Water Harvesting Research, 2017, 2(1): 57-67
DOI: 10.22077/jwhr.2017.596
www.jwhr.birjand.ac.ir
P-ISSN: 2476-6976, E-ISSN: 2476-7603

Efficiency assessment of AHP and fuzzy logic methods in suitability mapping for artificial recharging (Case study: Sarbisheh basin, Southern Khorasan, Iran)

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Received: 13 Januray 2016 / Accepted: 13 June 2017

Abstract

Recently, special attention has been paid to artificial groundwater recharge in water resource management in arid and semi-arid regions. Water resources distribution in these regions is extremely uneven, both in spatial and temporal forms and groundwater is the only water resource and is a major constraint on economic and social development. Artificial groundwater recharge is considered an appropriate strategy for overcoming the problem of water scarcity in these areas. Parameters considered in selecting groundwater artificial recharge locations are diverse and complex. In this study factors such as: land slopes, infiltration rate, depth of water table in aquifers, quality of alluvial sediments, land use, land owner density, geological consideration, and water quality and quantity are considered in determining the most suitable areas for groundwater recharge at Sarbisheh basin in the eastern part of Iran. Thematic layers for the above parameters were prepared, classified, weighted, and integrated in a GIS and RS environment by means of Analytic Hierarchy Process and fuzzy logic. Land-use maps were developed from satellite images and other digital maps of topography and geology alongside field investigations were also prepared. The results indicate that Analytic Hierarchy Process and fuzzy logic are reasonably suitable. However, the AHP is better than Fuzzy for practical purposes. Using different approaches for localizing provides the region with suitable context for developing and improving groundwater state. According to the results, employing Fuzzy methods, Boolean, and AHP are compatible with the proper location and this compatibility proves the goodness of the results.

Keywords: *Artificial recharge, Analytic Hierarchy Process (AHP), Fuzzy Logic, GIS.*

