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Assessment of water resources carrying capacity for the Island of Cres

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Preliminary report

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Water resources carrying capacity (WRCC) is defined as the maximum number of persons (inhabitants) that can be sustained without limitation in a given area, using available renewable water resources. WRCC can be used in sustainability assessments and in the management and strategic planning activities. Data needed for WRCC assessment are often imprecise or stochastic in nature. Sensitivity and uncertainty analysis can be used to quantify reliability of assessment based on imprecision of input data. WRCC assessment for the Island of Cress, based on the above mentioned method, is presented in the paper.

Key words:
water resources carrying capacity, uncertainty analysis, Monte Carlo simulation, sensitivity analysis

Prethodno priopćenje

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Procjena nosivog kapaciteta vodnih resursa otoka Cresa

Nosivi kapacitet vodnih resursa (NKVR) predstavlja maksimalni broj osoba (stanovnika) koje mogu neograničeno obitavati na nekom području, koristeći se pritom dostupnim obnovljivim vodnim resursima. NKVR se može primijeniti prilikom procjene održivosti te prilikom radnji vezanih uz gospodarenje i strateško planiranje. Podaci potrebni za procjenu NKVR često su nedovoljno pouzdani ili stohastičke naravi. Primjenom analize osjetljivosti i neodređenosti moguće je na temelju nepouzdanosti ulaznih podataka odrediti pouzdanost dobivene procjene. Ovaj rad sadrži procjenu NKVR otoka Cresa primjenom prethodno spomenute metode.

Ključne riječi:
nosivi kapacitet vodnih resursa, analiza neodređenosti, Monte Carlo simulacija, analiza osjetljivosti

Vorherige Mitteilung

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Beurteilung der tragenden Kapazität der Wasserressourcen der Insel Cres

Die tragende Kapazität der Wasserressourcen (TKWR) stellt die maximale Anzahl an Personen (Einwohner) dar, die unbegrenzt auf einem Gebiet ansässig sein können, unter Nutzung der verfügbaren erneuerbaren Wasserressourcen. Die TKWR kann bei der Einschätzung der Nachhaltigkeit sowie bei Handlungen in Bezug auf das Management und die strategische Planung angewendet werden. Die für die Beurteilung der TKWR benötigten Daten sind häufig nicht ausreichend zuverlässig oder von stochastischer Natur. Durch Anwendung der Sensitivitäts- und Unsicherheitsanalyse ist es möglich, die Zuverlässigkeit der erhaltenen Einschätzungen anhand der Unzuverlässigkeit der Eingangsdaten zu ermittelt.

Schlüsselwörter:
tragende Kapazität der Wasserressourcen, Unsicherheitsanalyse, Monte Carlo Simulation, Sensitivitätsanalyse

1. Introduction

1.1. Water resources carrying capacity concept

An access to sufficient quantity of water resources is a crucial requirement for the development and overall well-being of a society. Availability of water can dictate the health of a society and impose constraints on its progress and growth. This paper examines how regional availability of water resources influences the society's maximum population size. The maximum sustainable human population size limited by availability of water resources is referred to as the water resources carrying capacity. Almost all human activities are significantly affected by the lack of sufficient water resources. For that reason, the WRCC assessment is considered to be an important component of any sustainability assessment. Most currently available attempts at WRCC assessment can roughly be divided into two groups. The first group of assessments is based on complex deterministic models, such as the system dynamics (e.g. [1, 2]), while the second one is based on probabilistic approach (e.g. [3]). The method proposed in this paper is based on the latter approach, as it is usually more suitable for solving environmental management tasks [4].

1.2. Motivation for stochastic approach to WRCC assessment

Parameters needed for the assessment, such as rainfall intensity, volume of ground water reserves, evapotranspiration, and municipal and industrial water consumption, are very often either stochastic in nature or insufficiently known. Mean values and trends of some parameters are often known, but are usually accompanied by significant temporal and spatial stochastic deviations from the mean value. As exact values of these parameters can rarely be predicted with sufficient accuracy, it is hardly ever possible to produce a reliable deterministic WRCC result.
An approach based on uncertainty and sensitivity analysis is used in order to incorporate these unavoidable uncertainties in the WRCC assessment. The method proposed in the paper relies on Monte Carlo simulations to provide a probability distribution of WRCC values. By evaluating the nature and extent of uncertainties in the system, the model can produce a range of possible outcomes, which can in turn be used to make informed water resource management decisions. The sensitivity analysis is performed in order to identify the parameters that have the greatest influence on the unreliability of assessment.

