SMISAO FUZZY LOGIKE U HIDROGEOLOŠKOJ PRAKSI

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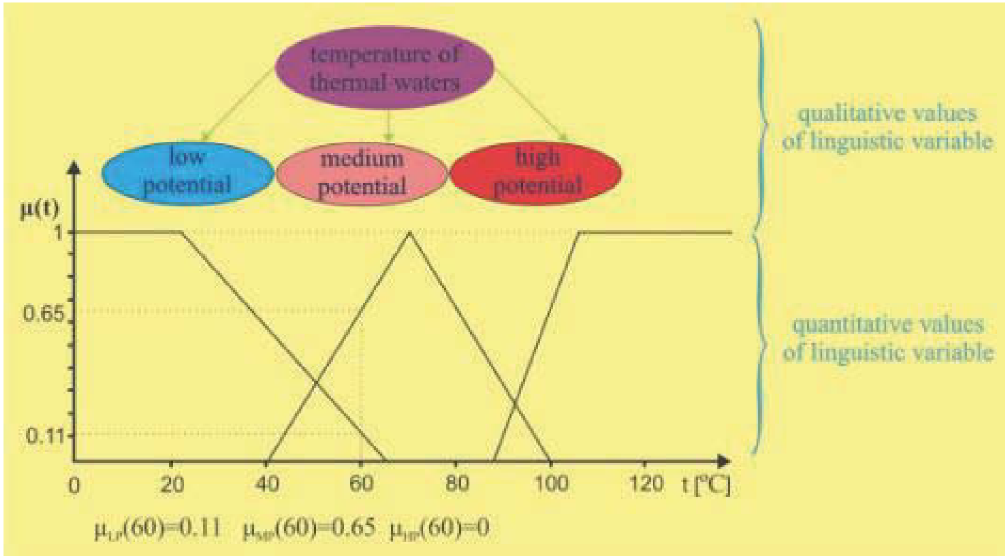
Najbolji način na koji inženjer ili naučnik može izraziti svoje mišljenje je ustvari svakodnevni verbalni način izražavanja. On predstavlja značajan izvor neizvesnosti, kako zbog prenosa informacija, tako i znanja koje prati različite vrste neodređenosti i nepreciznosti (Kosko, 1993). Zbog toga se izdvajaju fuzzy logički sistemi jer je njihova suština rad sa znanjem koje može biti veoma neprecizno i izraženo u verbalnom obliku. To „znanje" se u fuzzy logičkim sistemima predstavlja u obliku produkcionih (ekspertskih) pravila koja su pogodan verbalni oblik za izražavanje znanja svakog čoveka. Na taj način, fuzzy logika predstavlja kodifikaciju zdravog razuma (Graham, 1991; Lai, Hwang, 1996). Umesto diferencijalnih jednačina, koristi se znanje eksperta za opis nekog sistema. Znanje se izražava na prirodan način - lingvističkim varijablama, pa se može reći da je fuzzy logika „računanje rečima" (Zadeh 1965, Zadeh 1975).
Kao što je pomenuto, osnovna jedinica za prikaz znanja kod fuzzy logike je, lingvistička varijabla sa svojim lingvističkim vrednostima koje čine fuzzy skupove. Kombinacije varijabli i njenih vrednosti čine lingvistički iskaz (izraz), koji predstavlja most između brojčanog predstavljanja informacija u računaru i čovekovog načina razmišljanja. U svom radu: „The Concept of a Liguistic Variable and its Application to Approximate reasoning", Zadeh (1975) prvi uvodi „lingvističku (fuzzy) promenljivu" što je ustvari vrednost neizvesnosti opisana lingvističkim iskazom. Lingvistička ili fuzzy promenljiva se definiše kao promenljiva čije su dozvoljene vrednosti reči prirodnog jezika, a ne brojevi. Drugim rečima, lingvistički iskazi se u pristupu „soft računarstva" (Mayer, 1990) nazivaju ustvari lingvističke promenljive. Dalji razvoj nauke - matematike i fuzzy logike, dovodi do toga da se lingvističke promenljive realnije kvalitativno opišu. To podrazumeva uvođenje lingvističkih modifikatora kako bi se bliže opisale osnovne vrednosti lingvističke promenljive.
Uzmimo da razmatramo na primer lingvističku promenljivu „kvalitet podzemnih voda". Ova lingvistička promenljiva može da se opiše lingvističkim izrazima „ekstremno dobar", „veoma dobar", „dobar", „loš", „veoma loš". U ovom slučaju, lingvistički modifikatori su „ekstremno" i „veoma". Na taj način, lingvistička promenljiva „kvalitet podzemnih voda" koja je opisan lingvističkim izrazom „ekstremno dobar" je bolja od lingvističke promenljive „kvalitet podzemnih voda" koja je opisana lingvističkim izrazom „veoma dobar".
Pored simbolične lingvističke forme, lingvističke varijable imaju i definisanu kvantitativnu analitičku formu - funkciju pripadnosti, pa se zaključuje da je dualne prirode. Tako ovaj dualni identitet čini lingvističke varijable podesnim za izvršavanje i kvalitativnih - simboličkih i kvantitativnih - numeričkih računanja. Na ovaj način se ostvaruje veza između prirodnog jezika koji koristi čovek i numeričkih podataka koje koristi računar.
Kao primer, uzećemo lingvističku varijablu „temperatura termalnih voda" i pripadajuće lingvističke vrednosti: „nisko potencijalne", „srednje potencijalne" i „visoko potencijalne". Ovo je prikazano na sl. 1, gde se mogu videti njihove i kvalitativne i kvantitativne vrednosti - funkcije pripadnosti (μ). Posmatrana lingvistična varijabla ima i stvarni fizički domen u kome elementi iz posmatranih lingvističkih vrednosti poprimaju i svoje numeričke vrednosti. Ovde je to prikazano funkcijom pripadnosti (μ) za 60ºC.



