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Application of Rescaled Adjusted Partial Sums (RAPS) method in hydrology – an overview

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Abstract:
To describe the behaviour of watercourses, numerous parameters should be considered, such as water flow, depth/water level, velocity, and the amount of deposit in a waterbed. In addition, many other parameters should be analysed to understand the mechanism of specific watercourses. The most typical parameters are those associated with water quality, such as water temperature, and pH value, and temperature, as well as various climate parameters, such as precipitation, evaporation, and insolation, which are visualised in the form of a time series. The measurement frequency can differ for each parameter. Depending on the number of available measurements, hourly, daily, monthly, and yearly data can be obtained, which can then be used to form a time series. Many well-established and applicable procedures and models for time-series analyses exist, including the rescaled adjusted partial sums method (RAPS). This method is devised to detect possible irregularities and/or fluctuations within the original time series, which cannot be achieved using typical time-series analysis methods. This paper presents a comprehensive review of the application of the RAPS method in hydrology, where the advantages and disadvantages of the method are discussed.

Keywords:
Analysis; hydrology; RAPS; subperiods; time series

1 Introduction

Hydrology describes the occurrence, movement, distribution, balance, and properties of water on Earth, including groundwater and surface water. Furthermore, it depicts the correlation between water and the environment within every phase of the hydrological cycle. Hydrology is a modern, complex, and multifaceted science, with numerous branches including potamology or fluviology, which pertains to the analysis of surface watercourses. Watercourse flow is an important component of the hydrological cycle. Enough surface water is a prerequisite for the sustainability of many ecosystems. Water is a unique medium, whose movement is characterised by a complex and stochastic process.

Researchers have used different approaches to explain and describe the characteristics of flow. Among them, physical-based models that imitate hydrological processes [1], [2] have been widely used. However, these models typically require many parameters associated with the hydrological cycle and long time series, rendering their usage complex. Meanwhile, conceptual-based models have been frequently applied to represent hydrological processes using simplified mathematical equations [3]. However, conceptual models require the deduction of parameters from observed data and are not directly measurable [4].

Notably, water quality and quantity data accessible by scientists and engineers are limited. Data acquisition requires continuous and extensive monitoring using expensive devices and depends on the availability of laboratory facilities, staff, and technical expertise. Hence, a reliable method must that can be applied easily and provide basic statistical parameters, such as average and standard deviation, must be selected to test the consistency of time series.

The rescaled adjusted partial sums (RAPS) is a typically used method for the analysis of time series in hydrology, regardless of the quantity and quality of the time series. This method requires only the analysed time-series average values and standard deviations. It is based on visualising a new (obtained) subseries from an original continuous data series. Based on the average and standard deviation of the analysed time series, a graphical presentation of the sums of the calculated RAPS can provide insights into the new subseries, which shows data aberrations and similar incidences. This method is based on the following equation:

$$RAPS_k = \sum_{t=1}^{k} \frac{Y_t - \bar{Y}}{S_y}, \quad (1)$$

where Yt is the individual value of the analysed member of the analysed time series, $\bar{Y}$ the average value of all members in the analysed time series, Sy the standard deviation of all members in the analysed time series, k the number of all members in the analysed time series, and t = 1, 2, ..., k the counter during the summation process [5]. The final RAPS must be 0 to verify whether the calculation is provided correctly because the time-series counter completes the summation of the time-series members. The authors of [6] concluded that a change in the slope of the RAPS values only indicates a change in the slope size of the original time series. A negative slope for the RAPS does not imply a negative slope in the original time-series.

In the analysis presented herein, in addition to flow parameters, water quality and meteorological parameters are considered because they directly affect water flow. This review paper presents the possibilities for the application of the RAPS method. In addition, based on strength, weakness, opportunity, and threat (SWOT) analysis, the advantages and disadvantages of the RAPS method are discussed.

2 Examples of application of RAPS method

A detailed elaboration of the RAPS method, including a comprehensive theoretical description and case study applications, is presented in [5]. The authors provided an example of a RAPS subseries obtained based on the linear trend lines of the original time series for a random variable (Figure 1). The intention was to define a rule for segmenting the original time series into subseries, if they exist.

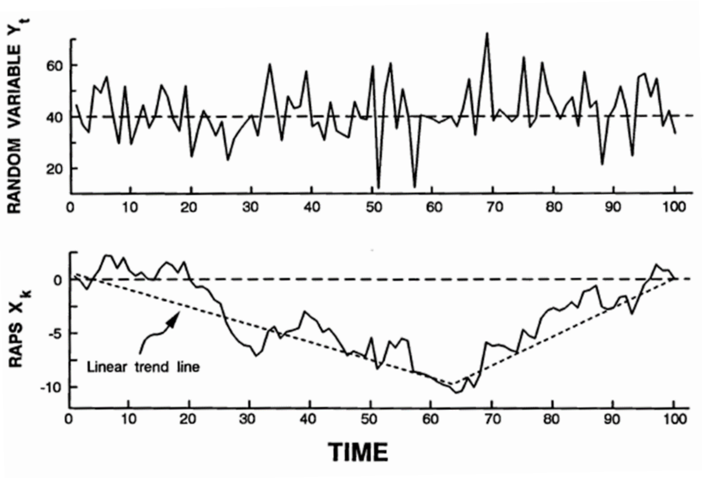

Figure 1. Example of linear subseries trend obtained using RAPS method.

The purpose of the present study is to justify the rules of the “highest peak” and “lowest valley.” Although deviations in the original time series were not evident at first sight, the original time series was observed to be segmented by deviations after applying the RAPS method. A break or valley was observed after approximately 65 units (Figure 1.).

The dashed line in the upper graph of Figure 1. shows a linear trend. In the lower graph, the dashed lines show linear trends, which are defined based on the RAPS and are transparent. This example is presented to prove that the application of the RAPS method is based on the rule of the “highest peak” and “lowest valley”, regardless of the order of occurrence.

The application of the RAPS method can be explained based on four levels. In the first level, the original time series is segmented into a series of subseries. At the second level, trend lines (in most cases, linear) are added to the subseries. In the third level, the new (obtained) subseries are tested based on statistics. In the fourth level, the correlation between the values of the RAPS is defined.

2.1 Level I of RAPS application

The authors of [7] applied the RAPS method to the time series of the mean annual discharge of the Drava River in Croatia at the Botovo measuring station. Figure 2. shows the typical procedure for defining the linear trend of flow values during the observed years. The coefficient of determination R2 shows an insignificant correlation in the discharge analysis.