1.3. Study area

The region selected for WRCC assessment is the island of Cres, located in the northern part of the Adriatic Sea. Cres is the largest Croatian island, with a total land area of 405,8 [km^2]. According to the 2011 population census, 3079 people inhabit the island permanently [5]. During the peak of the tourist season (usually attained in July and August), tourists often outnumber the local population and, in this case, the total population of the island often exceeds permanent population by more than two times.
The water supply of the island is entirely dependent on rainfall, which drains from the island's surface into Vrana Lake, a natural reservoir located in the central part of the island. The quantity of rainfall and water demand (water consumption) are characterized by pronounced seasonal variations. Generally, summer periods are dry and accompanied by an increased demand for water, mainly caused by the previously mentioned large influx of tourists. This scenario usually puts significant pressure on the water supply, and information on maximum sustainable population supported by regional water availability (i.e. WRCC) can be very useful in the regional planning and water management activities, especially when the goal of such activities is to achieve sustainability.
The map of the island of Cres, showing location of Vrana Lake (blue colour), larger settlements and popular tourist destinations, as well the existing water supply network (dashed blue line) is given on Figure 1.

Figure 1. Map of Cres

2. Methods

2.1. WRCC calculation

Carrying capacity limits water are dictated by replenishment rates and the ability of the population to harness and store this water resource [6]. The water replenishment rate in the study area cannot be influenced, as it depends on the quantity of rainfall in the area, but the storage capacity can be significantly influenced by human intervention. With this in mind, the WRCC of the proposed study area has been calculated for two scenarios. A major difference between the two simulated scenarios is in the size of storage units capable to retain water generated by precipitation. Storage units can be either natural (e.g. lakes) or artificial (e.g. reservoirs).

This paper is only a preliminary analysis (initial assessment) of the WRCC, and so easily calculable scenarios have been chosen. Nevertheless, they still provide plenty of significant information.

2.1.1. Scenario 1

The first scenario represents the current situation; it is assumed that the only source of water for the island of Cres water supply is generated by rainfall within the Vrana Lake catchment area, i.e. Vrana Lake is considered to be the only reservoir capable of storing water for later use. The WRCC for the first scenario is calculated by Eq. (1)

$$NKVR_1 = \frac{10^3(1-c_n)\sum_{i=1}^{12} H_i A_V}{\sum_{i=1}^{12} \frac{D_i}{(1-c_{t,i})}} \tag{1}$$

where:

$NKVR_1$ - water resources carrying capacity according to Scenario 1 [person, inhabitant]

c_n - natural losses coefficient

$c_{t,i}$ - monthly technical losses coefficient

H_i - monthly rainfall height [mm]

A_V - Vrana Lake catchment area [km^2]

D_i - monthly water consumption per capita [m^{3}person^{-1}month^{-1}]

A part of precipitation that can be used for water supply is actually just a fraction of the total quantity of rain reaching the surface of this island. Most precipitation is lost through the processes of evaporation, evapotranspiration, and infiltration (due to the karstic nature of the island), and by runoff into the sea. All these processes greatly reduce the amount of water available for human consumption, and are presented in the form of a coefficient c_n, which represents the percentage of rainfall lost due to previously mentioned processes. It will be referred to in the paper as the *natural losses coefficient*. Expected values of this coefficient are presented in Section 3.3.4.

Water losses due to leakage from water pipes during the process of water abstraction, transport and distribution are taken into account by means of the coefficient c_t. This coefficient will be referred to in this paper as *technical losses coefficient*; its expected values are given in Section 3.3.3.

2.1.2. Scenario 2

The second scenario is an idealized situation in which all of the water generated on the island by rainfall (reduced by natural losses) can be stored during the course of the year and used for water supply when needed. In this case, the WRCC is calculated according to Eq. (2).

$$NKVR_2 = \frac{10^3(1-c_n)\sum_{i=1}^{12} H_i A_C}{\sum_{i=1}^{12} \frac{D_i}{(1-c_{t,i})}} \tag{2}$$

where:

A_C - surface area of Cres [km^2]

$NKVR_2$ - water resources carrying capacity according to Scenario 2 [person, inhabitant].

Volume of the additional retention area for water storage (apart from Vrana Lake) needed to sustain the population whose size is determined by Eq. (2) can be calculated by Eq. (3) and Eq. (4).

$$\Delta W_i = 10^3(1-c_{n,i})H_i A_C - WRCC_2 \frac{D_i}{(1-c_{t,i})} \tag{3}$$

$$V = \left(1-\frac{A_V}{A_C}\right)\left(\max\{\Delta W_1,\ldots,\Delta W_{12}\} - \min\{\Delta W_1,\ldots,\Delta W_{12}\}\right) \tag{4}$$

where:

ΔW_i - monthly difference between water generated on the island by precipitation (reduced by natural losses) and water consumed by the estimated maximum sustainable population [m^3]

V - additional retention volume needed to retain water generated by precipitation in order to supply the estimated maximum sustainable population [m^3]

2.2. Monte Carlo simulation

Most of the variables used for calculating equations (1) to (4) either have stochastic features (usually with a large degree of variability) or their exact values cannot be determined with sufficient accuracy. This uncertainty is quantified by assigning probability distributions to uncertain input values. Th uncertainty of input data propagates through the proposed model and the output data (results) are represented by a probability distribution.

