Primena fuzzy optimizacije u hidrodinamičkoj analizi

Dragoljub Bajić, Dušan Polomčić, Jelena Ratković, Predrag Pajić

XVII Конгрес геолога Србије	Књига апстраката	429-432	Брњачка Бања, 17-20 мај 2018.
XVII Geological Congress of Serbia	Book of Abstracts		Vrnjačka Banja, May 17-20, 2018.

PRIMENA FUZZY OPTIMIZACIJE U HIDRODINAMIČKOJ ANALIZI

Dragoljub Bajić[1], Dušan Polomčić[1], Jelena Ratković[1], Predrag Pajić[2]

[1)] Univerzitet u Beogradu, Rudarsko-geološki fakultet, Departman za Hidrogeologiju, e-mail: dragoljub.bajic@rgf.bg.ac.rs
[2)] Institut za vodoprivredu „Jaroslav Černi"

Ključne reči: znanje eksperta, optimizacija, trougaoni fuzzy brojevi, upravljanje podzemnim vodama, fuzzy logika, hidrodinamički model.

UVOD

Rad tretira aktuelnu i kompleksnu problematiku upravljanja podzemnim vodama - odbrane od podzemnih voda. Navedena problematika je posebno izražena u uslovima dinamičkih sistema podložnih kontinuiranim promenama koji zahtevaju efikasan i fleksibilan sistem odbrane od podzemnih voda, posebno u kompleksnim hidrogeološkim sredinama. U cilju razvoja metodologije, napravljen je algoritam povodom rešavanja problema vezanih za odbranu od podzemnih voda i izbora optimalnog sistema odbrane od podzemnih voda.

Za projektovanje i izbor karakteristika sistema odbrane od podzemnih voda primenjena je metoda hidrodinamičkog modeliranja režima podzemnih voda. Tako su definisani elementi sistema za odbranu od podzemnih voda, njihove karakteristike (npr. kapaciteti bunara), njihov raspored u planu i profilu i redosled izvođenja drenažnih objekata. Rezultat primene metode hidrodinamičkog modeliranja režima podzemnih voda predstavlja dobijajnje više varijantnih rešenja, tj. „scenarija"/„alternativa" sistema odbrane od podzemnih voda, te je tako omogućeno sagledanje efekata rada različitih sistema odbrane (Bajić & Polomčić, 2014; Polomčić & Bajić, 2015).

Polazeći od činjenice da je često neizvestan veliki broj elemenata prilikom kreiranja modela za donošenje odluka i od toga da nije u moguće u većini slučajeva odrediti tačne numeričke vrednosti za poređenje odluka (Bajić et al., 2014), određeni podaci mogu biti subjektivno izraženi u vidu „znanja" od strane eksperta, što zahteva heuristički pristup rešavanju problema pomoću fuzzy logike. Na taj način, u radu je primenjena savremena metoda odlučivanja u cilju izbora optimalnog sistema odbrane od podzemnih voda, te su „težine" svih rešenja utvrđivane primenom metode fuzzy optimizacije, tj. fuzzy analitičko hijerarhijskog procesa, baziranog na trougaonim fuzzy brojevima (Bajić, 2016; Bajić et al., 2017a). Primenom navedene metode analizirani su različiti kriterijumi i njihovi podkriterijumi (Bajić et al., 2015), koji utiču na donošenje optimalnog rešenja. Shodno navedenom, omogućena je održiva odluka o izboru sistema odbrane od podzemnih voda dobijena prethodnom hidrodinamičkom analizom.

