**University of Nis**
**Faculty of Civil Engineering and Architecture**
Chairs of Water Management and Hydraulic Engineering

# GAF HydroResearch Group

*Faculty of Civil Engineering and Architecture*

# GAF HydroResearch Group

## Research

GAF HydroRresearch group is working on multidisciplinary research in the field of water resources management.

Main research topics

- Evapotranspiration (ET)
- Hydroinformatics
  - ET estimation by ANNs
  - Embanking dam stability assessment by ANNs
- Hydrological Hazards
  - Droughts
  - Floods
  - Urban Stormwater
  - Trend Analysis
- Macrophytes in Wastewater Treatment

## Meet the team

The permanent staff of our research team consists of 3 full professors, 2 associate professors, 3 assistant professors, and 1 assistant with additional PhD and undergraduate students involved in temporary research activities.


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# EVAPOTRANPIRATION

# Background

The hydrologic cycle involves the continuous circulation of water in the Earth-Atmosphere system. At its core, the water cycle is the motion of the water from the ground to the atmosphere and back again. Of the many processes involved in the hydrologic cycle, the most important are: evapotranspiration and precipitation. Accurate estimates of ET are necessary for crop production, water resources management, irrigation scheduling, and environmental assessment.

A common procedure for estimating ET is to first estimate reference ET ($ET_0$). Crop coefficients, which depend on the crop characteristics and local conditions, are then used to convert $ET_0$ to the ET. $ET_0$ is defined as "the rate of evapotranspiration from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 s $m^{-1}$) and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water."

The FAO-56 Penman-Monteith combination equation (FAO-56 PM) has been recommended by the Food and Agriculture Organization of the United Nations (FAO) as the standard equation for estimating reference evapotranspiration ($ET_0$). The main shortcoming of FAO-56 PM equation is that it requires numerous weather data that are not always available for many locations. To overcome this problem, our research team has been investigating various $ET_0$ approaches in several scientific research projects.

# GAF HydroResearch Group Results

## Estimating Reference Evapotranspiration Using Limited Weather Data

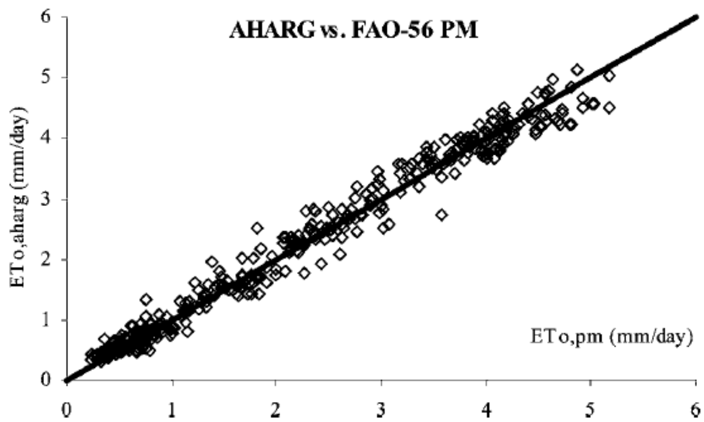
**Hargreaves**

Several studies have shown the Hargreaves equation may provide reliable estimates of reference evapotranspiration for five days or longer time steps. FAO has proposed that when sufficient data to solve the FAO-56 PM equation are not available then the Hargreaves equation can be used. However, this equation generally overestimates ET0 at humid locations.

Our research indicate that the calibration of the Hargreaves equation should be done through the adjustment of the Hargreaves exponent (HE). Data from Palic, Sarajevo, and Nis have been used for estimating the adjusted HE. A value of 0.424 is proposed instead of the original 0.5 as one which should be used in the adjusted Hargreaves equation (AHARG) for the Western Balkan locations. The ET0 values estimated by AHARG were compared with FAO-56 PM estimates for eight humid locations (Varazdin, Zagreb, Bihac, Novi Sad, Negotin, Kragujevac, Nis, and Vranje).

Estimates by AHARG were in close agreement with FAO-56 PM estimates at most of the locations. The SEE ranged from 0.17 mm day$^{-1}$ for Varazdin to 0.24 mm day$^{-1}$ for Vranje, averaging 0.21 mm day$^{-1}$. The average overestimation was about 1%. These results strongly support the use of the adjusted Hargreaves equation at humid Western Balkan locations in the case when only the temperature data are available.

$$ET_{0,\mathrm{AHarg}} = 0.0023 \cdot R_a \cdot (T_{\max} - T_{\min})^{0.424}\left(\frac{T_{\max} + T_{\min}}{2} + 17.8\right)$$




*Adjusted Hargreaves (AHARG) versus FAO-56 Penman-Monteith (FAO-56 PM) ET0 estimates*

*Statistical Summary of Monthly ET0 Estimates for Validation Locations*

| Location | Hargreaves (HARG) $ET_0$ (mm d$^{-1}$) | HARG $ET_0/ET_{0,pm}$ | HARG SEE (mm d$^{-1}$) | HARG $pET_0$ (mm d$^{-1}$) | HARG $pET_0/ET_{0,pm}$ | Adjusted Hargreaves (AHARG) $ET_0$ (mm d$^{-1}$) | AHARG $ET_0/ET_{0,pm}$ | AHARG SEE (mm d$^{-1}$) | AHARG $pET_0$ (mm d$^{-1}$) | AHARG $pET_0/ET_{0,pm}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Varazdin | 2.5 | 1.21 | 0.56 | 5.0 | 1.19 | 2.1 | 1.01 | 0.17 | 4.1 | 0.98 |
| Zagreb | 2.6 | 1.29 | 0.70 | 5.1 | 1.27 | 2.1 | 1.06 | 0.22 | 4.2 | 1.04 |
| Novi Sad | 2.7 | 1.15 | 0.45 | 5.1 | 1.17 | 2.2 | 0.95 | 0.19 | 4.2 | 0.97 |
| Bihac | 2.6 | 1.21 | 0.64 | 5.4 | 1.28 | 2.2 | 1.00 | 0.21 | 4.4 | 1.04 |
| Negotin | 2.8 | 1.18 | 0.53 | 5.4 | 1.12 | 2.3 | 0.98 | 0.22 | 4.5 | 0.93 |
| Kragujevac | 2.7 | 1.29 | 0.71 | 5.1 | 1.22 | 2.2 | 1.07 | 0.21 | 4.2 | 1.01 |
| Nis | 3.0 | 1.27 | 0.80 | 6.1 | 1.27 | 2.5 | 1.05 | 0.22 | 5.0 | 1.03 |
| Vranje | 2.7 | 1.17 | 0.47 | 5.1 | 1.14 | 2.3 | 0.97 | 0.24 | 4.2 | 0.94 |
| Average | 2.7 | 1.22 | 0.61 | 5.3 | 1.21 | 2.2 | 1.01 | 0.21 | 4.4 | 0.99 |

Note: $ET_0/ET_{0,PM}$=the ratio of mean annual (A)HARG estimated $ET_0$ and FAO-56 PM estimated $ET_0$, $pETeq/ET_{PM}$=the ratio of (A)HARG estimated $ET_0$ and FAO-56 PM estimated $ET_0$ in the peak month (July).

## Thornthwaite

The Thornthwaite equation is widely used as a simple method for $ET_0$ estimation. Many well-known drought indices (such as PDSI, RDI, SPEI) use the Thornthwaite equation for estimating evapotranspiration. This equation correlated mean monthly temperature with evapotranspiration as determined by water balance studies carried out for the eastern/central USA and is most appropriately applied to climatic conditions similar to that where it was developed. In fact, weak results can be expected when the Thornthwaite equation is extrapolated to other climatic regions without recalibrating the constants involved in the equation.

The main objectives of our research were (1) to develop optimal adjusted equation, and (2) to consider the spatial variability of the empirical coefficient(s) of adjusted equation for the study area of Vojvodina region, Serbia.

$$ET_{0th} = \begin{cases} 0, & T_{avg} < 0^{o}C \\ 16\cdot\left(\frac{10\cdot T_{avg}}{I}\right)^{a}, & 0^{o}C \leq T_{avg} \leq 26.5^{o}C \\ -0.43\cdot T_{avg}^{2} + 32.24\cdot T_{avg} - 415.85, & T_{avg} > 26.5^{o}C \end{cases}$$

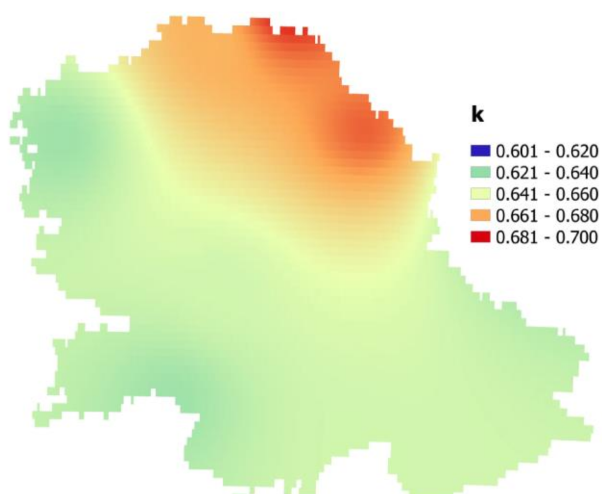
In this research, we tried to improve the performance of the Thornthwaite method using an effective temperature ($T_{eff}$) instead of the $T_{avg}$.

$$T_{eff} = k\cdot(T_{avg} + A) = 0.5\cdot k\cdot(3\cdot T_{max} - T_{min})$$

The new Th65 approach (the optimum k = 0.65 is obtained through the trial-and-error method in order to gain the lowest value of RMSE for five Serbian locations). This equation was compared to the full set FAO-56 PM equation using weather data from five Serbian locations (Palic, Kikinda, Sombor, Novi Sad, Sremska Mitrovica) and using data from three CLIMWAT stations (Szeget, Timisoara, Belgrade).

The new Th65 approach provided very good estimates of both peak and annual ET0 at all Serbian locations. This equation slightly underestimated annual FAO-56 PM $ET_0$ at all locations except Sombor. The RMSE values varied from 0.33 to 0.37 mm $day^{-1}$ and the MAE values ranged from 0.25 to 0.28 mm $day^{-1}$.

The Thornthwaite approaches were additionally tested using data from three CLIMWAT stations. The results suggest that $ET_0$ could be computed from the Th65 approach. The optimum k value has been obtained through the trial and error method in order to gain the lowest RMSE at each location. As a whole, k values ranged from 0.62 to 0.69 across the study area showing an average variation of 2% compared to the unique k value of 0.65. This indicates that using a single regional k value results in very accurate $ET_0$ estimations.

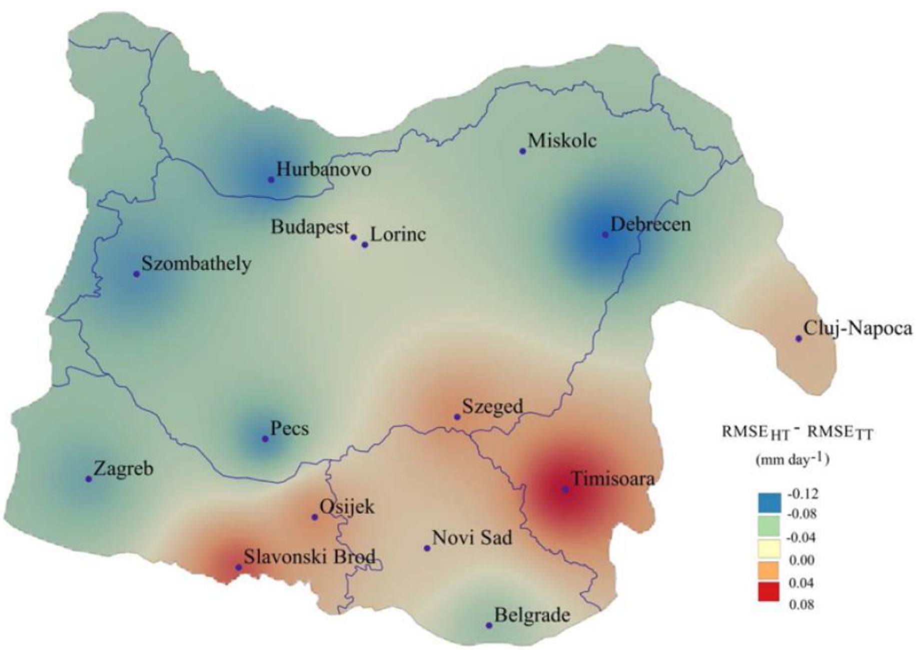



*Spatial distribution of k value in Vojvodina*

The map of spatial variability of the empirical k coefficient is ideally coinciding with the map of aridity in Vojvodina. This fact confirms a great influence of aridity type to optimal k values in Vojvodina. The north and northeastern parts of Vojvodina have sub-humid climate, while the southern part has humid climatic conditions. Generally, about 75% of the territory of Vojvodina is characterized by humid climate. As shown, the optimal k values tended to increase from the humid towards the sub-humid locations.
Hence, based on this study and the given map, reference evapotranspiration can be easily estimated for any location in the study area with the temperature data and the adjusted Thornthwaite equation.