The Monte Carlo simulation is performed by randomly sampling values from the probability distributions of input

data, and then by calculating the WRCC according to Eq. (1) and Eq. (2). In this paper, this action was performed 200.000 times, resulting in a large number of possible outcomes of $WRCC_1$ and $WRCC_2$, which are presented as a random variable with its accompanying probability distributions.
The accuracy of the result is influenced by the number of simulations (sample size); a larger sample size increases the accuracy but at the expense of increased computing time. The sample size of 200,000 was chosen as optimum because it was relatively computationally inexpensive to conduct this number of simulations. Calculations repeated with this number of simulations produced value groups $WRCC_1$ and $WRCC_2$ which did not greatly differ from one another. Smaller sample sizes exhibited more notable variations amongst repeated calculations, while the larger sample sizes produced almost no increase in accuracy.

2.3. Assigning probability distributions to input data

Descriptions and representations of probability distributions chosen to represent the input variables are given in this section.

2.3.1. Rainfall data

The amount of rainfall generated over the island's surface has been assessed by using the data gathered by the Meteorological and hydrological institute of Croatia in the period from 1978 to 2014 [7]. Temporal variability of the amount of water generated by rainfall is presented in Figure 2.
Large spread of the amount of precipitation during autumn and winter can be observed, as well as a significant variation in rainfall between different monthly periods. Each month is given the corresponding number, so January becomes month 1, February month 2, etc. This approach for indexing monthly periods is used throughout the paper.

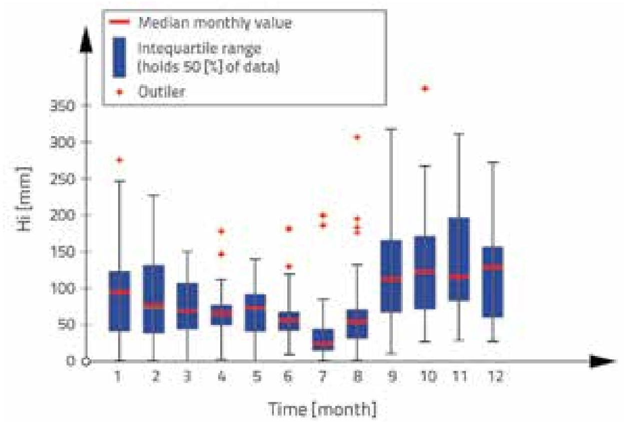

Figure 2. Boxplot diagram of monthly precipitation, expressed in [mm/month]

The mean, median and standard deviation values of rainfall have been computed for each month and presented in Table 1. The names of the probability distributions which have been fitted to this data are also presented in this table. All fitted distributions are asymmetric, with a positive skew.

2.3.2. Water consumption data

The data provided by the local public utility companies were used in order to assess the amount of water consumption [7]. According to the mentioned data, an average annual water demand per capita is D = 6.84 [m^3 $person^{-1}$ $month^{-1}$] = 228 [l $person^{-1}$ d^{-1}]. This value is not constant, and experiences variability from year to year. If an assumption is made that the data is normally distributed, the standard deviation results in a value of 1.26 [m^3 $person^{-1}$ $month^{-1}$].

Table 1. Statistics and chosen distributions of monthly rainfall

Month	Mean value [mm]	Median [mm]	Standard deviation [mm]	Fitted distribution
1	95.5	96.2	68.7	Rayleigh
2	85.7	76.6	59.6	Weibull
3	75.8	70.4	43.3	Log-logistic
4	68.7	65.7	34.0	Log-logistic
5	68.6	74.5	38.1	Gamma
6	61.8	56.2	37.7	Log-logistic
7	38.9	24.2	45.3	Log-logistic
8	66.8	55.1	64.4	Gamma
9	125.8	113.2	87.0	Gamma
10	130.9	124.2	77.1	Rayleigh
11	145.2	116.7	84.6	Weibull
12	119.6	130.1	62.1	Gamma
Total	**1083.2**	**1026.6**	**234.7**	-

The value D, used in the WRCC calculation, is therefore represented by a normally distributed variable with the mean value of 6.84 [m^3 $person^{-1}$ $month^{-1}$] and standard deviation of 1.26 [m^3 $person^{-1}$ $month^{-1}$].

