HYDROLOGICAL BASES OF REGIONAL MANAGEMENT OF WATER RESERVES IN THE HIGH KARST AS EXAMPLIFIED BY THE UPPER PART OF THE KUPA RIVER CATCHMENT AREA

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Abstract: Using the source of the Kupa river as the example this paper contemplates the problem of planning regional use and protection of strategically valuable water reserves in the high karst. The initial limitations to a more intensive use of these water resources are consequential to significant intra-annual fluctuations of the water regime and a relatively low yield when compared to the total water potential. The problem is compounded by the fact that the Kupa, except for its source which is entirely in Croatia, is a transboundary river marking the border between Croatia and Slovenia. This paper has placed a particular emphasis on analysing hydrological aspects of the existing water regime, whose impact on further elaborations of possible solutions are of great significance. The paper also offers proposals for a possible approach to future solutions to the issue within the context of the adopted EU Water Framework Directive.

The paper analyses hydrological elements that have a more significant impact on the choice of potential solutions and the assessment of optimum use of water resources of the high karst, in the upper part of the Kupa river catchment area, especially within the context of the observed climate changes and a planned increase in water demands. It further emphasizes analyses of the characteristics of fluctuations of the typical hydrological values and their trends, the occurrence of extreme hydrological conditions as well as the global and seasonal changes of the water regime.
Key words: karst, water resources, runoff regulation, management, Croatia

1. Introduction

The region of Gorski kotar is situated in the high Dinaric karst. Based on the precipitation quantities and specific discharge, it is the country's region with most abundant water quantities, hence its resources acquire a wider regional significance. Its major part gravitates towards the Danube river catchment area. Its most important watercourse is the Kupa river, with the total catchment area of approximately 10,000 sq. km, 75% of which (i.e. the upper parts of the catchment area) is located in the karst region. A part of the Kupa catchment area (approximtely 1125 sq. km) belongs to the neighbouring country of Slovenia, which makes the Kupa, along with its tributary, the Čabranka, transboundary watercourses for the length of 140 km. The upper part of the Kupa catchment area is one of the least populated regions in Croatia, with only about 36,000 inhabitants; therefore the managing of water resources in Gorski kotar is presently minimal. The water resources of Gorski kotar surpass its local significance, with a perspective of being strategic water reserves of the two neighbouring, most developed regions in Croatia (the costal area of the North Adriatic and the Zagreb-Karlovac region). Due to the fact that the Kupa and the Čabranka are for the most part transboundary watercourses between Croatia and Slovenia, the managing of their water resources requires a co-ordinated, joint approach by both countries. The assessment of solutions to potential water management activities in the catchment area mostly depends on the changes in the hydrological regime and the potential impact of these changes on environmental characteristics of these systems. Fig. 1 shows the upper part of the Kupa catchment area with marked hydrological gauging stations.

