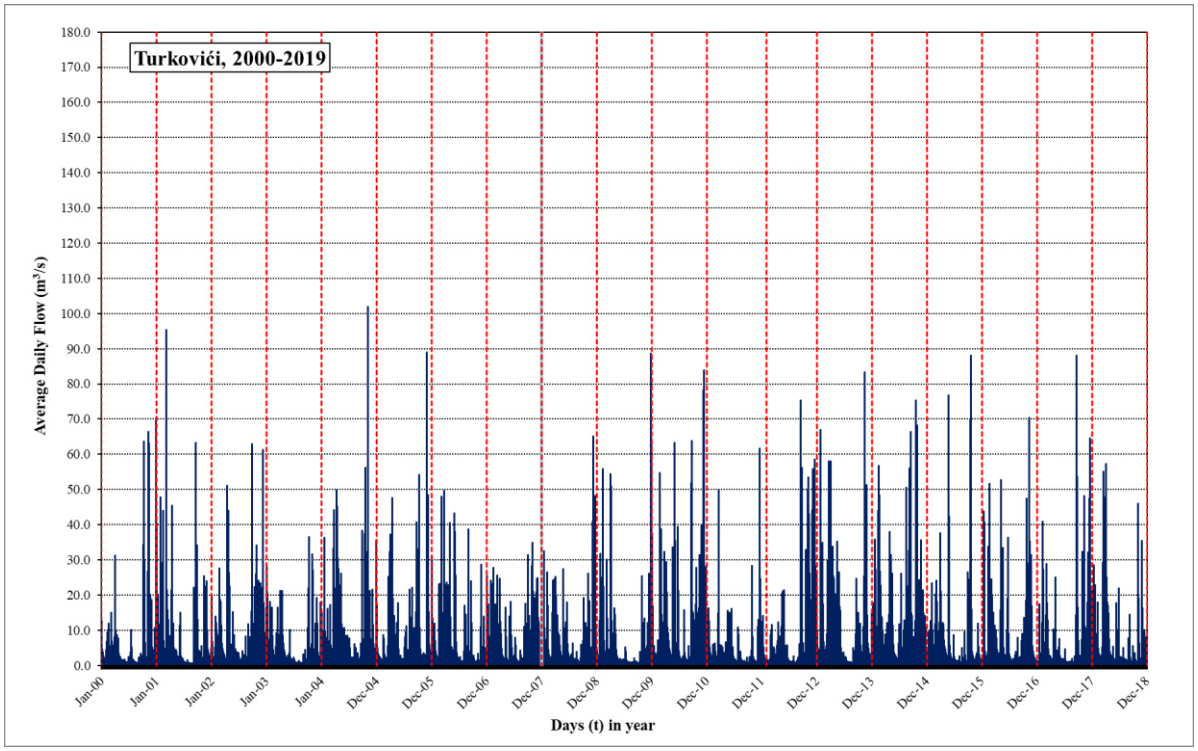


Figure 4. Hydrograph from Turkovići measuring station

A RAPS method was applied and shown in Figure 5 on given data of averaged daily flows.

