Fuzzy model for determination and assessment of groundwater quality in the city of Zrenjanin, Serbia

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Abstract

The application of the fuzzy logic for determination and assessment of the chemical quality of groundwater for drinking purposes in the city of Zrenjanin is presented in this paper. The degree of certainty and uncertainties is one of the problems in the most commonly used methods for assessing the water quality. Fuzzy logic can successfully handle these problems. Evaluation of fuzzy model was carried out on the samples from two representative wells that are located at depths of two aquifers from which water is taken to supply the population with drinking water. The samples were analyzed at 8 different chemical water quality parameters. In the research, the arsenic concentration (As^{3+} and As^{5+}) is considered as the dominant parameter due to its suspecting carcinogenic effects on human health. This type of research is for the first time conducted in the city of Zrenjanin, middle Banat region.

Keywords: groundwater quality, fuzzy logic, degree of certainty, arsenic.

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The availability and quality of groundwater as well as drinking water will be the main environmental and social issues in the future. Drinking water quality is currently defined only as the absence or presence of certain strictly limited undesirable substances. Water quality monitoring and quality decision-making based on the obtained data is a complex and multidimensional task for decision makers. The main reason of such heavy and chalanging work are uncertainties that occur in all steps, from sampling to analysis. The sets of the monitored data and limits should not be as crisp set, but as fuzzy sets [1].

In modeling complex of environmental problems, researchers often fail to define precise statements about input and outcomes of pollutants, but fuzzy logic could help to overcome these logical uncertainties. Fuzzy logic can be considered as a language that allows one to translate sophisticated statements from natural language into a mathematical formalism. Fuzzy logic can deal with highly variable, linguistic, vague and uncertain data or knowledge and therefore has the ability to allow a logical, reliable and transparent information stream from data collection to data usage in environmental application system. Fuzzy logic provides a framework to model uncertainty, the human way of thinking, reasoning and perception process [2]. The results on water quality obtained using the index developed on the basis of fuzzy set theory were found to be more useful than those derived from the Water Quality Index method that is currently used [3].

The assessment of the groundwater quality (GWQ) used as drinking water in the town of Zrenjanin, Vojvodina region, Serbia has been carried out by the flexibility of fuzzy set theory in decision-making through the environment assessment.

Problems with the water supply of the city of Zrenjanin are not solved through decades, therefore the population of the city of Zrenjanin has been long-term exposed to health risk and safering. In early 2004, Provincial Sanitary Inspection banned for drinking and cooking water from Zrenjanin due to multiple exceeded concentrations of maximum allowable concentration (MAC) of arsenic [4]. The ban is still in force. The groundwater is only chlorinated and without any purification process distributed to consumers. Drinking water is organoleptically not acceptable, which means that it has no appropriate phisical parameter as the colour, smell and taste. Application of fuzzy methodology to the selected chemical parameters of the quality of groundwater/drinking water is for the first time evaluated in Zrenjanin city and nearby surrounding.

MATERIALS AND METHODS

Fuzzy set theory

Fuzzy set theory is a generalization of classical set theory, since the elements membership to the fuzzy set may be characterized as a number in the interval [0,1].

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Fuzzy sets are the basic elements that describe the uncertainty. Fuzzy set theory allows the integration of information from different parameters in the processes of modeling and evaluation. A fuzzy set is defined in terms of a membership function (MF) which maps the domain of interest, *e.g.*, concentrations, onto the interval [0,1] [5]. The MF of the fuzzy set A defined over a domain *X* takes the form:[6]:

$$\mu_{\mathrm{A}}:\mathrm{X}\to\left[0,1\right] \quad (1)$$

Therefore, the fuzzy set A is defined by its MF:

$$\mu_A\left(x\right)=\left\{\left(\mu_A(x)\right),x\in X,\mu_A(x)\in\left[0,1\right]\right\} \quad (2)$$

In fuzzy water quality assessment the most often are used trapezoidal MFs. Trapezoidal MF achieves the highest classification accuracy in water quality assessment. Trapezoidal are preferable than triangular, due to certain water quality parameters cannot be determine, only one specific value with maximum MF as desirable is acceptable or not acceptable. These values should be included in certain intervals. In that way, trapezoidal MFs are characterizing the dynamic behavior of the water quality parameters. Changing the type of MF will affect the final output of fuzzy model, because the GWQ parameters would be assigned different MFs that were obtained by different formulas.

Fuzzy MFs are to be trapezoidal for all 8 analyzed parameters in this research due to nature of the parameters. Functions are created according to the allowable limits under current legislation and according to the studies and recommendations of the World Health Organization (WHO) and the perception of the authors (Table 1).

Equation (3) fuzzifies the data in terms of trapezoidal MF [6]:

$$\mu_A\left(x\right)=\begin{cases}0,x<\alpha\\ \dfrac{x-\alpha}{\beta-\alpha},\alpha\le x\le\beta\\ 1,\beta\le x\le\gamma\\ \dfrac{\delta-x}{\delta-\gamma},\gamma\le x\le\delta\\ 0,x>\delta\end{cases} \quad (3)$$

For a trapezoidal MF, α is the minimum value, δ is the maximum value and β and γ are the two values which represent the interval of the most likely value.