METODE

U cilju rešavanja zadatka prilikom izbora i projektovanja sistema odbrane od podzemnih voda primenjeni su različiti naučni metodološki postupci: numeričke metode konačnih razlika u okviru hidrodinamičkog modeliranja režima podzemnih voda, tj. hidrodinamička analiza, i fuzzy logika - metoda fuzzy analitičko hijararhijskog procesa (Chang, 1996; Deng, 1999). Savremena metoda hidrodinamičkih proračuna bazirana je na numeričkom rešavanju sistema parcijalnih diferencijalnih jednačina trodimenzionalnog kretanja podzemnih voda. U pogledu postavljanja prioriteta i donošenja optimalne odluke, podrazumevajući kvalitativne i kvantitativne pokazetelje, fuzzy analitičko hijerarhijski proces (FAHP) se pokazala kao veoma moćna i fleksibilna naučna metoda. Metoda FAHP predstavlja jednu od novijih metoda, korišćenih poslednjih godina u procesu višekriterijumskog odlučivanja kod kompleksnih problema, tj. za izbor neke od alternativa koji imaju različitu važnost. Širok spektar primene FAHP metode, kao npr. u odlučivanju, evaluaciji, alokaciji resursa, planiraju i razvoju, industriji, inženjerstvu, politici, obrazovanju, pokazuje da je ona danas jedna od često primenjivanih metoda višekriterijumske optimizacije (Bajić et al. 2017c).

REZULTATI I DISKUSIJA

Za potrebe rešavanja složenih hidrogeoloških i hidrodinamičkih problema kao što je odbrana od podzemnih voda kreiran je algoritam koji se sastoji iz 3 faze (Bajić, 2016).

U prvoj fazi primenjuje se kompleksna hidrodinamička analiza kojom se omogućava adekvatno formiranje menadžment scenarija za odbranu od podzemnih voda, kao i analiza efekata odbrane od podzemnih voda (Polomčić & Bajić, 2015).

U drugoj fazi postavljaju se i detaljno analiziraju faktori koji utiču na izbor optimalnog sistema odbrane od podzemnih voda. Izdvojeno je 3 kriterijuma i u okviru njih 11 podkriterijuma, koji se mogu smatrati univerzalnim (Bajić et al., 2015).

U trećoj fazi vrši se ocenjivanje kriterijuma, podkriterijuma i alternativa pomoću metode fuzzy analitičko hijerarhijskog procesa (Bajić et al., 2017). U ovoj fazi se donosi konačna odluka o optimalnom sistemu odbrane od podzemnih voda. Prema trećoj fazi, da bi se lakše vršili kompleksni matematički proračuni vezani za određivanje optimalnog rešenja i analiza osetljivosti, izrađena je namenska aplikacija FUZZY-GWCS® (Fuzzy - Groundwater Control System) (Bajić et al., 2017b). Algoritam fuzzy optimizacije u hidrodinamičkoj analizi za potrebe projektovanja sistema odbrane od podzemnih voda testiran je na istražnom području limonitskog ležišta „Buvač” i području crpne stanice „Bezdan 1”.

ZAKLJUČAK

Specifični algoritam, čiji se doprinos ogleda u optimalnom izboru sistema odbrane od podzemnih voda, formiran je zarad rešavanja aktuelnih i kompleksnih hidrogeoloških problema odbrane od podzemnih voda, kao i povodom odvodnjavanja različitih objekata, pod kojim se podrazumevaju: naselja, hidrotehnički objekti, priobalja, meliorativna područja i rudnici. Prikazanim interdisciplinarnim pristupom koji povezuje hidrogeologiju i hidrodinamiku sa fuzzy optimizacijom, odnosno, hidrogeologiju i hidrodinamiku sa matematikom, logikom i višekriterijumskim odlučivanjem, doprinosi se kvalitetnom i održivom upravljanju problematikom odvodnjavanja na područjima i na objektima ugroženim od podzemnih voda.

ZAHVALNOST

Autori se zahvaljuju Ministarstvu prosvete, nauke i tehnološkog razvoja Republike Srbije za finansiranje projekata OI-176022, TR-33039 i III-43004.

THE APPLICATION OF FUZZY OPTIMIZATION IN HYDRODYNAMIC ANALYSIS

Dragoljub Bajić[1], Dušan Polomčić[1], Jelena Ratković[1], Predrag Pajić[2]

[1)] University of Belgrade, Faculty of Mining and Geology, Department of Hydrogeology, e-mail: dragoljub.bajic@rgf.bg.ac.rs
[2)] ‘Jaroslav Černi’ Institute for the Development of Water Resources

Key words: expert knowledge, optimization, triangular fuzzy numbers, groundwater management fuzzy logic, hydrodynamic model.