Sl. 1. Lingvistička varijabla „temperatura termalnih voda“
Fig. 1. The linguistic variable "temperature of thermal waters"

Poslednjih godina moguće je uočiti nagli porast broja i različitih vrsta primene sistema baziranih na fuzzy teoriji. Što se tiče njenog značenja, u užem smislu fuzzy logika je logički sistem koji predstavlja proširenje više-vrednosne logike, a u širem smislu to je ustvari sinonim za teoriju fuzzy skupova – teoriju koja povezuje klase objekata sa ne tako oštrim granicama skupa (Klir and Yuan, 1995; Zimmermann, 1996). Dok je prvobitno korišćena za obradu podataka koji dopušta parcijalnu pripadnost skupovima kako bi se izbegao pristup po kome se potpuno pripada ili nepripada nekom skupu, danas, fuzzy logika predstavlja upravljačku metodologiju koja je, iako mlada, počela da se koristi u svim naučnim oblastima (Ross, 2004), pa tako i u hidrogeologiji.

Ako krenemo od osnovnog koraka u hidrogeologiji - prikupljanja i dobijanja informacija o nekom istražnom području, već se javlja problem i pitanje - da li su podaci sigurni, kompletni i precizni?

Kao jedan primer nesigurnih i nepreciznih podataka, navešće se primer sa površinskog kopa „Drmno“. Uporednom analizom proticaja bunara i registrovanih nivoa podzemnih voda konstatovano je da proticaji i nivoi bunara nisu međusobno u saglasnosti. U ne malom broju bunara registrovane su relativno velike depresije za relativno male proticaje, dok su, sa druge strane, nivoi u bunarima koji ne rade, kao i u pratećim pijezometrima bili relativno visoki. Pored toga, registrovana je i pojava neodgovarajućih nivoa podzemnih voda kao posledica promene kapaciteta bunara, bez osetnijeg uticaja okolnih bunara u radu. Na slici 2 su prikazane navedene pojave samo dela drenažnih bunara i samo dela perioda osmatranja, uzetih nasumice.

Žutom bojom su prikazani bunari u kojima tokom opadanja kapaciteta dolazi i do opadanja nivoa podzemnih voda, u manjem ili većem obimu. Nasuprot ovome, sivom bojom su označeni bunari u kojima tokom povećanja kapaciteta dolazi do porasta nivoa podzemnih voda. Plavom bojom su označeni bunari u kojima su za identične kapacitete crpenja registrovani različiti nivoa podzemnih voda. U nekim bunarima razlike u registrovanim vrednostima nivoa vode pri konstantnom kapacitetu su reda veličine nekoliko metara. Na kraju, roze bojom su označeni bunari u kojima su nivoi podzemnih voda nepromenjeni za različite kapacitete crpenja.