Significant monthly variations of water consumption have been observed as well, and expressed in a form of a monthly demand coefficient, $c_{D,I}$, which show how much the monthly water consumption deviates from the average value. Monthly demand coefficient values can be seen in Figure 3. It can be observed that the water consumption during the month of August (month 8) is more than twice the average value.

Total monthly water consumption (demand) per capita used in the model is calculated as shown in Eq. (5).

$$D_i = c_{D,i}D \tag{5}$$

where:

D_i - monthly water consumption per capita [$m^3 person^{-1} month^{-1}$]

$c_{D,I}$ - monthly water demand coefficient

D - average water consumption per capita [$m^3 person^{-1} month^{-1}$]

2.3.3. Water losses during water abstraction, transport and distribution (technical losses)

The data on water losses generated by leakage during water abstraction, transport and distribution was gathered from the same public utility companies mentioned in Section 3.3.2 [7]. These types of losses will be referred to in this paper as *technical losses*.

An average amount of technical water losses in one year is expressed as the percentage of water abstracted from Vrana Lake that does not reach the consumer, i.e. the amount lost due to leakage. The average value of coefficient representing these losses is c_t = 0,43 = 43 %. This value varies from year to year and is taken into account in the model. The coefficient of technical losses, c_t, is expressed as a normally distributed variable with the mean value of 0.43 (43 %) and standard deviation of 0.075 (7,5 %).

Analogous to Section 3.3.2., the coefficient $c_{tc,i}$ is introduced in order to quantify monthly deviations in technical water losses. The monthly variation in the coefficient $c_{tc,i}$ is inversely related to the monthly water demand coefficient, $c_{D,I}$, as can be seen in Figure 3.

The monthly value of technical losses coefficient used in model is calculated as shown in Eq. (6).

$$c_{t,i} = c_{tc,i}c_t \tag{6}$$

where:

$c_{t,i}$ - monthly value of technical losses coefficient

$c_{tc,i}$ - monthly variation of technical losses coefficient

c_t - average value of technical losses coefficient.

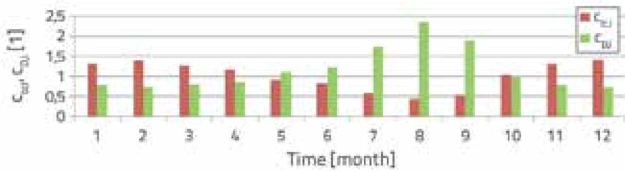

Figure 3. Monthly values of coefficients $c_{D,i}$ and $c_{tc,i}$

2.3.4. Losses due to evapotranspiration, infiltration and runoff into the sea (natural losses)

Significant amount of water generated by precipitation is lost due to processes of infiltration, runoff into the sea, evapotranspiration and evaporation from Vrana Lake. These water losses will be referred to as *natural losses*.

The island of Cres is highly karstified, which results in a high level of infiltration. Large amount of precipitation that falls on the island's surface ends up in the sea by surface runoff or through underground karstic channels. The evapotranspiration process is necessary for the stability of the environment, and this amount of water can be effectively considered as the amount of water needed to ensure sustainability of natural environment. The evaporation from Vrana Lake is very high (especially during the summer); average yearly amount of rain which falls on the surface of the lake is less than the amount of water that evaporates from it [8].

Influences of all of these effects on the amount of water available for water supply (natural losses) have been combined in form of a single coefficient. Water balance investigations of Vrana Lake have shown that the vast majority of water generated in Vrana Lake catchment area (over 95 %) is lost due to natural losses [8]. As a high degree of uncertainty accompanies this assessment, a larger range of possible values is used in the model.

The natural water losses coefficient, c_n, is expressed as a uniformly distributed random variable within an interval ranging from 0.7 to 0.99. In simpler terms, the amount of natural water losses is assumed to be between 70 and 99 %.

2.3.5. Vrana Lake catchment area

The topographic catchment area of Vrana Lake is 25 [km^2] [8]. However, due to the highly karstified nature of the island of Cres, it is quite possible that the total catchment area is larger, as it is possible that the water generated by precipitation reaches Vrana Lake through underground channels from areas that are not part of the topographic catchment area [9]. With no other information available, the Vrana Lake catchment area has been defined in the model proposed by this paper as a uniformly distributed random variable within an interval ranging from 25 to 50 [km^2].

2.4. Sensitivity indices calculation

The sensitivity analysis represents a group of methods and tools that are used to quantify the way in which the uncertainty of input values influences the uncertainty of the result [10]. Sensitivity indices are used as a tool to quantify this influence of input data uncertainty on the reliability of results.

