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Identification of groundwater artificial recharge sites in Herat city, Afghanistan, using Fuzzy logic

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***Abstract*— Special attention has been paid to artificial groundwater recharge in water resource management in arid and semi-arid regions. Parameters considered in the selection of groundwater artificial recharge locations are diverse and complex. In this study, factors such as: slope, infiltration rate, depth to groundwater and electric conductivity (EC) are considered, to determine the areas most suitable for groundwater artificial recharge in aquifer in the Herat city of Afghanistan. Thematic layers for the above parameters were prepared, classified, weighted based on centroid method of de-fuzzification and integrated in a GIS environment by algebraic product operator of Fuzzy logic. Land use map of research area used to filter the artificial recharge map. The results of the study indicate that about 17.74% of the study area is suitable and 82.26% is unsuitable for artificial groundwater recharge. To validate the model a comparison between mean of water level points which located in suitable zone of suitability map and water level classes done.**

***Index Terms*— Artificial recharge, de-fuzzification method, GIS, Groundwater**

I. INTRODUCTION

Water is indispensable for any life system to exist on earth and is a very important component for the development of any society [1]. A growing population and changing dietary trends mean a steeply rising water demand [2]. Demand for the worlds increasingly scarce water supply, is rising rapidly, challenging its availability for food production and putting global food security at risk, even as demand for water by all users grows, groundwater is being depleted [3]. Groundwater as a source of water supply has great advantages over surface water from streams, rivers, or lakes [4] and with increasing demands for water, ground resources are gaining much attention [5].

Afghanistan's climate is arid to semi-arid where the weather is cold in winter and hot and dry in summer with temperature that ranges from −20°C in winter to 50°C in summer. The annual precipitation in Afghanistan varies according to region, ranging from75*mm* in the southwest up to 1270 *mm* in the northeast with an average annual precipitation of 300*mm* [6]. According to the Ministry of Energy and Water [7] of Afghanistan, long-term total annual precipitation in Afghanistan is 164 billion m^3, evaporation is 87 billion m^3 (53% of the total annual precipitation), surface water runoff is 61 billion m^3 (37% of the total annual precipitation) groundwater recharge is 16 billion m^3 (10 % of the total annual precipitation), and the total annual available water resources are 77 billion m^3 (Table 1).

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II. RESEARCH PROPOSE

Above statistics indicate that just 10 % of the total annual precipitation recharge groundwater naturally and since more than 15% of the agricultural land is being irrigated by groundwater in karez wells fed by springs and shallow wells in Afghanistan [7] therefore, it is important to augment the groundwater resource by artificial recharge. Effective management of aquifer recharge is becoming an increasingly important aspect of water resource management strategies [8]. Conservation of soil and its proper utilization must also be considered as a natural resource, in water resource management plans. So, artificial recharge of groundwater will be helpful to rising water level.

III. RELATIONAL STUDIES

There are many approaches for selection of suitable location for artificial recharge (AR). The application of traditional data processing methods in site selection for artificial groundwater recharge is very difficult and time consuming, because the data is massive and usually needs to be integrated [11]. Different operators of Fuzzy logic such as AND, OR, algebraic sum, algebraic product and gamma are capable to develop information in different thematic layers and integrating them with sufficient accuracy and within a short period of time. The application of these methods is indispensable for such analyses. Many studies have used fuzzy operators for locating most suitable sites for artificial recharge. (Nirmala et al,2011) [9] used hybrid algorithm to stud artificial recharge of groundwater in Sathyamangalam and Melur villages, Chennai. (Ghayomian et al, 2007) [11] applied Fuzzy logic among GIS techniques to determine most suitable areas for artificial groundwater recharge in a coastalaquifer in Gavbandi Drainage Basin, Also, (Nouri et al,2005) [12] have had the same studies and used Fuzzy algebraic product to carry out their study.

Table .1 Annual precipitation data by basin in Afghanistan (MEW, 2016)

Basin	Area (km²)	Annual mean precipitation (mm)	Total precipitation (billion m³/year)	% of total precipitation
Kabul	108392	298	32.3	20
Helmand	202,006	180	36.3	22
Amu	101,498	393	39.8	24
North	78,099	268	20.9	13
Harirod	162,659	210	34.1	21
Total	652,654	270	163.3	100

IV. Research Area

The research area (Herat city) located in the center of Herat province, Afghanistan located between (34.248° and 34.474°) latitudes, and (61.942° and 62.442°) longitudes with an area of 730 km^2 (Fig. 1). Land-surface elevation in the research area ranges from 858 to 1636 above sea level, with an average of 1247*m*. The mean annual precipitation is recorded as 210*mm* [7]. Exploitation of groundwater resources in the study area includes use of qanat, springs, and deep and semi-deep wells. The average well discharge is approximately 200 *Lit/min*. The research area also consists of 230 wells where water is withdrawn from the alluvial fan and the well depths range between 7 and 90*m*. The general trend of groundwater flow is from the east to west.