1. Introduction

Effective management of aquifer recharge is becoming an increasingly important aspect in water resource management strategies (Gale, 2005). The great part of Iran is characterized as an arid and semi-arid region. In most parts of such regions, groundwater is the only water resource and is a major constraint on economic and social development. Soil and water conservation must also be considered in water resource management plans. Water resources distribution in Iran is very uneven from both spatial and temporal points of views. The magnitude of flood volume resulting from ephemeral rivers is of the order of 65 billion m3 out of 127 billion m3 of the total surface flow from the country, most of which ends up in salt lakes, deserts, swamps, and the ocean (Ghayoumian and et al, 2007). Artificial recharge is an effective technique for augmentation of groundwater resources. A variety of methods have been developed to recharge groundwater and most use variations or combinations of direct-surface, direct sub-surface, or indirect recharge techniques. The most widely applied practical methods are direct-surface water techniques including surface flooding, ditch and furrow systems, and basins and stream channel modification. The advantage of these direct-surface techniques lies in their ability to replenish underground water supplies in the vicinity of metropolitan and agricultural areas, where groundwater overdraft is severe; there is also the added benefit of filtering effect of soils and transmission of water through the aquifer (Asano, 1985). There are many factors to be considered when determining whether a particular site will be receptive to artificial recharge. Application of traditional data processing methods in site selection for artificial groundwater recharge is cumbersome and time consuming due to the fact that data is massive in volume and usually needs to be integrated. Analytic hierarchy process (AHP) developed by Saaty (1980), is a method which determines the relative importance of a set of activities in a multi-criteria decision problem. In the literature, AHP, has been widely used for solving many complicated decision-making problems (Ramanathan, 2001; Wang et al., 2008). Su et al., (2012) presented a comprehensive early-warning model for evaluating the status of grain security in China. The model is based on the analytic hierarchy process (AHP) method and the Dempster–Shafer theory (DST). Results show that the model which conforms to the reality of China is effective and can be used as a grain security pre-warning monitoring tool. In addition to the usefulness of AHP three distribution network in selecting the priority of different researches, it can define a meaningful relation between different variables of various fields. The results yield that AHP model gives optimal values for allocation of financial and human resources in different fields of research works. AHP method is based on the principles of differentiation, pair comparison, and priority of choices. Many decision making problems in city planning and programming are related to evaluation of multi-variable's type. In other words for multi-variable decision making it is possible to evaluate various variables using different criterion indexes. Correct analysis and evaluation in multivariable decision making within recent decades have become the most powerful programming method with a perfect framework for complicated decision making. The strongest ability of analyzing multivariable decision making is the selection and the evaluation of problems, which are coincided by different opposing benefits and are overlying and coincidence of lines of indexes excesses the base of experimental and mental judges. Based on fuzzy logic, membranes of elements in summation may not be in complete form and each element may have a membrane value of zero or one. Unlike Boolean algebra logic, fuzzy logic considers no certainty in selecting land areas, which means that either one area is quite suitable for ground artificial recharges or not. GIS and RS along with AHP and fuzzy logic help decision makers to reach optimal locations. Frequent visits of the site along with different DEM layer maps influence the flood spared like geological layers of the catchment and its upstream, water quality, water volume, infiltration rate, water turbidity, suspended load in runoff, thickness of aquifer, land uses, and social and economic effects. On the other hand, influences of the parameters on conservation or destruction of operation systems and hydrological and hydro-geological behaviors of sites indicated that the suggested sites resulting from AHP model coincide more and are judged by evaluation indexes and governed equations of flood wide-sparing system. Therefore the AHP method along with GIS and RS software can select suitable site locations for flood wide-sparing. The works of Krishnamurty (2000) showed that compared to parametric methods, AHP is more flexible, accurate, clear, and applicable. Analytical hierarchy process (AHP) is one of most complete designed systems for multivariable decision making that is based on three principles of: differentiation, comparative judgment, and combination of priority. This process uses different choices in decision making and has the ability of sensitivity analysis on different selected evaluation and sub-evaluation indexes. Moreover, given the coefficient of determination and non-determination in decision making, recognition and priority of variables are amongst other abilities of this software (Bigloo, 2008). Despite the many abilities of AHP software, there are also some problems in comprehension of big size problems and use of scales in the ranges of 1 to 10. Employing GIS, RS, and AHP along with the elimination indices can be used for developing information in different thematic layers and integrating them with sufficient accuracy within a short period of time. The application of these techniques is indispensable for such analyses. Several studies have been carried out for the determination of areas most suitable for artificial recharge (Krishnamurthy and Srinivas, 1995; Krishnamurthy et al., 1996; Saraf and Choudhury, 1998; Han, 2003; El-Awar and Jaber 2004; Ghayoumian et al 2007). In addition, the identification of suitable sites for flood spreading as an artificial groundwater recharge technique have been practiced in recent years (Ghayoumian et al., 2002, 2005; Zehtabian et al., 2001; Nouri, 2003). An overview of artificial recharge is given by Bouwer (2002), who points out the major factors to be considered. The success of artificial groundwater recharge via surface infiltration is discussed by Fennemore et al. (2001) and Haimerl (2001). Kheirkhak Zarkesh (2005) developed a DSS* for floodwater spreading site selection and the conceptual design of floodwater spreading schemes in the semi-arid regions of Iran. Maleki et al (2009) worked in Boolean and multiclass maps. The optimum site location for artificial ground water recharges in Merek basin was declared. The results showed that using AHP model and developing it by means of overlaying the layers in GIS within the least possible time evaluated the best model among site-localizing models in the region. However, the fuzzy model was not among the used models. Recharge basins are created in highly permeable areas, and this method is most suitable in Iran because of its relatively high practicability, efficiency, and easy maintenance.

The high depression of ground water tables in arid and semi-arid regions such as south Khorasan province aquifers demands the accurate selection of site locations for artificial recharge so that constructional operation, considering available finance and time scheduling design of management works become successful. For suitable artificial recharge and efficiency, AHP and Fuzzy Logic assessment methods were used in

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* - Decision Support System

Sarbishe basin.

Site of artificial recharge via recharge basins was considered as south Khorasan province in the east of Iran. In normal years the potential precipitation of the province is approximately 13 billion cubic meters, of which 12 and 0.9 billion cubic meters of become out of access due to evaporation and runoff, respectively. The normal annual precipitation in south Khorasan province is 90 mm in plains and 310 mm in mountainous areas (the average weight of 140) which is equal to 53% of the annual precipitation of Iran and 17.5% of the annual precipitation in the world. Annually, the average water table falling in Iran is 50 cm and about 80 cm in south Khorasan province. Owing to available data and previous researches, this study investigated the finding of proper sites (locations) in artificial recharges by the help of AHP, Fuzzy, and elimination indexes. The present paper mainly focused on:

1-Application of fuzzy method in site selection for groundwater artificial recharging

