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Evaluation of water management solutions for a river catchment under climate change and other pressures – case study of the Pek River

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ABSTRACT

This paper presents three different multi-criteria decision analysis (MCDA) approaches in search for the best water management solution for the Pek River catchment area (CA). The three objectives of this paper are: (1) present some outcomes of an important international project that might help improve water management in other regions worldwide; (2) show how optimal water management is addressed in a catchment that exhibits a declining water resources trend, in this case in Serbia; and (3) demonstrate that three different MCDA approaches, if all input parameters are selected properly and consistently, do not result in any significant differences in the final selection of the best solution (there are minor variations in the final relative values, but the ranking of the analyzed alternatives does not change).

Keywords: CCWaterS; Multi-criteria decision analysis; Decision making process; Pek River; Veliko Gradište; Kučevo; Climate change; Water demand

1. Introduction and description of the pilot area

This paper presents some of the outcomes of the international project "Climate Change and Impacts on Water Supply(CCWaterS)" in South East Europe [1]. Generally, the aim of this project was to analyze the climate change impact on different existing water source capacities (1st part of the project) and to find the best additional water management solutions for users (2nd part of the project), if needed (if the foreseen water source availability is lower than the predicted future water demand). Presentation of the results of the 2nd part of the project is the aim of this paper and particularly the part which compares results of three different multi-criteria decision analysis (MCDA) approaches applied in the decision-making process in the pilot area.

The project partners chose pilot areas with different types of water sources. Our pilot area was the Pek River (a Danube tributary) catchment (Fig. 1) with its two alluvial water sources: Jelak – providing drinking water supply for the city of Veliko Gradište (located at the mouth of the Pek river) and Mlaka – for water supply of the city of Kučevo (located in the central part of the Pek River catchment).

The Pek River catchment area (CA) is in the central-eastern part of Serbia (Fig. 1). The Pek River is a tributary of the Danube and their confluence is at the City of Veliko Gradište. The size of the Pek CA is 1,230 km^2, with a population of approximately 45,000. The total drinking water demand in the CA is approximately 5.3 Mm^3/year (or about 170 L/s), of which three cities receive: Majdanpek 70 L/s, Kučevo 25 L/s, and Veliko Gradište 40 L/s. Veliko Gradište exhibits a clear increasing and Majdanpek a clear decreasing water demand trend, while Kučevo is stagnant. During summer, drinking water demand increases significantly in Veliko Gradište, but not as much in Kučevo and Majdanpek. The water quality at two alluvial sources is generally good:

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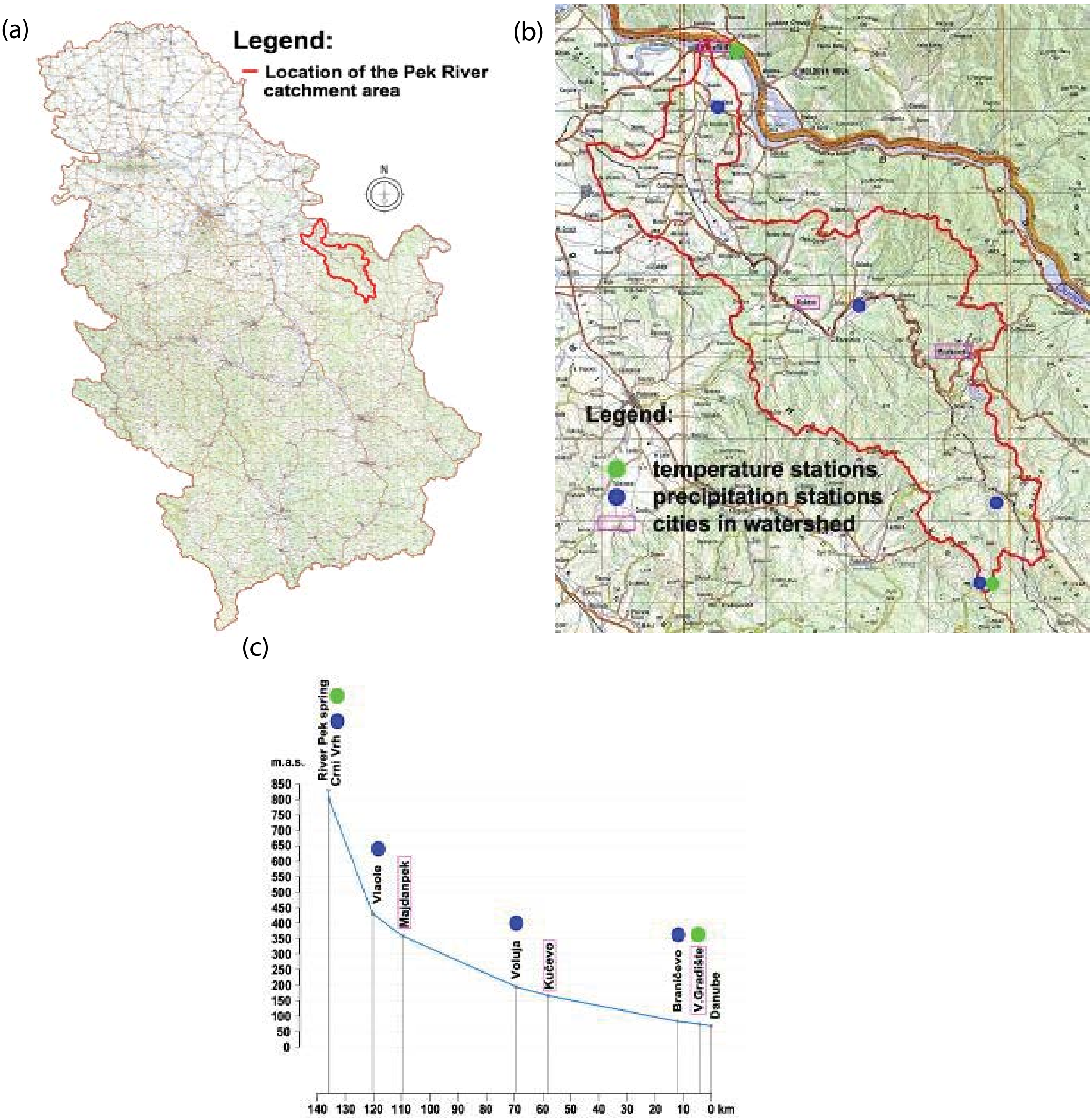
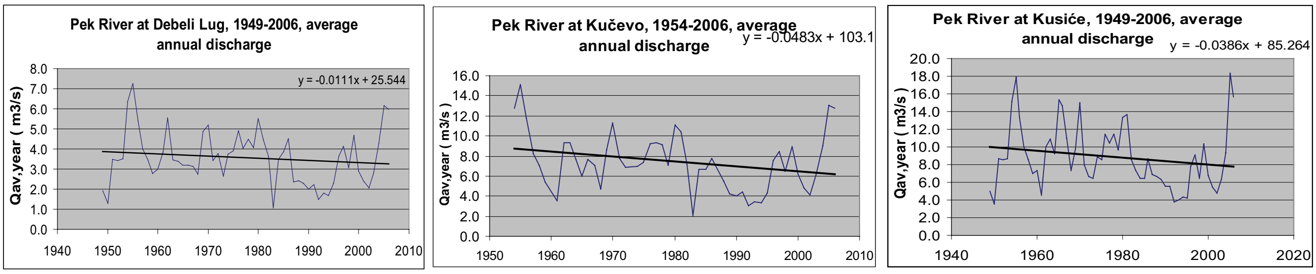


Fig. 1. Location of the Pek River CA within Serbia (a), and positions and elevations of the cities and, temperature (●) and precipitation (●) stations in the catchment (b) and (c).