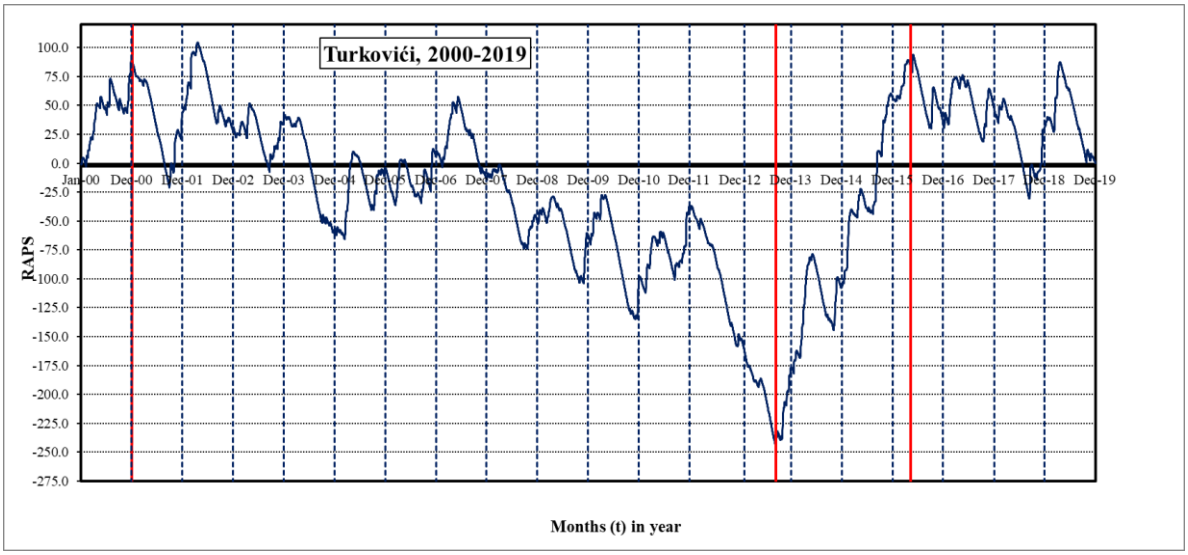


Figure 5. RAPS analysis for the average daily flows for measuring station Turkovići

The analysis of the RAPS diagram for the river Gornja Dobra at Turkovići station shows four subperiods. The first subperiod began at the beginning of the year 2000. The second subperiod is from the end of 2000 to the end of 2013, while the third began at the end of 2013 and lasted till the end of 2015. The fourth period starts from the beginning of 2016 and extends further. It can be noticed that there are periods of ''low flows'' in the second subperiod, while

in the third subperiod, “high flows” years appear. Figures 6 and 7 show the average daily flow on Luke station and RAPS on the same collected data.