2-The comparison of the results of various methods with AHP method

3- The mapping of optimal locations for artificial recharge in the Sarbisheh plain

2. Materials and methods

The study area is in the Sarbisheh Basin located in the east of Iran, between 59º 32' and 59º 58' E longitude and 32º 15' and 32º 51' N latitude (Fig. 1). The Sarbisheh Basin includes ten independent basins that have entered the Sarbisheh plain. Total area is 1480 km2; of which 203 km2 consist of Piedmont Plains and the rest is mountains. The amount of annual rainfall over the region varies from 95 mm in dry years to 375 mm in wet years; long-term (1978-2008) average temperature is 12.2ºC and average annual rainfall is 206 mm. Average actual evaporation obtained by Contain empirical model is 158.6 mm, which is about 77% of the annual rainfall. Annual runoff input volume to Piedmont Plain varies from 27.9 to 113.1 million cubic meters and Runoff is programmable from 20.6 to 83.6 million cubic meters in dry and wet years. Minimum and maximum height are 1920 and 2887 meters respectively and its weight average is 2205 meter.

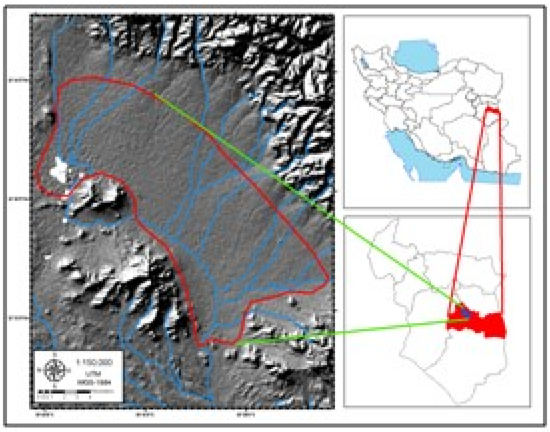

Fig. 1. Research site location in south Khorasan province

In order to determine the most suitable locations for artificial groundwater recharge, factors such as slope, infiltration rate, depth to groundwater, quality of alluvial sediments, land use, owner density, geology, and water quality and quantity of the flood regions were used. For this purpose different thematic maps were prepared from existing maps and data sets, remote-sensing images, and field investigations. Thematic layers for these parameters were prepared, classified, weighted, and integrated in a GIS (ArcMap 9.3) and RS (Erdas 9.1) environment by means of Analytic Hierarchy Process (AHP) and elimination index. To determine relationships between above digital layers and appropriate sites for groundwater artificial recharge, land-use maps were developed from remote-sensing images. Slope is one of the main factors in the selection of flood spreading areas. Water velocity is directly related to angle of slope and depth. On steep slopes, runoff is more erosive, and can more easily transport loose sediments down slope (Saraf and Choudhury, 1998; Ghayoumian et al., 2005). Topographic maps of the case area at the scale 1:25,000 were used to develop a slope map by means of a Digital Elevation Model (DEM). On the slope map, slopes were classified into five classes (Table 1, Fig. 2).

Table 1. Classes of slope by AHP method in Sarbisheh Plain

Class of Slope	Area	%	Suitability of classes
<2	186.0	91.5	very suitable
2-4	14.4	7.1	suitable
4-8	2.3	1.1	moderately
> 8	0.7	0.3	unsuitable

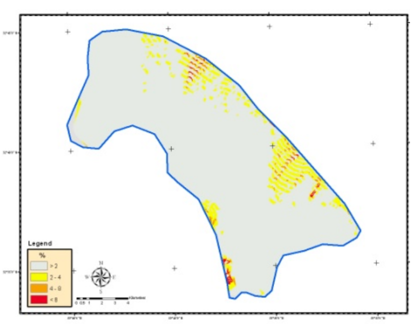

Fig. 2. Slope map in Sarbisheh Plain

Digital Geology map of scale 1:100000 was applied using Arc map 9.3 software. The Sarbisheh plain has a main NW–SE trend. Lithological features of formations in the basin are presented in Table 2. Infiltration values were determined based on double ring infiltrometer tests and texture permeability relationships were established by Food and Agriculture Organization (FAO, 1979). Thirteen samples were taken from the surface of the plain in order to analyze the texture and develop the infiltration rate map. Table 2 gives the texture and determined infiltration values for the samples.