**Regionally calibrated temperature-based ET equations**

Temperature-based approaches have a key role in evaluating $ET_0$ due to the inability to use the standard PM equation in many data-poor regions worldwide. In our research, temperature-based equations were compared with the PM equation by using data from fifteen CLIMWAT stations located in the Pannonian Basin.
The Thornthwaite approaches resulted in a poor estimation of $ET_0$ except the new regionally calibrated TT which was the second ranked approach. This indicates very clearly that the Thornthwaite equation can be successfully used only after the regional calibration that includes an effective temperature and introduces the regional p value.
The HT equation yielded almost perfect agreement to the PM at most locations. It yielded the lowest RMSE at seven locations and the second lowest RMSE at three locations. This suggests that the HT approach originally developed using data from Western Balkans can be successfully applied in a much wider region.




*Spatial Distribution of Differences between HT-Based and TT-Based RMSE in the Pannonian Basin*

The spatial distribution of differences between HT and TT-based RMSE ($RMSE_{HT}$-$RMSE_{TT}$) in the Pannonian Basin clearly presents an advantage of the HT approach across the biggest part of the Pannonian Basin except for a few southeast locations. The HT equation yielded lower RMSE than the TT approach at ten stations and gave slightly higher RMSE at four locations (Slavonski Brod, Osijek, Szeget and Timisoara). The TT approach significant falls behind the HT approach at many stations situated at west, north or east part of the Pannonian Basin (Zagreb, Pecs, Szombathely, Hurbanovo, Debrecin).

The HT and TT approaches gave the lowest average RMSE for all fifteen locations (0.28 and 0.30 mm $day^{-1}$, respectively). The overall statistics demonstrate the precedence of the HT equation in the biggest part of the Pannonian Basin except for a few southeast locations where the TT equation dominated. All other temperature-based approaches significantly fall behind those equations. Finally, it can be concluded that the regionally calibrated equations (HT and TT) are the most suitable temperature-based approaches for the assessment of reference evapotranspiration in the Pannonian Basin.

# HYDROINFORMATICS

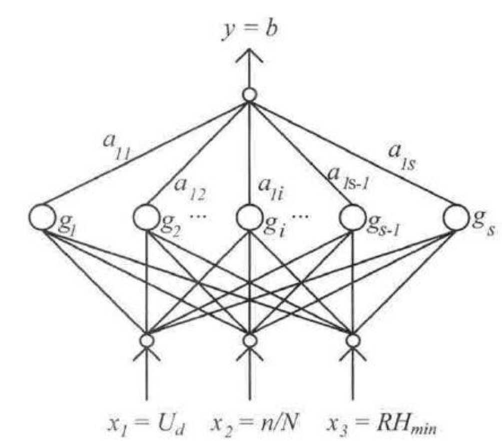
# Background

Hydroinformatics is a relatively new field of research that combines simulation and decision-making models with information and communication technologies to help solve challenging water management problems in hydraulics, hydrology and environmental engineering.

# GAF HydroResearch Group Results

## Estimating of Reference Evapotranspiration by Artificial Neural Networks

**Estimation of FAO-24 Blaney-Criddle b factor by RBF Networks**
In the early 1970s, the Food and Agriculture Organization of the United Nations (FAO) developed a practical procedure to estimate crop-water requirements that has become a widely accepted standard, in particular for irrigation studies. Tabular values of the FAO-24 factors are given in FAO-24 publication. The usual approach for estimating FAO-24 factors requires the use of regression expressions. Our team develop new approach based on the RBF networks that would be simple to use, because it wouldn't demand from a user any background knowledge of Artificial Neural Networks (ANNs).



*Structure of RBF network*

Samples (216 tabular values) are divided in to two groups. For the RBF network training, 186 randomly chosen training samples were used. All samples (216 tabular values) are used for verification of RBF networks, obtained in a stage of training. Thus, the b values produced by RBF networks can be compared to the regression estimates and table values. Thirty table b values found in the verifying set only were used for controlling the ability of the networks to generalize the knowledge obtained during the training stage. A network with 20 neurons in the hidden layer, which gave the minimum error at the verifying stage, was chosen for use.

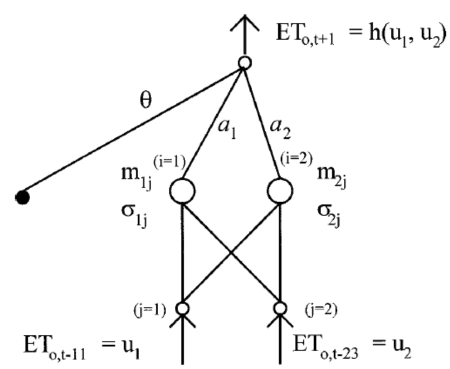
*Comparation of models*

| Model (1) | MARE (%) (2) | MXARE (%) (3) | NE > 2% (4) | DEV (%) (5) | $r^2$ (6) |
|---|---|---|---|---|---|
| Frevert et al. (1983) | 3.07 | 14.4 | 126 | 2.72 | 0.989 |
| Allen and Pruitt (1991) | 1.69 | 11.8 | 64 | 1.68 | 0.998 |
| RBF network | 0.34 | 1.8 | 0 | 0.31 | 1.000 |

In this table MARE denotes mean absolute relative error; MXARE the maximum absolute relative error; NE the number of test samples with an error greater than 2% (NE>2%); DEV is the standard deviation of absolute relative error and r 2 is the coefficient of determination. The comparative analysis showed that the RBF networks guarantees a more accurate estimation of FAO-24 factors when compared to regression expressions.

**Forecasting of Reference Evapotranspiration by Artificial Neural Networks**

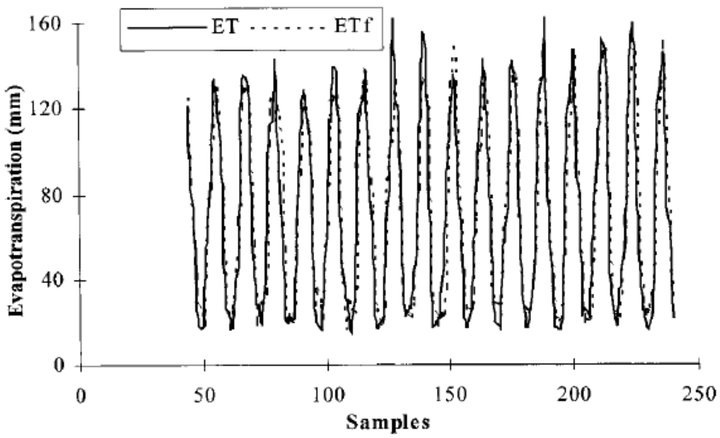
The ability to forecast reference evapotranspiration is of utmost importance for operating irrigation systems effectively in agricultural areas where crop production is the principal user of water. In this research, a sequentially adaptive radial basis function network is applied to the forecasting of reference evapotranspiration ($ET_0$). The sequential adaptation of parameters and structure is achieved using an extended Kalman filter. The criterion for network growing is obtained from the Kalman filter's consistency test, while the criteria for neuron/connection pruning are based on the statistical parameter significance test.




*Structure of radial basis function network*

The weather parameter data (air temperature, relative humidity, wind speed, and sunshine) were available at Nis, Serbia, from January 1977 to December 1996. The monthly reference evapotranspiration data were obtained by the Penman-Monteith method, which is proposed as the sole standard method for the computation of reference evapotranspiration. The reference evapotranspiration ($ET_0$) ranged from 15.8 to 161.5 mm, and the average was 71.3 mm. The

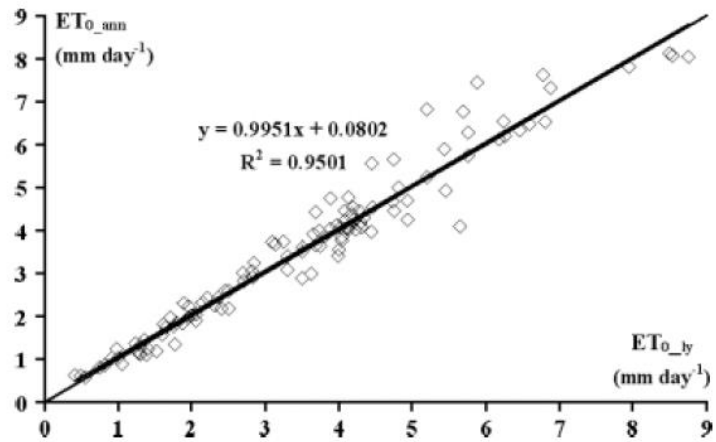
sequence of 240 samples of $ET_0$ was scaled (1,1). The network learned to forecast $ET_{0,t+1}$ based on $ET_{0,t-11}$ and $ET_{0,t-23}$. The adaptive RBF network learns from the data, which arrive continuously and are shown in the network only once. The RBF network simultaneously forecasts and learns. On the basis of the forecast error in the last sample, the parameters and structure of the RBF network change, and the changed network gives the forecast for the next sample, where another error is obtained, which again changes the parameters and the structure of the RBF network. In such a manner the RBF network gives a realistic forecast of the analyzed time series.
After the completed training, the RBF network has the following structure: the input layer contains two neurons that receive information on the $ET_{0,t-11}$ and $ET_{0,t-23}$ values; the hidden layer contains two neurons; and the output layer contains one neuron giving the $ET_{0,t+1}$value.




*Forecasting of reference evapotranspiration*

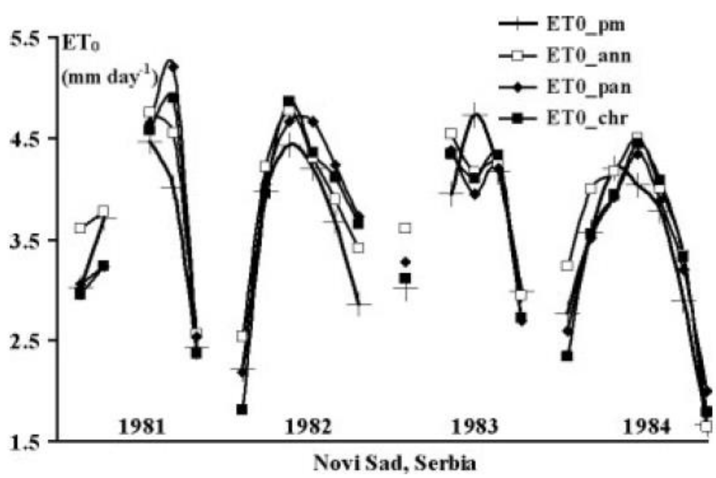
The results show that ANNs can be used for forecasting reference evapotranspiration with high reliability.

**Converting from pan evaporation to reference evapotranspiration by RBF networks**
In this research, a sequentially adaptive RBF network was applied to estimate reference evapotranspiration ($ET_0$). Policoro pan evaporation and lysimeter data from 1981 to 1983 were used to train the RBF network. The training data set had a total of 385 patterns. The RBF network was trained with pan evaporation and extraterrestrial radiation data as input and lysimeter data as output. The solar radiation received at the top of the atmosphere on a horizontal surface is called the extraterrestrial radiation ($R_a$). Daily values of $R_a$ can be estimated as a function of the local latitude and Julian date. The RBF network was trained to estimate $ET_0$ based on $E_{pan}$ and $R_a$.
After completing training, the RBF network has the following structure: input layer—two neurons that receive information on $E_{pan}$ and $R_a$; hidden layer—two neurons; output layer—one neuron giving the $ET_0$ value.