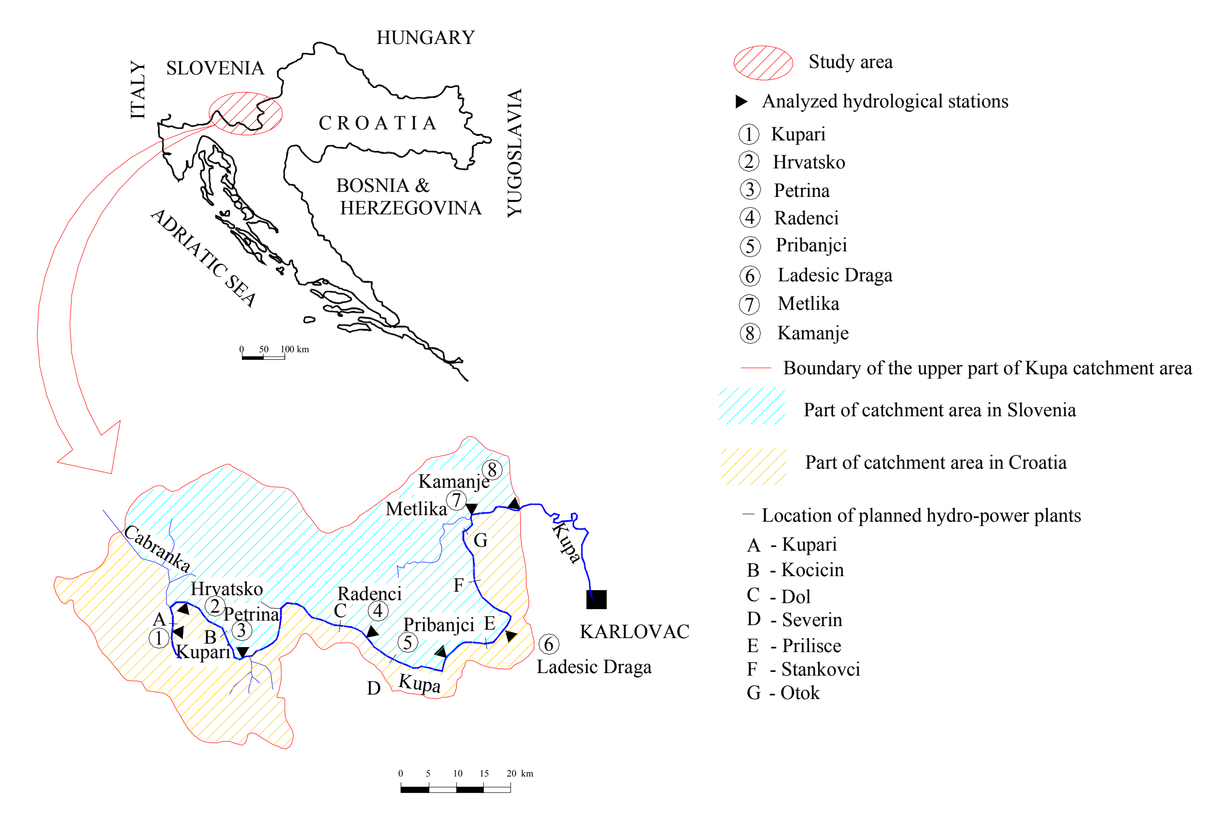

Fig. 1 - The upper part of the Kupa catchment area

The most important water resource in this area of high karst is the source the Kupa river itself, with the status of protected hydrological nature monument. It is located marginally to the Risnjak National Park, which encompasses the area of 62 sq. km, also the main recharge area of the source. The mean annual discharge of the source is over 13 m^3s^{-1}, making it the largest karst spring in Gorski kotar and the North Adriatic area. Unfortunately, the minimum discharge of only app. 0.5 m^3s^{-1} limits the potential of its immediate use for water supply. There have been a number of plans to include the spring into the regional pipeline systems due to the fact that aside from its large capacity, it is also characterized by adequate water quality. However, the precondition for constructing a water intake in the source zone of the Kupa is to ensure a re-distribution of its water budget, i.e. to construct a storage reservoir. The most recent document which considered the construction of a storage reservoir in the upper part of the Kupa catchment area was a study entitled "A Complex Regulation of the Kupa River Catchment Area" (Elektroprojekt, 1989). The study, primarily made for the purpose of using the region's hydropower potential, included a plan of constructing an entire system of reservoirs in the Kupa catchment area. The analysis focused on the possibility to build a total of 12 reservoirs on the main stretch of the Kupa. However, due to the establishment of two separate countries which followed after the project's completion, and the subsequent changed interests regarding the plans for the use of the Kupa area as evidenced in the adopted physical plans of Croatia and Slovenia, the elaboration and realization of this project was abandoned.

In the current plans the area of the Kupa valley has the status of a protected landscape, i.e. the use of the Kupa water and the surrounding area is set aside primarily for recreational and protection purposes. However, considering the pronounced trends of a decrease in the budget of medium and low water levels in the greater region, and growing problems to ensure adequate water quality along the Kupa river, particularly in dry periods, as well as the expressed demands for clean water which can be offered by high karst springs, including the source of the Kupa, the existing physical plans should not pose an obstacle to considerations of a possible construction of a storage reservoir itself in the spring area of the Kupa, which would not only ensure significant water quantities for water supply, but also enable controlled increasing of the Kupa's minimum discharges. This would ensure more adequate envirnomental conditions along the Kupa for purposes of both conserving organisms endangered by extremely low water levels and increasing its autopurification capability. It is, of course, also possible that the construction of a storage reservoir may have negative impacts (e.g. on the changes in temperature regime, dynamics of sediment transfer, biological and environmental characteristics in the impacted area); therefore it is necessary to consider this aspect of the problem as well when assessing the potentials of constructing such a reservoir. This paper has no intention to advocate the construction of such an object; its aim is to take into consideration hydrological elements which influence such potential solutions, and also, within the context of the adopted WFD, to consider a manner in which to analyse possiblities of planning, i.e. theoretical, study-based considerations of such solutions prior to making decisions on their potential realisation. The first step in such regional planning must definitely be hydrological assessments of the existing state, the topic of this paper.