Table 2. Classification of Infiltration rates using AHP method in Sarbisheh Plain

Class of infiltration-(mm/day)	Area	%	Suitability of classes
>45	152.8	75.1	very suitable
25-45	32.9	16.2	suitable
15-25	8.8	4.3	moderately
< 15	8.9	4.4	unsuitable

To verify the texture-infiltration relationship, five ring infiltrometer tests were performed. The results of these tests allowed the area to be classified into four infiltration classes (Table 2, Fig. 3).

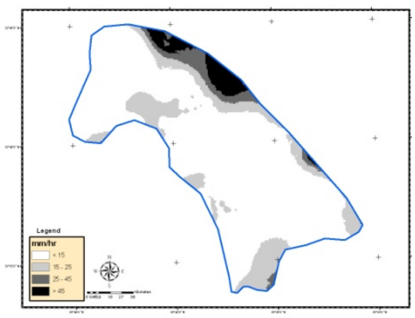

Fig. 3. Map of infiltration rate in Sarbisheh Plain

Observation water level surface in irrigation and Piezometer well and Mother subterranean wells were used to determine depth to groundwater level. The area was classified into four classes based on experience in Iran (Ghayoumian et al, 2007) (Table 3, Fig. 4).

Table 3. Water table classification using AHP method in Sarbisheh Plain

Class of W.T- (m)	Area	%	Suitability of classes
>30	0.6	0.3	very suitable
20-30	6.1	3.0	suitable
10-20	8.3	4.1	moderately
<10	188.3	92.6	unsuitable

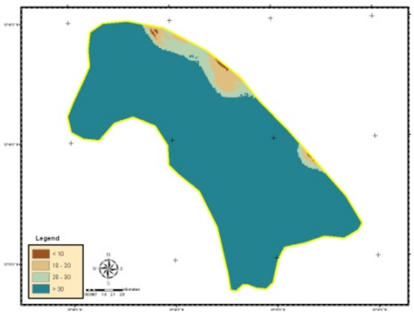

Fig. 4. Map of water table in Sarbisheh Plain

Electrical Conductivity (EC) and Total Dissolved Solids (TDS) variations have similar trends over the area, so the EC factor was used as an indicator of water quality (Raghonath's 1987). Average electrical conductivity data from observation wells and quant measured over a 15-year period were used to develop the EC map (Fig.5). Salinity classification was used to divide the area into four classes on the basis of electric conductivity (Table 4). Digital images of Landsat-7 satellite ETM+ sensor taken in the year 2002 were used together with data collected during field studies in order to develop land use maps of the study area. Appropriate band combinations were selected for visual interpretation. ERDAS software was applied to these combinations to develop the relevant maps. A band combination of 4-3-2 (RGB) and 5-4-3 (RGB) was used to prepare the map of current land-use in which four land types were distinguished (Fig. 6). The area covered by each land use type is shown in Table 5. Evaluation and estimation of water body was carried out using Justin, ICAR, Contain and Barolo empirical methods and thereafter by site visit and indigenous knowledge. Justin method was selected as an optimal method and programmable volume of water was calculated. The programmable volume was classified into four classes. Number of rechargeable G.W recourses and easy operation were classified into four classes. Finally relative priorities were determined using Analytic Hierarchy process and elimination index.

Table 4. Water quality classification using AHP method in Sarbisheh Plain

Class of Ec (ds/m)	Area	%	Suitability of classes
< 1000	0.0	0.0	very suitable
1000-2250	78.9	38.8	suitable
2250-4000	124.5	61.2	moderately
> 4000	0.0	0.0	unsuitable

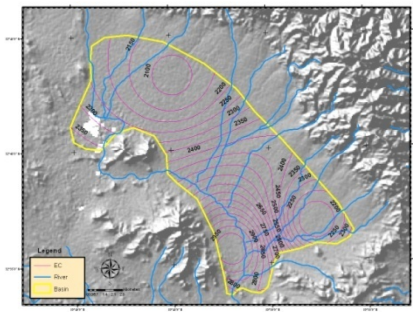

Fig. 5. Map of water quality in Sarbisheh Plain

Table 5. Land use classes obtained by AHP method in Sarbisheh Plain

Coverage	Area	%	Suitability of classes
range land	157.3	77.3	very suitable
forest	2.3	1.1	suitable
agriculture	36.0	17.7	moderately
other	7.8	3.8	unsuitable