Two types of sensitivity indices have been calculated, i.e. the first order indices and the total effect indices, using the method proposed by Saltelli et al. [11]. Both types of indices are the tools that are used in the sensitivity analysis approach called the variance based sensitivity analysis. These indices can specify to what extent the result variance (in this case, WRCC) is caused by variance of each input parameter. In other words, they can inform us how much the dispersion of results is due to dispersion/variability of input parameters.

The first order index determines the extent to which the variancie of an individual input parameter influences variance of the results, not considering the influence of interaction between individual input parameters and variability of the remaining input values. The total effect index measures contribution of a single parameter to the variance of the results as well, but it is more comprehensive, as it includes all interactions with other input parameters. Both indices will be calculated so as to obtain a good quality information about the extent of influence of individual input parameters on the WRCC.

2.5. Limitations of the model

As already mentioned, the proposed method can be considered as a preliminary analysis of the WRCC of the island of Cres. The analysis is based on Monte Carlo simulations, which requires a large number of simulations (computational runs). In order to make the analysis computationally inexpensive, the use is made of a simplified, but still sufficiently comprehensive model of the processes regarding the hydrological cycle and water abstraction and consumption. The sensitivity analysis is introduced in the proposed WRCC assessment method so that further steps can be defined if it becomes clear that the model simplification causes an unacceptably large dispersion of results. If it is observed that some of the parameters, which were introduced to replace a highly complex process (e.g. the natural losses coefficient, c_n), have a large influence on the variability of the result, then they can further be investigated and replaced by a more complex model of the process in order to increase reliability of the assessment. If the influence of the parameter is small, the use of a more complex modelling can be avoided.

The calculation of WRCC$_1$ (the current water supply scenario) was conducted under the assumption that the rainfall draining into Vrana Lake can safely be used for water supply. However, recent increase of average annual air temperatures caused an increased evaporation from Vrana Lake, which has brought down water level in Vrana Lake [9]. If this trend continues, it is possible that saltwater intrusion in the lake trough karstic underground will make this reservoir an unsuitable source of water supply.

3. Results and discussion

3.1. Results of uncertainty analysis

Results of uncertainty analysis, based on 200.000 Monte Carlo simulations, are presented in Figure 4. The left part of Figure 4 shows probability distribution of WRCC$_1$, i.e. probability distribution of water resources carrying capacity corresponding to the current water supply scenario (in which water is abstracted from Vrana Lake only). The probability distribution is highly skewed, and the most probable WRCC$_1$ values are located near the value of 20,000 inhabitants.

The right-side part of Figure 4 shows probability distribution of WRCC$_2$, i.e. probability distribution of water resources carrying capacity in the idealized "best case" scenario. In this

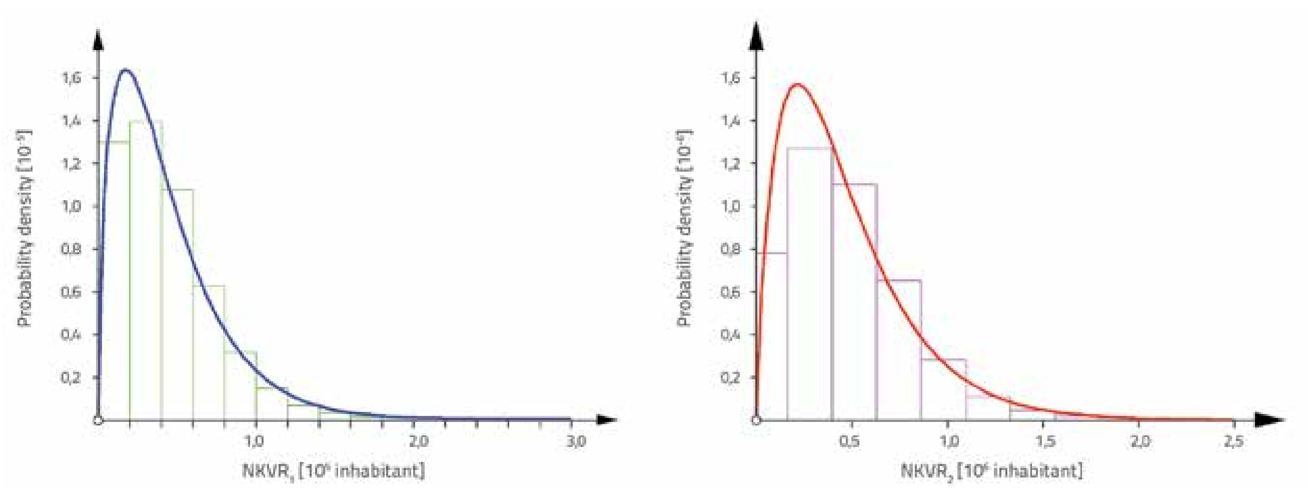

Figure 4. Probability distributions of WRCC$_1$ and WRCC$_2$

scenario, it is assumed that the entire island rainfall, reduced by natural losses, can be stored for later use. This scenario assumes construction of many reservoirs in which this quantity of water would be stored. Under this assumption, the WRCC is significantly larger. The distribution of this value is also skewed, and the most probable values lie in the interval between 150,000 and 300,000 inhabitants.