Jelak (Veliko Gradište) complied with standards before 2006, then NO_3 exceedance was recorded at one well (and the well was shut down) and there have been no issues in the past 10 years and Mlaka (Kučevo) always complied with standards.

The water scarcity problem is growing due to the fact that this region, in addition to temperature (and evapotranspiration) increases, is facing a slightly decreasing precipitation trend [2–5]. The consequence is that the Pek River already exhibits a decreasing discharge trend. There are three hydrological stations on the Pek River: an upstream station at Debeli Lug (near Majdanpek), a central station at Kučevo, and a downstream station at Kusiće (near Veliko Gradište). Fig. 2 shows their observed annual discharges and trends. The longest existing time series for these stations were included and a national study indicates that the registered long-term trend of the Pek River is about (−35% to −40%)/100 years.



Tren d = –0.0111 x 10000/3.561 = –31.2%/100 y. Trend = –0.0483 x 10000/7.414 = –65.2%/100 y. Trend = –0.0386 x 10000/8.877 = –43.5%/100 y.

Fig. 2. Observed annual trends at the three hydrological stations on the Pek River.

The capacity of the water sources in the Pek river CA in the near and distant future under the impact of climate change and other changes, has been analyzed in the 1st part of the CCWaterS project and the methodology and results were published [2]. By way of illustration, Fig. 3 shows the Jelak water source: layout, boundary conditions and coverage of the mathematical model for calibration purposes and groundwater level chart on September 14th, 2010.

In brief, the basic assumption of the methodology was that only the following will change in the future, relative to the present: temperature; precipitation; upstream drinking water and irrigation water demand; and, as a consequence of climate change: recharge, evapotranspiration; river discharge (water level) and upland boundary conditions. The results indicate that the capacities of both alluvial water sources are expected to decline in the near future by about 10%–15%. This percentage is higher in the distant future: about 30% for Jelak and about 45% for Mlaka. Past approximately 10 years, additional amounts of water were already needed in Veliko Gradište Municipality. Other parts of the Pek catchment will need additional amounts of water in the future, with increasing irrigation water demand, supported by climate change.

Generally, river basin management plans (RBMPs) need to be addressed in accordance with the actual situation in the region, the current water balance and applicable legislation, as well as people's customs and mindset and the estimated water balance in the near and distant future. If the water balance of the given region (or any of the neighboring regions) lacks or exhibits excessive water, the water balance must be addressed jointly with neighboring regions – which is not the case in Pek CA. To ensure successful (near-optimal) water management in the long term (the end of the 21st century), it is necessary to first determine which long-term solution is best for the given region, and then see which initial steps are optimal (for the entire region or parts of the region), making sure that these initial steps are consistent with the long-term solution for the region. All circumstances, including climate change, suggest that the best long-term solution for the Pek CA should be sought for an amount of water which corresponds to the sum of the capacities of the two alluvial water sources, that is, roughly 60 L/s, or some 2.0 Mm^3/year (in any regional development scenario the water demand would be met over at least the next 20–30 years), whereby the solution should be checked against a much higher level, for example, a potential deficit in the distant future of 300 L/s (significant increase in water demand for irrigation), or about 10.0 Mm^3/year.

The following questions were addressed:

- Should a regional system (RS) be built in the Pek catchment? What is the sensitivity of the best solution to the parameters and criterion weights?
- Does the solution differ depending on the amount of water for which the RS is sized?
- If an RS is needed, should it be built now?
- If an RS should not be built now, what are the best water management solutions for the near future?
- How reliable are MCDA methods, for example, do they have any traps?

2. Alternatives considered in the pilot area

Additional amounts of water can be provided via RSs in three ways:

- *Alternative 1*: Building of an RS based on a Danube alluvial water source (Fig. 4)
- *Alternative 2*: Building of an RS based on a Danube surface water source (Fig. 5)
- *Alternative 3*: Building of an RS based on a dam in the upper course of the Pek (Fig. 6)

2.1. Alternative 1

Assumes water abstraction from an alluvial water source within the riparian zone of the Danube, treatment to drinking water standards and dispatch to consumers. Given that the water passes through alluvial sediments and is subjected to final treatment at a water treatment plant, a consistently high-water quality is expected. Water safety in accident situations (pollution arriving along the Danube) is rated particularly high. In the first phase, this system could be developed only up to Veliko Gradište and in the second phase, including pumping, it could be extended to Kučevo. The criteria considered for Alternative 1 are presented in Table 1 for additional 60 and 300 L/s.

2.2. Alternative 2

Assumes water withdrawal directly from the Danube, treatment to drinking water standards and dispatch to