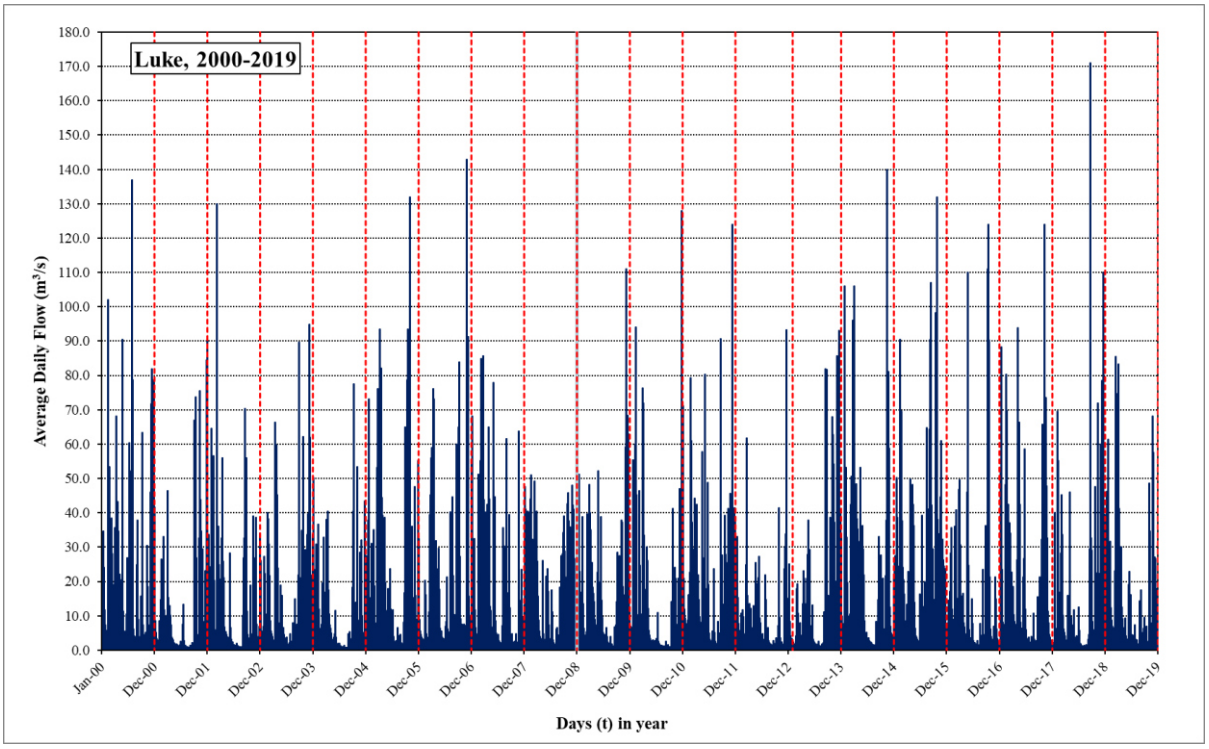


Figure 6. Hydrograph from Luke measuring station

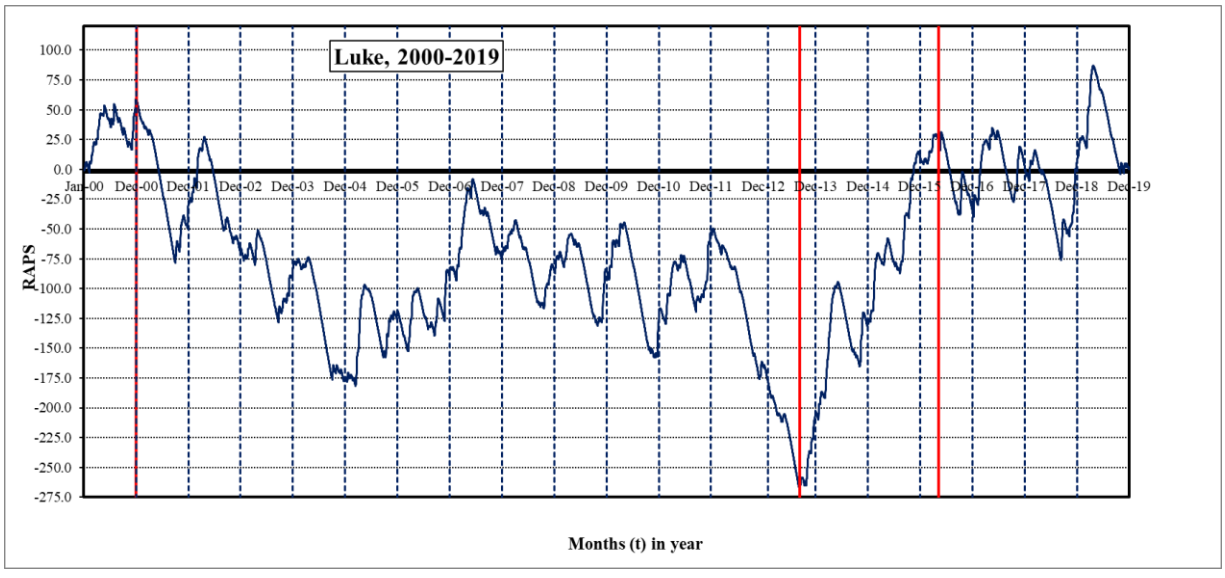


Figure 7. RAPS analysis for the average daily flows for measuring station Luke

Luke station gives data that shows four subperiods when analyzed by the RAPS method. Same as at Turkovići station, subperiods begin in the first part of the 2000 year, second from the beginning of 2001 year and last till the end of 2013 year, while the third comes after and last till

the beginning of 2016. The fourth subseries starts at the beginning of 2016 and extends further. Like on Turkovići station, RAPS analysis gives insight into “low flows” periods in the second and third subperiods with “high flows” years.

From the RAPS analysis, partial overlapping of the RAPS patterns can be seen in Figure 8.