Zadeh [9] proposed the following definitions for the operations on the fuzzy sets:

1. The union of two fuzzy sets A and B is fuzzy set C with its MF:

$$\mu_C\left(x\right)=\mu_A\left(x\right)\wedge\mu_B\left(x\right)=\max\left\{\mu_A\left(x\right),\mu_B\left(x\right)\right\} \quad (4)$$

2. The intersection of two fuzzy sets A and B is fuzzy set C with its MF:

$$\mu_C\left(x\right)=\mu_A\left(x\right)\vee\mu_B\left(x\right)=\min\left\{\mu_A\left(x\right),\mu_B\left(x\right)\right\} \quad (5)$$

3. The complement of a fuzzy set A can be defined by MF $\mu_C(x)$:

$$\mu_C\left(x\right)=1-\mu_A(x) \quad (6)$$

Fuzzy rule evaluation

Fuzzy rules are standard mathematical rules in the form: if X = A, then Y = B (A → B), where *x* and *y* are linguistic variables, while A and B are linguistic values defined on the universal sets X and Y. “X is A” is called the antecedent, assumption, premise, fact. “Y is B” is called a consequence, conclusion, implication.

In accordance with the fuzzy rules the classification of the groundwater is consequent to the system of fuzzy rules. Each rule consists of a set of antecedent statements, which are the names of properties (pH, $KMnO_4$ consumption, arsenic,...) and values of characteristics, *i.e.*, linguistic descriptions (desirable, acceptable and not acceptable). Linguistic descriptions are assigned according to the information about the health implications of each parameter on the human health.

Fuzzy logic is based on the expert’s knowledge for developing a sopisticated system; the experts’ knowledge is used together with the other parameters through the rules defined in a fuzzy inference system to create a system based on the knowledge captured [10].

Mamdani fuzzy reasoning

All of the parameters in the research will be connected with the operator “Λ” – AND operator. Applying

Table 1. The prescribed limits [4,7,8]

Parameter	Unit	Limits by current legislation	WHO Guideline values
pH	–	6.8–8.5	6.5–9.2
$KMnO_4$ consumption	mg/l	8	1–19
Ammonia (NH_4^+)	mg/l	1	1.5
Total iron (Fe^{2+},Fe^{3+})	mg/l	0.3	0.3–1
Arsenic (As^{3+},As^{5+})	mg/l	0.01	0.001–0.01
Calcium (Ca^{2+})	mg/l	200	75–200
Magnesium(Mg^{2+})	mg/l	50	50–100
Sodium (Na^+)	mg/l	150	200

a fuzzy "Λ" operation will yield a result that is the minimum of the fuzzy value of the number of input variables. The aggregation of the rule will be the truncation of the output fuzzy set. This method is applied to all rules to obtain the final result which gives the final shape of the output fuzzy membership function after aggregation of all the rules, respectively. Then the union operation is applied to all the output fuzzy sets to yield the final fuzzy set [11]. For example: "*IF ammonia is Unacceptable Λ iron is Desirable THEN the GWQ is Acceptable*". This type of fuzzy system reasoning is called Mamdani implication of max.min operator. Mamdani system assumes that the output of the process of reasoning is fuzzy set (Fig. 1). This fuzzy set requires aggregation in the process of defuzzification. The use of fuzzy numbers and aggregation of fuzzy sets are proposed as a suitable technique for handling the uncertainties in decision-making on environmental quality criteria [12].

Deffuzification

Defuzzification is the last step in the process of fuzzy reasoning. Defuzzification is the process of transforming the results obtained in the form of fuzzy set to the numeric value. In this study two defuzzification methods have been used: mean of maxima (MOM) and center of area (COA) or centroid method.

MOM method is given by the expression [13–15]:

$$z^* = \frac{a+b}{2} \quad (7)$$

where *a* and *b* are as defined in Fig. 2.

COA procedure is the most prevalent and physically appealing of all the defuzzification methods [13–15] and it is given by the algebraic expression:

$$z^* = \frac{\int \mu_C(x) z \mathrm{d}z}{\int \mu_C(x) \mathrm{d}z} \quad (8)$$