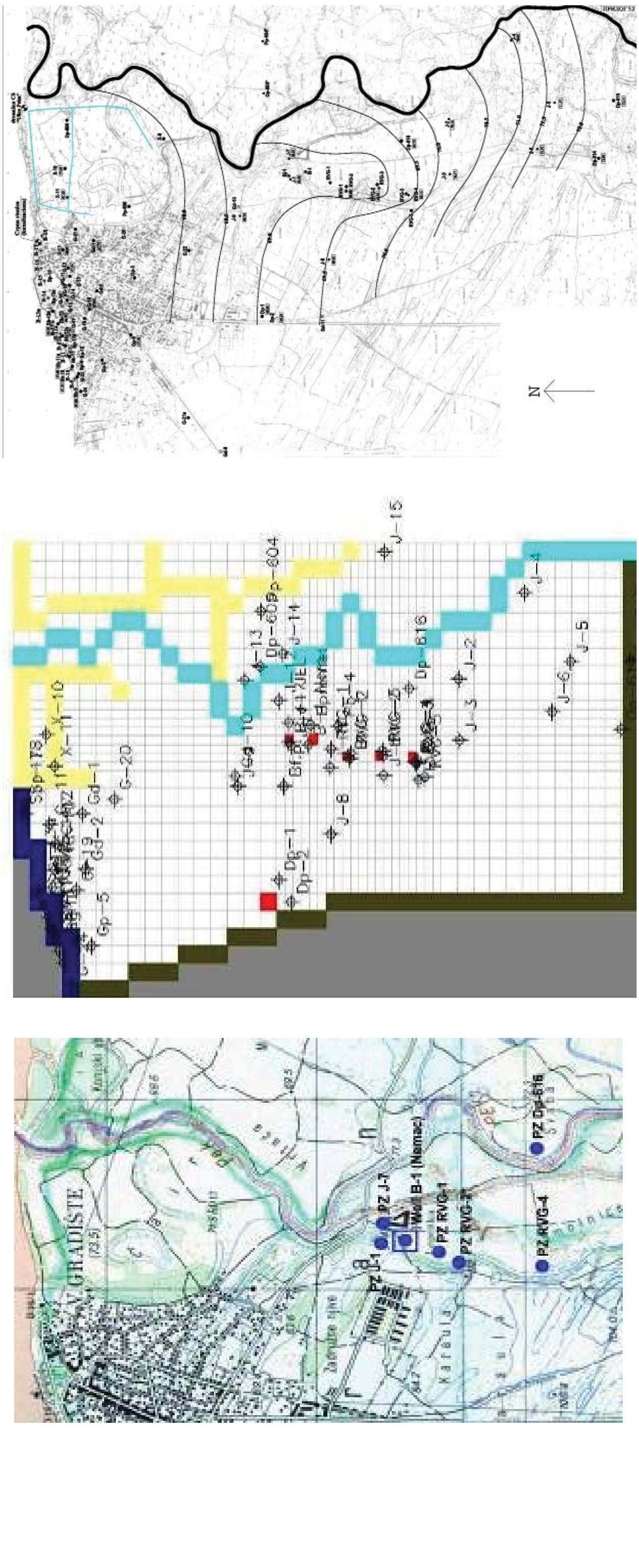


Fig. 3. Layout of the Jelak source (a), boundary conditions and coverage of the mathematical model of Jelak (b) and groundwater level chart on 14 September 2010 (c).

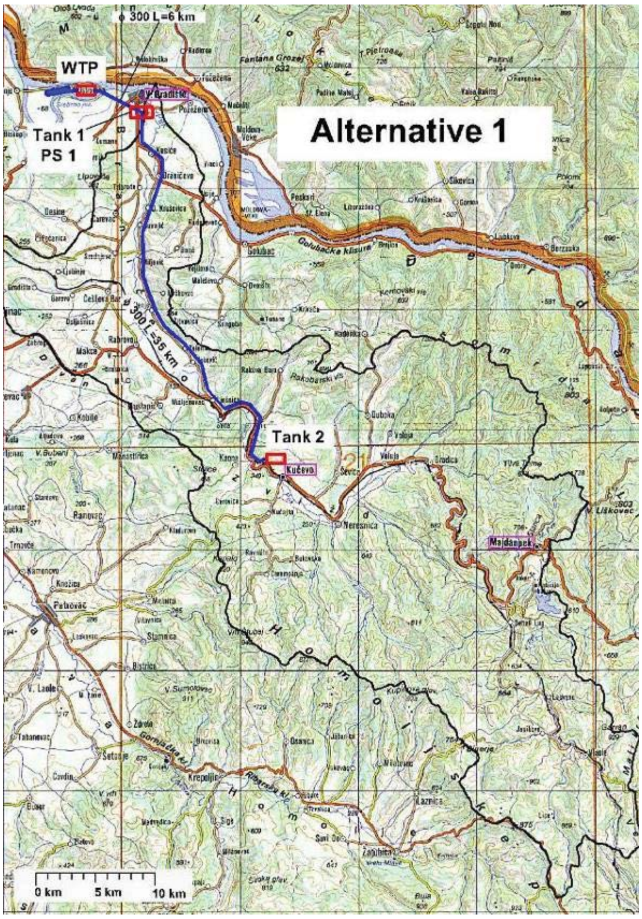


Fig. 4. Alternative 1: Regional system based on a Danube alluvial water source.

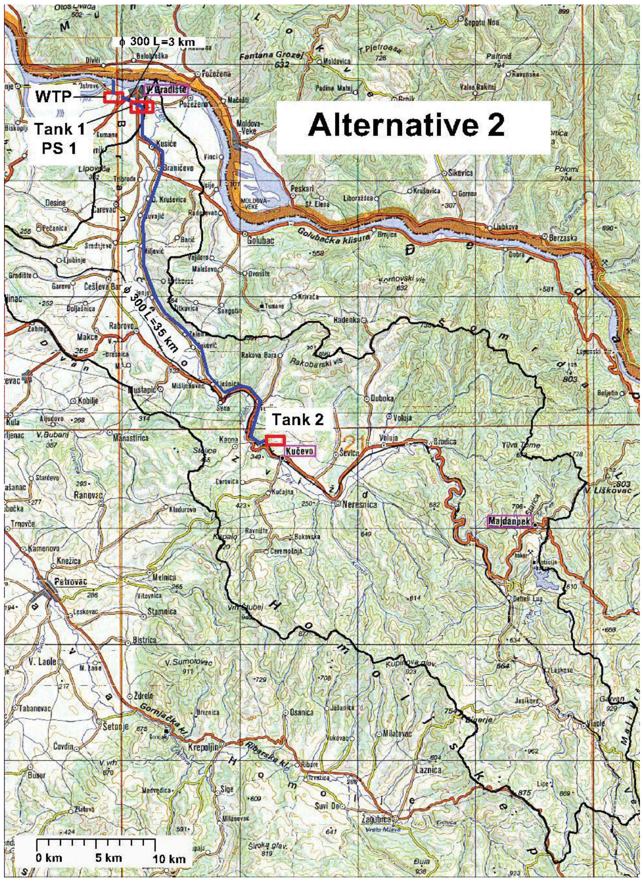


Fig. 5. Alternative 2: Regional system based on a Danube surface water source.

consumers. Although the water would be treated at a modern plant for river water, it is reasonable to expect breakthroughs of certain parameters (e.g., pharmaceuticals), so this alternative was given a lower score for quality and because in potential accident situations (e.g., oil spillage along this reach of the Danube) the plant might easily have to shut down. As in Alternative 1, this system could be developed only up to Veliko Gradište and then later, with the addition of pumping, to Kučevo. The criteria considered for Alternative 2 are presented in Table 2, for additional 60 and 300 L/s.