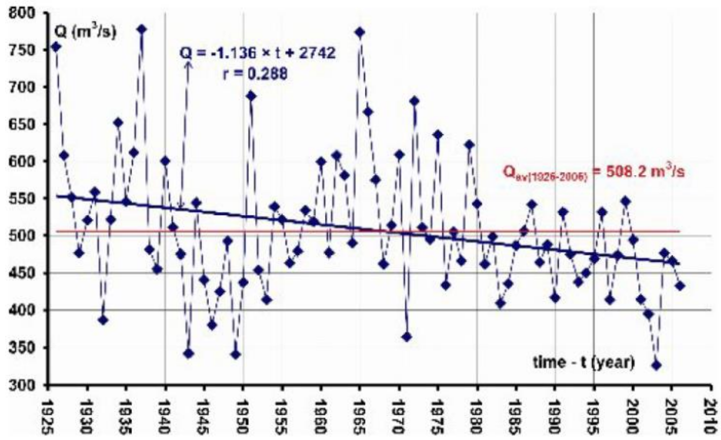

Figure 2. Time series of mean annual discharge of Drava River in Croatia at the Botovo measuring station, with a linear trend line for 1926–2006.

As mentioned earlier, the RAPS method can be used to examine not only the quantity, but also the quality of water. Figure 3. [8] shows the quantity and quality parameters for the Krka River in Croatia. In this figure, a vertical partitioning line is not defined. Nevertheless, irregularities can be observed by segmenting the original time series. The vertical lines drawn for years 1960 and 1980, are borders (top and bottom points of the series) that segment the original time series into subseries, and Yk is a value of the RAPS.
As shown in Figure 3., the RAPS for the time series of precipitation overlaps inversely with that of discharge, which supports the correlation between precipitation and water discharge.

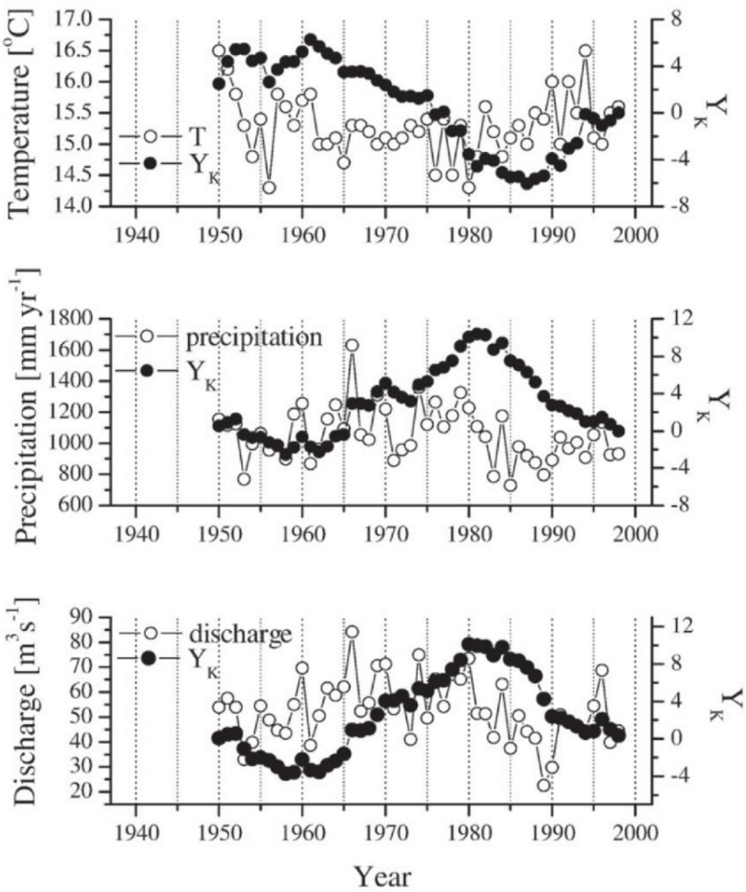

Figure 3. RAPS of air temperature, precipitation, and discharge of Krka River

Figure 4. [8] shows the previously determined and established connections between air temperature and discharge. The RAPS of the isotope values can be compared with the RAPS of temperature because a change in temperature can change the isotopic composition of precipitation and, consequently, the water in the catchment. The values of the analysed elements (Mg, Sr, and Ba) did not overlap with the analysed hydrological, meteorological, and chemical parameters. The presented analysis provides evidence that despite the overlapping of time series, the analysed parameters need not be overlapped. The intention of this study is not to investigate the cause of this non-overlapping but to demonstrate and explain the potential of the RAPS method. For all the scenarios presented, the appearance of deviations could not be observed by merely examining the original time series.

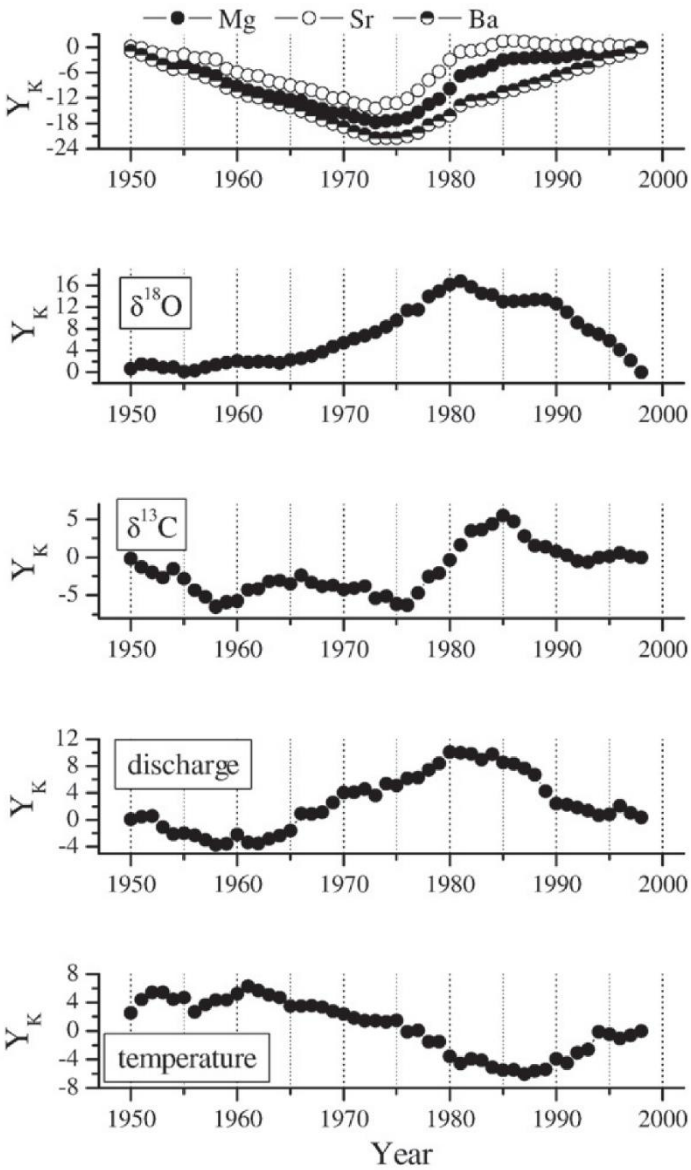

Figure 4. RAPS of mean annual temperatures, mean annual discharges, δ13C, δ18O, and metal concentrations of carbonate layers in Krka River.