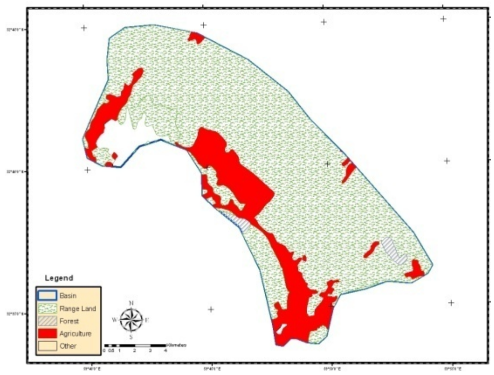

Fig. 6. Land use map in Sarbisheh Plain

3. Results and discussion

Parameters of most suitable artificial recharge areas were developed by Analytic hierarchy process and elimination index models using Arc Map 9.3 and Erdas9.1 software. Relative importance was developed in table 6. In this table, a value of 1 indicates the best condition and 9 the worst. Matrices were defined for AHP model and the above description for each parameter. Therefore slope, infiltration rate, depth to groundwater, quality of alluvial sediments, land use, owner density, geology, water quality and quantity regions were distinguished on the maps and coded as significance levels of 1, 2, 3 and 4, respectively. According to the study, flood plain was classified into four classes of very good (1), good (2), moderate (3) and inappropriate (4) for artificial groundwater recharge plans. For determination of relative priority of parameters and illustration of non-determination coefficients the Expert Choice software was used. Also, by means of literature review and local knowledge alongside views of experts, optimum limits of influenced factors in artificial recharges and flood dissipations such as: land slope, programmable discharges, ground water table elevation, geological structure, water quality, land uses, infiltration rate, number of consumers, reachable roads, and water resources were declared and their relative impotency was estimated (table. 6). Determination coefficients were calculated for assuring certainty of accuracy of AHP outputs. Different weight values are observed for the parameters for first level (Fig. 7).

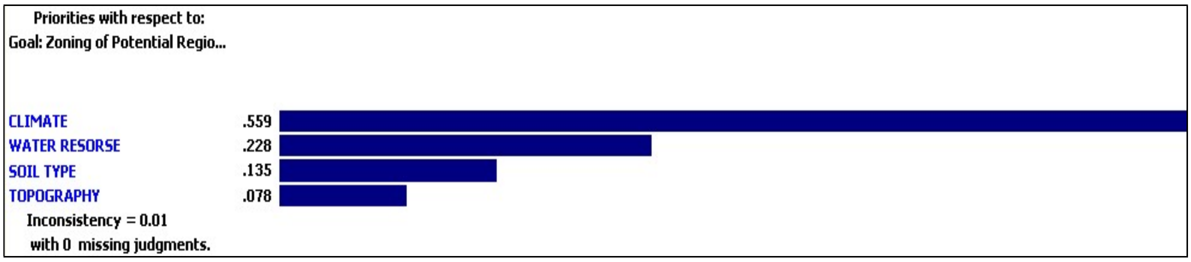

Figure. 7. Inconsistency rate for the main factor

As a result and with respect to relative importance of various parameters and abilities of Arc GIS, relative importance maps of the mentioned parameters were prepared and by the overlaying of these maps, the suitable locations of flood spreading and artificial recharges were determined. The values of each pixel in this map show its relative potentials. The result of overlaying the maps of all parameters and areas suitable for artificial groundwater recharge using analytic hierarchy process is shown in fig 11. According to the different types of land-use, only range lands were always appropriate for artificial recharge. Considering analytic hierarchy process it can be indicated that programmable volume of water, infiltration rate and slope are the most important factors for eliminate index overlaying of all maps and selection of suitable areas for artificial groundwater recharge (Fig 9). Integrating thematic layers using eliminate index and

AHP indicates a 12% area coverage in the eliminate index as appropriate for artificial recharge, with a corresponding area coverage of 12% in the AHP model.