2.3. *Alternative 3*

Assumes an increase in the height of an existing dam on the Pak upstream from Majdanpek (or construction of a new dam, which is a less favorable sub-alternative), and the provision of additional amounts of water for downstream consumers. The water would be treated to drinking water standards. Sound water quality is expected. There is no major accidental pollution threat, but the vicinity of main roads is a potentially aggravating circumstance. The upside of this alternative is gravitational delivery of water to consumers, and the downside is CAPEX. This project would have no phases and would extend to Veliko Gradište. The criteria considered for Alternative 3 are presented in Table 3 for additional 60 and 300 L/s.

For each of these alternatives, the considered decision-making criteria include capital expenditure (CAPEX), annual operating expenditure (Annual OPEX), overall water quality (assessment of all parameters), and overall water security (including both water quality and system performance). Figs. 4–6 show a summary of the three alternatives based on the criteria of CAPEX, annual OPEX, water quality and water security, for the construction of an RS which would provide 60 or 300 L/s of water to consumers. In all the three alternatives, the development of irrigation is the same – unhindered.

In addition to the above alternatives, a base alternative of "business as usual" (do nothing) was also considered. This alternative required an additional criterion – water shortage. It is clear that in Alternatives 1–3, involving an RS, there is no water shortage (except in catastrophic circumstances), while the base alternative features maximum water shortage corresponding to the point in time for which the comparison was made.

3. Methodology: description of three different MCDA approaches used to find the best water management option

Human needs and the ecological status of any area are generally opposing. Water and land management decisions

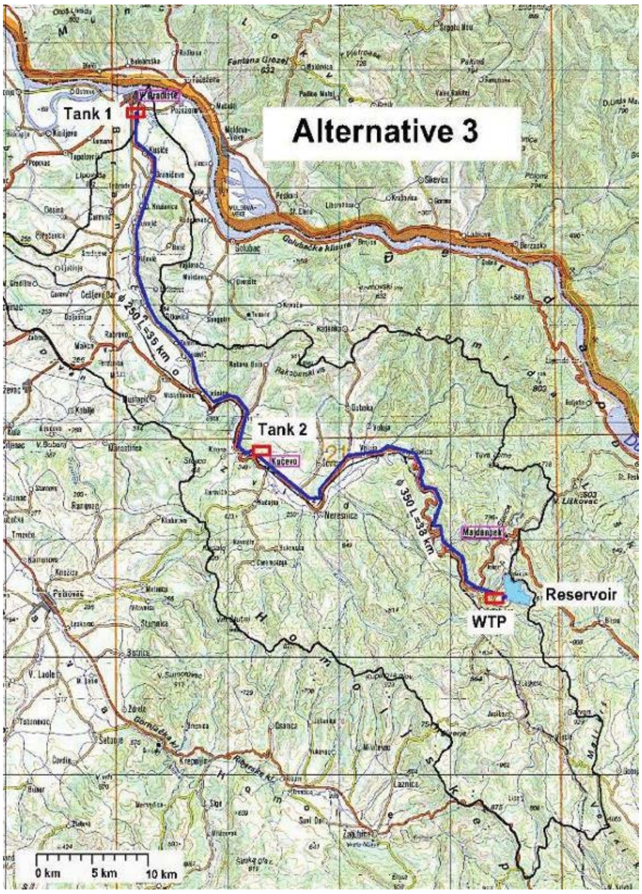


Fig. 6. Alternative 3: Regional system based on a dam on the upper course of the Pek.

Table 1
Values of considered criteria for Alternative 1

60 L/s	Criterion	Alternative 1
1	CAPEX (10^6 €)	12.7
2	Annual OPEX (10^6 €/year)	0.450
3	Water quality (maximum 100)	80
4	Water security (maximum 100)	90
300 L/s	Criterion	Alternative 1
1	CAPEX (10^6 €)	39.0
2	Annual OPEX (10^6 €/year)	1.658
3	Water quality (maximum 100)	80
4	Water security (maximum 100)	90

within a catchment often require the consideration of multiple factors. Using the MCDA approach for catchment scale studies is quite frequent in the world and many papers describe different problems, alternatives and the ways to find best solutions.

In Gloucestershire, UK, MCDA was used in a payment analysis for ecosystem services to evaluate options for delivering good ecological status in Tortworth Brook. Following a process of stakeholder engagement, the final options

Table 2
Values of considered criteria for Alternative 2

60 L/s	Criterion	Alternative 2
1	CAPEX (10^6 €)	12.7
2	Annual OPEX (10^6 €/year)	0.467
3	Water quality (maximum 100)	60
4	Water security (maximum 100)	50
300 L/s	Criterion	Alternative 2
1	CAPEX (10^6 €)	40.4
2	Annual OPEX (10^6 €/year)	1.778
3	Water quality (maximum 100)	60
4	Water security (maximum 100)	50

Table 3
Values of considered criteria for Alternative 3

60 L/s	Criterion	Alternative 3
1	CAPEX (10^6 €)	21.9
2	Annual OPEX (10^6 €/year)	0.279
3	Water quality (maximum 100)	70
4	Water security (maximum 100)	60
300 L/s	Criterion	Alternative 3
1	CAPEX (10^6 €)	61.4
2	Annual OPEX (10^6 €/year)	1.200
3	Water quality (maximum 100)	70
4	Water security (maximum 100)	60

considered were: (1) doing nothing; (2) modifying existing sewage treatment works; (3) a single integrated constructed wetland (ICW) targeting multiple ecosystem service outcomes; and (4) catchment wide multiple ICWs. The analysis concluded that the "do nothing" option and modifying the existing works are both likely to provide poor utility and value for money. Both ICW options offered the greatest utility in terms of optimizing the benefits to all stakeholders [6].

In South Africa, the MCDA approach was used to identify critical alternative courses of action and to develop a decision-making framework for sustainable groundwater management [7]. In Ireland, MCDA was used for comparison of the catchment in terms of maximizing agricultural landuse and intensity and defining areas of predominantly grassland and arable enterprises [8]. In the United States, the implementation of integrated catchment management (ICM) is hampered by the lack of a conceptual framework for explaining how landowners select farming systems for their properties. Benefit–cost analysis (a procedure that estimates the costs and benefits of alternative actions or policies) has limitations in this regard, which might be overcome by using MCDA, which evaluates and ranks alternatives based on a landowner's preferences (weights) for multiple-criteria and the values of those criteria. An MCDA approach to ICM is superior to benefit–cost analysis which focuses only on the monetary benefits and costs [9]. In India, soil erosion causes many environmental problems in some catchments, such as loss of beneficial storage, breach of banks, loss of nutrients, etc. MCDA has been used to prioritize vulnerable areas of a catchment [10].

German researchers are investigating possible measures for RBMPs. Measures are aggregated from smaller spatial units (e.g., water bodies) to the catchment or basin scale. They are evaluated using multiple criteria, for example, ecological and socio-economic criteria, etc. Aggregation often combines spatial analysis and MCDA. They investigate: (1) the effect of applying different aggregation pathways on the outcome of the RBMP using the technique for order of preference by similarity to the ideal solution as an MCDA method, (2) the scaling effects considering water body, sub-catchment, and river basin scales, and (3) the effect of using global and local criteria weighing on the final ranking of alternatives. The results suggest that scaling effects are recommended to be considered in spatial MCDA [11].