2. Hydrological characteristics of the source of the Kupa

The Kupa river and its tributary, the Čabranka, present the base for discharges of numerous strong karst springs, whose recharge occurs in the karst part of the catchment area. The most important spring, the source of the Kupa, is located 319 m a.s.l. The past tracings showed that the Kupa source recharges in the Risnjak and Gerovski regions, whose largest part belongs to the Risnjak National Park, which was in 1997. extended to also include the Kupa source zone. This part of the catchment area is characterized by a relatively high water yield, with specific discharges exceeding 30 l/s/km^2 and the coefficient of the annual discharge of over 0.7.

Based on the results of the processed collected hydrological data (Table 1), the mean annual discharge in the profile of Kupari - Kupa, i.e. at the end of the source zone of the Kupa, amounts to 13.4 m^3s^{-1} (in the analysed period of 1952-1998), with variations in range between 9.6 and 17.9 m^3s^{-1}. The mean value of maximum discharges is also quite high (142 m^3s^{-1}), with minimum water levels equaling 1.1 m^3s^{-1}. The calculated values for the occurrence of minimum water levels range from 1.0 m^3s^{-1} (2-year return period) to only 0.506 m^3s^{-1} (100-year return period). All of the above illustrates the fact that without regulating discharge in the upper Kupa a more extensive use of the spring's water potential is not possible.

Table 1 - Characteristic observed and calculated discharge values at the Kupa source

OBSERVED ANNUAL DISCHARGE				
Parameter	**medium (m^3s^{-1})**		**minimum (m^3s^{-1})**	**maximum (m^3s^{-1})**
mean	13.42		1.10	142
σ	2.16		0.39	22.4
Cv	0.161		0.35	0.16
Cs	0.177		0.86	
Min.	9.55		0.525	97.8
Max.	17.9		2.05	195
CALCULATED CHARACTERISTIC DISCHARGE				
Return period	**minimum (m^3s^{-1})**	**maximum (m^3s^{-1})**	**minimum (m^3s^{-1})**	**maximum (m^3s^{-1})**
2 years	13.4	13.4	1.019	140
5 years	11.6	15.2	0.776	160
10 years	10.7	16.2	0.679	172
20 years	9.98	17.1	0.611	182
50 years	9.19	18.1	0.545	194
100 years	8.67	18.7	0.506	202

Fig. 2 shows the fluctuations of medium and minimum annual discharges of the Kupa source. There is a visible trend of a decrease in values, which was also observed elsewhere in the greater region (Ožanić, Rubinić, 1998.)

Fig. 3 shows the intra-annual distribution of medium and minimum discharges of the Kupa source, confirming a variability too great in the springs's yield as opposed to extremely low water levels in dry season, which poses a great problem to its potential use for water supply.