Wells	2/13/2008		2/20/2008		2/27/2008		3/5/2008		3/11/2008	
	GWL (m)	Q(l/s)	GWL (m)	Q(l/s)	GWL (m)	Q(l/s)	GWL (m)	Q(l/s)	GWL (m)	Q(l/s)
PLC-X-1	26.97	3.55	27.16	3.19	27.18	3.33	27.57	2.98	27.39	3.20
SLC-X-1	30.60	4.50	30.79	4.50	30.33	4.62	29.99	4.42	29.77	4.04
PLC-X-2	20.76	4.71	20.54	4.62	20.17	4.58	19.55	4.18	19.16	4.50
SLC-X-2	28.40	3.07	28.57	3.25	28.39	3.59	27.06	3.80	26.79	3.40
PLC-X-3	10.18	2.61	8.96	2.62	8.68	2.61	8.85	2.65	8.38	2.53
SLC-X-3	14.80	3.59	13.91	3.63	13.51	4.00	13.27	3.25	11.59	2.99
SLC-X-4	13.07	1.69	13.18	1.71	13.34	1.65	12.18	1.65	12.46	1.68
PLC-X-5	18.10	1.29	17.20	1.27	17.80	1.15	19.31	1.19	17.24	1.21
B-2	19.08	5.69	18.86	5.47	19.05	5.50	18.90	5.47	17.21	5.49
SLC-X-5	18.76	2.66	17.17	2.45	18.92	3.33	17.29	3.04	17.41	2.52
PLC-X-6	27.55	1.98	27.43	1.80	27.32	1.83	27.65	1.85	25.46	2.01
SLC-X-6	23.02	4.04	23.74	5.00	24.78	3.73	22.35	3.55	22.17	3.17
PLC-X-7	31.69	4.44	31.34	5.52	31.01	4.92	31.00	4.97	30.09	4.73
SLC-X-7	33.22	4.65	33.60	4.78	32.80	5.15	32.55	4.95	32.71	4.31
PLC-X-8	44.27	2.93	44.15	2.80	44.49	2.48	50.96	2.46	43.66	2.89
SLC-X-8	43.47	4.44	43.51	4.85	43.38	4.56	43.29	4.50	43.03	5.07
PLC-X-9	38.13	3.04	36.64	3.20	38.16	3.36	38.24	3.20	36.26	3.20

LEGEND:

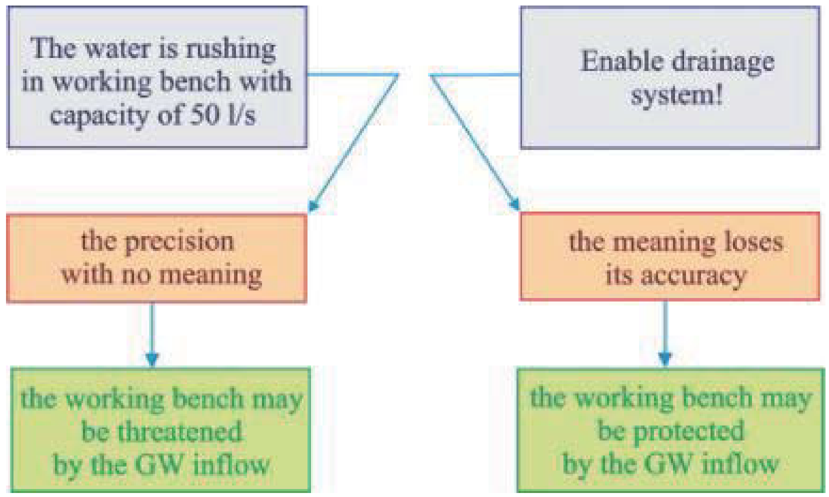
- ↑GWL - ↓Q; ↓GWL - ↓Q; ↑ or ↓ GWL - Q = const; GWL=const - ↓Q; ↑GWL - ↑Q — ILLOGICAL
- ↓GWL - ↑Q; ↑GWL - ↓Q — LOGICAL

Q - well capacity (l/s)
GWL - groundwater level

Sl. 2. Problem oko nepreciznosti, neizvesnosti i neodređensti kod ulaznih podataka
Fig. 2. Problem with imprecision, uncertainty and vagueness in the input data

Ovim primerom je pokazano da je jezik značajan izvor neizvesnosti i da prenos informacija i znanja prate različite vrste neodređenosti i nepreciznosti. Zaključno, u kontekstu kao glavi izvori neizvesnosti se najčešće pojavljuju nepoduzdani izvori podataka i informacija, zahtevana energija za dobijanje sigurnosnih podataka, nepreciznost prirodnog jezika, mnoštvo nepotrebnih podataka, nedostatak razumevanja, konfliktni ili komplementarni izvori činjenica i sl., dok se izvor (klasifikacija) neizvesnosti može pokazati kao eksperimentalna greška pri merenju, neizvesnost u proceni, slučajan događaj, nedostatak evidencije ili nedostatak izvesnosti u evedenciji.