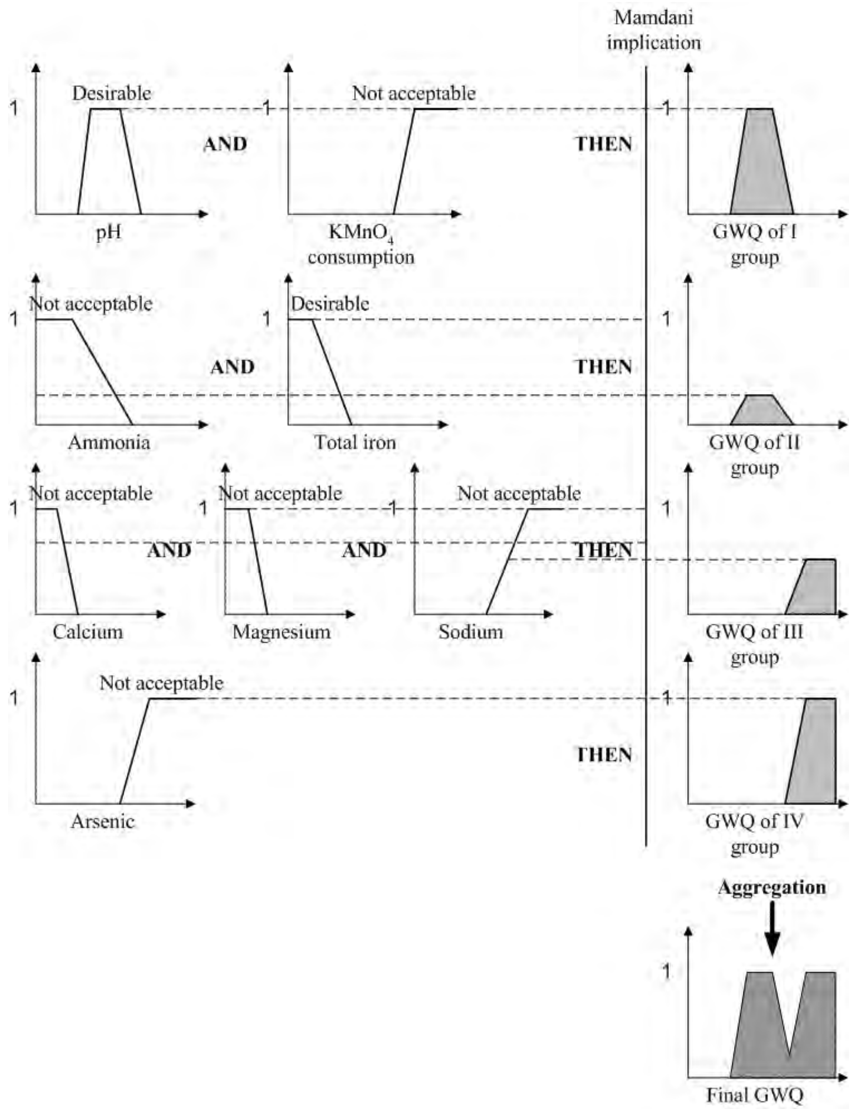

Figure 1. Graphical representation of Mamdani implication.

where $\int$ denotes an algebraic integration. This method is shown in Fig. 3.

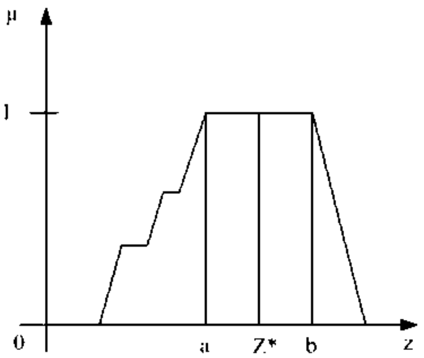

Figure 2. MOM defuzzification method.

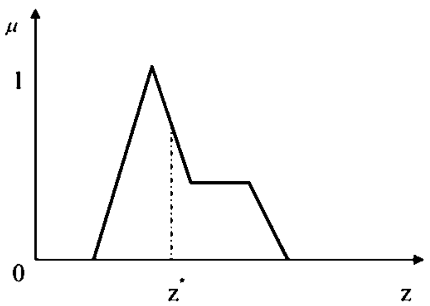

Figure 3. COA defuzzification method.

RESULTS AND DISCUSSION

Study area

City of Zrenjanin is situated on the western edge of the region Banat, in the province of Vojvodina, at 20°23’ east longitude and 45°23’ north latitude. Most of the population and the economy of the city is supplied with water from shallow (30–75 m) and deep (90––135 m) aquifers, which are characterized by high mineralization, a high content of iron, ammonia, manganese, sodium, organic matter, arsenic, unbalanced organoleptic properties. The water is oxygen-poor and loaded with dissolved sulfur hydrogen and methane. The main groundwater aquifers in Zrenjanin have extremely adverse physical characteristics according to the strategic development material focused inter alia on the quality of grounwater/drinking water [16].

Water supply of the City of Zrenjanin is based on utilization of groundwater from the two main aquifer with the wells located northwest of the city with a total of 35–40 wells. All wells were perforated to a depth of two aquifers and therefore this research was applied only on two representative wells from these depths. In Zrenjanin groundwater directly engages the pipeline system and it supplies the population as drinking water. The groundwater only passes through the microbiological treatment before enters the pipeline system.

The data of chemical parameters of groundwater used in this research are taken from the Institute of Public Health Zrenjanin (Table 2). The research was conducted from October 2010 to July 2011. The first well is located at a depth of 98–118 m while the second is at a depth of 36–61 m. Eight relevant parameters have been selected: pH, $KMnO_4$ consumption, ammonia, total iron, calcium, magnesium, sodium and arsenic on which the fuzzy logic approach would be applied. The observed parameters are selected on the basis of their concentrations which are above the permissible limits or significantly below the limit. In legislation on water quality, there are not considered extremely low concentrations of certain parameters, which can have adverse effects on human health.

For the selected GWQ parameters, fuzzy sets are assigned whose MFs are shown in the following Figures 4–11.