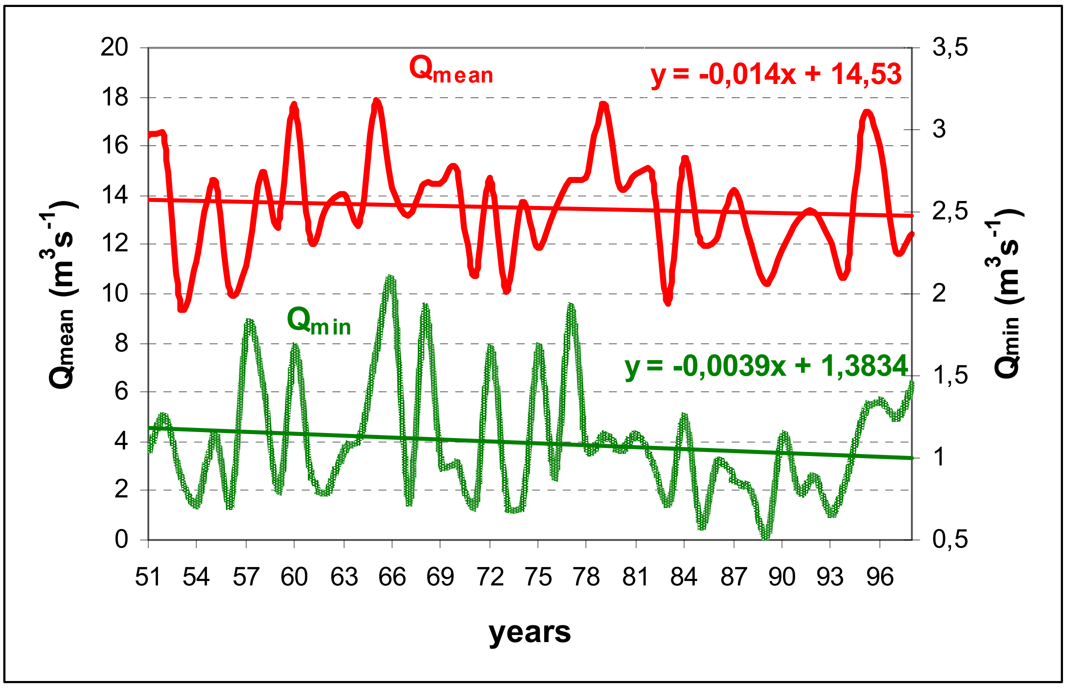

Fig 2 - Fluctuations of mean and minimum annual discharges of the Kupa source

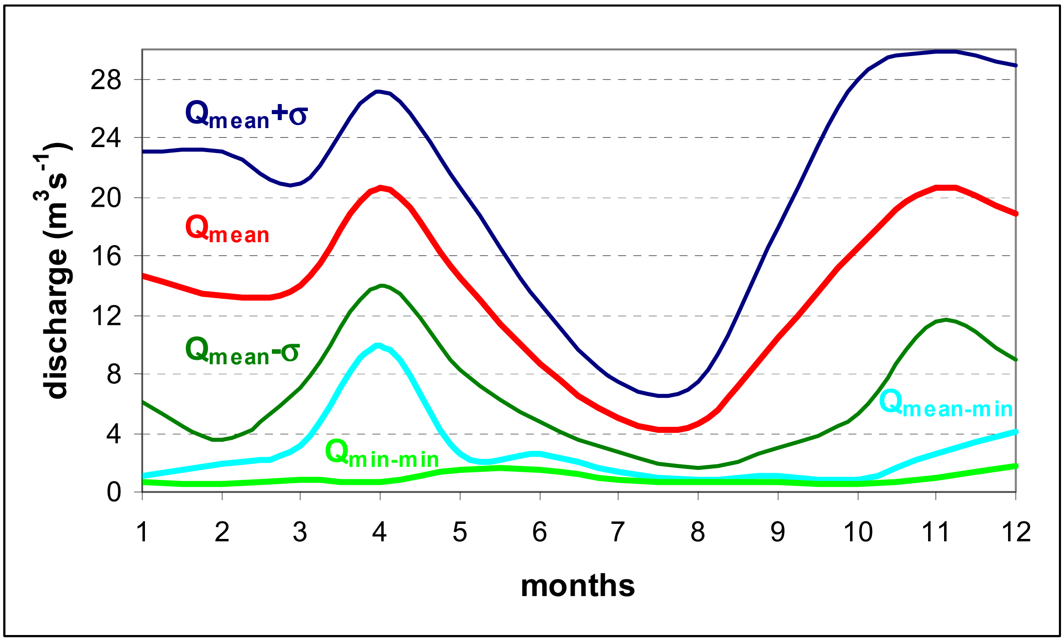

Fig 3 Intra-annual distribution of minimum and mean annual discharges of the Kupa source

To enable a better insight into the distribution of low water levels along the Kupa flow, Table 2 gives an overview of observed low water levels, as well as the calculated values for characteristic probability of their occurrence, in several hydrological gauging stations in the upper and middle part of the Kupa river, i.e upstream from the confluence with the Dobra, its first important left-bank tributary.