2.2 Level II of RAPS application

Previously, the precipitation time series was segmented based on linear trends [9]. Figure 5. shows increasing and decreasing linear trends during the year, but without the equations of the trends and the R^2. The linear trend lines were defined by applying Equation (1) to the original time series, which indirectly defined the three subseries showing the local climate properties.

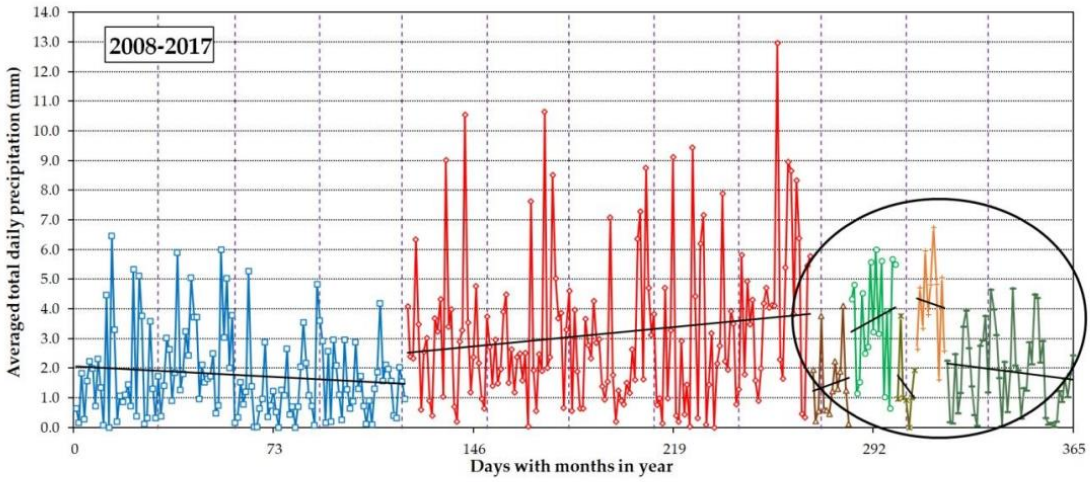

Figure 5. Subseries of precipitation with linear trends obtained by applying values of RAPS for the city of Varaždin, Croatia.

In this case, general and regional climates were observed even without applying the RAPS method. Many subseries were observed in the autumn of the year. Notably, the clay excavation period should be analysed. Third, the final subseries is problematic as it shows many deviations. The first and second subseries did not exhibit significant deviations. This implies that applying the RAPS method can be used to effectively determine and avoid the problematic period of the year during fieldwork and economic activities such as clay excavation. In addition, linear trends can be defined using the corresponding equations (see Figure 6.) [10].

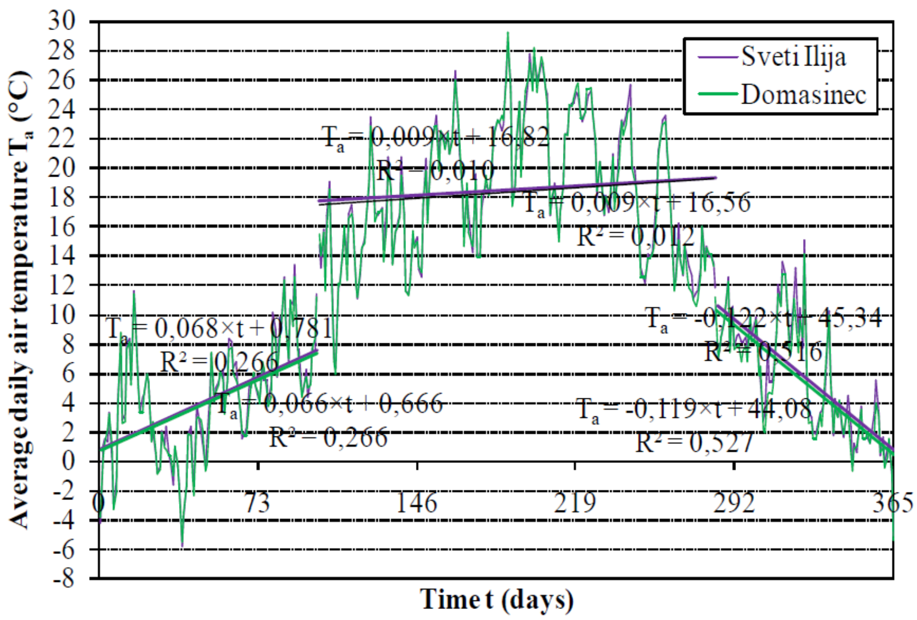

Figure 6. Subseries of average daily air temperature for Sveti Ilija and Domašinec, Croatia.

Additionally, this example shows the local climate characteristics, which can be predicted without using the RAPS method. However, data analysis using the RAPS method allows characteristic periods with changes in the air temperature to be determined. The example presented involved three distinct climate seasons in the observed area.

2.3 Level II of RAPS application

The authors of [11] analysed two karst rivers in Croatia: Lika and Gacka. The annual mean air temperatures for the Gospić meteorological station and the annual mean water discharge for the Gacka River at the Vivoze hydrological measuring station were analysed using the RAPS method (Figures 7. and 8.).