V. Materials and Methods

A. Thematic layers

Among effective factors in locating suitable areas for artificial recharge slop, depth to groundwater, infiltration rate, electric conductivity and land-use factors were selected and examined [13]. Among these, slop, depth to groundwater, infiltration rate, electric conductivity factors which have direct impact on artificial recharge were used as principle factors and land use factor which shows feasibility of implementation were used as a filter.

The main source of groundwater is the water derived from rain and snow-melt that has permeated through the alluvium and usually this water has a good quality. After permeating the soil, rain water quality will change because of the contact with alluvium and dissolving different minerals in it. This qualitative change depends on constituting particles of aquifer, duration of contact with the bedrock, utilization rate of the groundwater, and groundwater level. Therefore, the quality of groundwater in alluvium as an essential parameter was investigated in the artificial recharge. Since electric conductivity and total dissolved solids (TDS) variations have similar trends, the EC factor was used as an indicator for water quality. Fig.3a illustrate electric conductivity map of research area which prepared based on the actual data of 169 well and Inverse Distance Weighting (IDW) method interpolation [24].

Infiltration in its most narrow and precise sense can be defined as the process water entering into soil through the soil surface. Although a distinction is made between infiltration and percolation *the movement of water within the soil* the two phenomena are closely related since infiltration cannot continue unimpeded unless percolation removes infiltrated water from the surface soil. The soil is permeated by noncapillary channel through which gravity water flows downward towards the ground water, following the path of least resistance. Capillary forces continuously divert gravity water into pore spaces, so that the quantity of gravity water passing successively lower horizons is steadily diminished. This leads to increasing resistance to gravity flow in the surface layer and a decreasing rate of infiltration as a storm progresses. The rate of infiltration in the early phases of a storm is less if the capillary pores are filed from a previous storm. There is maximum rate at which water can enter soil at a point under a given set of conditions; this rate is called the infiltration capacity. The actual infiltration rate equals the infiltration capacity only when the supply rate rainfall intensity less rate of retention) equals or exceeds. Fig.3b

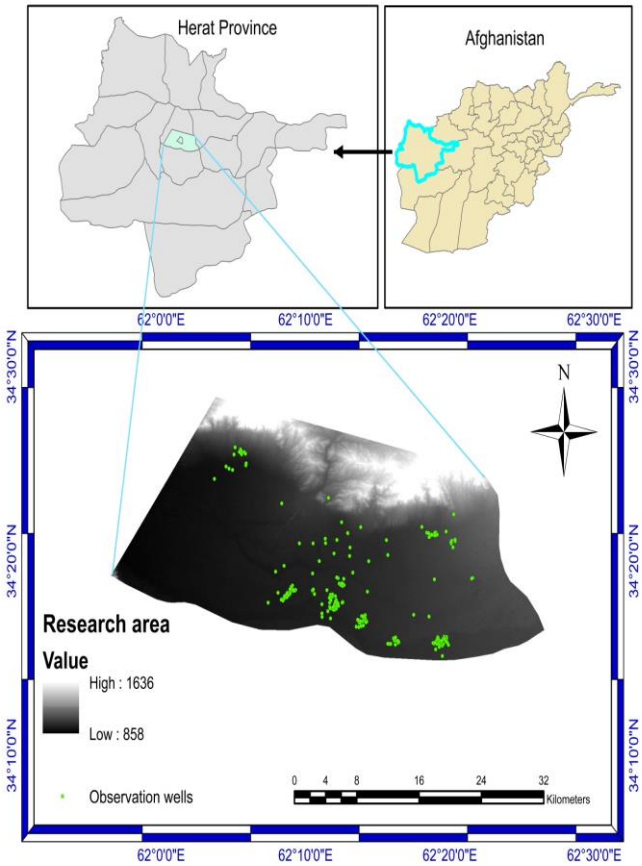


Fig. 1 Research area

Table .2 Membership functions of thematic layers

Thematic layers	Classes	membership
slope(%)	0-2	0.83
	2-4	0.69
	4-8	0.44
	8-10	0.18
	>10	0.01
Infiltration Rate(mm/hr)	13	0.42
	18	0.49
	25.9	0.58
	61.2	0.78
Water Level(m)	0-4	0.01
	4-15	0.42
	16-25	0.65
	26-35	0.7
	36-45	0.81
	46-63	0.88
Electric Conductivity (ms/s)	740-1300	0.89
	1400-1900	0.82
	2000-2400	0.74
	2500-3000	0.65
	>3000	0.27

illustrates the infiltration rate of research area based on the Herat city soil types and hydrologic soil properties [19].