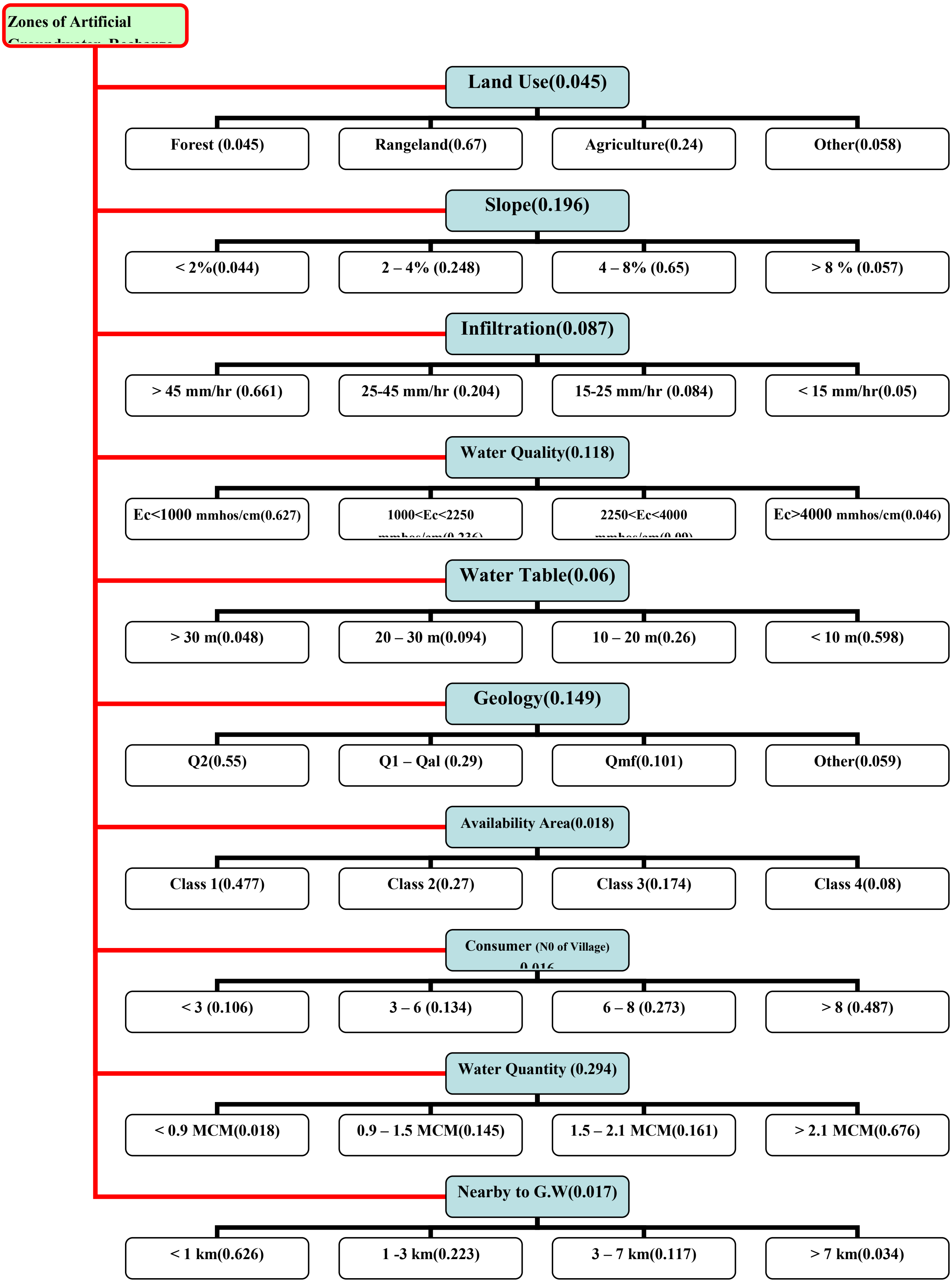

Fig. 8. Schematic diagram of the criteria

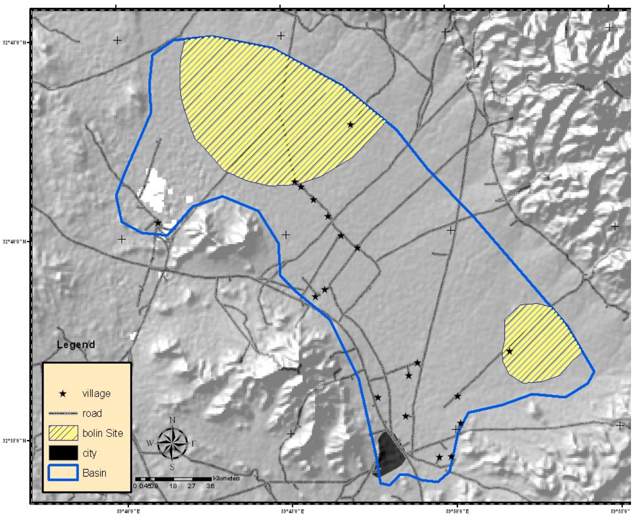

Fig. 9. Map of Suitable site for Boolean Classification

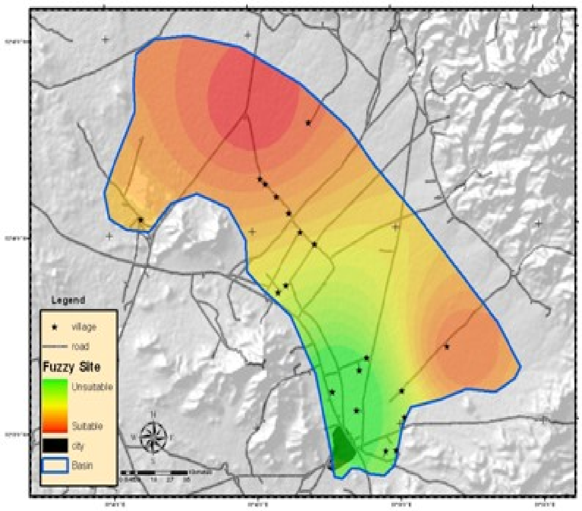

Fig. 10. Map of Suitable site for Fuzzy logic Classification

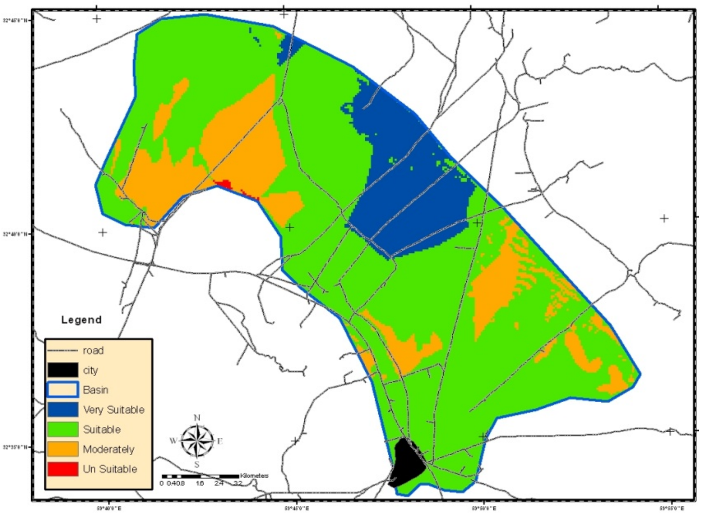

Fig. 11. Map of Suitable site for AHP Classification

4. Conclusion

Parameters considered in the selection of groundwater artificial recharge locations are diverse and complex. In order to identify artificial recharge sites in a semi arid aquifer in the Sarbisheh Basin in the east part of Iran, thematic maps illustrating slope, infiltration rate, depth to groundwater, quality of alluvial sediments, land use, owner density, geology, and water quality and quantity and their characteristics were prepared. Satellite data proved to be very useful for ground surface studies, especially for the preparation of maps of current land-use plant cover. Integrated assessment of these thematic maps using analytic hierarchy process and elimination index, based on GIS techniques proved a suitable method for identifying preferred artificial recharge sites. According to this investigation, the north part of the Sarbisheh Basin proved to be a suitable artificial ground water recharge site. The relationships between geology, soil texture, slope, and their characteristics with appropriate areas for groundwater recharge indicate that the majority of these sites are located in the Quaternary formation. The Quaternary formation can be considered as an appropriate site for artificial recharge at the reconnaissance stage of investigation. A slope of less than 2% and infiltration rate of over 25mm/h are parameters which indicate the area suitable for natural groundwater recharge. The result also shows that Analytic Hierarchy process is better than elimination index model for practical purposes

5. References

Dale, A. Quattrochi. (2004). Thermal Remote sensing, Jhan Willy publication.

ERDAS. (1999). ERDAS Filed Guide, Fifth Edition, ERDAS@, Inc, 698p.

FAO, Soil Bulletin. (1979). Soil Survey Investigations for Irrigation. FAO, No. 42. Fennemore, G.G., Davis, A., Goss, L., Warrick, A.W., 2001. A rapid screening-level method to optimize location of infiltration ponds. Groundwater 39 (2), 230–238.