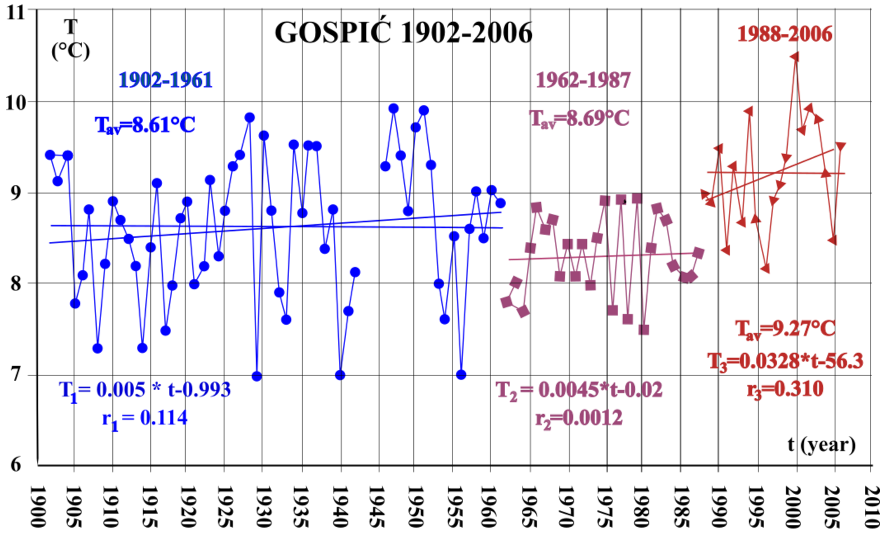

Figure 7. Trends of mean annual air temperatures measured at the Gospić meteorological station for three sub-periods.

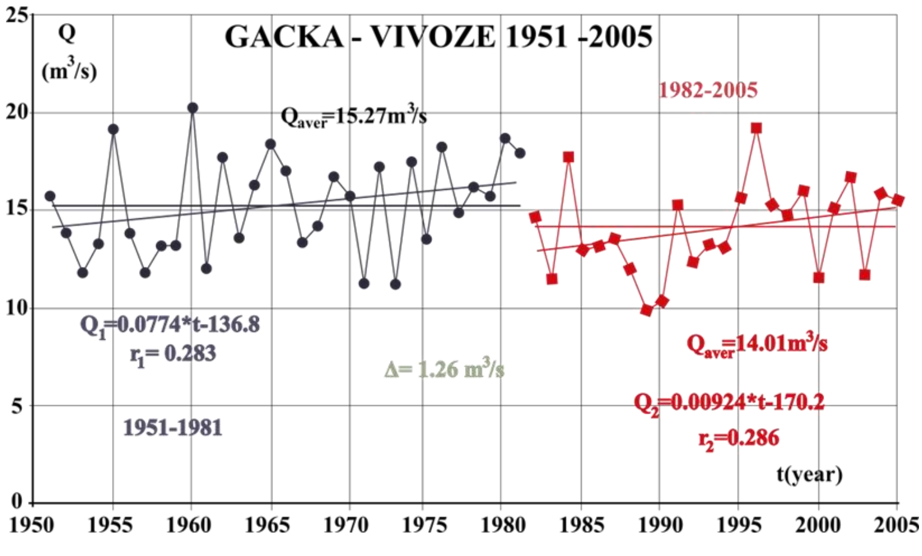

Figure 8. Trends of mean annual discharges in Gacka River measured at Vivoze for two subperiods.

Subseries with linear trends were defined simultaneously with the R2 (squared root R) and r, which is the squared root of R^2. The Student's t-test was used to investigate the significance of the differences between the average values of the three average subperiod discharges, with a $p < 0,01$ level of significance, which is satisfactory. Although the r values of the squared roots of the newly obtained subseries were not significant, the presence of subtrends was evident. In [12], the Mann–Whitney U test was applied, similar to the test for Sacramento River in the USA (Figure 9.).

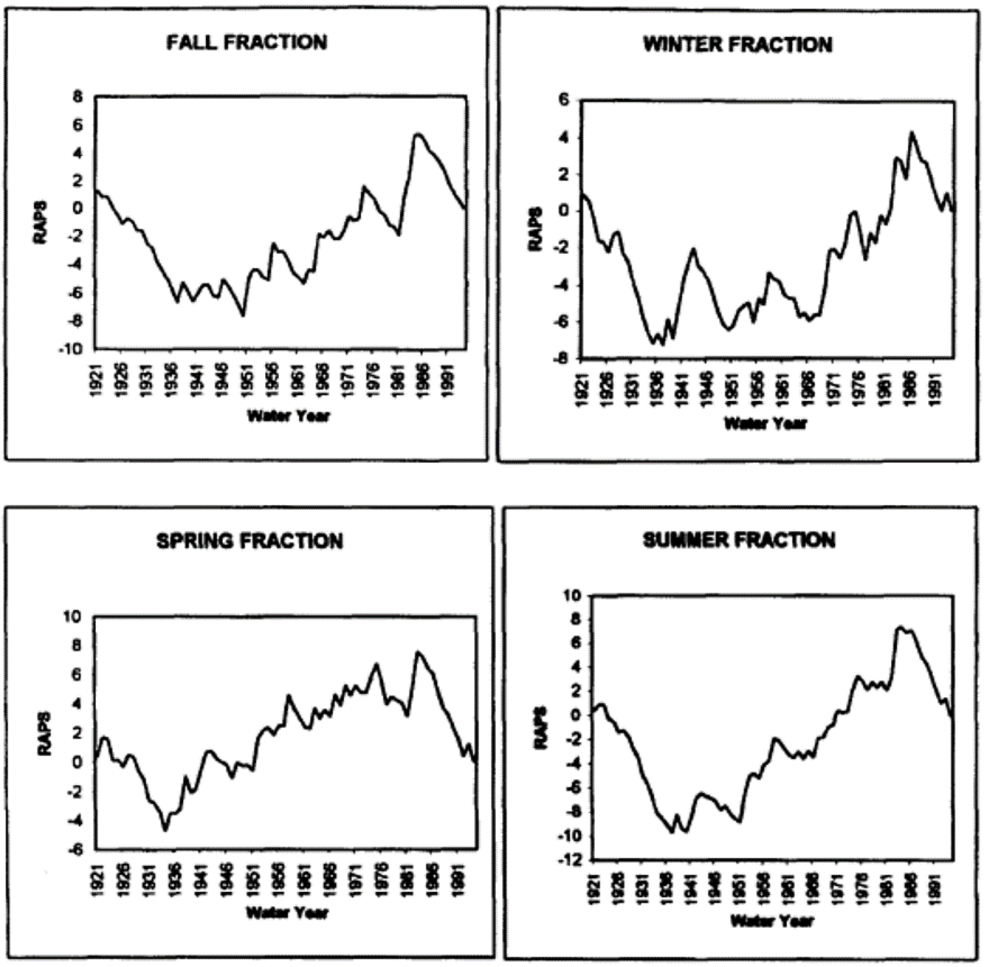

Figure 9. RAPS for seasonal fraction of annual flows of Sacramento River, 1921 to 1994.