Although, according to Figure 4, the $WRCC_1$ and $WRCC_2$ probability distributions may appear to be very similar, a significant difference in their variability can be observed when they are plotted on the same graph (Figure 5). $WRCC_2$ has a much larger spread of possible results compared to $WRCC_1$.

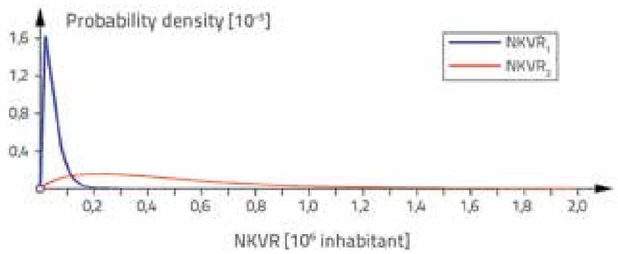

Figure 5. Comparison of probability distributions of $WRCC_1$ and $WRCC_2$

Data on the most probable WRCC values may not be optimal for sustainability assessment purposes. It would be wiser to examine the data that can be used to quantify the possibility of long-term subsistence of this island's population. For example, the median value of $WRCC_1$ is 37,020 people. If this population inhabits the island, every second year (on an average) would result in a water scarcity scenario. On the other hand, if the population is 2,713 people (which corresponds to the value of the first percentile of the probability distribution of $WRCC_1$), then water scarcity will occur on average once in every 100 years. Some of the percentile values for both $WRCC_1$ and $WRCC_2$ are presented in Table 2, and so a comparison can be made between the population size and the probability of a water scarcity scenario.

Table 2. Percentile values for $WRCC_1$ and $WRCC_2$

Percentile	$WRCC_1$ (inhabitant)	$WRCC_2$ (inhabitant)
1	2.713	30.955
2	3.516	40.123
5	5.698	63.919
10	9.058	102.210
50 (median)	37.020	412.370

Additionally, calculations were made to determine the additional reservoir volume (apart from existing Vrana lake) needed to sustain the $WRCC_2$. These results are presented as a scatter plot in Figure 6.

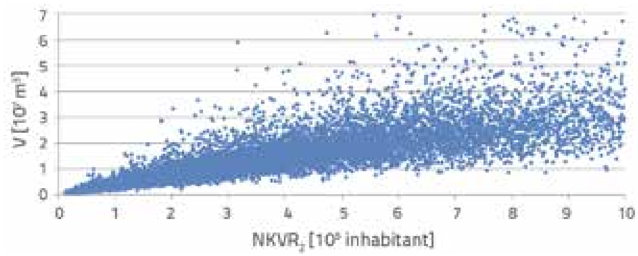

Figure 6. Scatter plot of additional reservoir volume needed versus $WRCC_2$

3.2. Sensitivity analysis results

The sensitivity analysis was conducted in order to identify the most influential parameters of WRCC assessment uncertainty. Scatter plots, presented in Figures 7 and 8, show how a change in a single parameter value influences the result (in this case, $WRCC_1$). $WRCC_2$ exhibits a behaviour that is very similar to $WRCC_1$ when influence of individual parameters is examined. Parameter influences on the $WRCC_2$ are almost identical to the ones on $WRCC_1$, and, for that reason, are not shown in this paper.

Figures 7 and 8 contain data regarding four parameters: average water consumption (D), natural losses coefficient (c_n), technical water losses coefficient (c_t), and Vrana Lake catchment area (A_C). The values of these parameters can be defined more precisely if additional investigations are made. Rainfall data, on the other hand, exhibits stochastic behaviour, and this variability cannot be significantly reduced through acquisition of additional data.