INTRODUCTION

This paper deals with the actual and complex issue of groundwater management - groundwater control. It is especially salient in the conditions of dynamic systems which are subjected to continual changes requiring an efficient and flexible system of groundwater control, particularly in complex hydrogeological environments. With the aim of developing methodology, it has created an algorithm for solving groundwater control problems and for the selection of an optimal system of groundwater control.

The method of hydrodynamic groundwater regime modelling was applied in the design and selection of groundwater control system properties. In this way, the elements of the groundwater control system were defined, their properties (e.g. well capacities), their distribution in the plan and profile and the sequence of drainage object execution. The result of the application of the hydrodynamic groundwater regime modelling resulted in multiple variants of solutions i.e. 'scenarios'/ 'alternatives' for groundwater control systems. This, in turn, allows us to observe the impacts of the functioning of different groundwater control systems (Bajić & Polomčić, 2014; Polomčić & Bajić, 2015).

Given the fact that a large number of elements is often uncertain during the creation of a decision-making model and that it is often impossible to determine the exact numerical values for decision comparison (Bajić et al., 2014), certain data can be subjectively expressed expert 'knowledge', which requires a heuristic approach when solving problems by using fuzzy logic. Thus, it has applied a modern decision-making method in this paper so as to select the optimal groundwater control system, where the 'weights' of all the solutions were determined by utilizing the fuzzy optimization method, i.e. the fuzzy analytical hierarchy process, based on triangular fuzzy numbers (Bajić, 2016; Bajić et al., 2017a). By utilizing this method, different criteria and their sub-criteria (Bajić et al., 2015) which affect the choice of the optimal solution were analyzed. What this does is enable a sustainable decision regarding the choice of groundwater control to be made in accordance with the previously conducted hydrodynamic analysis.

METHODS

With the aim of resolving any issues during groundwater control system selection and design, various scientific methods were utilized: finite-difference methods within the scope of hydrodynamic groundwater regime modelling, i.e. hydrodynamic analysis, and fuzzy logic - the method of the fuzzy analytical hierarchy process (Chang, 1996; Deng, 1999). The modern method of hydrodynamic calculations is based on the numerical solving of systems of partial differential equations of three dimensional groundwater movement. As far as setting priorities and making the optimal decision is concerned, also taking into account qualitative and quantitative indicators, the fuzzy analytical hierarchy process (FAHP) has proved itself to be a powerful and flexible scientific method. In recent years, FAHP has been one of the new methods being used in the process of multicriteria decision-making in complex problems, i.e. for selecting one of possible alternatives of varying importance. The wide spectrum of applications of the FAHP method such as, for example, in decision-making, evaluating, allocating resources, planning and development, industry, engineering, politics, education, shows that it is currently one of the frequently used methods of multicriteria optimization (Bajić et al. 2017c).

RESULTS AND DISCUSSION

A three-phase algorithm was created for the purpose of solving complex hydrogeological and hydrodynamic problems such as groundwater control (Bajić, 2016).

In the first phase, a complex hydrodynamic analysis, which enables the adequate formation of a management scenario for groundwater control, and an analysis of the impacts of groundwater control are applied (Polomčić & Bajić, 2015).

In the second phase, the factors which affect the selection of the optimal system of groundwater control are set and thoroughly analyzed. Three criteria and eleven sub-criteria were singled out which could be considered universal (Bajić et al., 2015).

In the third phase, the criteria, sub-criteria and alternatives are evaluated by using the fuzzy analytical hierarchy process method (Bajić et al., 2017). It is in this phase that a decision is made regarding the optimal system of groundwater control. In accordance with the third phase, in order to conduct complex mathematical calculations for establishing optimal solutions and sensitivity analyses, a dedicated application called FUZZY-GWCS® (Fuzzy - Groundwater Control System) was created (Bajić et al., 2017b). The algorithm of the fuzzy optimisation in hydrodynamic analysis done for the purpose of designing a system of groundwater control was tested in the research area of the limonite deposit ‘Buvač’, in the area of pumping station ‘Bezdan 1’.