In some cases, MCDA is also used to escape potential conflicts and political tensions between neighboring countries, who share transboundary aquifer resources [12].

MCDA of the alternatives for the Pek CA was undertaken and is presented using three approaches:

- Simple weighing of maximum and minimum scores of the alternatives by criterion (maximum weight = 1.00; minmum weight = 0.00), and linear interpolation in-between, then assigning relative weights to each criterion (hereafter: criterion weights), followed by multiplication and finally addition (best alternative has the highest total weight). This MCDA approach is sound if a quick comparison of alternatives is needed;
- Reduction of all economic criteria to one criterion, and of all non-economic criteria to another criterion, followed by weighing as above. With this approach, first all economic criteria needed to be reduced to one criterion and all non-economic to another criterion. This was accomplished based on parameter values and the correlation between individual criterion weights, which was virtually the only way in the case of non-economic criteria, while economic criteria additionally allowed for the (preferred) application of an economic analysis method. This was achieved here by reducing all costs over a period of 50 years to the present value. The estimated discount rate is very important and 4% was assumed for the calculation in the present case study. This MCDA approach is sound if alternatives need to be compared and there are important economic considerations; and
- Using Fuzzy Decimaker software version 2.0.

Fuzzy Decimaker is a fuzzy multi-criteria decision making (MCDM) tool that helps the user in deciding among the best solutions when multiple alternatives exist under a number of conflicting criteria called indicators, and the indicator values are fuzzy numbers. The problem is represented by a hierarchical (tree-like) structure of indicators, that is, factors that might affect the outcome of the problem. Each of the indicators is represented by a node in a tree. By varying the values of these factors (nodes), the user can decide which combination produces the best result. This approach is the most applicable in different fields of MCDA and software has been developed, providing various graphs as outputs. Another advantage over the other approaches is that it offers a possibility to include the most likely interval instead of one value for each criterion in any of the alternatives.

3.1. Further advantages of using the Fuzzy Decimaker software MCDM methodology are as follows

- Both quantitative and qualitative data can be normalized, compared and used to rank systems. These data can originate from various groups that may conflict with each other (e.g., ecology, economics and political issues).
- The MCDM hierarchal structure can be developed to be as simple or complex as the user specifies.
- The idea of developing a ranking based on distance from an ideal reference point can easily be understood and described for all types of individuals involved in the ranking process.

From the early application of fuzzy logic to hydrology [13], a large amount of research has been undertaken and, at present, fuzzy logic is increasingly becoming a practical tool in hydrologic analysis and water resources decision making. Similar to the subject-matter of this paper, fuzzy logic was applied in regional water resources management to choose among alternative management approaches with small data sets and imprecisely known or modeled objectives [14–17]. Reservoir operation planning [18–20] may apply fuzzy logic to derive operation rules. Multi-criterion decision making involving uncertainty can be used when water resources systems face multiple and conflicting criteria [21–23]. It is also used for fuzzy risk analysis, which considers uncertainty in any or all elements of risk analysis: exposure or load, resistance or capacity and consequence [24,25]. Fuzzy logic is used in many other fields, too, such as fuzzy regression, hydrologic forecasting, hydrological modeling, groundwater flow and transport modeling, climatic modeling of hydrologic extremes, etc.

4. Results

4.1. Should an RS be built in the Pek catchment? What is the sensitivity of the best solution to the parameters and criterion weights?

If we consider whether an RS should be built, keeping in mind that the projections include the end of the 21st century (funding need not be provided right away), non-economic criterion weights (water quality, water quantity and water security) should certainly predominate economic criterion weights (CAPEX and annual OPEX). This has a ratio of 1.5:1 or more. The results are presented in Table 4.

Alternative 1 is clearly the best solution in all three approaches. A somewhat different (possibly more realistic) distribution of criterion weights, keeping the 1.5:1 ratio of non-economic to economic criteria weights, is shown in Table 5. Changes from Table 4 (identified in red) include an increase in the criterion weight for CAPEX vs. annual OPEX and an increase in the criterion weights for water quality and water quantity vs. water security.

Table 4
Comparison of regional systems providing 60 L/s with three different approaches

1st approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	CAPEX (10^6 €)	12.7	12.7	21.9	0	21.9	0	0.422	0.423	0.000	1	**1**	0.42	0.42	0.00	1.00
2	Annual OPEX (10^6 €/year)	0.450	0.467	0.279	0	0.467	0.000	0.036	0.000	0.402	1	**1**	0.04	0.00	0.40	1.00
3	Water quality (maximum 100)	80	60	70	40	80	40	0.8	0.6	0.7	0.4	**1**	0.80	0.60	0.70	0.40
4	Water security (maximum 100)	90	50	60	30	90	30	0.9	0.5	0.6	0.3	**1**	0.90	0.50	0.60	0.30
5	Water quantity (maximum 100)	100	100	100	0	100	0	1	1	1	0	**1**	1.00	1.00	1.00	0.00
										Total		**5**	**3.16** **0.63**	**2.52** **0.50**	**2.70** **0.54**	**2.70** **0.54**

2nd approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	Economic (10^6 €, present value, for 70 years)	26.6	27.1	30.6	0	30.6	0	0.130	0.113	0.000	1	1	0.13	0.11	0.00	1.00
2	No - Economic (average weight)	90	70	76.7	23.3	90.0	23.3	0.9	0.7	0.767	0.233	1.5	1.35	1.05	1.15	0.35
										Total		**2.5**	**1.48** **0.59**	**1.16** **0.47**	**1.15** **0.46**	**1.35** **0.54**

3rd approach

Ver1	Pek CA DF 60 L/s	Relative weight	Balance factor	Ideal value	Worst value	SCENARIOS: Base				Alternative 1				Alternative 2				Alternative 3			
						MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH
Risk 0.6	Water quality (1–10)	0.3333	1	1	10	4	8	2	10	2	3	1	5	3	5	1	8	2	4	1	7
	Water quantity-shortage (L/s)	0.3333	1	0	60	40	50	10	60	0	0	0	0	0	0	0	0	0	0	0	0
	Water security (1–10)	0.3333	1	1	10	6	8	4	10	2	3	1	5	4	6	3	8	3	5	2	8
Realization	CAPEX (Mil. Euro)	0.5	1	0	25	0	0	0	0	12	13.4	10	15.4	12	13.4	10	15.4	21	22.9	19	24.8
0.4	Annual OPEX (Mil. Euro/year)	0.5	1	0	0.7	0	0	0	0	0.4	0.5	0.3	0.6	0.42	0.52	0.3	0.62	0.2	0.33	0.18	0.38