The water depth in infiltration basins should select carefully, while high hydraulic heads produced by deep water result in high infiltration rates, they also tend to compress clogging layers. Fig.3c shows the water level situation of Herat city based on 230 actual data that collected during overseas research.

Another extremely important factor for identification of suitable site is slope. This parameter plays an important role to control factors like runoff, erosion, material transportation and permeability. Fig. 3d shows slope percent in research area which classified in 5 classes.

B. Fuzzy logic

In the classical setting an element either belongs to a set or not. If *A* is a classical set, then the formula $x \in A$ is either absolutely true or absolutely false. In the case of a fuzzy set *A*, an element *x* can attain more than two degrees of its membership. Thus, the formula $x \in A$ may be only partially satisfied [13]. Hence then, fuzzy subsets have been applied to diverse field [14]. In contrast to Boolean logic; no certainty exists in fuzzy logic. Therefore, no unit is satisfactory or unsatisfactory in this logic. Since in previous studies on artificial recharge of groundwater membership values of different classes of a thematic layer have assigned empirically so, here tried to define these values using fuzzy logic.

Given two or more maps with fuzzy membership functions for the same set, a variety of operations can be employed to combine the membership values together [11]. Zimmermann and Zysno (1980) discuss a variety of combination rules [15]. There are five operators that were found to be useful for combining exploration datasets, namely the fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum and fuzzy gamma operator [10]. The fuzzy OR and AND operators are used, only one of the contributing fuzzy sets influences the resultant value. The fuzzy algebraic sum and algebraic product operators make the resultant set larger than, or equal to the maximum value and smaller than, or equal to the minimum value among all fuzzy sets, respectively. The fuzzy gamma operator has the value between that of the fuzzy algebraic product operator and that of the fuzzy algebraic sum operator. Fuzzy algebraic product which selected here because of its high sensitivity in specifying artificial recharge areas [11] defined as [14]:

$$\mu_{comb} = \Pi \mu_i \qquad (1)$$

where μ_i is the fuzzy membership function for the *i*th map, and *i* = (1, 2, 3,...,*n*), maps are to be combined. In fuzzy algebraic product operator as a *t*-norm, the weight of compositional layer in the multilayer intersection section is equal to their products and for other sections is zero. Therefore, mentioned operator has a decrease effect [15]. Although the fuzzy algebraic product gives an output that is decreasive in nature, it does utilize every membership value to produce the result, unlike the fuzzy minimum [16]. Fuzzy logic with range of zero to one is considered for different satisfactory levels.

In this study as a new approach centroid method de-fuzzification which showed better result than other method of de-fuzzification [18] used to determine membership degree of each class of thematic layers. Basically, this logic system consists of the following:

1. **Fuzzification:** Converting the crisp inputs to membership functions which comply with intuitive perception of system status.
2. **Rules Processing**: Calculating the response from system status inputs according to the pre-defined rules matrix (control algorithm implementation).
3. **Inference**: Evaluating each case for all fuzzy rules
4. **Composition**: Combining information from rules
5. **De-Fuzzification**: Converting the result to crisp values.

To prepare standard fuzzy set as an input Gaussian Function used to convert crisp values

$$f(x) = ae^{-\frac{(x-b)^2}{2c^2}} \qquad (2)$$

Where the parameter *a* is the height of the curve's peak (here in fuzzy logic is 1), *b* is the position of the center of the peak and *c* the standard deviation . After processing input in the inference engine as illustrated in Fig.2, the result of the process must be converted to a crisp value, by composition of the crisp values the membership curves for different classes of thematic layers will prepared.

VI. EXPERIMENTS

The objective of this study is to firstly determine membership values for different classes of four mentioned layers and secondly to integrate thematic layers in order to prepare groundwater artificial recharge map of research area.

Table.2 shows membership degrees for different classes of thematic layers which prepared by centroid method of de-fuzzification in Fuzzy Inference System (Fig.2). Then algebraic product operator of fuzzy logic was used to overlay these layers.