This example shows that the statistical significance can be verified/test without drawing the trends. Suppose that the obtained graphs are examined based on the number of peaks and valleys in the line. In this case, one can conclude that in the winter, the flows show more significant changes in intensity compared with the case in other seasons.

2.4 Level IV of RAPS application

The primary purpose of using the RAPS method in hydrology is to determine the possible fluctuations of the time series and to determine the subseries with such irregularities. Although the form/shape and application of the RAPS method are simple, it offers the possibility of testing the irregularities between two analysed time series, i.e., those between two locations. This analysis was conducted to determine the relationship between ocean water level changes and rainfall in the Chao Phraya River Basin in Thailand (Figure 10.) [13]. The analysis was performed to evaluate the extent to which the increase in the sea level indicators (southern oscillation index, SOI) and NINO sea surface temperature indices within the box 0°–10°S, 90°–80°W (which is NINO3) is correlated with precipitation. In other words, all irregularities between the indicators and precipitation were expressed based on a linear trend of the RAPS.

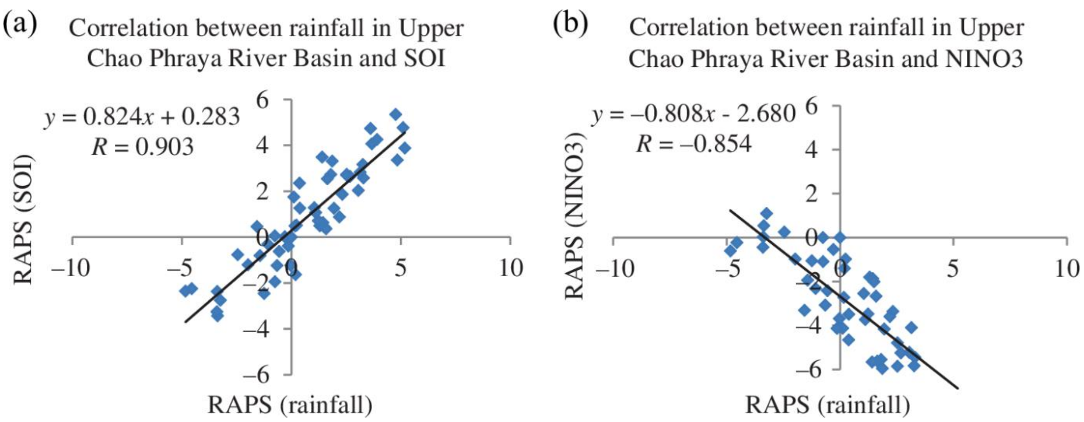

Figure 10. Correlation between the RAPS of SOI and NINO3 time series with rainfall (a) and (b), respectively.

Higher values of r indicate a significant connection between parameters. In addition, they imply possible connections but also irregularities if they exist.

The methodology presented in [14] shows the correlations among single values of the RAPS (Figure 11.) and the correlations between the summed values of the RAPS (Figure 12.) for the average daily increase in seawater level.

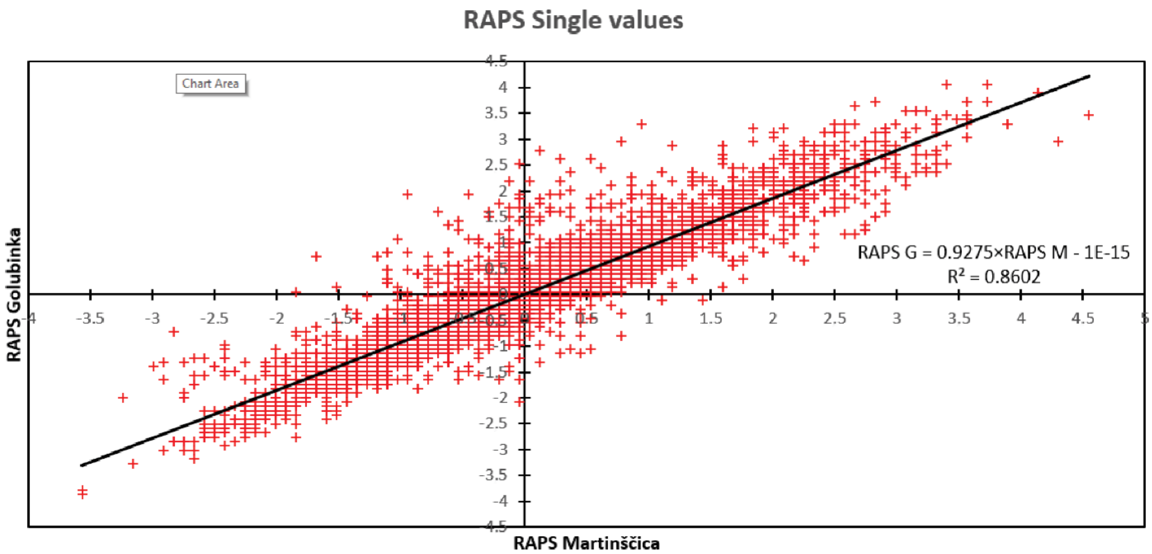

Figure 11. Correlation among single values of RAPS measured at Golubinka and Martinščica for average increase in daily seawater level

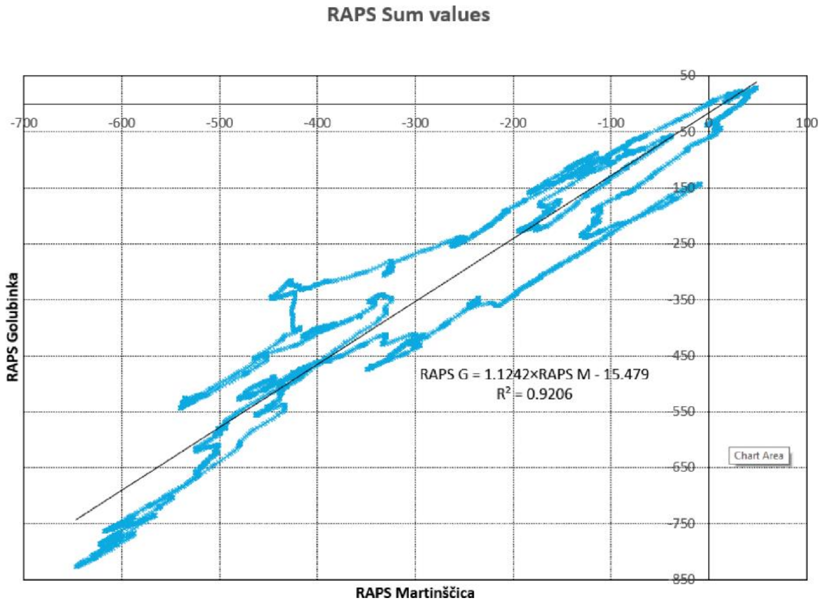

Figure 12. Correlation between summed values of RAPS measured at Golubinka and Martinščica.