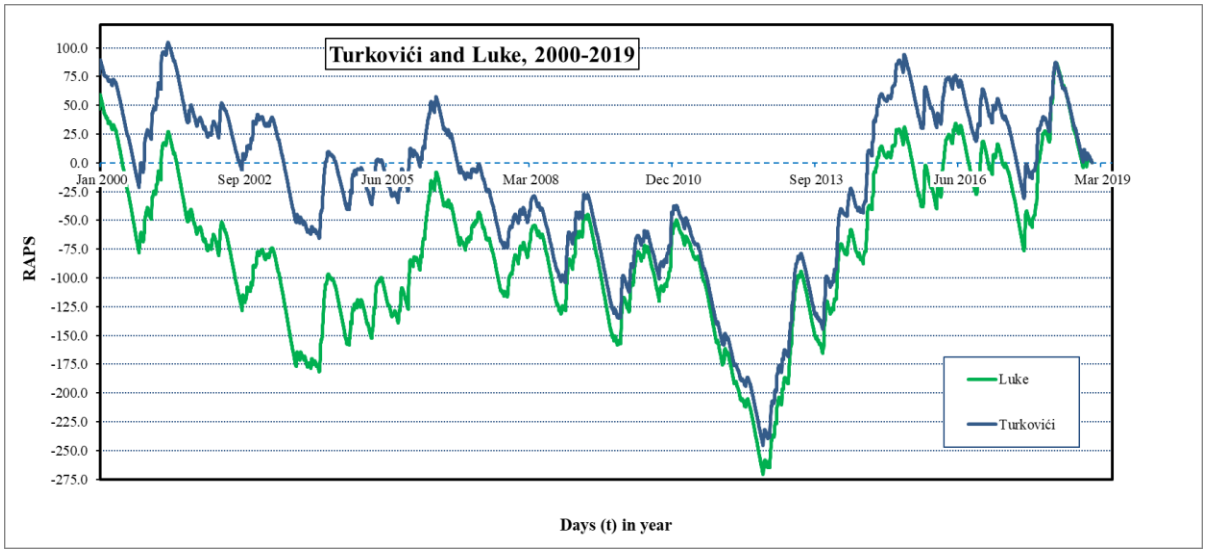


Figure 8. Comparison of the RAPS analysis for the average daily flows for both measuring stations Luke and Turkovići

One of the reasons for the joint period by the beginning of 2010 could be explained by the fact that there are no significant tributaries between these two stations. Also, the overlapping of the shapes of the RAPS diagrams is visible throughout all analyzed periods. RAPS analysis is very useful for detecting the subperiods where anthropogenic or natural appearances have an impact. The building of the Hydropower plants Lešće (42,29 MW) and Gojak (56 MW) [8] has changed hydrogeological conditions, especially because they are built in the karst area, which is usually very hard for analysis. HPP Lešće uses an accumulation lake, while HPP Gojak uses a hydro-technical tunnel to input the water. Due to the literature analysis from the work in [9,10], it is a very difficult and complex task to quantify the real impact of both HPPs. Climate change also has a significant role in this issue.

However, further analysis is needed to define a possible relationship between the average daily flows at the measuring stations Luke and Turkovići. By this, changing the flow at the upstream station Luke could affect changing the flow at the downstream station Turkovići. Such is important, especially when the water wave comes from the measuring station Turkovići. Figure 9 shows the correlation relationship of river flow between the Luke and Turkovići stations.

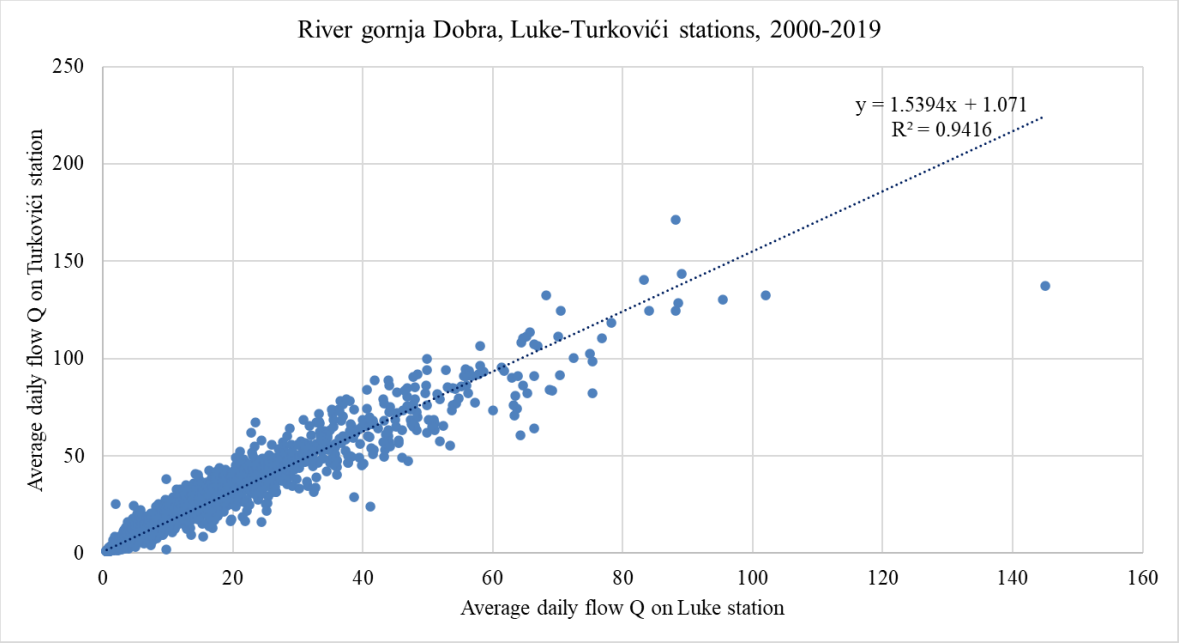


Figure 9. Correlation of average daily river flows on Luke and Turkovići stations