Fuzzy model of GWQ is created by dividing 8 selected parameters into 4 different categories, *i.e.*, groups according to predefined quality criteria. Groups were formed according to the main characteristics of the chemical composition of the groundwater. The first group consists of: pH and $KMnO_4$ consumption, which are the primary indicators of the chemical composition of the groundwater and the parameters to be tested in the initial survey of the water quality. The second group includes the total iron and ammonium cat ions which are micro components of the groundwater, and their presence does not affect the type of water, but

Table 2. Chemical parameters of groundwater from the city of Zrenjanin; concentrations are given in mg/l

Sample	pH	$KMnO_4$ consumption	NH_4^+	Fe^{2+}, Fe^{3+}	Ca^{2+}	Mg^{2+}	Na^+	As^{3+},As^{5+}
Well 1, October, 2010	7.97	37.16	1.46	0.22	14.3	15.6	315.8	0.187
Well 2, October, 2010	7.69	41.23	1.75	1.55	53.9	20.7	236.1	0.005
Well 1, January, 2011	8.2	38.37	1.04	0.19	13	15.4	225	0.17
Well 2, January, 2011	7.72	41.73	1.69	1.53	57.4	23.7	212.5	0.005
Well 1, April, 2011	8.12	32.62	1.17	0.01	14.9	12.1	160.8	0.155
Well 2, April, 2011	7.57	34.68	1.75	0.2	13.8	41.4	150	0.007
Well 1, July, 2011	7.44	36.79	1.58	0.23	23.6	4	250	0.102
Well 2, July, 2011	7.63	39.13	1.74	1.07	57.1	21.8	312.5	0.04

have a huge impact on the specific composition of the groundwater and often determine its ability to be used. The third group is structured by calcium, magnesium and sodium ions representing macro components which make up the basic composition of the groundwater and the type of water is determined on the basis of their content. The fourth group is composed of the ionic forms of arsenic. Arsenic compounds are considered separately because arsenic is one of the most important hazards, the key parameters of the groundwater quality of the examined area. Intoxication by arsenic through drinking water is accumulative nature. Long-term exposure with arsenic causes cancer of some organs, especially the skin, lung, bladder and kidney. Common signs of acute toxic effects include: vomiting, dry mouth and throat, muscle cramps, hallucinations [17]. Geological area in Zrenjanin and in the Banat region is well known of the content of the arsenic ions. Therefore the source of cat ions of arsenic is of geologically origin but it could be also of anthropogenic activities.

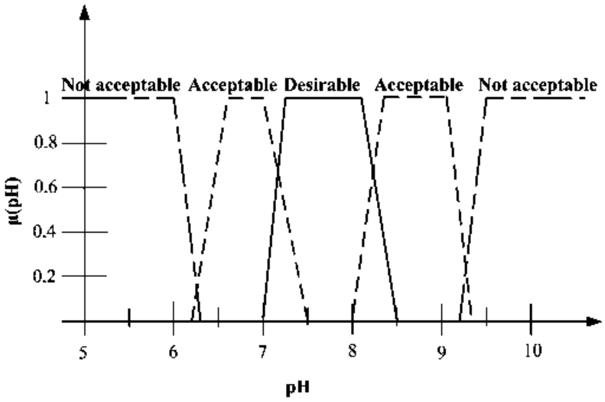

Figure 4. MF of the pH defined for the GWQ.

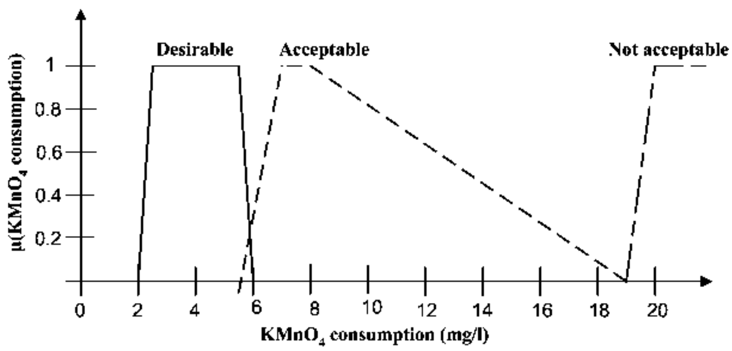

Figure 5. MF of the $KMnO_4$ consumption defined for the GWQ.

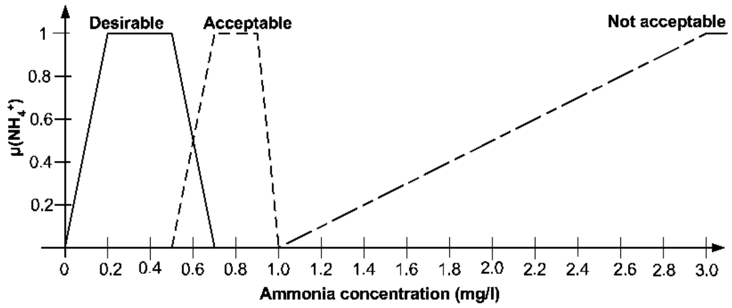

Figure 6. MF of the ammonia concentration defined for the GWQ.

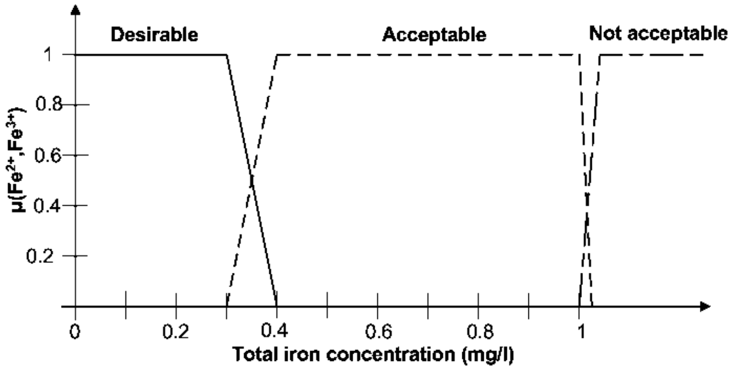

Figure 7. MF of the total iron concentration defined for the GWQ.