*Daily ET0 estimated by RBF network ($ET_{0\_ann}$) versus lysimeter ET0 ($ET_{0\_ly}$) at Policoro, Italy*

The RBF network obtained on the basis of the daily data from Policoro, Italy and pan-based equations were further tested using mean monthly data collected in Novi Sad, Serbia, and Kimberly, Idaho, USA.




*Comparison of monthly $ET_0$ calculated for four growing seasons at Novi Sad, Serbia*

The overall results favoured use of the RBF network for pan evaporation to evapotranspiration conversions. The use of the RBF network is very simple and does not require any knowledge of ANNs. Users require only code (RBF network), $E_{pan}$ data and corresponding $R_a$ data.

## Embanking dam stability assessment by ANNs

Dam safety and potential failure is one of the issues with the highest risk in water resources management. Embankment rockfill dams are the most common dam construction types used in the world today. One third of all embankment dam failures are caused by dam slope instability. The dam is stable when the slopes are stable.

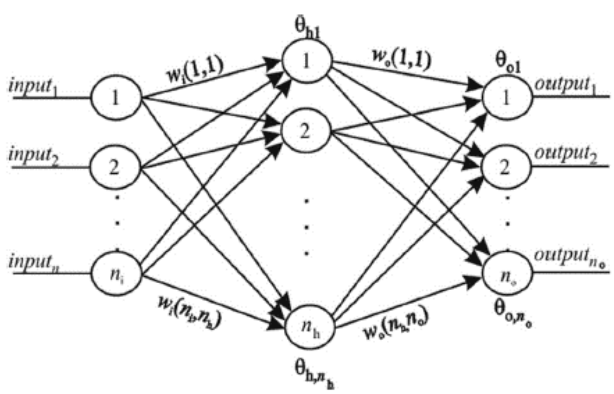
Slope safety of dam is monitored by the instruments installed in the dam. Progressively with the dam construction the instruments and devices required for dam monitoring are installed. It is possible during the dam operation period to have one or more cells malfunctioning, after years of operation.

Sometimes it is technically not possible to replace the cell or the costs of the replacement are too high and not economically justified. At the Pridvorica Dam, several instruments - cells for pore and total pressure monitoring malfunctioned. Solution of cells replacing, implying dam clay core destruction, can significantly jeopardize dam stability. Thus new theoretical approaches have been considered as alternative.

*The Pridvorica Dam*

### A New Method for Pore Pressure Prediction on Malfunctioning Cells Using ANNs

A new method for pore pressure prediction on malfunctioning cells has been developed using several successive artificial neural networks (ANNs) to obtain high accuracy of the predicted values.




*Feed-forward ANN*

It is a fully connected network with one hidden layer. n, n0 and n' are the number of neurons in the input, hidden, and output layer, respectively. θji is the threshold of the i-th neuron in the j-th layer, while w(p,i) (q,j) is the weight of the connection between the j-th neuron in the p-th layer and the i-th neuron in the q-th layer. Activating function is following:

$$z_i = \frac{1}{1+e^{-\lambda_1 \cdot s_i}}$$

In the output layer for the neurons was used:

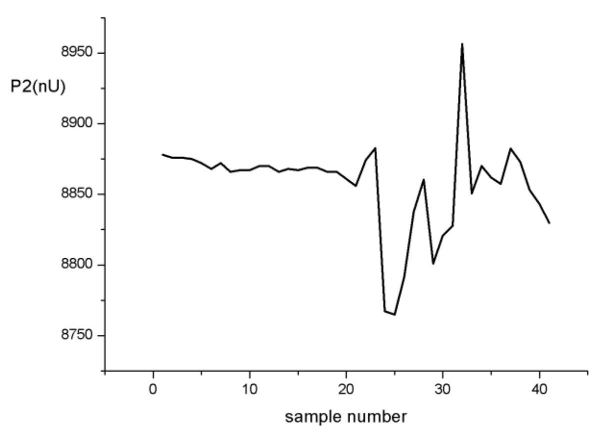
$$y_i = \lambda_2 \cdot q_i$$

where:
λ1 , λ2 - constants,
zi , yi - the responses of the neurons in the hidden and the output layer, respectively. In addition

$$s_i = \sum_{j=1}^{n} w(1,j)(2,i) \cdot x_j + \theta_{2i}$$

$$q_i = \sum_{j=1}^{n_0} w(2,j)(3,i) \cdot z_j + \theta_{3i}$$

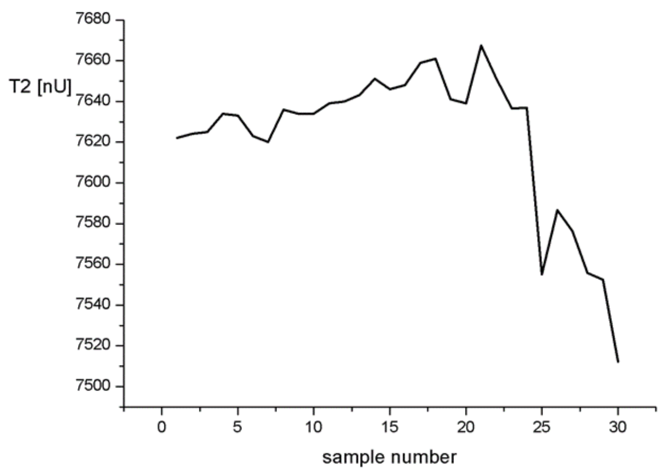
where:
xj - the input signals of the corresponding neurons.
Based on these predictions, new dependency for the cell P2 was obtained. The results show that these predicted values are more precise than values we could have obtained using only one artificial neural network for prediction.
The results obtained indicate a high degree of correlation between the input and output data, thus the application of this method is justified and possible. Consequently, this points to the great possibility of using this method in the technical monitoring of dams when problems arise, or when certain cells at which measurement is performed malfunction. Once developed, the model can be used as a predictive management tool for further monitoring activities.



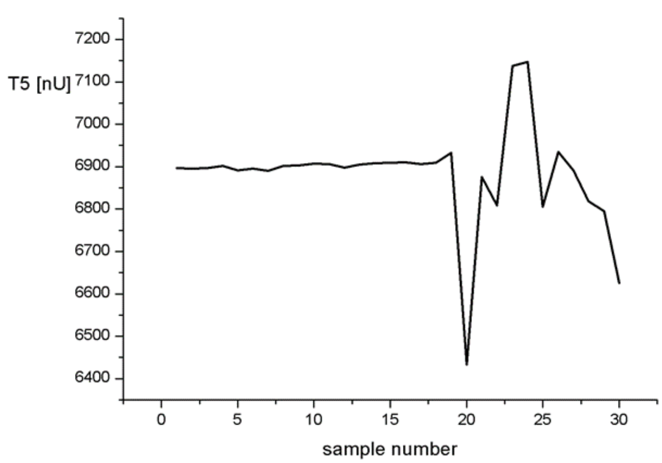

*P2 dependency- measured and predicted values over time using ANN4*

**ANN Model for Prediction of Rockfill Dam Slope Stability**

In this research prediction ANN model was applied in order to obtain accurate prediction of pore and total pressure data at any instrument in the dam where the measuring cells malfunctioned.
We found that the prediction of the pore pressures at the malfunctioned cell is possible using the values at the nearby total pressure measurement cell. Further, the prediction of the values at the malfunctioned total pressure cell is possible using the values of all pore pressure cells in the dam body. In addition we achieved the prediction of the values at the two total pressure measurement cells using the measurement of all total pressure cells in the dam body. The obtained results indicate a high degree of correlation between the input and output data, thus the application of this method is justified and possible.




*T2 dependency- measured and predicted values over time*




*T5 dependency- measured and predicted values over time*

# HYDROLOGICAL HAZARDS

# Background

Hydrological hazards of various types present a myriad of technical and public policy issues worldwide. Defined as extreme events associated with water occurrence, movement, and distribution, hydrological hazards include droughts and flooding and related events (e.g., landslides and river scour and deposition). Hydrological hazards and their impacts are associated with climate variability, demographic trends, land-cover change, and other causative factors and could be exasperated by global climate change. The increase in greenhouse gases in the atmosphere will continue leading to global warming and an intensification of the hydrological cycle, making hydrological extreme studies more complex and challenging.

Because of the immense impacts of hydrological hazards on society and its economies, it is important to consider novel approaches, techniques, or methods for the prediction, prevention, and mitigation of hydrological extremes. Given the complexity of the nonstationary hydrometeorological and hydro-climatological processes, it is critical to utilize recent technological developments and scientific knowledge to improve our understanding of hydrological hazards and our ability to cope with droughts and floods.