CONCLUSION

The specific algorithm whose contribution is reflected in the optimal choice of groundwater control system, was created in order to solve actual and complex hydrogeological problems in groundwater control, as well as concerning the dewatering of various objects which include: settlements, hydrotechnical facilities, coastal areas, meliorative areas and mines. The interdisciplinary approach defined herein, which combines hydrogeology and hydrodynamics with fuzzy optimization, that is to say, hydrogeology and hydrodynamics with mathematics, logic and multi-criteria decision-making, contributes to superior and sustainable management of dewatering in areas and objects threatened by groundwater.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank the Serbian Ministry of Education, Science and Technological Development for funding projects ’OI-176022’, ’TR-33039’ and ’III-43004’.

LITERATURA / REFERENCES

Bajić D., Polomčić D., Jemcov I. 2014. The purpose of fuzzy logic in hydrogeological practice. In Cvetković V. (Ed.), Proceedings of the XVI Serbian Geological Congress, Donji Milanovac, Serbia, 22-25 May 2014, pp. 424–429. Belgrade: Serbian Geological Society.

Bajić D. & Polomčić D. 2014. Fuzzy optimization in hydrodynamic analysis of groundwater control systems: Case study of the pumping station “Bezdan 1”, Serbia. Geološki anali Balkanskoga poluostrva, 75: 103–110. DOI: 10.2298/GABP1475103B

Bajić D., Polomčić D. & Močević J. 2015. Factors that influence the selection of an optimal groundwater protection system at open-pit mines. Proceedings of the VII International Conference “Coal 2015”, Zlatibor, Serbia, 14-17 October, 2015; Pavlović V, Eds.; Yugoslav Opencast Mining Committee: Belgrade; pp. 9–16.

Bajić D. 2016. Fazi optimizacija u hidrodinamičkoj analizi za potrebe projektovanja sistema odbrane od podzemnih voda. (Fuzzy optimization in the hydrodynamic analysis for the purposes of groundwater control system design). Doktorksa disertacija, 296 pp.

Bajić D., Polomčić D. & Ratković J. (2017a). Multi-criteria decision analysis for the purposes of groundwater control system design. Water Resources Management, 31(15): 4759-4784. DOI: 10.1007/s11269-017-1777-4

Bajić D., Polomčić D., Dašić T., Ratković J. & Čokorilo Ilić M. (2017b). Determining the optimal groundwater control system using Fuzzy-GWCS® application. (Određivanje optimalnog sistema odbrane od podzemnih voda korišćenjem Fuzzy-GWCS® aplikacije). Proceedings of the VIII International Conference “Coal 2017”, Zlatibor, Serbia, 11-14 October, 2017; Pavlović V, Eds.; Yugoslav Opencast Mining Committee: Belgrade; pp. 9–16.

Bajić D., Polomčić D., Ristić Vakanjac V., Ratković J. & Čokorilo Ilić M. (2017c). Application of the VIKOR and FAHP multi-criteria optimisation methods for choosing the optimal groundwater control system: case of pumping station Bezdan 1 (Serbia). Proceedings of the national conference with international participation „Geosciences 2017“, Sofia, Bulgaria, 07-08 December, 2017; Yotzo Y., Ed.; Bulgarian Geological Society: Sofia; pp. 131–132.

Chang D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, 95: 649-655.

Deng H. (1999). Multicriteria analysis with fuzzy pair-wise comparison. International Journal of Approximate Reasoning, 21: 215–231.

Polomčić D. & Bajić D. (2015). Application of Groundwater modeling for designing a dewatering system: Case study of the Buvač Open Cast Mine, Bosnia and Herzegovina. Geologia Croatica, 68(2): 123–137. doi:10.4154/gc.2015.07