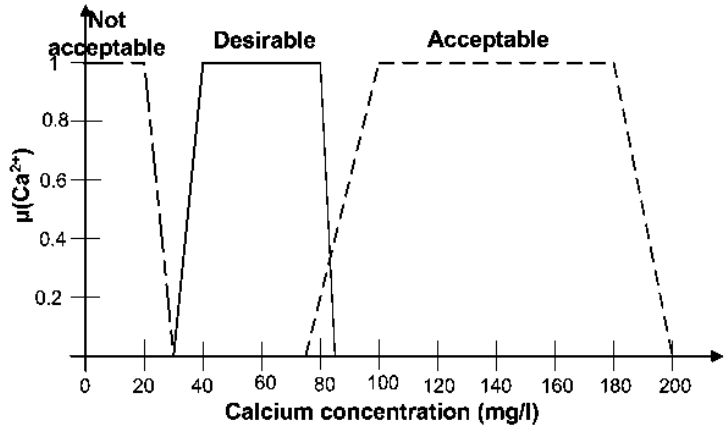

Figure 8. MF of the calcium concentration defined for the GWQ.

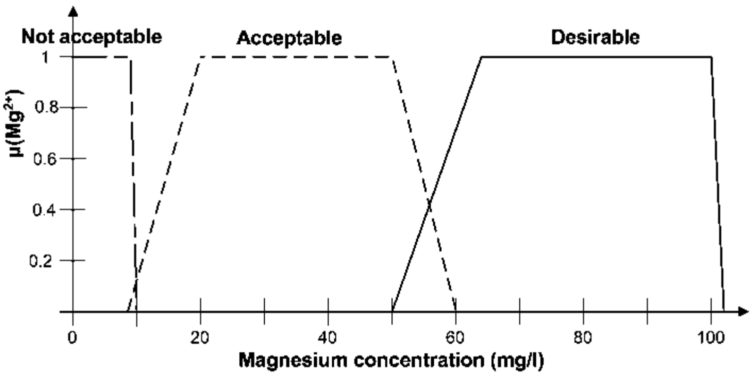

Figure 9. MF of the magnesium concentration defined for GWQ.

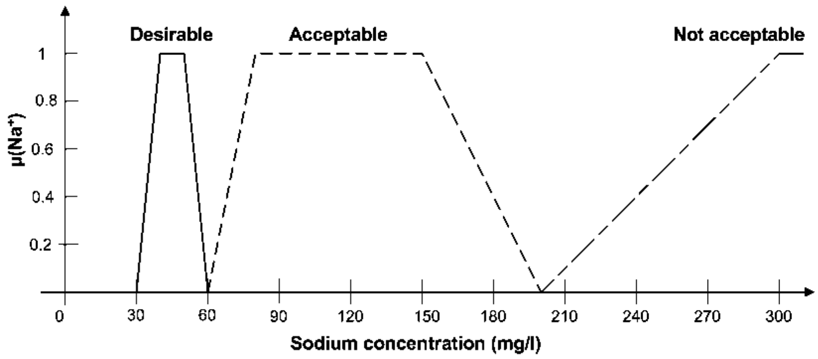

Figure 10. MF of the sodium concentration defined for the GWQ.

Under natural conditions, the greatest range and the highest concentrations of arsenic are found in groundwater as a result of the strong influence of the water––rock interactions and the favorable physical and geochemical conditions in aquifers for the mobilization and accumulation of arsenic. Arsenic is particularly mobile at pH values typically found in groundwater (pH 6.5–8.5) under both oxidizing and reducing conditions [18].

Inorganic arsenic compounds are classified by the International Agency for Research on Cancer (IARC) in Group 1 (carcinogenic to humans) on the basis of sufficient evidence for carcinogenicity in humans and limited evidence for carcinogenicity in animals [8]. There are numerous data on the relationship between the risk of cancer and drinking water with high content of arsenic, but has not yet assessed the risk caused by low concentrations of arsenic in water. Considering all the uncertainties related to the risk assessment, the World Health Organization in 1993 recommended the MAC of arsenic in drinking water of 10 μg/l. Recommendations from these have been adopted in the legislation of the Republic of Serbia in the Book of Regulations on the Hygienic Correctness of Drinking Water [7].