# GAF HydroResearch Group Results

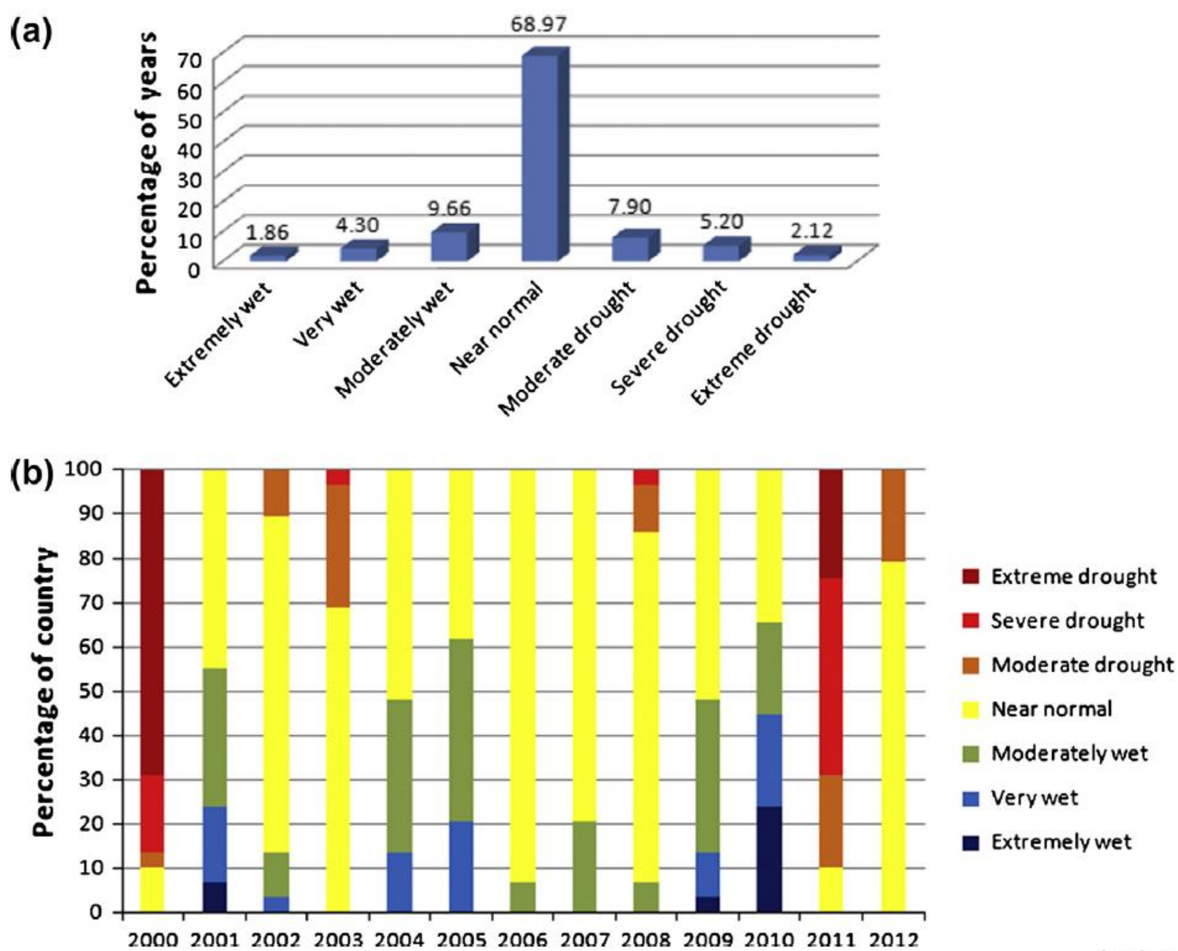
## Drought

**Spatiotemporal characteristics of drought in Serbia**

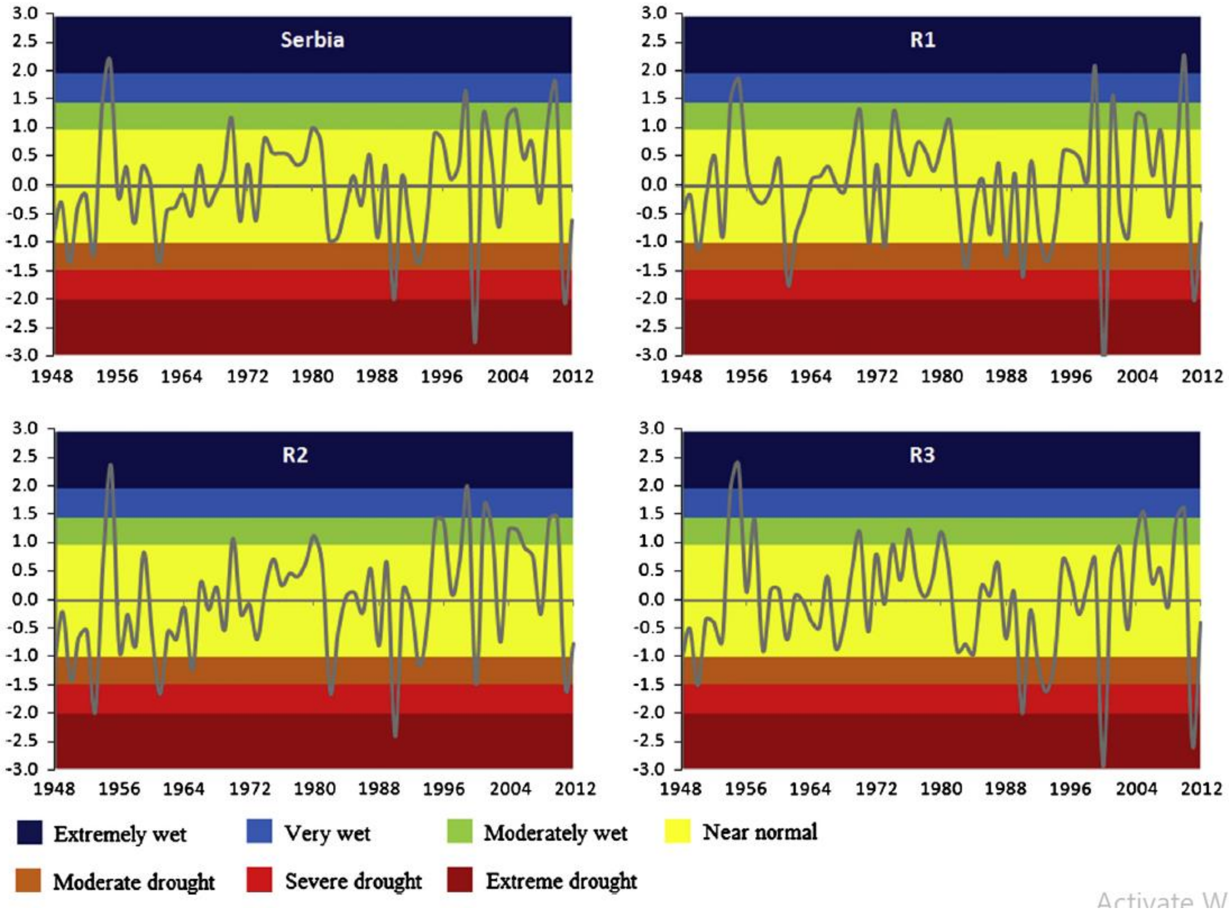
The drought was investigated in Serbia using monthly precipitation time series from 29 stations during the period of 1948–2012. The temporal and spatial patterns of drought were analyzed by applying the S-mode PCA to the SPI estimated on 12- and 24-month timescales. According to the error bars of the North rule of thumb and scree plot, two principal components were retained.

These components were well localized in space three distinct subregions, characterizing by different drought variability. The AHCA was confirmed the PCA analysis and identified three different drought sub-regions too: (1) region R1 includes the north and the northeast part of Serbia; (2) region R2 includes the western part of Central Serbia and southwestern part of Serbia; and (3) region R3 includes the central, east, south and southeast part of Serbia.

The results of both the PCA and AHCA analysis were confirmed by a very similar time variability of the regional SPI-12. The characteristics of drought were analyzed in terms of the temporal evolution of the SPI-12 values and the frequency of drought at the country level and for three regions. The linear regression method was used for time variability analysis of drought in each identified sub-region as well as for the whole country. The frequency of drought was 15.22%, while the distribution of wet periods was 15.82% in the given regions. Approximately 70% of the frequency of drought belongs to the near normal drought category. According to the SPI-12, the average number of the dry years in the detected regions was about 30 years during the period 1948–2012. The year 2000 was the driest, while 1955 was the wettest during the observed period. Three years (1990, 2000, and 2011) were detected as the severe and extremely dry in the majority of the country and analyzed by the percent of normal precipitation index computed with respect to 1961–1990 climate normal.




*(a) Percentage of years affected by various drought severity levels, 1948–2012 and (b) percentage of Serbia affected by drought, 2000–2012.*




*Time series of SPI-12 for Serbia and three sub-regions.*

The obtained results can be included in an adequate water resources planning and improve water resources management in the area. Further research will be aimed at detection of the trends of drought in Serbia and comparative analysis of the drought indices based on precipitation and evapotranspiration and their impact on agricultural production.

**Water Surplus Variability Index**

Significant changes in air temperature and precipitation because of global warming and greenhouse gas emissions cause changes in the magnitude and frequency of drought. In addition, they will affect the planning and management of future water resources and agricultural production. Thus, it is needed not only to consider precipitation but also the other meteorological parameters such as air temperature, humidity and evapotranspiration in describing and assessing drought.

Our research presents the new climatic drought index: the Water Surplus Variability Index (WSVI). The procedure to calculate WSVI includes the importance of evapotranspiration through the water surplus (the difference of the precipitation and evapotranspiration).

$$WSVI_k{}^{(i)} = \frac{D_k{}^{(i)} - \mu}{\sigma}$$

$$D_k{}^{(i)} = \sum_{j=1}^{k} \left(P_{ij} - ET_{ij}\right), i = 1(1)N$$

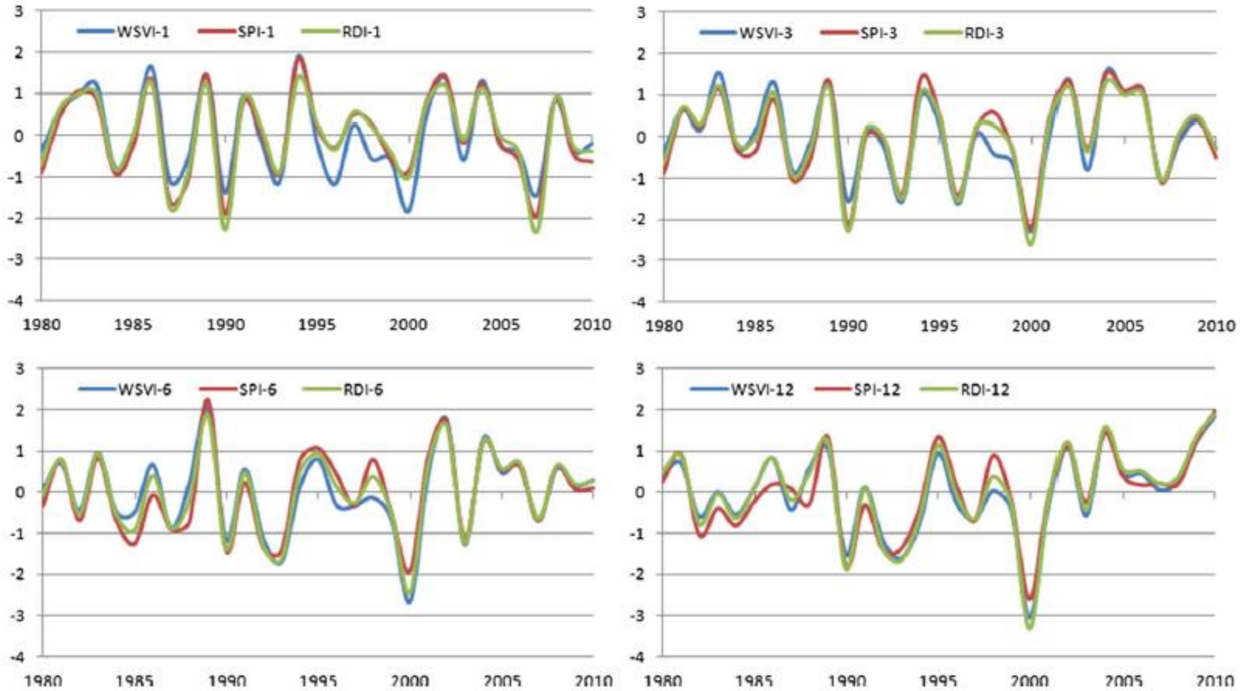
*Drought classification of WSVI and corresponding event probabilities*

| Drought class | WSVI value | Probability (%) |
|---|---|---|
| Extremely wet | WSVI≥2.0 | 2.3 |
| Very wet | 1.5≤WSVI<2.0 | 4.4 |
| Moderately wet | 1.0≤WSVI<1.5 | 9.2 |
| Near normal | −1.0≤WSVI<1.0 | 68.2 |
| Moderate drought | −1.5≤WSVI<−1.0 | 9.2 |
| Severe drought | −2.0≤WSVI<−1.5 | 4.4 |
| Extreme drought | WSVI<−2.0 | 2.3 |

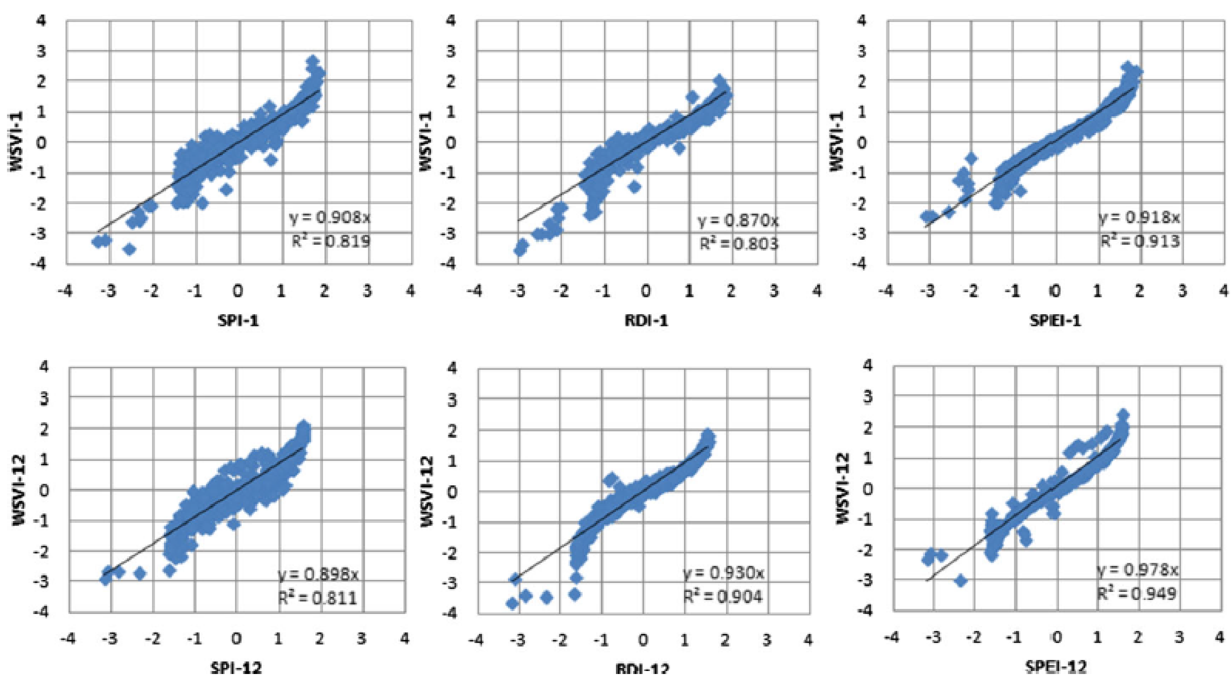
The drought index WSVI developed in this study was compared with other drought indices based on precipitation and evapotranspiration, such as SPI, RDI and SPEI based on 1-, 3-, 6- and 12-month timescales. The WSVI is similar to SPEI and following the concept of RDI.