Uvođenjem pojma „fuzzy skup“ (Zadeh, 1965), na matematički način prikazujemo „nejasnosti u svakodnevnom životu“. Zadeh navodi da „u dosta slučajeva nije potrebna matematika i precizno izražavanje za rešavanje problema.“ Iz ovog potiče i njegova poznata izjava na kojoj se dalje mnogi naučnici nadovezuju: „Kako kompleksnost raste, precizne izjave gube svoj smisao, a smislene izjave svoju preciznost.“ To bi značilo da kada se povećava kompleksnost sistema, naša mogućnost da napravimo precizno, a u isto vreme i značajno tvrđenje o njegovom ponašanju se smanjuje dok se ne dostigne prag posle čega preciznost i značaj postaju gotovo isključive osobine. Jedan ovakav primer smisla fuzzy logike, prikazan je na slici 3. Ako izjavimo: „Voda navire u radnoj etaži kapacitetom od 50 l/s“, shvatamo da je to preciznost bez smisla, jer tom izjavom nećemo zaštititi kop od priliva voda. Izjavom: „Uključi drenažni sistem!“, smisao gubi preciznost, ali time možemo zaštititi radnu etažu od priliva voda. Zbog toga je Zadeh predložio da se sa složenim problemima treba izboriti tako što umesto ka rigoroznosti i što većoj preciznosti opisa i razmišljanja o pojavama, treba krenuti upravo u suprotnom pravcu i dozvoliti da oni budu neprecizni. Tu se vidi i sam smisao fuzzy logike - da se izvrši transformacija nejsanog u nešto što je od koristi.



Sl.3. Smisao fuzzy logike
Fig. 3. The point of fuzzy logic

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LITERATURA / REFERENCES:

Graham, I. (1991): Uncertainity and expert systems, University of Bristoll, Bristol.

Klir G. J., Yuan B. (1995): Fuzzy Sets and Fuzzy Logic: Theory and Application, Prentice Hall Inc.

Kosko B. (1993): Fuzzy thinking: The new science of fuzzy logic, Hyperion, New York.

Lai, Y. J., & Hwang, C. L. (1996): Fuzzy multiple objective decision making. Berlin: Springer.

Mayer W. (1990): Expert systems in factory management: Knowledge-based CIM, Ellis Horwood Ltd, Chichester – United Kingdom

Ross T.J. (2004): Fuzzy Logic with Engineering Applications, Wiley.

Zadeh L. A. (1965): Fuzzy Sets, *Information and Control*, 8(3), 338-353.

Zadeh L. A. (1975): The concept of a linguistic variable and its application to approximate reasoning, *Information sciences*, 8, 199-249.

Zimmermann H. J. (2001): Fuzzy sets theory and its applications, Kluwer Academic Publishing, Norwell - USA.

THE PURPOSE OF FUZZY LOGIC IN HYDROGEOLOGICAL PRACTICE

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The best way for an engineer or scientist to express their opinion is actually everyday verbal way of expression. It represents a significant source of uncertainty, due to the transfer of information as well as knowledge associated with different types of vagueness and imprecision (Kosko, 1993). Therefore, fuzzy logic systems stand out as their core is working with the knowledge that can be very imprecisely expressed in verbal form. This "knowledge" in the fuzzy logic systems is represented in the form of the expert rules that are suitable verbal form of expressing the knowledge of every man. In this way, fuzzy logic represents a codification of a common sense (Graham, 1991; Lai, Hwang, 1996). Instead of differential equations, the knowledge of experts is used to describe a system. Knowledge is expressed in a natural way - by linguistic variables, so we can say that the fuzzy logic is "computation with words" (Zadeh 1965, Zadeh 1975).

As mentioned, the basic unit of knowledge representation in fuzzy logic is a linguistic variable with its linguistic values that make fuzzy sets. Combinations of variables and their values consists of linguistic expression, which represents a bridge between the numerical (re)presentation of information in the computer and the human way of thinking. In his paper: "The Concept of a Liguistic Variable and Its Application to approximate reasoning", Zadeh (1975) first introduced "linguistic (fuzzy) variable" which is actually the value of the uncertainty, described by linguistic evidence. Linguistic or fuzzy variable is defined as a variable whose allowed values are words of natural language, not the numbers. In other words, the linguistic expressions in the approach of "soft computing" are actually called linguistic variables (Mayer, 1990). Further development of science - mathematics and fuzzy logic results in the linguistic variables with more realistic qualitative description. This includes the introduction of linguistic modifiers in order to describe in detail the basic values of the linguistic variable.