Results from bar graph			
Alt. 1	Alt. 2	Alt. 3	Base
0.6	0.58	0.60	0.60

Table 5
Comparison of regional systems providing 60 L/s with changed criterion weights

1st approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	CAPEX (10^6 €)	12.7	12.7	21.9	0	21.9	0	0.422	0.423	0.000	1	**2.4**	1.01	1.01	0.00	2.40
2	Annual OPEX (10^6 €/year)	0.450	0.467	0.279	0	0.467	0	0.036	0.000	0.402	1	**1.6**	0.06	0.00	0.64	1.60
3	Water quality (maximum 100)	80	60	70	40	80	40	0.8	0.6	0.7	0.4	**2.4**	1.92	1.44	1.68	0.96
4	Water security (maximum 100)	90	50	60	30	90	30	0.9	0.5	0.6	0.3	**1.2**	1.08	0.60	0.72	0.36
5	Water quantity (maximum 100)	100	100	100	0	100	0	1	1	1	0	**2.4**	2.40	2.40	2.40	0.00
										Total		**10**	**6.47**	**5.45**	**5.44**	**5.32**
													0.65	**0.55**	**0.54**	**0.53**

2nd approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	Economic (106 €, present value, for 50 years)	26.6	27.1	30.6	0	30.6	0	0.130	0.113	0.000	1	**1**	0.13	0.11	0.00	1.00
2	No - Economic (average weight)	90	70	76.7	23.3	90	23.3	0.9	0.7	0.767	0.233	**1.5**	1.35	1.05	1.15	0.35
										Total		**2.5**	**1.48**	**1.16**	**1.15**	**1.35**
													0.59	**0.47**	**0.46**	**0.54**

3rd approach

Ver1.4	Pek CA DF 60 L/s	Relative weight	Balance factor	Ideal value	Worst value	SCENARIOS															
						Base				Alternative 1				Alternative 2				Alternative 3			
						MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH
Risk 0.6	Water quality (1–10)	**0.4**	1	1	10	4	8	2	10	2	3	1	5	3	5	1	8	2	4	1	7
	Water quantity-shortage (L/s)	**0.4**	1	0	60	40	50	10	60	0	0	0	0	0	0	0	0	0	0	0	0
	Water security (1–10)	**0.2**	1	1	10	6	8	4	10	2	3	1	5	4	6	3	8	3	5	2	8
Realization	CAPEX (Mil. Euro)	**0.6**	1	0	25	0	0	0	0	12	13.4	10	15.4	12	13.4	10	15.4	21	22.9	19	24.8
0.4	Annual OPEX (Mil. Euro/year)	**0.4**	1	0	0.7	0	0	0	0	0.4	0.5	0.3	0.6	0.42	0.52	0.3	0.62	0.2	0.33	0.18	0.38

Results from bar graph			
Alt. 1	Alt. 2	Alt. 3	Base
0.68	0.61	0.60	0.60

It appears that Alternative 1 is the best solution in all three approaches, even when parameters are varied within acceptably realistic limits. A higher non-economic to economic ratio of criterion weights shows even further that Alternative 1 is preferable. The results are presented in Table 6, only for the 3rd approach (with changes from Table 4 identified in red), where the relative weight is increased for risk and decreased for realization, which is the relevant long-term guideline for the development of the Pek CA.

If the relative weight for water quality increases vs. the relative weight for water quantity and water security (which would likely be the case), the advantage of Alternative 1 increases further against other solutions, due to the highest value of this parameter (high score for water quality – 80/100). It is also important (not considered here) that consumers prefer treated water from alluvial water sources compared with treated water from surface water sources (Danube River or Pek River reservoir).

4.2. Does the solution differ depending on the amount of water for which the RS is sized?

A comparison of RSs that would provide 300 L/s is shown in Table 7 (keeping the criterion weights as in Table 4):

It is apparent that as the size of the RS increases, the Base Alternative gains favor over the other three alternatives. This outcome is as expected and suggests that when the time comes to build an RS, its capacity should be addressed very carefully. Out of the three alternatives involving an RS, Alternative 1 always comes on top.

4.3. If an RS is needed, should it be built now?

If we consider whether an RS should be built now (for which funding needs to be provided right away), then the economic criteria become at least as important as the non-economic criteria (expressed as 1:1 or more in favor of economic criteria). A comparison in the case of 60 L/s is shown in Table 8.

The table shows that it is much better not to build an RS now (in the near future) and that a solution should be sought at the local (municipal) level.

4.4. If an RS should not be built now, what are the best water management solutions for the near future?

At the local (municipal) level, one new criterion is important – consumers' acceptance of the proposed water management action. Generally, it is the lowest in the case of price change (even if it is also in consumer' interests), and the highest in the case of new capital project or water loss reduction. Multi-criteria ranking for both cities was undertaken applying solely the third MCDA approach (Fuzzy Decimaker software).

Due to a drinking water deficit during summer, Veliko Gradište Municipality proceeded with a new capital project, comprised of Danube alluvial wells, a water treatment plant, a pipeline, and a water tank near the city. As shown in Table 9, that is the best water management solution in the moment. It fits well with the RS identified under Alternative 1, which will likely be operational someday.

Table 6
Results for higher non-economic vs. economic ratio of criterion weights for 3rd approach

						SCENARIOS															
Ver1.1	Pek CA DF 60 L/s	Relative weight	Balance factor	Ideal value	Worst value	Base				Alternative 1				Alternative 2				Alternative 3			
						MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH
Risk 0.7	Water quality (1–10)	0.3333	1	1	10	4	8	2	10	2	3	1	5	3	5	1	8	2	4	1	7
	Water quantity-shortage (L/s)	0.3333	1	0	60	40	50	10	60	0	0	0	0	0	0	0	0	0	0	0	0
	Water security (1–10)	0.3333	1	1	10	6	8	4	10	2	3	1	5	4	6	3	8	3	5	2	8
Realization 0.3	CAPEX (Mil. Euro)	0.5	1	0	25	0	0	0	0	12	13.4	10	15.4	12	13.4	10	15.4	21	22.9	19	24.8
	Annual OPEX (Mil. Euro/year)	0.5	1	0	0.7	0	0	0	0	0.4	0.5	0.3	0.6	0.42	0.52	0.3	0.62	0.2	0.33	0.18	0.38