The WSVI was positively correlated with the SPI, RDI and SPEI, which suggests good agreement with them in the case of obtaining the dry and wet periods. The WSVI was highly correlated with SPEI (r>0.95), RDI (r>0.89) and SPI (r>0.85) in humid and sub-humid climate. The WSVI was well correlated with the SPI and the RDI (r>0.62) in arid and semi-arid stations. This can indicate that the WSVI can be used for drought monitoring.

The WSVI showed the excellent results in humid and sub-humid locations, while the RDI and the SPI can be used as solutions for drought characterization in arid and semi-arid locations. Both the WSVI and the SPEI have similar behavior in arid and semi-arid climate. Besides, the proposed index can be applied for reference periods smaller than a year (viz. 1, 3, 6, 9) and can identify different drought types. It has clear and simple calculation procedure.




*Comparison of WSVI and both SPI and RDI at 1-, 3-, 6- and 12-month timescales at the Vranje station*




*Scatter plots of SPI, RDI and SPEI vs. WSVI in Vranje at 1- and 12-month timescales*

## Floods

### Calculation of Design Floods at Confluences

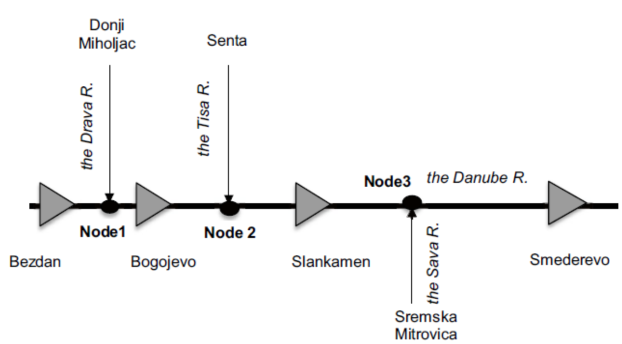
Planning and design of flood adaptation and control measures relies on a probabilistic estimation of flood wave parameters. The definition of design flow on rivers is necessary for a variety of engineering purposes, the most prominent of which is the determination of design water levels in order to design a flood control system, which includes structures such as embankments.

The established practice is to use probabilistic analysis and determine the theoretical values of maximum annual flows measured at the nearest gauging station. However, the complexity of floods has imposed the need to approach this event as a multidimensional phenomenon. If river reaches include tributaries, such an approach cannot be justified, because at least two flows (mainstem and tributary) have to be considered. Accordingly, the complexity of flood occurrence and its assessment require the linking of marginal distributions of multiple variables in order to define a unique distribution law that describes the flood.

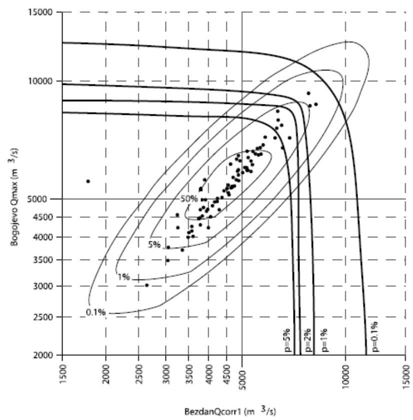
In confluence areas, where river flow slowdowns can be substantial, the selection of design flows for the purpose of designing a flood control system directly depends on flood waves at the mainstem and its tributaries. The aim of this research is twofold: to elaborate a procedure that will define the flood exceedance probability in the analyzed area within a multidimensional probability space and to develop a methodology for defining flood coincidence in the mainstem reach with its main tributaries and thus determine design flows in order to design the flood control system in the confluence area.

Mathematical models are based on (1) two-dimensional probability distribution (PROIL model) and (2) the copula function (Archimedean class of copulas), and fitted to a practical application in a two-dimensional probability distribution space. In case of random variables, simultaneous quantitative characteristics of flood wave (water flow) hydrographs for the mainstem and a tributary are considered.

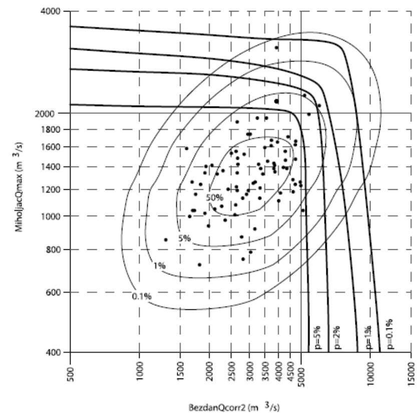
The PROIL model and the copulas can also provide assistance in the forecasting of maximum mainstem flow after the confluence with each tributary. If the forecasts of input hydrographs (by the Hydro Meteorological Services) are known, the established dependences (coincidences) can be used to calculate the theoretical value at the downstream profile and thus determine the hydrological scenario that can help implement an adequate flood control strategy.



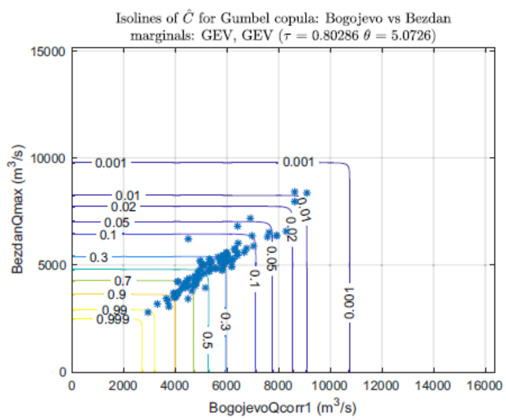

*Combinations of GS by nodes for the Danube reach from its entry into Serbia to the city of Smederevo*

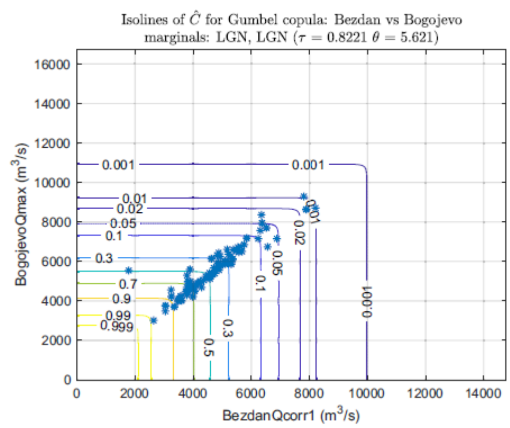



Coincidence $Q_{max}$ at Bogojevo GS and $Q_{corr1}$ at Bezdan GS




Coincidence $Q_{max}$ at D. Miholjec GS and $Q_{corr2}$ at Bezdan GS




*Correlation coefficients, parameter of copulas, and goodness of fit p value*

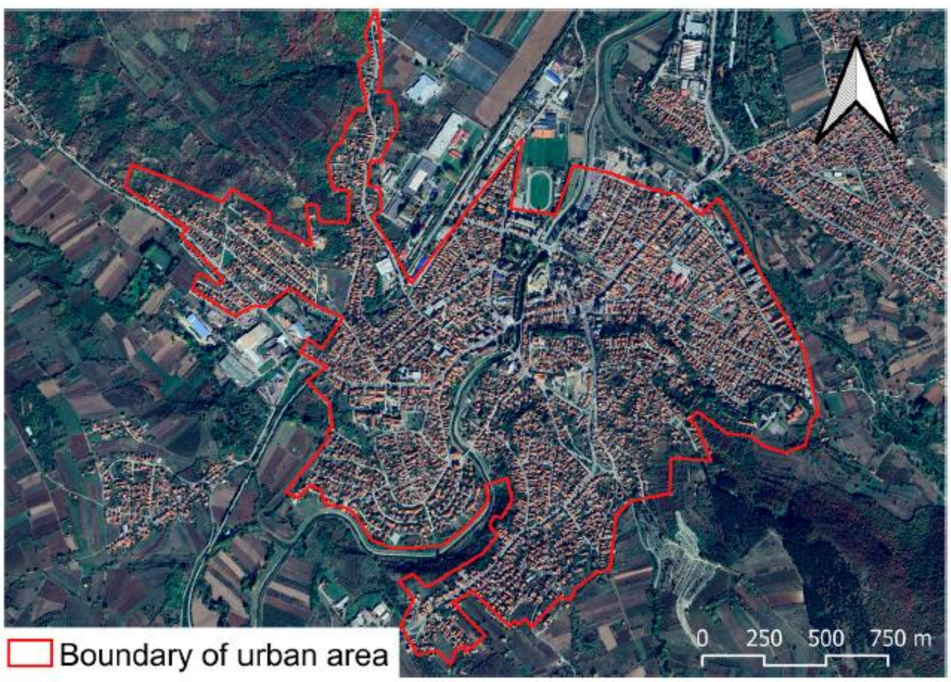
| Node | GS | Combination | $\tau$ | $\rho_s$ | C | $\theta$ | $p$ |
|---|---|---|---|---|---|---|---|
| 1 | BEZ–DM | max–corr1 | 0.0836 | 0.1290 | Gm | 1.091 | 0.935 |
| | | corr2–max | 0.3111 | 0.4464 | Fr | 0.304 | 0.716 |
| | | max–max | 0.1033 | 0.1596 | Cl | 0.231 | 0.630 |
| | DM–BOG | max–corr2 | 0.3449 | 0.5020 | Fr | 3.446 | 0.481 |
| | | corr2–max | 0.1504 | 0.2254 | Gm | 1.177 | 0.806 |
| | | max– max | 0.1787 | 0.2754 | Cl | 1.652 | 0.724 |
| | BEZ–BOG | max–corr1 | 0.8029 | 0.9240 | Gm | 5.073 | 0.592 |
| | | corr1–max | 0.8221 | 0.9417 | Gm | 5.621 | 0.177 |
| | | max–max | 0.8272 | 0.9494 | Gm | 5.788 | 0.776 |
| 2 | BOG–SENT | max–corr1 | 0.1689 | 0.2444 | Gm | 1.203 | 0.198 |
| | | corr2–max | 0.2724 | 0.3939 | Fr | 2.612 | 0.480 |
| | | max–max | 0.2139 | 0.3166 | Gm | 1.272 | 0.701 |
| | SENT–SLAN | max–corr2 | 0.4817 | 0.6591 | Fr | 5.414 | 0.236 |
| | | corr2–max | 0.3184 | 0.4665 | Gm | 1.467 | 0.370 |
| | | max– max | 0.3935 | 0.5529 | Gm | 1.649 | 0.905 |
| | BOG–SLAN | max–corr1 | 0.6871 | 0.8620 | Gm | 3.020 | 0.869 |
| | | corr1–max | 0.6298 | 0.8024 | Gm | 2.701 | 0.906 |
| | | max–max | 0.6927 | 0.8767 | Gm | 3.254 | 0.833 |
| 3 | SLAN–SM | max–corr1 | 0.1111 | 0.1685 | Gm | 1.125 | 0.861 |
| | | corr2–max | 0.1126 | 0.1739 | Gm | 1.127 | 0.630 |
| | | max–max | 0.2928 | 0.4115 | Gm | 1.414 | 0.934 |
| | SM–SMED | max–corr2 | 0.3314 | 0.4692 | Gm | 1.496 | 0.538 |
| | | corr2–max | 0.3495 | 0.4909 | Gm | 1.537 | 0.707 |
| | | max–max | 0.4666 | 0.6318 | Gm | 1.875 | 0.932 |
| | SLAN–SMED | max–corr1 | 0.5386 | 0.7176 | Gm | 2.167 | 0.246 |
| | | corr1–max | 0.6110 | 0.7994 | Gm | 2.571 | 0.893 |
| | | max–max | 0.5559 | 0.7512 | Gm | 2.252 | 0.526 |