In the created fuzzy rules, all of the statements are coordinate with the intersection (AND) operator while other operators (OR and NOT operators) are not imple-

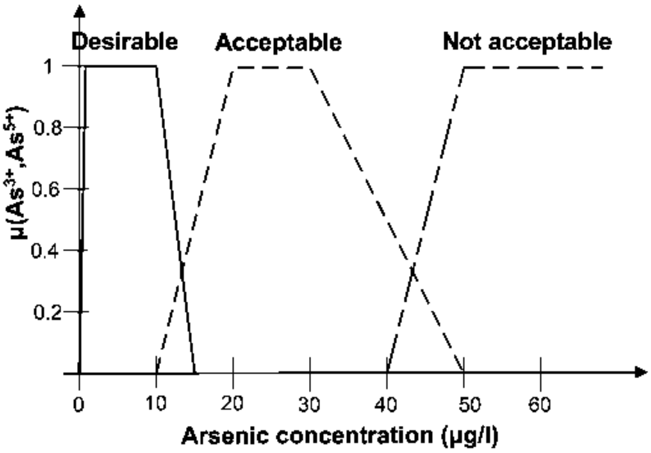

Figure 11. MF of the arsenic concentration defined for the GWQ.

mented. This is because, AND operator is more flexible and adaptive for such assessment. Operator is selected on the basis of previous experiences and on the perception of the authors.

Fuzzy rules defined for the first group of parameters: Rule 1: *If pH is Desirable AND $KMnO_4$ consumption is Not acceptable THEN GWQ of group 1 is Acceptable*. Rule 2: *If pH is Acceptable AND $KMnO_4$ consumption is Not acceptable THEN GWQ of group 1 is Acceptable*.

Acceptable pH indicates the significance of the aquatic environment existence of toxic cationic forms of arsenic, which is in accordance with the positive physical-chemical principles of oxidation-reduction process. The results of analyzed water samples are in excellent correspondence with the mathematical rules of fuzzy logic.

Fuzzy rules defined for the second group of parameters: Rule 3: *If ammonia is Not acceptable AND iron is Desirable THEN GWQ of group 1 is Acceptable*. Rule 4: *If ammonia is Not acceptable AND iron is Acceptable THEN GWQ of group 1 is Not Acceptable.* Rule 5: *If ammonia is Not acceptable AND iron is Not acceptable THEN GWQ of group 1 is Not Acceptable.*

The presence of ammonia in potable water supplies is often accompanied by the presence of iron and manganese cat ions in the concentrations above the permitted limits [19]. Simultaneous processes of microbial disintegration of sediment organic matter and reduction of some chemical species leads to the origin of unusual concentrations of ammonia (NH_4^+(aq)), dissolved organic carbon, iron (Fe^{2+}(aq), Fe^{3+} (aq)) [20].

Fuzzy rule defined for the third group of parameters: Rule 6: *If calcium is Not acceptable AND magnesium is Not acceptable AND sodium is Not acceptable THEN GWQ of group 2 is Not Acceptable.* Rule 7: *If calcium is Not acceptable AND magnesium is Acceptable AND sodium is Not acceptable THEN GWQ of group 2 is Acceptable.* Rule 8: *If calcium is Not acceptable AND magnesium is Acceptable AND sodium is Acceptable THEN GWQ of group 2 is Acceptable.* Rule 9: *If calcium is Desirable AND magnesium is Acceptable AND sodium is Not acceptable THEN GWQ of group 2 is Acceptable.*

The main components that determine the mineralization and the chemical type of groundwater are sodium, magnesium and calcium. They represent the macro components or the basic cat ions of groundwater.

Fuzzy rule defined for the fourth group of parameters: In this group there is only one parameter – arsenic. Results from the first three groups will be combined with a fourth group to obtain the final classification of the groundwater. The special rule has been created for this group which says: *If arsenic is Not acceptable then the GWQ is Not Acceptable, regardless of the other three groups. If arsenic is Desirable or Acceptable then the final GWQ is Acceptable*, but the degree of certainty is determined on the basis of all parameters.

Until recently, arsenic was often not on the list of constituents in drinking water routinely analyzed by national laboratories, water utilities and non-governmental organizations and so the body of information about the distribution of As in drinking water is not as well known as for many other drinking water constituents [21]. Indeed, As is now recognized as the most serious inorganic contaminant in drinking water on a worldwide basis. In the city of Zrenjanin groundwater arsenic is analyzed once a year.

A hierarchical structure for groundwater classification resulting in a set of fuzzy rules is constructed on the basis of knowledge from authors and experts in this scientific expertise. Experts, consulted in the creation of fuzzy rules, are from the field of physical chemistry and chemistry from the Institute of Public Health dealing with these issues as well as mathematicians focused on fuzzzy logic. The main condition for the support of hierarchy for created fuzzy rules is the impact of selected parameters on human health. This was carried out through dividing of parameters in different categories. The greatest importance is assign to a group 4, followed by group 2, 1 and 3.

Hierarchical structure for groundwater classification:

– IV group: Arsenic has with reason assigned the greatest emphasis due to carcinogenic effect on humans.

– II group: Iron in groundwater provides the typical well water "rust" taste. Health effects are not expected at levels normally found in natural waters. It can be indicator of some toxic elements in groundwater. Increased concentrations of iron are capable of releasing dangerous amounts of arsenic into the groundwater. The ability of arsenic to mobilize and enter into the aquifer is attributed to a process known as the reductive dissolution of iron. The process that is responsible for the reduction of insoluble ferric iron to soluble ferrous iron is known as reductive dissolution [22]. If the environment is such that a reduced iron form is produced, groundwater will contain higher concentrations of iron. The most frequent cause of reducing reactions is the presence of organic matter [23]. The ammonium is also interesting in regard to the high arsenic levels since infiltrating water from surface sources could contain high quantities of organic material which could decrease oxygen levels and redox conditions even more, which might increase the mobilization of arsenic. Ammonium does not pose a risk for people's health in concentrations that can be expected in groundwater. However, there is health implication with high concentrations of nitrate in drinking water, which ammonium can be oxidized to if exposed to oxygen. High ammonium concentrations are also a common sign that surface water influenced by anthropogenic activities are infiltrating to the groundwater [24].