Results from bar graph			
Alt. 1	Alt. 2	Alt. 3	Base
0.71	0.61	0.64	0.54

Table 7
Comparison of regional systems for 300 L/s

1st approach

300 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	CAPEX (10^6 €)	39.0	40.4	61.43	0	61.43	0	0.365	0.342	0	1	1	0.365	0.342	0	1
2	Annual OPEX (10^6 €/year)	1.658	1.778	1.200	0	1.778	0	0.068	0	0.325	1	1	0.068	0	0.325	1
3	Water quality (maximum 100)	80	60	70	40	80	40	0.8	0.6	0.7	0.4	1	0.8	0.6	0.7	0.4
4	Water security (maximum 100)	90	50	60	30	90	30	0.9	0.5	0.6	0.3	1	0.9	0.5	0.6	0.3
5	Water quantity (maximum 100)	100	100	100	0	100	0	1	1	1	0	1	1	1	1	0
										Total		**5**	**3.13** 0.63	**2.44** 0.49	**2.62** 0.52	**2.70** 0.54

2nd approach

300 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	Economic (10^6 €, present value, for 50 years)	90.3	95.4	98.6	0	98.6	0	0.084	0.032	0.000	1	1	0.08	0.03	0.00	1.00
2	No - Economic (average weight)	90	70	76.7	23.3	90.0	23.3	0.9	0.7	0.767	0.233	1.5	1.35	1.05	1.15	0.35
										Total		**2.5**	**1.43** **0.57**	**1.08** **0.43**	**1.15** **0.46**	**1.35** **0.54**

3rd approach

Ver1	Pek CA DF 300 L/s	Relative weight	Balance factor	Ideal value	Worst value	SCENARIOS: Base MLIL	Base MLIH	Base LLIL	Base LLIH	Alternative 1 MLIL	Alternative 1 MLIH	Alternative 1 LLIL	Alternative 1 LLIH	Alternative 2 MLIL	Alternative 2 MLIH	Alternative 2 LLIL	Alternative 2 LLIH	Alternative 3 MLIL	Alternative 3 MLIH	Alternative 3 LLIL	Alternative 3 LLIH
Risk 0.6	Water quality (1–10)	0.3333	1	1	10	4	8	2	10	2	3	1	5	3	5	1	8	2	4	1	7
	Water quantity-shortage (L/s)	0.3333	1	0	300	50	150	30	300	0	0	0	0	0	0	0	0	0	0	0	0
	Water security (1–10)	0.3333	1	1	10	7	9	5	10	2	3	1	5	4	6	3	8	3	5	2	8
Realization 0.4	CAPEX (Mil. Euro)	0.5	1	0	70	0	0	0	0	37.0	40.9	33.9	44.8	38.4	42.4	35.2	46.5	58.4	64.5	53.4	70.0
	Annual OPEX (Mil. Euro/year)	0.5	1	0	2	0	0	0	0	1.57	1.74	1.44	1.91	1.69	1.87	1.55	2.00	1.14	1.26	1.04	1.38

Results from bar graph			
Alt. 1	Alt. 2	Alt. 3	**Base**
0.65	0.54	0.57	**0.66**

Table 8
Should an RS be built now – comparison of alternatives at 60 L/s

1st approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	CAPEX (10^6 €)	12.7	12.7	21.9	0	21.9	0	0.422	0.423	0.000	1	**1.5**	0.632	0.634	0.000	1.00
2	Annual OPEX (10^6 €/year)	0.450	0.467	0.279	0	0.467	0.000	0.036	0.000	0.402	1	**1.5**	0.055	0.000	0.604	1.00
3	Water quality (maximum 100)	80	60	70	40	80	40	0.8	0.6	0.7	0.4	**1**	0.80	0.60	0.70	0.40
4	Water security (maximum 100)	90	50	60	30	90	30	0.9	0.5	0.6	0.3	**1**	0.90	0.50	0.60	0.30
5	Water quantity (maximum 100)	100	100	100	0	100	0	1	1	1	0	**1**	1.00	1.00	1.00	0.00
										Total		**6**	**3.39**	**2.73**	**2.90**	**3.70**
													0.56	**0.46**	**0.48**	**0.62**

2nd approach

60 L/s	Criterion	Alter. 1	Alter. 2	Alter. 3	Base	Max. value	Min. value	Alter. 1	Alter. 2	Alter. 3	Base	Criter. weight	Alter. 1	Alter. 2	Alter. 3	Base
1	Economic (10^6 €, present value, for 50 years)	26.6	27.1	30.6	0	30.6	0	0.130	0.113	0.000	1	**1**	0.13	0.11	0.00	1.00
2	No - Economic (average weight)	90	70	76.7	23.3	90	23.3	0.9	0.7	0.767	0.233	**1**	0.90	0.70	0.77	0.23
										Total		**2**	**1.03**	**0.81**	**0.77**	**1.23**
													0.51	**0.41**	**0.38**	**0.62**

3rd approach

Ver1.2	Pek CA DF 60 L/s	Relative weight	Balance factor	Ideal value	Worst value	SCENARIOS: Base MLIL	Base MLIH	Base LLIL	Base LLIH	Alternative 1 MLIL	Alternative 1 MLIH	Alternative 1 LLIL	Alternative 1 LLIH	Alternative 2 MLIL	Alternative 2 MLIH	Alternative 2 LLIL	Alternative 2 LLIH	Alternative 3 MLIL	Alternative 3 MLIH	Alternative 3 LLIL	Alternative 3 LLIH
Risk 0.5	Water quality (1–10)	0.3333	1	1	10	4	8	2	10	2	3	1	5	3	5	1	8	2	4	1	7
	Water quantity-shortage (L/s)	0.3333	1	0	60	40	50	10	60	0	0	0	0	0	0	0	0	0	0	0	0
	Water security (1–10)	0.3333	1	1	10	6	8	4	10	2	3	1	5	4	6	3	8	3	5	2	8
Realization 0.5	CAPEX (Mil. Euro)	0.5	1	0	25	0	0	0	0	12	13.4	10	15.4	12	13.4	10	15.4	21	22.9	19	24.8
	Annual OPEX (Mil. Euro/year)	0.5	1	0	0.7	0	0	0	0	0.4	0.5	0.3	0.6	0.42	0.52	0.3	0.62	0.2	0.33	0.18	0.38

Results from bar graph			
Alt. 1	Alt. 2	Alt. 3	**Base**
0.64	0.55	0.56	**0.67**

Table 9
Multi-criteria ranking for the Veliko Gradište water supply system

Ver1	Results from bar graph:					Veliko Gradište 30 L/s				Base			
Scenarios	Base	**NCP**	PC	LR	LR + PC	Relative weight	Balance factor	Ideal value	Worst value				
Results	0.61	**0.65**	0.59	0.63	0.62					MLIL	MLIH	LLIL	LLIH
Risk 0.5	Water quality (1–10)					0.333	1	1	10	4	8	2	10
	Water quantity-shortage (L/s)					0.333	1	0	30	10	15	5	30
	Water security (1–10)					0.333	1	1	10	6	8	4	10
Realization 0.5	CAPEX (Mil. Euro)					0.333	1	0	3	0	0	0	0
	Annual OPEX (Mil. Euro/year)					0.333	1	0	0.20	0	0	0	0
	Acceptance (1–10)					0.333	1	1	10	4	6	2	9