Suppose that we consider for example the linguistic variable "the quality of groundwater". This linguistic variable can be described by linguistic values such as: "extremely good", "very good", "good", "bad", "very bad". In this case, the linguistic modifiers are "extreme" and "very". Thus, the linguistic variable "the quality of ground water", which is described by linguistic values "extremely good" is better than the linguistic variable "the quality of groundwater" which is described by the linguistic value "very good".

In addition to the symbolic linguistic form, linguistic variables also have a defined quantitative analytical form - the compatibility (membership) function, and therefore it has been concluded that it has a dual nature. In this way, this dual identity makes linguistic variables suitable to perform the qualitative - quantitative and symbolic - numeric computations. In this way a link between the natural language used by man and numerical data used by the computer is being established.

As an example, it will take the linguistic variable "temperature of thermal waters" and the corresponding linguistic values: "low potential", "medium potential" and "high potential". This is shown in Fig. 1, where one can see their qualitative and quantitative values - membership functions (μ). Observed linguistic variable also has the actual physical domain in which elements from observed linguistic values also take their numerical values. Here it is shown by a membership function (μ) for 60 º C.

In recent years it is possible to observe a rapid increase in number and different types of application of systems based on a fuzzy theory. As for its meaning, in the narrow sense, fuzzy logic is a logical system that is an extension of multi-valued logic, and in a broader sense, it is actually synonym for the theory of fuzzy sets - a theory that links the classes of objects with not so sharp set boundaries (Klir and Yuan, 1995; Zimmermann, 1996). While it was originally used for data processing which allows partial set membership in order to avoid approach in which there is either complete total belonging to some set or total dis-belonging to some set, today, fuzzy logic represents a management methodology that, although young, began to be used in all fields of science (Ross, 2004) and therefore in hydrogeology, too.

If we start from the basic step in hydrogeology - collecting and obtaining information about an exploration area, there is already a problem and question - whether the data is secure, complete and accurate?

As an example of uncertain and imprecise data, it will take the example of the open pit mine “Drmno”. Comparative analysis of the wells capacity and registered groundwater levels showed that well flow rates and groundwater levels are not mutually in compliance. In quite a number of wells it has been registered relatively large depression in a relatively small well capacity, while, on the other hand, the levels in wells that do not work as well as accompanying piezometers, were relatively high. In addition, there has been registered the occurrence of inadequate groundwater levels as a result of changes in the capacity of wells without significant impact of surrounding wells in operation. Fig. 2 shows these mentioned phenomena only in part of the drainage wells, and only in part of the period of observation, taken at random.

The wells in which the decline in capacity leads to the decline of groundwater levels, to a lesser or greater extent are shown in yellow. In contrast, wells in which during the increase in capacity also occurs the increase in groundwater levels are shown in grey. Wells in which for the identical pumping capacity are registered different groundwater levels, are shown in blue. In some wells, the differences in the registered values of the groundwater level at a constant capacity are of the order of several meters. Finally, wells in which groundwater levels are unchanged for different pumping capacities are shown in pink.

This example has shown that language is an important source of uncertainty, and that the transfer of information and knowledge are followed by different types of vagueness and imprecision. In conclusion, in the context, as the main sources of uncertainty most often are mentioned unreliable sources of data and information, energy required for obtaining security data, imprecision of natural language, a lot of unnecessary data, lack of understanding, conflicting or complementary sources of facts, etc., while the source (classification) uncertainty may prove to be an experimental error in measuring, the uncertainty in the estimate, a random event, the lack of records or lack of certainty in the records.

By introducing the term “fuzzy set” (Zadeh, 1965) it show “the vagueness in everyday life” in mathematical way. Zadeh states that “in many cases math and accurate expressing are not required for solving the problem.” From this comes and his famous statement which many scientists followed: “as complexity rises, precise statements lose meaning and meaningful statements lose precision”. This would mean that when you increase the complexity of the system, our ability to make precise, and at the same time a significant assertion about its behavior decreases until it reaches a threshold, after which precision and significance become almost the only characteristics. One such example of a sense of fuzzy logic, is shown in Fig. 3. If we state: “The water is rushing in working bench with capacity of 50 l/s”, we realize that it is the precision with no meaning, because that statement will not protect the open pit mine from the water inflow. With a statement: “Enable drainage system!”, the meaning loses its accuracy, but this can protect working bench from water inflow. That is why Zadeh proposed that we should deal with complex problems in such a way that instead of rigorousness and the greatest possible accuracy of the description and thinking about phenomena, we should move in exactly the opposite direction and allow them to be inaccurate. This is where the very meaning of fuzzy logic can be seen - to transform the vague into something useful.

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