This analysis shows the effect of sea-level changes on coastal areas, which provides useful information for the salinisation of drinking water sources and changes in water quality.

3 Examples of non-concise analyses using RAPS method

The authors of [15] segmented the original time series of runoff (Figure 13.) and sediments (Figure 14.) into subsegments by applying Equation (1) and visualising the ”highest peak” and ”lowest valley.”

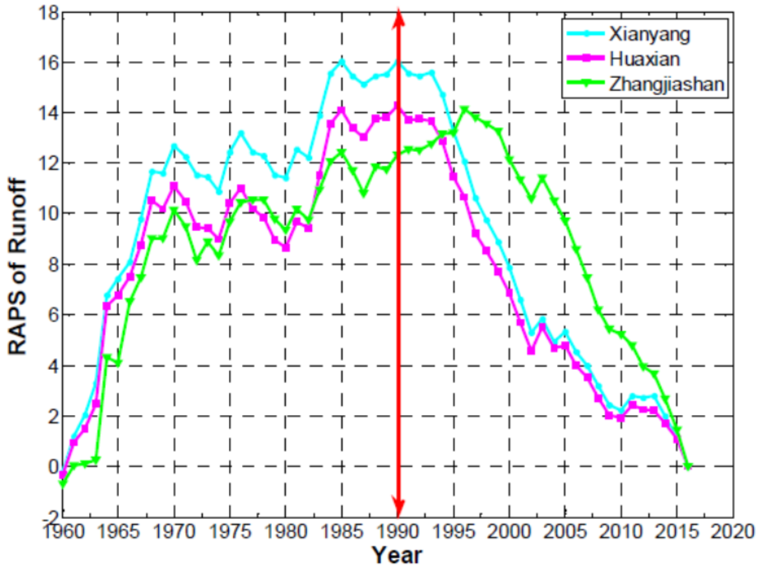

Figure 13. Visualisation of RAPS of annual runoff.

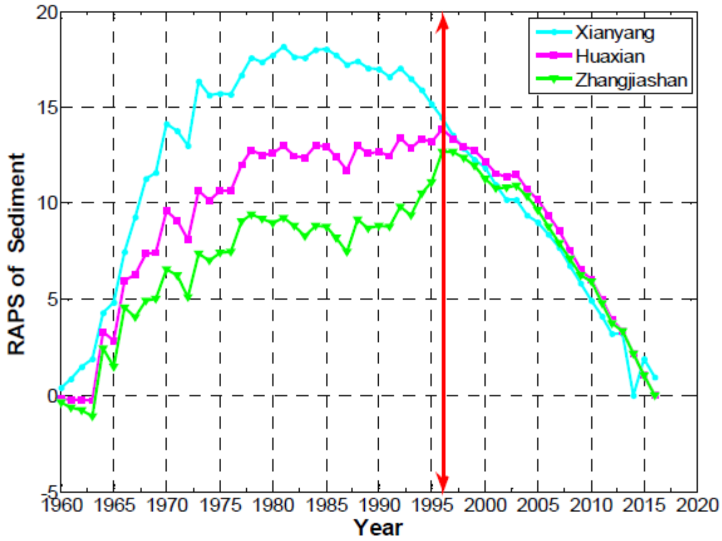

Figure 14. Visualisation of RAPS of annual sediment

The RAPS were analysed without defining a trend and performing a statistical test on the significance level of the obtained subseries. In the example presented, the annual runoff values are segmented into two subseries, where the boundary year is 1990. By comparing this analysis with the RAPS of the sediments, two sets of results were observed. First, the years that partition the subseries did not overlap with the boundary year for the sediments recorded close to 1995. Second, the partitioning year in Figure 13 was selected subjectively, and the highest (top) peaks were not aligned vertically for the Xianyang River. This clearly shows that although the RAPS is not a complicated method, it should be utilised with caution to avoid incorrect conclusions. In a previous study [16], the RAPS method was applied to compare and analyse the relationship between the average air temperature Ta and average river water temperature Tw, as shown in Figure 15.