Gale, M.I. (2005). Techniques for management of aquifer recharge in arid and semi-arid regions. In: Proceedings of Regional Workshop on Management of Aquifer Recharge and Water Harvesting in Arid and Semi-arid Regions of Asia, Yazd, Iran.

Ghayoumian, J., Shoaei, Z., Karimnejad, H.R., Ghermezcheshmeh, B., & Abdi, P. (2002). Some examples of artificial recharge of aquifers by flood spreading in Iran. In: Van Rooy, J.L., Jermy, C.A. (Eds.), Proceedings of the 9th Congress of the International Association for the Engineering Geology and the Environment. Balkema, Rotterdam, pp. 1529–1537.

Ghayoumian, J., Ghermezcheshmeh, B., Feiznia, S., & Noroozi, A.A. (2005). Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran. Environmental Geology 47 (4), 493–500.

Haimerl, G. (2001). Talsperren zur Grundwasseranreicherung in ariden Gebieten-Bewirtschaftungsstrategien und Optimierungsmo¨glichkeiten. Report of the Institute of Hydraulic and Water Resources Engineering. Technical University, Munich, Germany.

Han, Z. (2003). Groundwater resources protection and aquifer recovery in China. Environmental Geology 44 (1), 106–111.

Kheirkhak Zarkesh, M. (2005). Decision support system for floodwater spreading site selection in Iran. Ph.D. Thesis, International Institute for Geo-information Science & Earth Observation, Enschede, The Netherlands, 259 p.

Krishnamurthy, J., & Srinivas, G. (1995). Role of geological and geomorphological factors in groundwater exploration: a study using IRS LISS data. International Journal of Remote Sensing 16 (14), 2595–2618.

Krishnamurthy, J., Venkatesa Kumar, N., Jayaraman, V., & Manivel, M. (1996). An approach to demarcate groundwater potential zones through remote sensing and geographical information system. International Journal of Remote Sensing 17 (10), 1867–1884.

Maleki, A., Hesadi, H., & Naderian, P. (2009). demarcate potential zones of groundwater recharge in Merg basin. Geographical Research Quarterly. 24(92).53-78

Nouri, B. (2003). Identification of suitable sites for groundwater artificial recharge using remote sensing and GIS in Gavbandi Watershed. M.Sc. thesis, Faculty of Natural Resources, Tehran University, Iran, 106 p.

Raghonath, K.R. (1987). Groundwater Assessment, Development and Management. McGraw-Hill Publishing Company Limited, 720 p.

Ramanathan, R. (2001). A Note on the Use of the Analytic Hierarchy Process for Environmental Impact Assessment. J. Environ. Manage., 63(1): 27-35.

Robinov, C.J. (1989). Principles of logic and the use of digital geographic information systems. In: Ripple, W.J. (Ed.), Fundamentals of Geographic Information

Systems Compendium. American Society for Photogrammetry and Remote Sensing, pp. 61–80.

Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw-Hill, New York, USA.287 P.

Saraf, A.K., & Choudhury, P.R. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. International Journal of Remote Sensing 19 (10), 2595–2616.

Sharifi, F., & Ghafouri, A. (1998). Flood spreading in Iran. An integrated approach. Journal of Rain Drop (ICRCS) Series 2, 7.

Soil Conservation and Watershed Management Research Institute (SCWMRI) (1999). Technical Report for artificial recharge through flood spreading in I. R. Iran.

Su, X. Y., Wu, J. Y., Zhang, H. J., Li, Z. Q., Sun, X. H., & Deng, Y. (2012). Assessment of Grain Security in China by Using the AHP and DST Methods. J. Agr. Sci. Tech. Vol. 14: 715-726.

Wang, Y. M., Liu, J. & Elhag, T. M. S. (2008). An Integrated AHP-DEA Methodology for Bridge Risk Assessment. Comput. Ind. Eng., 54(3): 513-525.

Zehtabian, G.R., Alavipanah, S.K., & Hamedpanah, R. (2001). Determination of an appropriate area for flood water spreading by remote sensing data and GIS. In: Proceedings of the International Conference on New Technology for a New Century, Seoul, Korea, pp. 1–6.

Zimmermann, H.J., & Zysno, P. (1980). Fuzzy Set Theory-and Its Application. Kluwer-Nijhoff Publishing, Boston, Dordrecht, Lancaster, 363 p.

parhizgar, A. (2006). GIS and multi criteria decision analysis, Yachk Malchfsky, published by the Samt