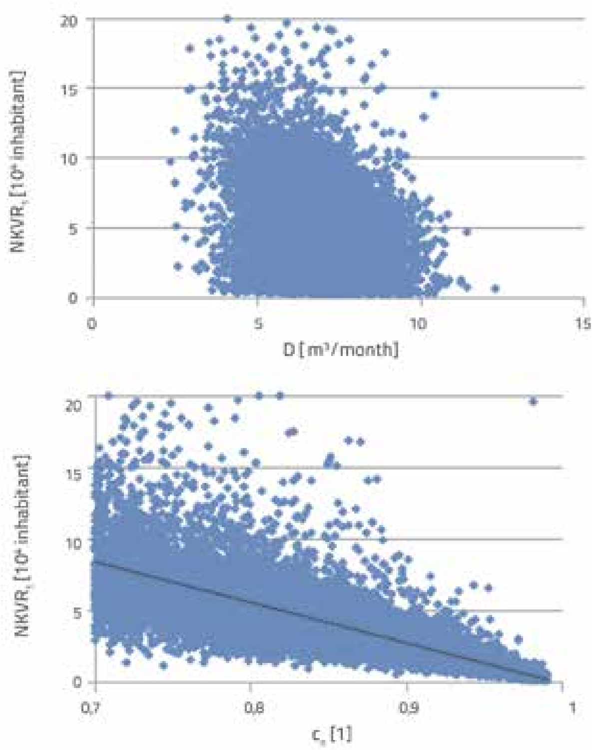

Figure 7. Scatter plots of D and c_n versus $WRCC_1$

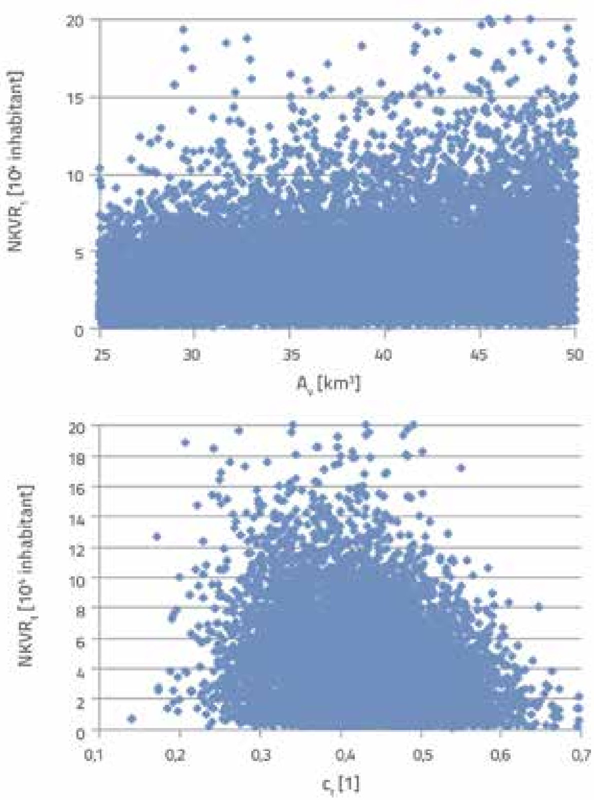

Figure 8. Scatter plots of c_t and A_C versus $WRCC_1$

It can be observed that almost all of these parameters, apart from c_n, have very little effect on the $WRCC_1$ and its variability. The natural water losses coefficient, c_n, is the only parameter that exhibits a more pronounced influence on the $WRCC_1$.

The first order and total effect indices have been calculated and presented in Table 3 in order to quantify the influence every parameter has on the variability of $WRCC_1$ and $WRCC_2$. An effect of each parameter on the variability of $WRCC_1$ and $WRCC_2$ was quantified. Additionally, the same process was done with relation to the additional reservoir volume (V) needed to sustain the population size determined by $WRCC_2$. It can be seen that the parameters influencing the most the variability of calculated results are rainfall values for March and July and the coefficient c_n.

4. Conclusion

The water resource carrying capacity of the island of Cres was assessed by the method proposed in this paper, based on uncertainty and sensitivity analysis. Probability distributions of WRCC were created, and these results can be used to easily assess probability of occurrence of a water scarcity scenario, as related to the population size.

The WRCC assessment was made for two scenarios, the existing water supply scenario ($WRCC_1$) and the one that assumes that all rainfall generated on the island, reduced by natural losses, can be stored and used for water supply ($WRCC_2$). The second scenario was calculated so as to assess theoretically attainable maximum value of WRCC (although unattainable in practical terms). The WRCC of the second scenario is roughly ten times larger than that of the first one. The total volume of additional