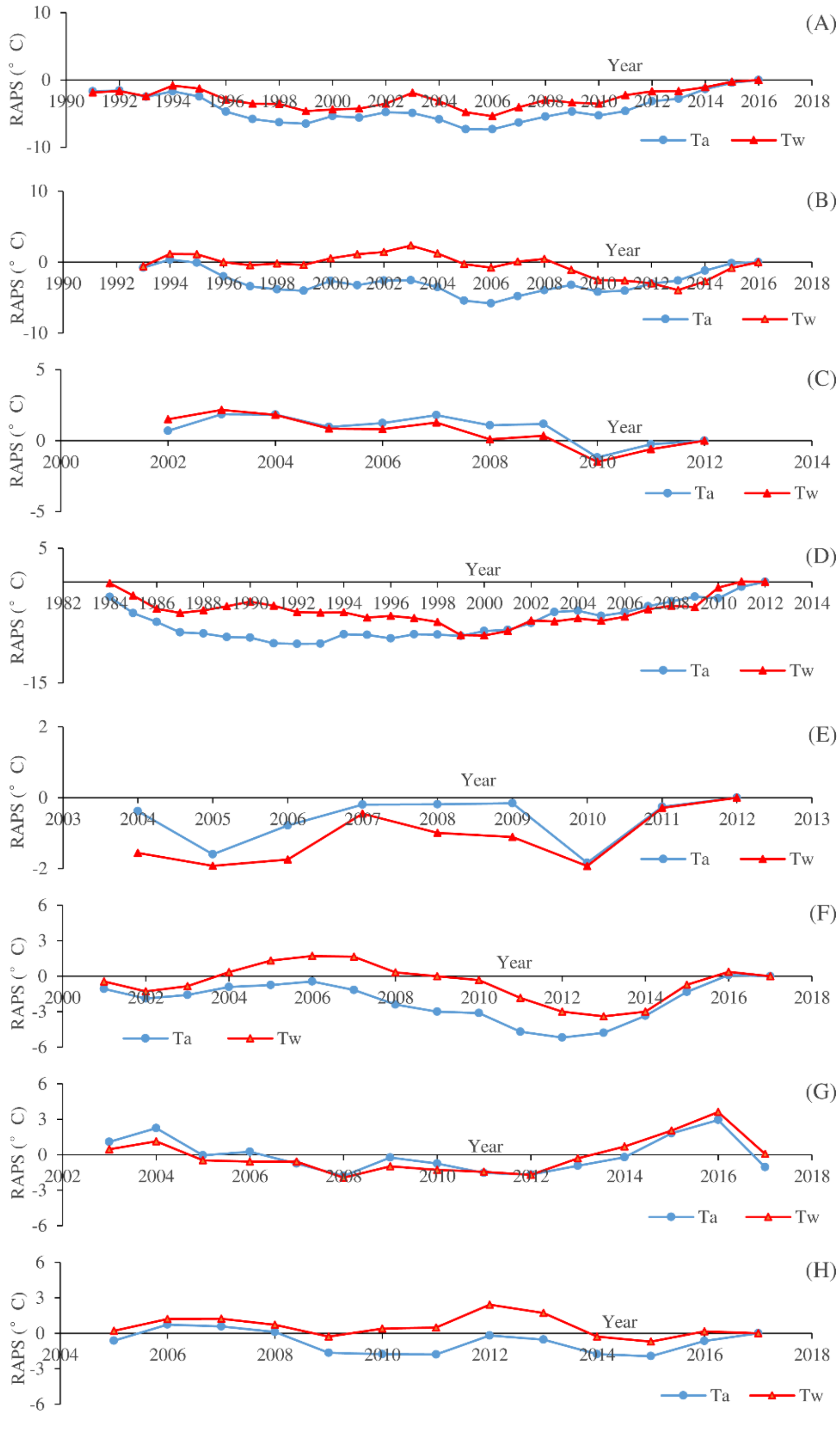

Figure 15. Time series of RAPS for average air temperature and average water temperatures based on several observed locations/rivers.

The presented time series showed mutual overlap. The air temperature in Figure 15 G should be 0. In fact, the RAPS should always end at 0. Hence, one can conclude that an error occurred when calculating the RAPS. Notably, the RAPS do not reflect values expressed by the analysed parameter. The result of an analysis presented in [5] is shown in Figure 16.

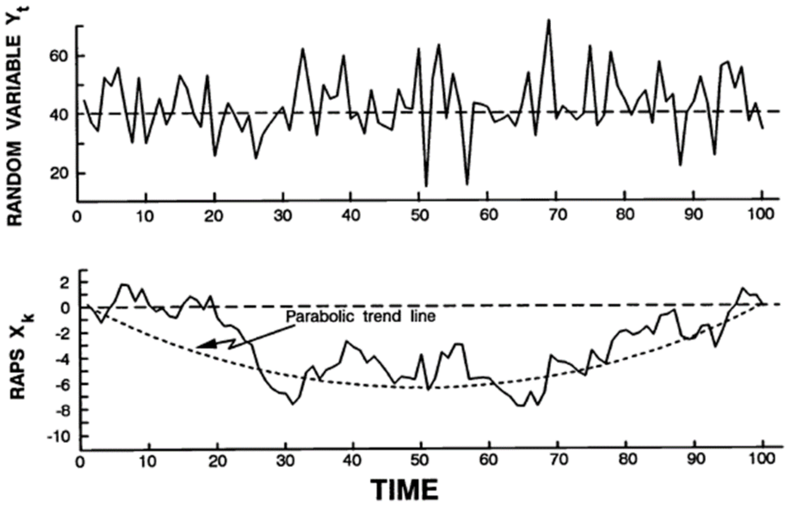

Figure 16. Example of parabolic subseries trend obtained using RAPS method.

The delineation of the parabolic line does not facilitate explanation because the rule of the ”highest peak” or the ”lowest” valley must be complied with.

4 SWOT analysis based on example

SWOT analysis was performed to present all the advantages and disadvantages of the RAPS method. This is reported point-by-point in Table 1.

Table 1. SWOT analysis of RAPS method.

Strengths	Weaknesses
○ The RAPS method is not difficult to apply; the only prerequisite is the availability of the time series values without gaps and/or places without any values. ○ Only basic statistical prior knowledge is required, i.e., determining the average values and standard deviation of the analysed time series.	○ The weakness of the RAPS method is that the entire analysis is based on the visual interpretation of the obtained RAPS. ○ Superficial analysis, particularly when experience is insufficient, can result in inaccurate conclusions.
Opportunities	**Threats**
○ Obtaining the new subseries is sufficient to determine the irregularities and fluctuations in the original time series. ○ To elevate RAPS analysis to a higher level, statistical testing can be performed, e.g., the F-test and t-test.	○ Scepticism towards the method owing to its simplicity. ○ Possible errors in interpretation due to insufficient experience.

An example of the advantages and disadvantages of the RAPS method is presented in Figures 17. and 18., which show the time series of the increase in the average daily seawater level [15].

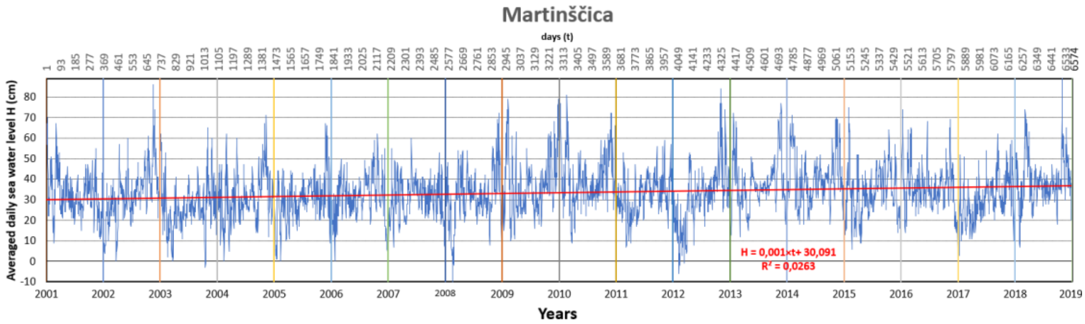

Figure 17. Example of defining linear trend for average daily seawater level time series.

The negligible value of R^2 shows that the defined established functional dependency, i.e., the calculated correlation, is not justified for any relationship between the average daily seawater level H (cm) and a previous period. This does not facilitate the reliable prediction of future increases in seawater levels. Regarding the RAPS method, the next step is to determine whether some irregularities affect the possibility of defining appropriate trends, as shown in Figure 18 [15].