– I group: Because we are dealing with high groundwater arsenic concentration, pH is the parameter which is also substantial for GWQ. The concentration of arsenic in groundwater in the first place depends on the pH of the water. Therefore, it is assigned a certain "weight" to this parameter. $KMnO_4$ consumption is a parameter indicating polluting organic compounds in the water. Organic matter in groundwater plays important roles in controlling geochemical processes by acting as proton donors/acceptors and as pH buffers, by affecting the transport and degradation of pollutants, and by participating in mineral dissolution/precipitation reactions. Dissolved and particulate organic matter may also influence the availability of nutrients and serve as a carbon substrate for microbially mediated reactions. Numerous studies have recognized the importance of natural organic matter in the mobilization of hydrophobic organic species, metals and radionuclides [25].

– III group: The least impact in assessment is assigned to the macro components of calcium, magnesium and sodium because they do not have severe implications on human health.

Fuzzy rules defined for the final GWQ are represented in the Table 3.

Changing in the fuzzy rules would not significantly affect final classification of GWQ. If within the group parameters would be changed certain statements this will affect the final class of groundwater. But the things that can most influence on the change in the final GWQ are concentrations of selected input parameters. Even small changes of concentration of one GWQ parameter can cause considerable changes of overall quality.

Final classification of GWQ from monitored locality has been divided into three categories: Desirable, Acceptable and Not acceptable. Inside those groups there are percentages which represent the degree of certainty. The degree of certainty shows on which level of safeness is drinking water reliable. MF of the final quality of the groundwater is shown in the following Fig. 12.

Table 4 shows the final classification of groundwater quality with its degree of certainty.

Advantage of this model is that it can be applied to any of locality with the proper selection of characteristic parameters for the site. Many authors have used fuzzy logic for assessing water quality [1–3,5,26–29]. Advantages and disadvantages of fuzzy models for assessing water quality are presented in the incoming Table 5.

Table 3. Created fuzzy rules for definition of the final GWQ

Rule	IF I group is…	AND II group is…	AND III group is…	AND fourth group is…	THEN GWQ is…
1	Acceptable	Acceptable	Acceptable	Not acceptable	Not acceptable
2	Acceptable	Not acceptable	Acceptable	Acceptable	Acceptable
3	Acceptable	Acceptable	Acceptable	Not acceptable	Not acceptable
4	Acceptable	Not acceptable	Acceptable	Acceptable	Acceptable
5	Acceptable	Acceptable	Acceptable	Not acceptable	Not acceptable
6	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
7	Acceptable	Acceptable	Not acceptable	Not acceptable	Not acceptable
8	Acceptable	Not acceptable	Acceptable	Acceptable	Acceptable

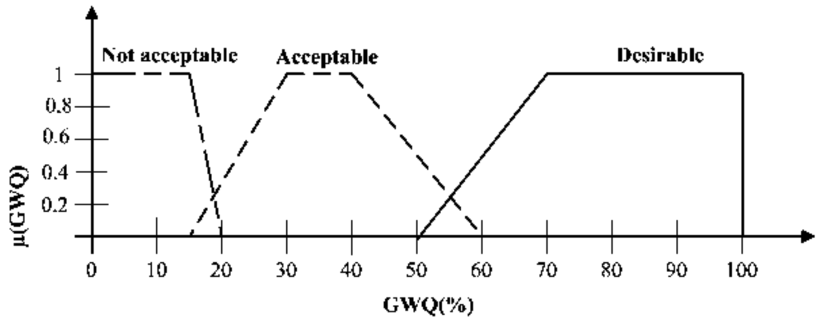

Figure 12. MF of the final GWQ.

Table 4. Final results of the GWQ

Sample	Groundwater quality	Degree of certainty	
		MOM / %	*COA* / %
Well 1, October, 2010	GWQ Not acceptable	22.5	27.05
Well 2, October, 2010	GWQ Acceptable	61.25	61.68
Well 1, January, 2011	GWQ Not acceptable	22.5	27.05
Well 2, January, 2011	GWQ Acceptable	61.25	61.68
Well 1, April, 2011	GWQ Not acceptable	22.5	27.05
Well 2, April, 2011	GWQ Acceptable	61.25	61.68
Well 1, July, 2011	GWQ Not acceptable	22.5	27.05
Well 2, July, 2011	GWQ Acceptable	22.5	27.05

Artificial intelligence technologies are becoming more and more important for water quality management in order to satisfy objectives of sophisticated water quality decision-making. The most important motive for choosing fuzzy logic for water quality assessment is flexible potential to combine different aspects. Fuzzy assessment of the water quality represents perspective for the future. In literature review are presented the latest researches in this scientific topic from 2013–2014.