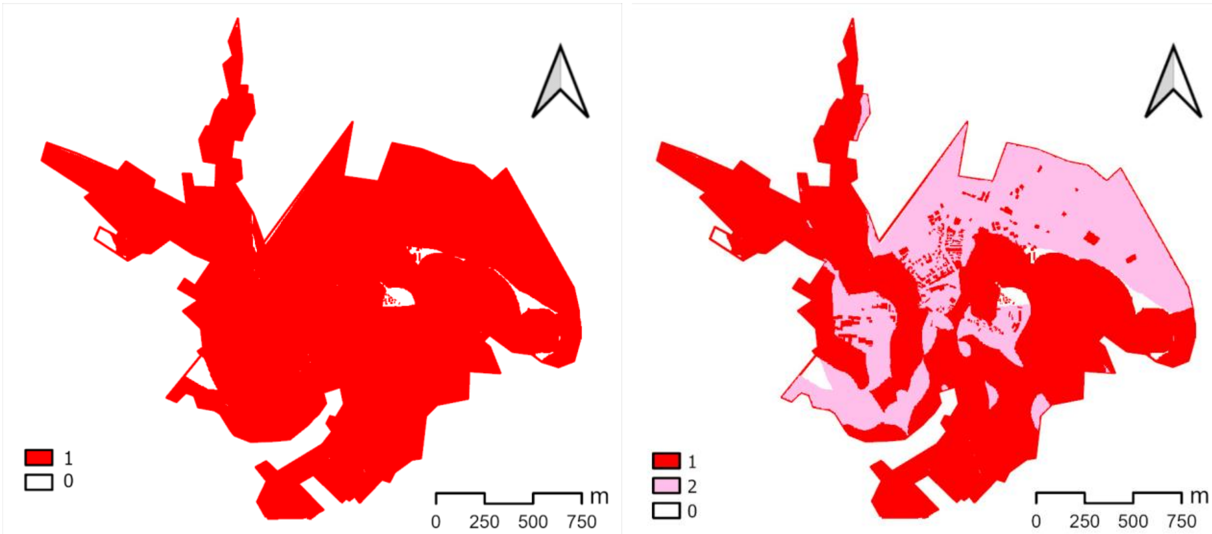
## Urban Stormwater

### Urban Stormwater Management Solutions

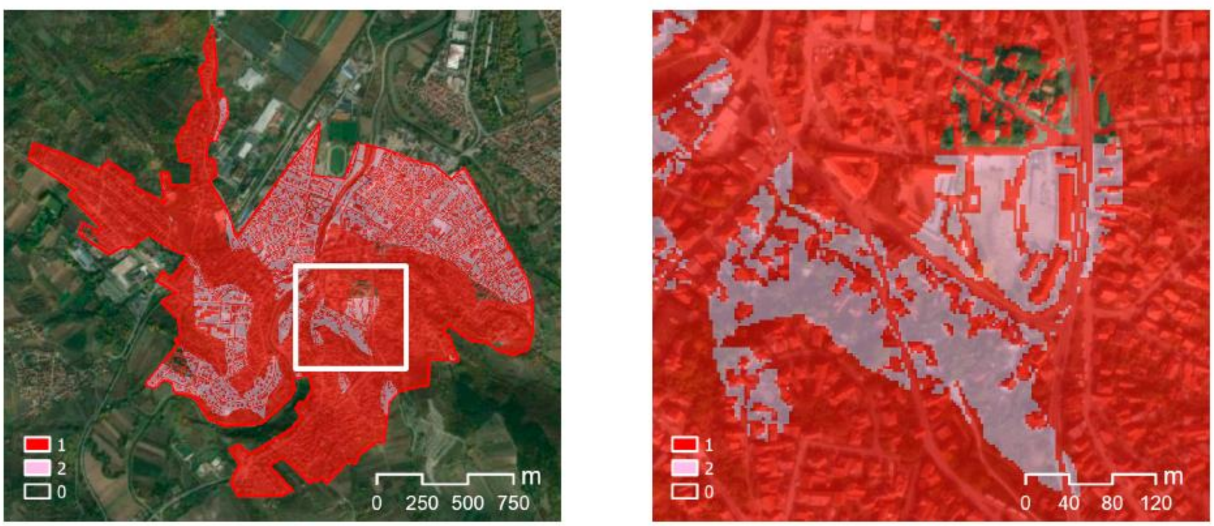
The development of the stormwater management strategies, e.g., low-impact development (LID), water-sensitive urban design (WSUD), and sustainable drainage solutions (SUDS), was initiated in the mid-1980s as a set of engineering approaches and technologies to reduce the harmful effects of stormwater. Over time, all of them evolved in the holistic, multidisciplinary approaches and, today, they are increasingly viewed and implemented under the umbrella term “Nature-based Solutions” (NbS). The technical elements and measures of these NbS represent various technical solutions, implemented i.a., according to the suitability of the site to achieve their maximum efficiency.

Currently, there are no standards or procedures for the application of NbS technologies in Serbia. To overpass this and encourage implementation, we carried out preliminary assessment of NbS elements suitability for application in eight urban settlements in the Region of Southern and Eastern Serbia. The assessment is based on publicly available data and performed according to the existing recommendations in the field of spatial planning and rainwater management for WSUD. The analyses were conducted by GIS tools that involved spatial analyses of various terrain characteristics and provided an insight into the criteria, i.e., constraints that are key to the placement of various technical elements, including bioretention, rain garden, and permeable pavement. Research findings point out that creation of the thematic maps with area suitability ratings for individual NbS stormwater elements might represent a good starting point for further investigation, planning, and design. The proposed framework for preliminary assessment is potentially useful for the countries and regions without regulations in the field of NbS for stormwater management.






***(a)*** *porous pavement with runoff detention;* ***(b)*** *vegetative swale.*
*Color key: 0 (white), area generally suitable; 1 (red), area generally not suitable; 2 (pink), area conditionally suitable with modification to the element(s) design.*




(a) (b)

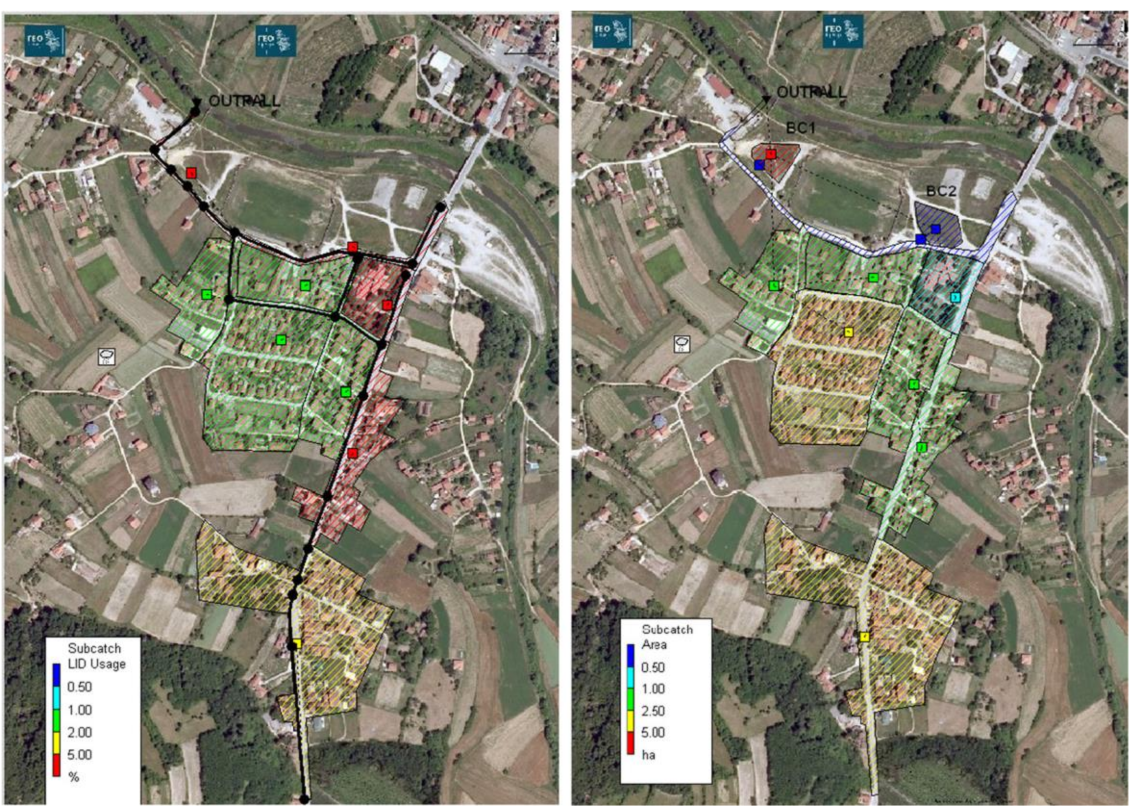
*Area suitability for vegetative swale upon the source data set update for land availability constraint:* ***(a)*** *the area;* ***(b)*** *zoom to the central part where all suitability classes are present.*

**LID technologies for drainage and protection of urban stormwater quality**

A comparative analysis of different solutions for the management of atmospheric stormwater for the Pek settlement was conducted. Three variant solutions based on the classical sewage system and LID techniques were analyzed. The results highlight the third variant solution based only on the LID techniques as the most effective solution for the reduction of stormwater quantity and quality. The first solution, i.e., the classical sewage system, yielded the poorest results. It is important to know that one of the goals in designing of the stormwater management is to retain all atmospheric water in one place where it occurs, until it penetrates into the ground.

On this way, a system imitates the natural processes. The application of the LID principles in the management of atmospheric water has a particular importance in terms of protecting the Danube River and its tributaries in Serbia from pollution by atmospheric waters.

At the end, authors single out, asmajor limitations in this paper, the lack of a practical verification of the effectiveness of the proposed solution (the solution has not yet been realized) and the lack of a cost-effective analysis of the proposed LID solutions. Also, it is important to mention that the proposed model did not perform the parameter verification due to the lack of actual monitoring data of the pipe network flow and data of pollutant concentration changes under stormwater. A construction of a pilot model on the one part of the study area is suggested, before realization of the entire solution. This step is necessary in order to verify the adopted technology and the required parameters.