Table 2 - Characteristic values of low water levels along the upper part of the Kupa river

Station	Sequence processing	Catchment area (km^2)	Observed discharges (m^3s^{-1})			Calculated min. discharge (m^3s^{-1})		
			Q mean per annum	Q mean min.	Q min.	Q_1 YR	Q_{25} YR	Q_{100} YR
KUPARI	1952.-1981.	208	13.7	1.17	0.723	0.71	0.62	0.55
HRVATSKO	1952.-1981.	370	21.4	2.19	0.739	1.30	1.00	0.70
PETRINA	1952.-1981.	438	26.6	2.82	1.77	2.06	1.87	1.67
RADENCI	1952.-1981.	1304	54.8	6.50	4.39	4.68	4.18	3.62
PRIBANJCI	1952.-1981.	1492	63.0	8.10	4.51	5.80	5.10	4.10
LADESIC DRAGA	1952.-1981.	1590	63.2	9.11	5.50	6.20	5.50	4.50
METLIKA	1952.-1981.	2115	77.7	9.30	5.74	6.54	5.78	4.97
KAMANJE	1957.-1981.	2192	78.3	10.1	5.74	7.00	5.70	4.20

It is evident from the above overview that, if we anticipate the use of the Kupa source in the proximity of 1 m^3s^{-1} for water supply, the loss in water budget already downstream of Radenci profile would be relatively small, under 2 % of the mean annual discharge. It is equally evident that in the upper part of the Kupa catchment area, in comparison with the size of the catchment area, low water levels are relatively rather low. This implies a this area's greater sensitivity to droughts. If a storage reservoir were to be constructed immediately downstream of the Kupa source zone, from the hydrological viewpoint it could be planned in such a manner to be the source of recharge in dry periods for the main part of the Kupa flow with water quantites of approximately 0.5 m^3s^{-1}, which would significantly improve hydrological conditions in this area. The existing fluctuation trends characteristic for mean and minimum annual discharges even more stress the need to consider the regulation of the discharge in the uper part of the Kupa flow.

3. Interstate aspects and approaches to planning optimum water use and protection of the Kupa river within the context of the WFD-implementation

In the Elektroprojekt study (1989), in the upper part of the Kupa river, upstream of the hydrological profile of Pribanjci, the construction of several larger reservoirs - the Kupari (7 mio. m^3), Kočićin (3 mio. m^3), Dol (44 mio. m^3) and Severin (12 mio. m^3) was planned. According to this project, the above reservoires would be used for power production and flood protection of the more downstream part of the Kupa catchment area. From the reservoir of Dol a water quantity of 3.2 m^3s^{-1} was planned to be used for water supply. Due to the fact that, with the exception of the profile of the Kupari reservoir, the reservoir planned the furthest upstream, the reservoirs would be on the transboundary water between Croatia and Slovenia, for the elaboration of the proposed sulution the interest and approval of both countries was necessary. Since such approval was not granted, the activities on the construction of the above reservoirs, as well as the system of several additional downstream reservoirs (three more on the more downstream transboundary part of the Kupa flow, with additional four on the more downstream part of the Kupa after it entered Croatia) were interrupted and have not been included in current physical plans.

A question raised by the above relates to the manner in which, in accordace with the principles of the EU guidelines adopted in 2001, the WDF in particular, to conduct the planning of regulation, use and protection of such transboundary watercourses as the Kupa river. Considering the given circumstances of the watercourse ananlysed, the preliminary assessment was that the construction of the Kupari revervoir, the one the furthest upstream on the Kupa river, is not necessarily environmentally unacceptable.

4. Conclusions

The presented paper points out problems of planning the optimum use of water resources under circumstances where possible changes in water regime are expected to have impact on certain sections of transboundary watercourses. From the hydrological viewpoint, it has been confirmend that the Kupa source, due to its total water potential, presents strategic water reserves. However, due to unfavourable distribution of discharges and the existing fluctuation trends characteristic of medium and low water levels, it is obvious that it will not be possible to use the source for water supply to a greater extent unless a re-destribution of the water budget is ensured by construction of multi-purpose reservoir in the uppermost part of the catchment area.

5. References

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