An interval fuzzy credibility-constrained programming (IFCP) method is developed for river water quality management by Liu *et al*. [31]. A real-world case for water quality management planning of the Xiangxi River in the Three Gorges Reservoir Region is then conducted for demonstrating the applicability of the developed method. Priya [32] has been developed Fuzzy Inference System (FIS) to classify ground water for irrigation purposes. The fuzzy model was validated using the ground water quality data collected from Karunya watershed. Srivastava *et al.* [33] designed and deve-

Table 5. Advantages and disadvantages of fuzzy models for assessing water quality [30]

Advantages	Disadvantages
Easy interpretable by natural language	Not free of eclipsing but can be handled with trial and error process
Can handle complex and vague situation	Cannot incorporate guidelines values for water quality parameters
Can incorporate exports opinion with hard data	Suffer rigidity to some extent (careful selection of parameters can reduce it)
Can describe a large number of nonlinear relationships through simple rules	Easy to manipulate or can be biased due to human subjectivity
Provides a transparent mathematical model	
Able to account interconnection (interdependencies) among parameters	
Capable to handle missing data without influencing the final water quality index value	
Free of ambiguity and can represent different water quality usage if parameters are selected carefully	

loped soft computing system to assess the water quality of rivers Ganga and Yamuna during the Maha Kumbh 2013 in and around Sangam Zone, Allahabad, by making use of physicochemical parameters relationship. Nasr *et al*. [34] has offered the creation of a new fuzzy water quality index (FWQI) to assess the degree of drinking water resources in rural areas of Yazd province, Iran. Wang *et al*. [35] created a model for assessing the water quality status of the Meiliang Bay of the Taihu Lake in China. Results show that the proposed model can determine the water quality level and provide an acceptable alternative based on optimized objectivity in determining water quality level. Zhou *et al.* [36] examined 15 groundwater samples from SuoLuoShu water resource with fuzzy mathematics. On this basis, the membership degrees of the groundwater samples in the 5 grades were calculated and by using the maximum membership principle, the groundwater grade of each samples were determined. Aghaarabi et al. [37] presented the use of two multi-criteria decision-making frameworks based on hierarchical fuzzy inference engines for the purpose of assessing drinking water quality in distribution networks.

CONCLUSION

Classical methods for assessing the water quality are representing only the facts that the environmental data are in or out of the prescribed limits. Therefore, classical assessment of the water quality classified water as acceptable or not acceptable. The main disadvantage of such analyzes is that none of the tested parameter has assigned proper “weight”. But, applied fuzzy model of GWQ observed each parameter in terms of impact on human health and thus to each parameter is assigned a specific “weight”.

One of the main advantages of fuzzy approach is that the final water quality has assigned degree of certainty. This method is much more convincing and more accessible to the decision makers and public which should be informed about the state of drinking water quality. Fuzzy model simply represent a clearer and better view of decision-making.

GWQ in the city of Zrenjanin is assessed by taking account only the chemical indicator parameters. Chemical characteristics of groundwater involve: key indicators of the chemical composition (pH and $KMnO_4$ consumption), macro components (calcium, magnesium and sodium) and micro components (iron, ammonium and arsenic).

From all physical parameters from analysis, color and electrical conductivity values were slightly above the permissible limits but were not included in the calculations because they cannot greatly influence the change in the final quality of groundwater. Groundwater at the city of Zrenjanin is chlorinated before distributed for human consumption and the water is microbiologically correct. Therefore, the microbialogical parameters of groundwater quality are not implemented in the assessment.

The fuzzy analysis showed that samples from well 1 provide an unacceptable quality of groundwater while samples from well 2 have acceptable quality. All values of final GWQ are very closely despite of the method of defuzzification. In the shallow aquifer the arsenic concentrations are below the MAC and this groundwater can be used for drinking purpose. But there is not sufficient water in upper layers of soil to supply the entire population of the city of Zrenjanin for drinking usage. Groundwater from deeper aquifer are not acceptable as drinking water due to its highly elevated arsenic concentrations. This implies that the quality of drinking water in Zrenjanin only depends on the geological structure of the soil. This is the real state of the geochemical properties of the area on which Zrenjanin is situated.

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IZVOD

FAZI MODEL ZA ODREĐIVANJE I PROCENU KVALITETA PODZEMNE VODE U GRADU ZRENJANINU

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U radu je predstavljena primena fazi logike za utvrđivanje i procenu hemijskog kvaliteta podzemnih voda za piće u gradu Zrenjaninu. Stepen pouzdanosti i neizvesnosti su neke od problema koje se sreću kod najčešće primenjivanih metoda za procenu kvaliteta vode. Fazi logika uspešno upravlja sa ovim poteškoćama. Evaluacija fazi modela je ostvarena na uzorcima iz dva reprezentativna bunara koji se nalaze na dubinima dva vodonosna sloja iz kojih se uzima voda za snabdevanje stanovništva grada Zrenjanina pijaćom vodom. U uzorcima je analizirano 8 različitih parametara hemijskog kvaliteta vode. U istraživanju, koncentracija arsena (As^{3+} i As^{5+}) je razmatrana kao ključni parametar zbog svojih kancerogenih efekata na ljudsko zdravlje. Ova vrsta istraživanja je po prvi put sprovedena u gradu Zrenjaninu.

Ključne reči: Kvalitet podzemne vode • Fazi logika • Stepen pouzdanosti • Arsen