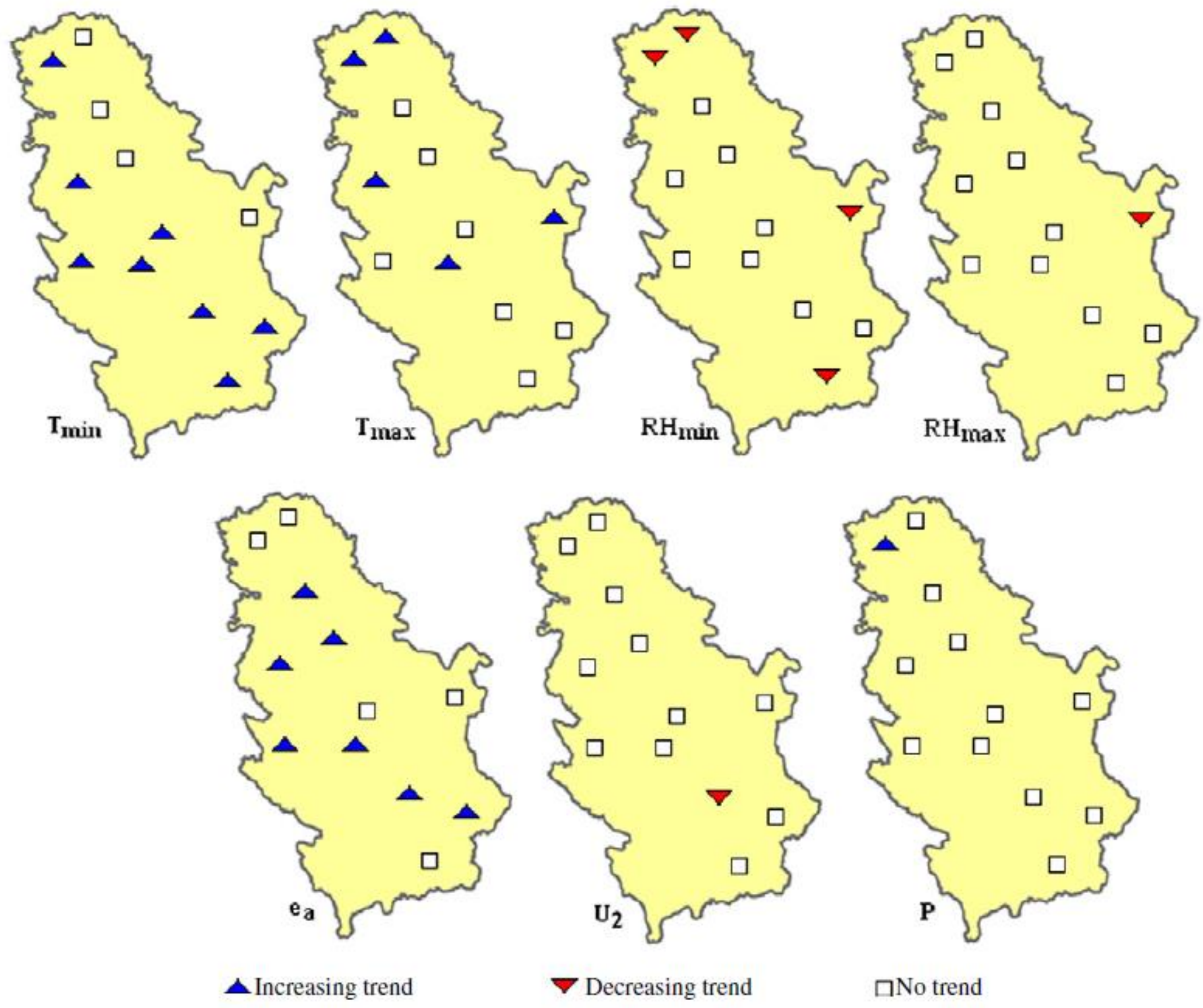



*Second variant solution (left) and third variant solution (right)*

# Trend analysis

**Meteorological parameters**

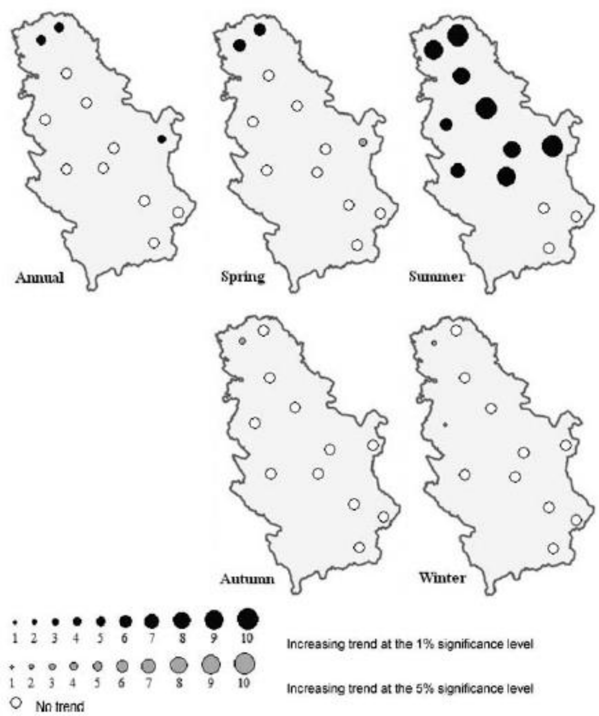
Trends in climate changes are important environmental issues that have a significant impact on hydrological parameters such as soil moisture, water flow, groundwater and evapotranspiration. Tests for the detection of significant trends in climatologic time series can be classified as parametric and non-parametric methods. Parametric trend tests require data to be independent and normally distributed, while non-parametric trend tests require only that the data be independent. In this research, two non-parametric methods (Mann-Kendall and Sen's slope estimator) were used to detect the hydrological time series` trends.



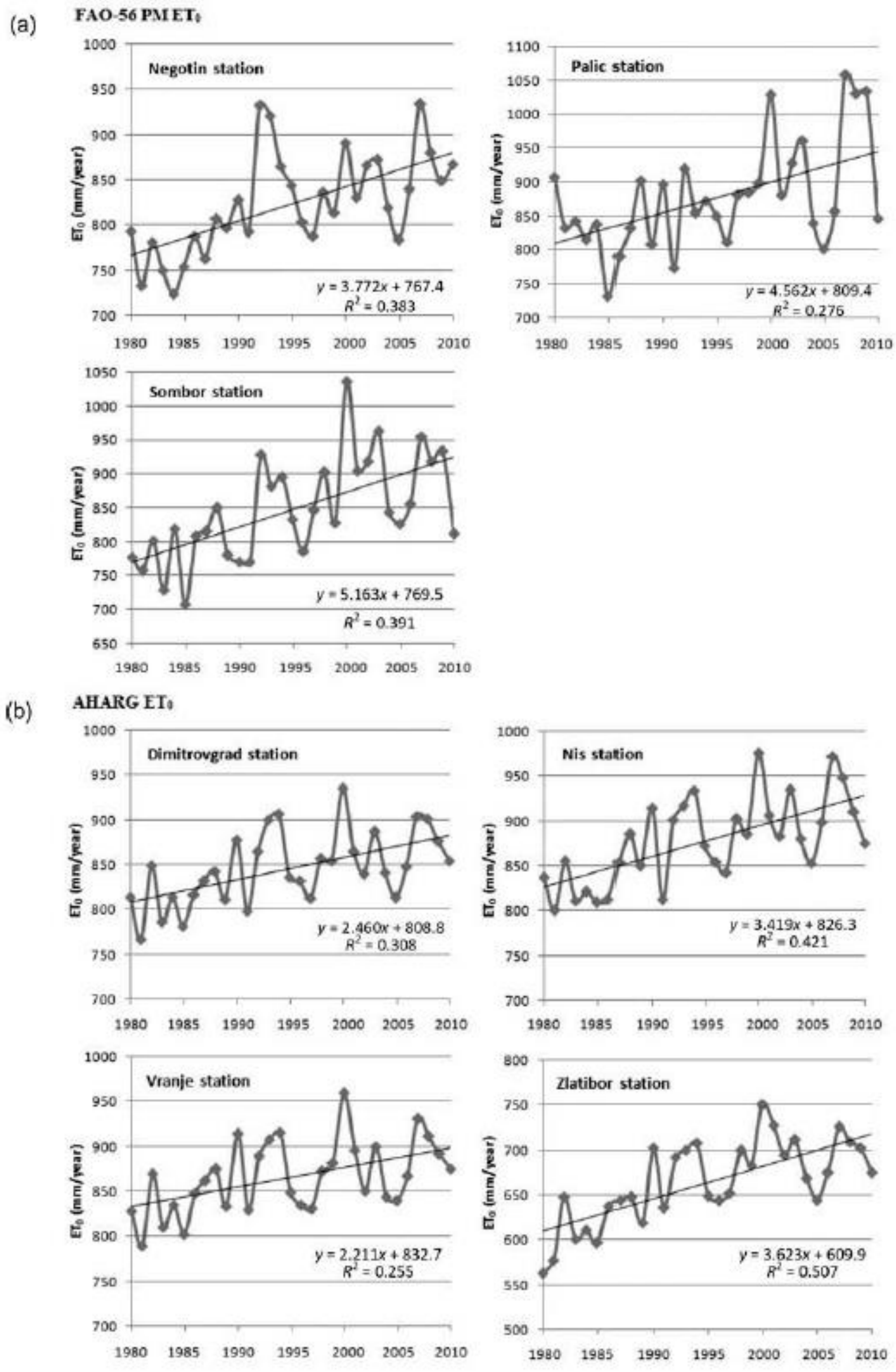

*Spatial distribution of weather stations with increasing, decreasing and no trends by the Mann-Kendall and Sen's tests for the annual data series during the period 1980–2010.*

In general, the results of using Mann-Kendall and Sen's slope estimator statistical tests pointed out the agreement of performance which exists in the detection of the trend for the meteorological variables.
The findings of this research can help in further analysis of possible causes of the increase or decrease in the reference evapotranspiration. Besides, further research in comparing between Mann-Kendall and another trend identification test is recommended.

**Evapotranspiration**
The linear regression, Mann-Kendall and Spearman's Rho tests were applied to analyse monthly, seasonal and annual trends in the FAO-56 PM and AHARG $ET_0$ series. Monthly weather data for this research were used from 12 weather stations in Serbia for the period 1980–2010.
The statistical analysis methods were developed as web services and are presented as the part of the trend analyser component. In general, this study showed that there is a great similarity between the statistical results from the three statistical methods.
On the annual time scale, the significant increasing trends varied from 3.772 mm/year at the Negotin station to 5.163 mm/year at Sombor station, for FAO-56 PM $ET_0$, and from 1.810 mm/year at the Sombor station to 3.623 mm/year at the Zlatibor station, for the AHARG ET0 series. The increasing trends were significant for 70% of the stations at the 1% and 5% significance levels.
The analysed results will be helpful for planning the efficient use of water resources to improve agricultural production. Further research in analysing relationships between meteorological variables and $ET_0$ trends is recommended.




*Spatial distribution of weather stations with trends at the 1 and 5% significance levels, identified by the Mann-Kendall test for the annual and seasonal FAO-56 PM $ET_0$ during 1980–2010. The circle size is proportional the size of the significant trend; open circles (o) indicate there was no trend.*




*Time series and linear trends of annual FAO-56 PM (a) and AHARG $ET_0$ (b) at the stations with significant trends at $\alpha = 0.01$.*

# MODELING OF MACROPHYTES GROWTH DYNAMICS

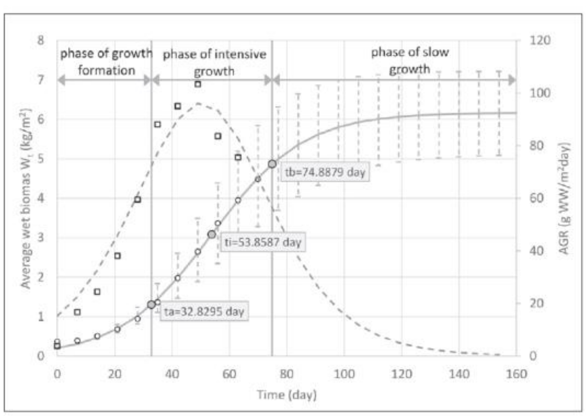
## Background

Invasive aquatic plants are an important factor in global changes, and pose a serious threat to biodiversity. Many scientists have focused on understanding the population dynamics of invasive species to discover the optimal method for managing and preventing the spread of these species within or outside their natural habitats.

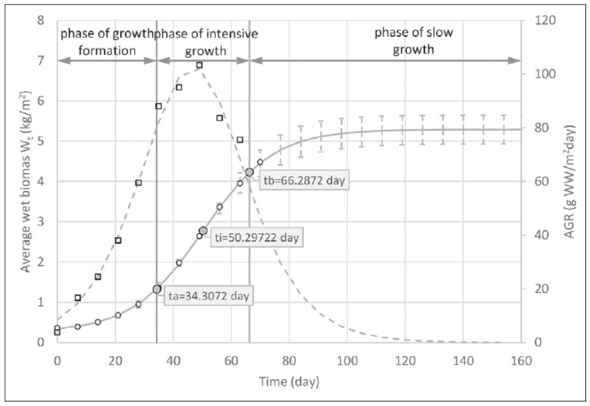
### GAF Hydroresearch Team Results

#### Modeling the Growth Dynamics of Water Lettuce, Pistia Stratiotes L. In Wastewater

Assessing water lettuce (Pistia stratiotes L.) biomass growth was tested at the Faculty of Civil Engineering and Architecture of Nis under partially controlled conditions during a 70-day-long test, with a mixture of communal wastewater and water from the shaft at the hydraulic engineering demonstration facility as a source of nutrient matter.
The biomass measured after the 70-day experiment ranged from 4.31 to 4.71 kg WW/m2 (average 4.48 kg WW/ m2). The daily absolute growth rate (AGR) was 58.81 g/m2 day, the daily increase rate (DIR) was 16.16 %/day, the average daily relative growth rate (RGR) was 0.0359 g/g day, and the biomass doubling time (DT) was 32.94 days. The following models were used to model the dynamics of water lettuce biomass growth: the exponential model, the logistic model, and the sigmoidal model. The research should be repetaed with more precise data (up to 50cm).
The logistic model (environmental capacity 6.1680 kg/m$^2$ after about 150 days, ti 53.8587 days, ta 32.8295 days, tb 74.8879), and sigmoidal model (environmental capacity 5.2903 kg/m2 after about 150 days, ti 50.2972 days, ta 34.3072 days, tb 66.2872 days) adequately describe the biomass growth of the growth phase of water lettuce with high precision, which is essential for planning appropriate preventive and active measures to control the spread of water lettuce as an invasive plant and minimize negative impacts on waterbodies in Serbia.