Table 3. Sensitivity indices

Parameter	First order indices			Total effect indices		
	$WRCC_1$	$WRCC_2$	V	$WRCC_1$	$WRCC_2$	V
Rainfall in month 1, H_1	0.0034	0.0052	0.0023	0.2752	0.4162	0.5307
Rainfall in month 2, H_2	0.0014	0.0027	0.0009	0.2737	0.4150	0.5301
Rainfall in month 3, H_3	**0.2532**	**0.2770**	**0.5314**	**0.4614**	**0.5507**	**0.6512**
Rainfall in month 4, H_4	0.0002	0.0014	0.0010	0.2733	0.4145	0.5302
Rainfall in month 5, H_5	0.0005	0.0018	0.0006	0.2734	0.4146	0.5300
Rainfall in month 6, H_6	0.0010	0.0024	0.0016	0.2734	0.4147	0.5304
Rainfall in month 7, H_7	**0.2803**	**0.3158**	**0.4811**	**0.6542**	**0.7284**	**0.8668**
Rainfall in month 8, H_8	0.0013	0.0028	0.0007	0.2735	0.4148	0.5302
Rainfall in month 9, H_9	0.0033	0.0051	0.0013	0.2749	0.4161	0.5303
Rainfall in month 10, H_{10}	0.0015	0.0029	0.0011	0.2738	0.4151	0.5302
Rainfall in month 11, H_{11}	0.0029	0.0042	0.0017	0.2744	0.4157	0.5305
Rainfall in month 12, H_{12}	0.0016	0.0031	0.0010	0.2738	0.4150	0.5302
Lake Vrana catchment area, A_V	0.0291	0.0001	0.0005	0.3479	0.4137	0.5307
Natural water losses, c_n	**0.2153**	**0.2549**	0.0311	**0.4814**	**0.6087**	**0.6448**
Technical water losses, c_t	0.0164	0.0205	0.0006	0.3051	0.4351	0.5301
Water demand per capita, D	0.0306	0.0368	0.0006	0.3489	0.4731	0.5300
Sum of indices	0.8420	0.9363	1.0576	5.3384	7.3613	9.0565

reservoirs needed to store water for the number of residents equal to $WRCC_2$ is presented in the results.

Results of sensitivity analysis show that most of the variability of the results is caused by parameters with stochastic features (rainfall). Further investigation that could result in more accurate values of water consumption, size of Vrana Lake catchment area, and technical and natural losses, will improve the reliability of the assessment, albeit not significantly, as the majority of variability of WRCC will still be caused by stochastic uncertainty associated with rainfall data.

The proposed method resulted in the provision of data that can be used in many activities, such as in physical space planning and water resources management. Uncertainty analysis results can be used for rough WRCC estimation for this island, while sensitivity analysis results can assist in defining priorities for further research, as they provide information on dominant sources of uncertainty of results.

REFERENCES

[1] Wang, S., Xu, L., Yang, F., Wang, H.: Assesment of water ecological carrying capacity under the two policies in Tieling City on the basis of the integrated system dynamics model, Science of the Total Environment, 472 (2014), pp. 1070-1081, https://doi.org/10.1016/j.scitotenv.2013.11.115

[2] Dou, M., Ma, J., Li, G., Zuo, Q.: Measurement and assessment of water resources carrying capacity in Henan province, China, Water Science and Engineering, pp. 1-12, 2015.

[3] Liu, R., Sun, C., Han, Z., Chen, L., Huang, Q., Chen, Y., Gao, S., Shen, Z.: Water environmental capacity calculation based on uncertainty analysis: a case study in the Baixi watershed area, China, Proceedia Environmental Sciences, 13 (2012), pp. 1728-1738, https://doi.org/10.1016/j.proenv.2012.01.166

[4] Uusitalo, L., Leihikoinen, A., Helle, I., Myrberg, K.: An overview of methods to evaluate uncertainty of deterministic models in decision support, Environmental Modelling and Software, 63 (2015), pp. 24-31, https://doi.org/10.1016/j.envsoft.2014.09.017

[5] Statistički ljetopis Republike Hrvatske, Državni zavod za statistiku, pp. 47., 2015.

[6] Lane, M.: The development of a carrying capacity assessment model for the Australian socio-environmental context, PhD thesis, Queensland University of Technology, 2014.

[7] Nacrt studije izvodljivosti vodoopskrbe i odvodnje aglomeracije Cres, Martinšćica, Mali Lošinj i Veli Lošinj, Hidroing d.o.o., 2016.

[8] Ozanic, N.: Hydrological model of Vrana lake on the island of Cres, PhD thesis, Faculty of Civil Engineering, University of Split, 1996.

[9] Bonacci, O.: Analiza varijacija razine vode jezera Vrana na otoku Cresu, Hrvatske vode, pp. 337-346, 2014.

[10] Saltelli, A., Annoni, P., Azzini, I., Campolongo, F., Ratto, M., Tarantola, S.: Variance based sensitivity analysis of model output. Design and estimator for the total sensitivity index, Computer Physics Communications, 2 (2010), pp. 259-270, https://doi.org/10.1016/j.cpc.2009.09.018

[11] Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., Tarantola, S.: Global Sensitivity Analysis: The Primer, Wiley, pp. 164-167, 2008.