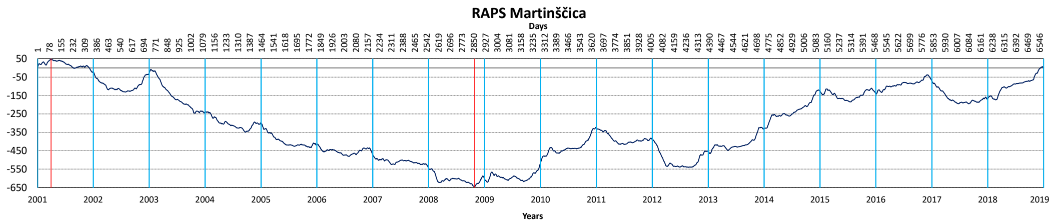

Figure 18. RAPS of averaged daily seawater levels measured at Martinšćica.

The values of RAPS presented suggest interruptions within the original time series. The observed subperiods cannot be determined via a simple analysis of the linear trend. As presented in this example, the R^2 is a standard statistical indicator for defining linear trends. However, negligible values of R^2 can be misleading and require additional analysis, as shown in Figure 16. Most analyses of climate change are based on the definition of such trends, regardless of the R^2 values. In addition, the frequent omission of R^2 indicates the unreliability of such an approach. Hence, the application of the RAPS method is justified.

5 Conclusions

The examples presented herein fully justified the RAPS method for the analysis of time series trends in hydrology. Even the "simplest" first level of analysis can be applied to evaluate possible irregularities and/or fluctuations in the analysed hydrological time series promptly and easily. The application of three other levels of analysis provided more detailed insights into the properties of the time-series values.

The RAPS method can be extended by testing the significance of the new/obtained subseries via statistics. For example, the Student's t-test, Pearson's chi-squared test, and Mann–Kendall test, among others, can be performed for the abovementioned purpose. In addition, RAPS can be easily calculated using spreadsheet software.

Notably, the RAPS method does not provide a cause for the observed fluctuations, which can be shown as a border between the new subseries. In fact, it can only be provided by experts in time-series analysis. The typical definition of trends cannot express or be used to determine sections of the original time series in which a disorder exists. In addition, incorrect interpretations of the RAPS diagram can result in incorrect analyses of observed or calculated values and misleading conclusions.

References

[1] Arnold, J. G. et al. Large area hydrologic modeling and assessment Part I. model development. *JAWRA Journal of the American Water Resources Association*, 1998, 34(1), pp. 73-89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

[2] Shen, C.; Phanikumar, M. S. A process-based, distributed hydrologic model based on a large-scale method for surface– subsurface coupling. *Advances in Water Resources*, 2010, 33(12), pp. 1524-1541. https://doi.org/10.1016/j.advwatres.2010.09.002

[3] Todini, E. The ARNO rainfall-runoff model. *Journal of Hydrology*, 1996, 175(1-4), pp. 339-382. https://doi.org/10.1016/S0022-1694(96)80016-3

[4] Kostić, S. et al.: Modeling of river flow rate as a function of rainfall and temperature using response surface methodology based on historical time series. *Journal of Hydroinformatics*, 2016, 18(4), pp. 651-665. https://doi.org/10.2166/hydro.2016.153

[5] Garbrecht, J.; Fernandez, G. P.: Visualization of trends and fluctuations in climatic records. *JAWRA Journal of the American Water Resources Association*, 1994, 30(2), pp. 297-306. https://doi.org/10.1111/j.1752-1688.1994.tb03292.x

[6] Zavarsky, A.; Duester, L. Anthropogenic influence on the Rhine water temperatures. *Hydrology and Earth System Sciences*, 2020, 24, pp. 5027-5041. https://doi.org/10.5194/hess-24-5027-2020

[7] Bonacci, O.; Oskoruš, D. 2008: The influence of three Croatian hydroelectric power plants operation on the river Drava hydrological and sediment regime. In: *XXIVth Conference of the Danubian countries on the hydrological forecasting and hydrological bases of water management,* Brilly, M.; Šraj, M. (eds). Slovenian National Committee for the IHP UNESCO.

[8] Lojen, S. et al. Continuous 60-year stable isotopic and earth-alkali element records in a modern laminated tufa (Jaruga, river Krka, Croatia): Implications for climate reconstruction. *Chemical Geology*, 2009 258(3-4), pp. 242-250. https://doi.org/10.1016/j.chemgeo.2008.10.013

[9] Težak, D. et al. Impact of Seasonal Changes of Precipitation and Air Temperature on Clay Excavation. *Sustainability*, 2019, 11(22). https://doi.org/10.3390/su11226368

[10] Đurin, B.; Ptiček Siročić, A.; Sakač, N.: Modelling of Meteorological Parameters for the Purpose of Sizing of the Solar Photovoltaic Irrigation Systems. *Agriculture and Forestry*, 2018, 64(1), pp. 15-21. https://doi.org/10.17707/AgricultForest.64.1.02

[11] Bonacci, O.; Andrić, I. Sinking karst rivers hydrology: the case of the Lika and Gacka (Croatia). *Acta Carsologica*, 2008, 37(2–3), pp. 185-196. https://doi.org/10.3986/ac.v37i2.146

[12] Shelton, M. L. Seasonal hydroclimate change in the Sacramento river basin, California. *Physical Geography*, 1998, 19(3), pp. 239-255. https://doi.org/10.1080/02723646.1998.10642649

[13] Rangsiwanichpong, P.; Kazama, S; Ekkawatpanit, C. Analysing the relationship between ocean indices and rainfall in the Chao Phraya River Basin. *International Journal of Climatology*, 2017, 37(S1), pp. 230-238. https://doi.org/10.1002/joc.4997

[14] Markovinović, D. et al. Identifying the Dynamics of the Sea-Level Fluctuations in Croatia Using the RAPS Method. *Symmetry*, 2021, 13(2). https://doi.org/10.3390/sym13020289

[15] You, Q. et al. Probability Analysis and Control of River Runoff–sediment Characteristics based on Pair-Copula Functions: The Case of the Weihe River and Jinghe River. *Water*, 2019, 11(3). https://doi.org/10.3390/w11030510

[16] Zhu, S. et al. 2019: Assessing the performance of a suite of machine learning models for daily river water temperature prediction. *PeerJ 7:e7065*. https://doi.org/10.7717/peerj.7065