*Logistic model. Measured and modeled amount of water lettuce biomass Wt and daily absolute growth rate ADR over time, with error bars indicating a 95% confidence interval for the forecasted values*




*Sigmoidal model. Measured and modeled amount of water lettuce biomass Wt and daily absolute growth rate ADR over time, with error bars indicating a 95% confidence interval for the forecasted values.*

**Modeling Water Hyacinth Growth Dynamics**

Evaluating the biomass growth of water hyacinth (Eichhornia crassipes [Mart.] Solms) under partially controlled conditions during a 70-day test using a mixture of municipal wastewater and water from a shaft as a source of nutrients was tested. The water hyacinth in a moderately continental climatic condition at latitude of 43$^{o}$N can achieve productivity of an average of 18.25 kg/m2 in partially controlled conditions, whereas under natural conditions and under conditions of controlled harvesting, larger amounts of biomass can be obtained. Considering the large amounts of biomass of over 1.5 t/ha per day, i.e. over 180 t/ha per year, produced, water hyacinth can be successfully used in wastewater treatment plants with very favorable economic effects if the biomass generated is used for energy production, as a nutrient or food, and for many other needs. The following models were used to model the dynamics of water hyacinth biomass growth: the exponential model (average MSE 0.3117, average R2 to 0.9793), second-order polynomial model (average MSE 0.0952, average R2 0.9937) and logistic model (average MSE 0.0508, average R2 0.9966).

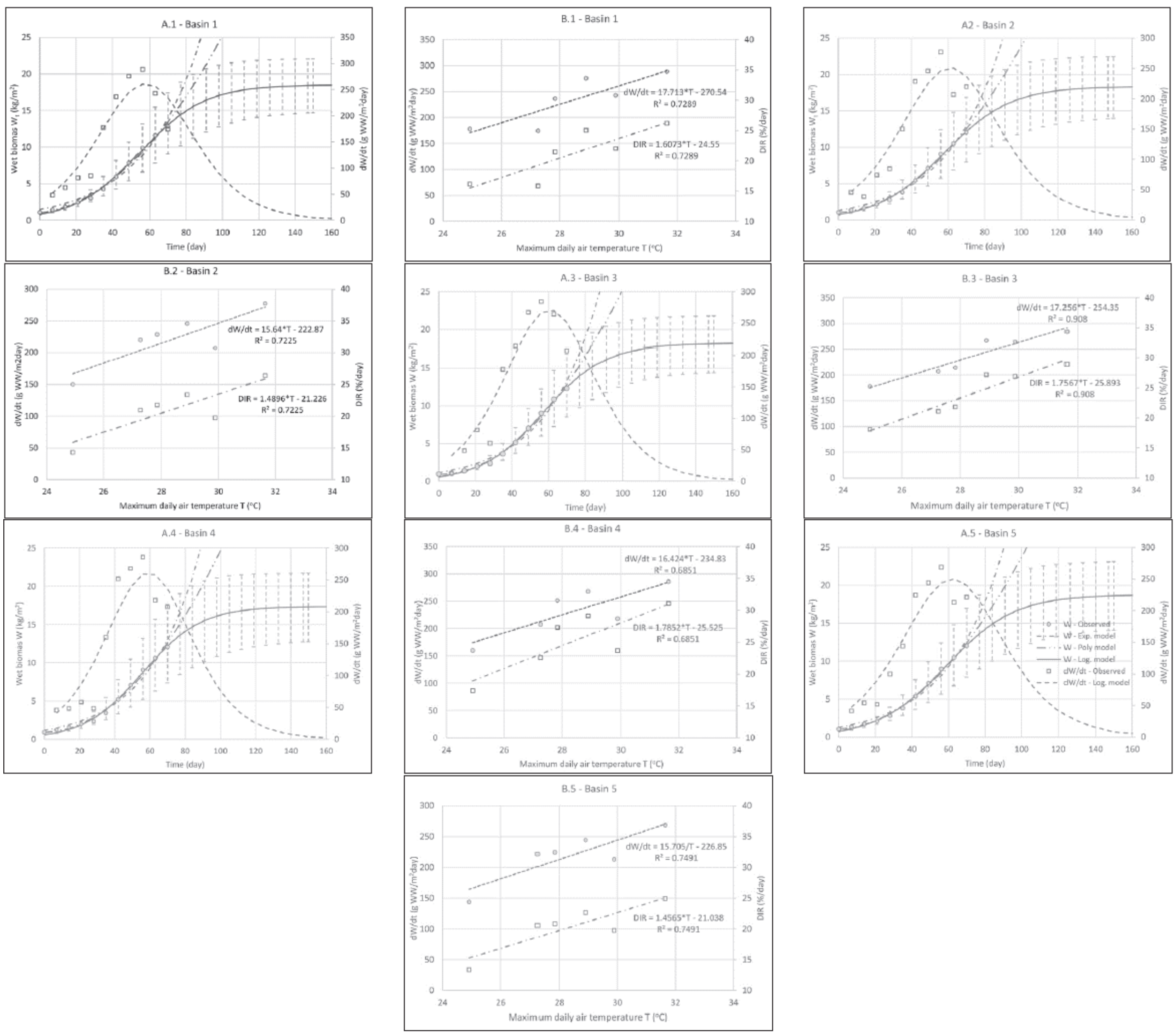
The exponential model and the second-order polynomial model give a continuous increase in biomass over time, practically to infinity, without taking into account that under conditions of increased plant density and reduced availability of resources, biomass growth slows down, and therefore, they are not suitable for application in real conditions. The logistic model (average environmental capacity 18.25 kg/m2, average growth rate 0.0571 g/day after about 150 days) adequately describes the growth of water hyacinth biomass with high accuracy, which enables the monitoring and control of the process operation and the achievement of the required quality of the treated wastewater.

The obtained results confirmed the earlier research conducted at the pilot facility in Sokobanja and at the Faculty of Civil Engineering and Architecture in Nis and the suitability of hydrophytoculture technologies for removing nutrients from wastewater. The obtained results open up the field of phytoremediation and management of pollution of natural environments.

| Basin | K (kg/m²) | a | r (g/g·day) | $W_o$ (kg/m²) | 1/r (day) | MSE | RMSE | MAE | R2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 18.5181 | 3.0927 | 0.0566 | 0.8039 | 17.6567 | 0.0521 | 0.2282 | 0.2110 | 0.9968 |
| 2 | 18.3735 | 3.1640 | 0.0548 | 0.7449 | 18.2356 | 0.0431 | 0.2075 | 0.1689 | 0.9970 |
| 3 | 18.2117 | 3.4143 | 0.0599 | 0.5801 | 16.7010 | 0.0423 | 0.2057 | 0.1821 | 0.9973 |
| 4 | 17.3699 | 3.3676 | 0.0605 | 0.5789 | 16.5352 | 0.0763 | 0.2761 | 0.2398 | 0.9949 |
| 5 | 18.7906 | 3.1419 | 0.0535 | 0.7782 | 18.6963 | 0.0403 | 0.2008 | 0.1746 | 0.9971 |
| Average | 18.2528 | 3.2361 | 0.0571 | 0.6972 | 17.5650 | 0.0508 | 0.2237 | 0.1953 | 0.9966 |

Initial biomass on wet biomass basis ($W_o$); growth limit value of the population or load capacity (K); the rate constant or growth (r), integration constant (a); mean squared error (MSE); root mean square error (RMSE); mean absolute error (MAE); coefficient of determination ($R^2$)

*Parameters of the logistical water hyacinth growth dynamics model*




*Measured and modeled amount of water hyacinth biomass Wt and daily biomass growth dW/dt over time (A.1-A.5) and variation of dW/dt and DIR as a function of maximum daily air temperature (B.1-to B.5), with error bars indicating 95% confidence interval for the predicted values*

## Research Projects

- Horizon Europe Project: Transforming advanced water skilling through the creation of a network of extended-reality water emulative centres - WATERLINE (HORIZON-WIDERA-2021-ACCESS-05, No 101071306), 2022-2024
- COST Action ES1004 (European framework for online integrated air quality and meteorology modeling (EuMetChem)), 2011-2015
- COST Action IC1408 (Computationally-intensive methods for the robust analysis of non-standard data (CRoNoS)), 2015-2020
- COST Action CA20138 (Network on water-energy-food nexus for a low-carbon economy in Europe and beyond (NEXUSNET)), 2021-2025
- Erasmus+ KA2 CBHE project: Development of master curricula for natural disasters risk management in Western Balkan countries (NatRisk) (573806-EPP-1-2016-1-RS-EPPKA2-CBHE-JP), 2017-2021
- Erasmus+ KA2 CBHE project: Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders (SWARM) (597888-EPP-1-2018-1-RS-EPPKA2-CBHE-JP), 2018-2022
- Erasmus+ KA2 CBHE project: Curricula innovation in climate-smart urban development based on green and energy efficiency with the non-academic sector (SmartWB) (101081724 — SmartWB — ERASMUS-EDU-2022-CBHE), 2022-2024
- Erasmus+ Jean Monnet Module, EU water policy and innovative solutions in water resources management (INNOWAT) (620003-EPP-1-2020-1-RS-EPPJMO-MODULE).
- Erasmus+ MODULE – Jean Monnet Module, Modern techniques to ensure environmental sustainability in Eastern Europe (MEET) (621118-EPP-1-2020-1-BA-EPPJMO-MODULE) 2020-2023.
- Erasmus+ Strategic partnership: Serious Games for Digital Readiness of Water Education (SMARTEN) (2020-1-NO01-KA226-HE-094221).
- CEEPUS network-Applied Hydroinformatics (CIII-RS-1112-04-1920), 2017-2020
- World University Service - Austrian Development Cooperation (WUS Austria) - Master Studies Development Programme: Master Program in Civil Engineering – Water Resources Engineering
- Bilateral project, Eötvös Loránd University, Budapest, Hungary and University of Nis, Serbia (Project changes of hydrological hazards (extreme precipitation and droughts) in Hungary and Serbia, No. 451-03-02294/2015-09/10; TÉT_16-1-2016-0135).
- Bilateral project, Technical University of Kosice, Slovakia and University of Nis, Serbia (Innovative approaches to drought risk assessment and management due to climate change).
- Serbian Academy of Sciences and Arts Branch in Nis, Integral Approach to Stormwater Management in Urban Catchment Areas in the South-East Serbia (O-15-18), 2018-2024

## Most Relevant Publications

- Trajkovic, S., Stankovic, M., and Todorovic, B. (2000) Estimation of FAO Blaney-Criddle b Factor by RBF Network, *Journal of Irrigation and Drainage Engineering*, 126(4), 268-271, https://doi.org/10.1061/(ASCE)0733-9437(2000)126:4(268)
- Trajkovic, S., Todorovic, B., and Stankovic, M. (2003) Forecasting of Reference Evapotranspirationn by Artificial Neural Networks, *Journal of Irrigation and Drainage Engineering*, 129(6), 454-457, https://doi.org/10.1061/(ASCE)0733-9437(2003) 129:6 (454)
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**Participation in international donor projects**

1. European Agency for Reconstruction (donor), Schools and Towns for Democracy (Implementer: International Management Group - IMG), 2001-2002
2. United States Agency for International Development (USAID) (donor), Community Revitalization through Democratic Action - CRDA (Implementer: Cooperative Housing Foundation- CHF), 2001-2006
3. United Nations (donor), Rapid Employment Programme, (Implementer: United Nations Development Programme (UNDP), 2002
4. The Italian Ministry of Foreign Affairs-Cooperazione Internazionale (donor), Improvement of the management conditions of hydro and environmental resources of the city of Niš (Implementer: Cooperazione Internazionale (COOPI), 2004 - 2007
5. The Danish Ministry of Foreign Affairs-Neighbourhood Programme (donor), Fruits & Berries Program, 2012-2016

***Outdoor Hydro Laboratory***