It could be seen that there is a significant, very high positive correlation between these measuring stations. Due to the earlier discussion, it is necessary to conclude that correlation will be applied, but this time between RAPS values, Figure 10. Such analysis was provided to analyze the flow in the alluvium media [11] and for the seawater level changes [12]. At the same time, it is applied for the flow analysis in the karst media.

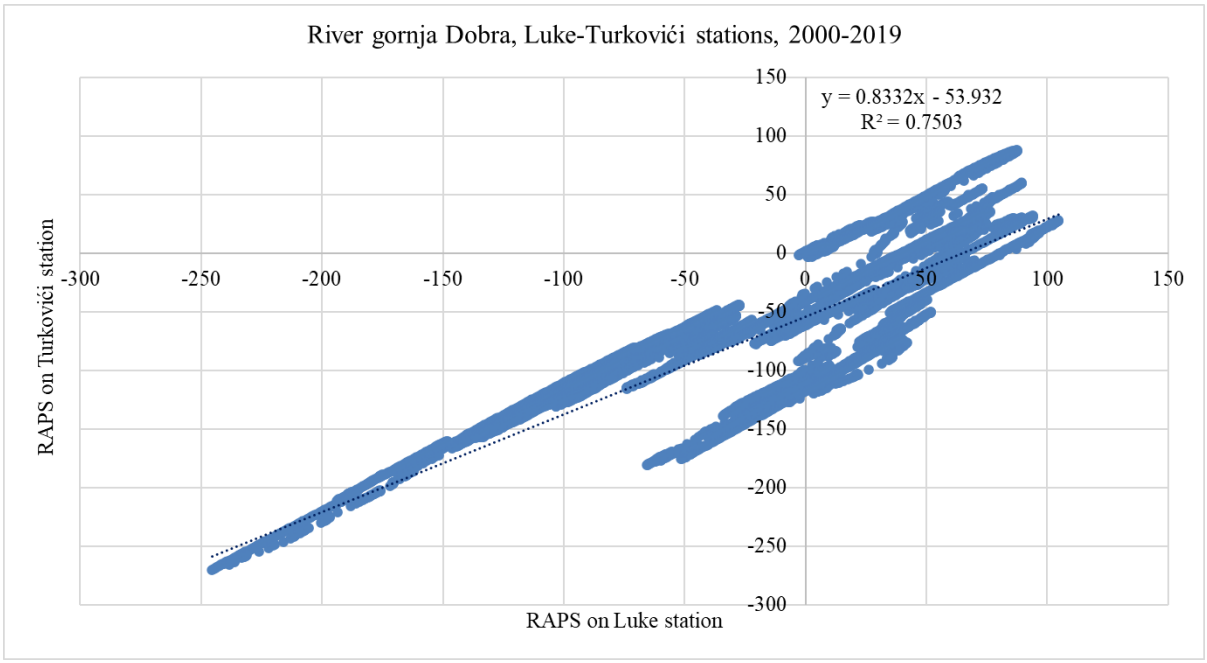


Figure 10. Correlation of RAPS data on Luke and Turkovići stations

In general, correlation coefficients on both diagrams show the positive relationship between the two variables: collecting data of averaged daily river flows and their RAPS values on Luke and Turkovići stations. The RAPS coefficient of the correlation also shows a high positive value.

## 4. CONCLUSION

Although the presented research explains the measured flows of the river Gornja Dobra, the relationship is only partially described. The paper pointed out the hydrological complexity of the analyzed area. Further analysis should involve precipitation analysis and analysis of the hydrogeological conditions of the watershed of both rivers, Gornja Dobra and Donja Dobra. The results of the RAPS analysis carried out in this research use RAPS as an excellent tool for forecasting the river flow, which is supported by the high values of $R^2$ in correlation analysis. Such analysis is a great starting point in making robust conclusions about the impact of global climate change or periodic surface runoff fluctuations of nature. Therefore, the study of case rivers requires more profound and long-term analysis in the future.

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