Table 10
Multi-criteria ranking for the Kučevo water supply system

Ver1	Results from bar graph:				Kučevo							
Scenarios	**Base**	PC	LR	LR + PC	Relative weight	Balance factor	Ideal value	Worst value	Base			
Results	**0.67**	0.58	0.60	0.57					MLIL	MLIH	LLIL	LLIH
Risk 0.4	Water quality (1–10)				0.5	1	1	10	4	7	2	9
	Water security (1–10)				0.5	1	1	10	6	8	4	10
Realization 0.6	CAPEX (Mil. Euro)				0.333	1	0	1.2	0	0	0	0
	Annual OPEX (Mil. Euro/year)				0.333	1	0	0.10	0	0	0	0
	Acceptance (1–10)				0.333	1	1	10	3	5	1	7

Table 11
Comparison of regional systems providing 60 L/s (1st approach) without Alternative 3

Ver1	Criterion	Alter. 1	Alter. 2	Base	Max. value	Min. value	Alter. 1	Alter. 2	Base	Criter. weight	Alter. 1	Alter. 2	Base
1	CAPEX (10^6 €)	12.68	12.66	0	12.68	0	0.000	0.002	1.00	**1**	0.00	0.00	1.00
2	Annual OPEX (10^6 €/year)	0.450	0.467	0	0.467	0	0.036	0.000	1.00	**1**	0.04	0.00	1.00
3	Water quality (maximum 100)	80	60	40	80	40	0.8	0.6	0.4	**1**	0.80	0.60	0.40
4	Water security (maximum 100)	90	50	30	90	30	0.9	0.5	0.3	**1**	0.90	0.50	0.30
5	Water quantity (maximum 100)	100	100	0	100	0	1	1	0	**1**	1.00	1.00	0.00
									Total	5	**2.74**	**2.10**	**2.70**
											0.55	**0.42**	**0.54**

The Kučevo water supply system (WSS) will certainly not have water quantity issues in the near future, so this criterion was removed. All things considered, this WSS should not undertake anything at this time (Table 10).

This does not mean, however, that water loss reduction to some extent and a price change, which are relevant water management actions for both WSSs, should be abandoned. Along with the increase in drinking water price, from welfare tariff (today approximately 0.5 €/m^3) to economic tariffs (for both WSS the estimated economic price is between 1.2 and 1.5 €/m^3), there is a need to improve efficiency of water supply companies and a need to raise consumer awareness of the usefulness of such measures. That will likely happen with the implementation of new Serbian water legislation.

4.5. How reliable are MCDA methods, e.g., do they have any traps?

If we compare just two alternatives, then the only "trap" is the degree of objectivity in the assignment of values to parameters and criteria weights. It should be noted, in general, that MCDA methods reduce the impact of bias in decision making about option selection.

However, one needs to be cautious and critical of the assessment results for at least two reasons:

SCENARIOS															
New Capital Project				Price Change				Loss Reduction				Loss Red. + Price Ch.			
MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH
2	3	1	5	3	5	2	8	3	5	2	8	2	4	1	7
0	0	0	0	5	10	0	25	5	10	0	25	0	5	0	20
2	3	1	5	4	6	2	9	4	6	2	9	3	5	1	7
2.0	2.5	1.5	3.0	0.4	0.6	0.3	0.8	0.8	1.2	0.6	1.6	0.96	1.44	0.72	1.92
0.10	0.12	0.08	0.15	0.02	0.05	0.01	0.07	0.04	0.08	0.02	0.12	0.05	0.10	0.02	0.15
3	5	2	7	8	9	7	10	2	5	1	6	5	7	4	8

S C E N A R I O S											
Price change				Loss reduction				Loss Red. + Price Ch.			
MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH	MLIL	MLIH	LLIL	LLIH
3	5	2	8	3	5	2	8	2	4	1	6
3	5	2	8	3	5	2	8	2	4	1	6
0.24	0.36	0.18	0.48	0.48	0.72	0.36	0.96	0.58	0.86	0.43	1.15
0.01	0.03	0.01	0.04	0.02	0.05	0.01	0.07	0.03	0.06	0.01	0.09
8	9	7	10	2	5	1	6	5	7	4	8

- The individual conducting MCDA assigns scores based on his or her personal convictions, which may differ at times from objective assessments of certain parameters. This personal impression, although reduced by the MCDA approach, is also present in sensitivity analyses of parametric assessments and, particularly, of relative weights.
- If we compare more than two alternatives, then attention should be paid to additional trap. Depending on the selection of the third, fourth, or other poorer options, the ultimate results indicating the merit of each option (in this case the choice of water management approach) may differ. For example, if Alternative 3 is excluded from Table 4 (by far the highest CAPEX), the ratio of the top two alternatives (Alternative 1 and the base Alternative) would change and become almost equal: (0.55:0.54 in Table 11) instead (0.63:0.54 in Table 4).

5. Conclusions

5.1. Conclusions regarding the results related to the Pek CA

The Pek catchment RS should probably be built one day (answer to question A), but not at this time (answer to question C). When the time comes to build an RS, its capacity should be addressed very carefully (answer to question B). Alternative 1 offered the best solution among the considered RSs. It should serve as a guideline for the development of local solutions. Alternative 3, in addition to the convenience of gravitational transport and relative protection of the drainage area of the river reservoir, would be the best solution for an appreciably richer society and in the unlikely event of accidental pollution of the Danube's alluvial waters (comment related to questions A and B).

Today, the best water management approach should be sought at the local level of each municipality. Veliko Gradište Municipality proceeded with a new capital project, which comprise Danube alluvial wells, a water treatment plant, a pipeline and water tank near the city. This is the best water management action at the moment. It fits well with the RS identified under Alternative 1. The Kučevo WSS will not have water quantity issues in the near future. Definitely good measures, such as water loss reduction and price change, along with improved efficiency of water supply companies and raised consumer awareness of the usefulness of such measures, will likely result from the implementation of new Serbian Water Law (answer to question D). Our impression is that the traps, which always exist in any MCDA method, were successfully avoided in the MCDA presented in this paper and that the results (selection of best alternative) reflect the best possible choice (answer to question E).

5.2. Conclusions regarding three different MCDA approaches

The three MCDA approaches consistently yielded the same ranking of the alternatives, albeit with slight differences in the results (provided that the same values of the parameters and relative weights were assigned), attesting to the proper conduct of the MCDA assessments. So, all three are relevant for the issue analyzed in the paper and similar issues, and the implementation of anyone of them depends on the need, as mentioned under Section 3.

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