Suitability map of artificial recharge which developed by applying fuzzy logic models to the thematic layers shows that 20.08% percent of area is suitable (Fig.4e). Land-use map of research area as illustrated in figure.4f classified in five classes and coded as one (suitable) and zero (unsuitable). This classification is applied to the map of areas suitable for recharge, as a filter. After filtration the suitable area decreased to 17.74% as illustrated in Fig .4g

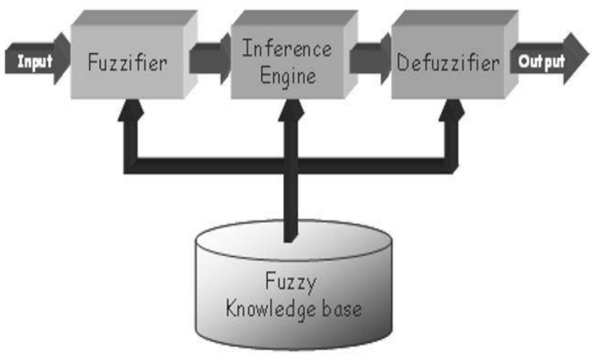
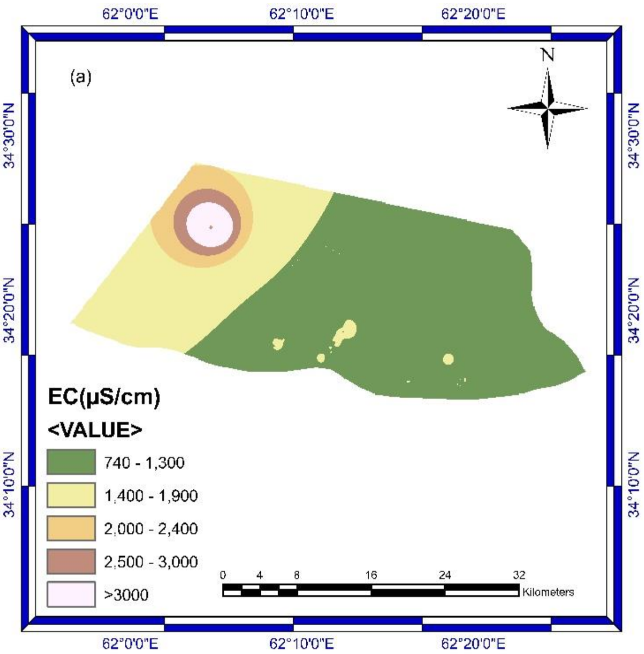
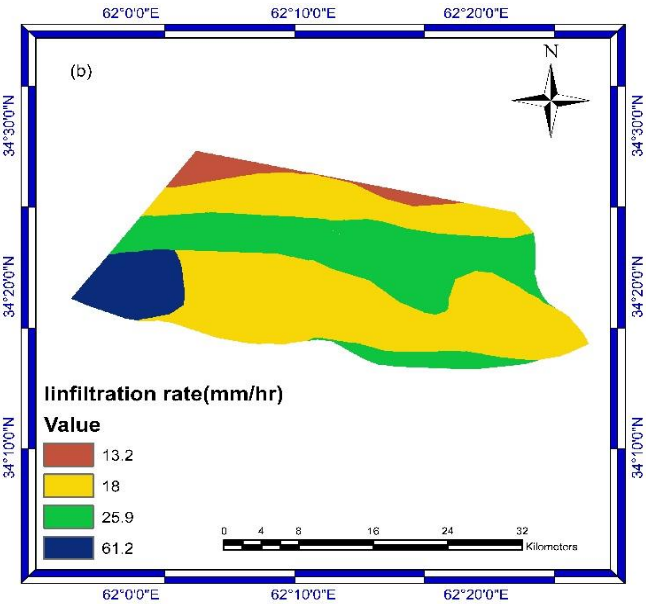
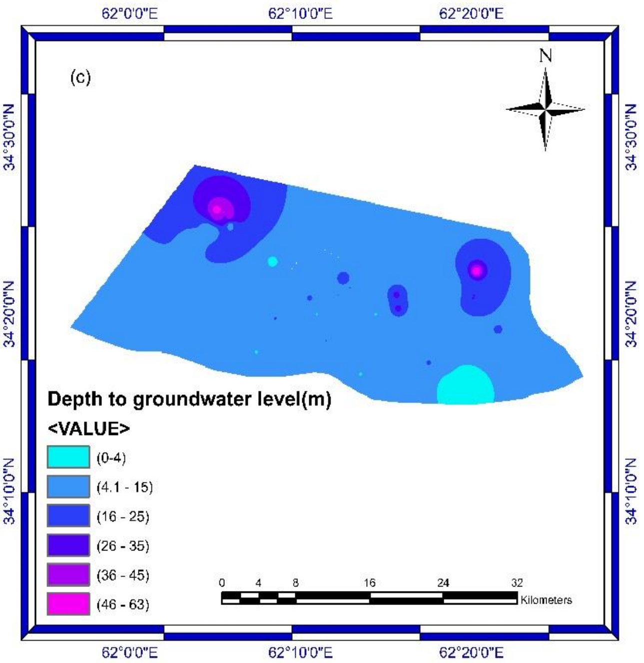


Fig. 2 Fuzzy Inference Systems







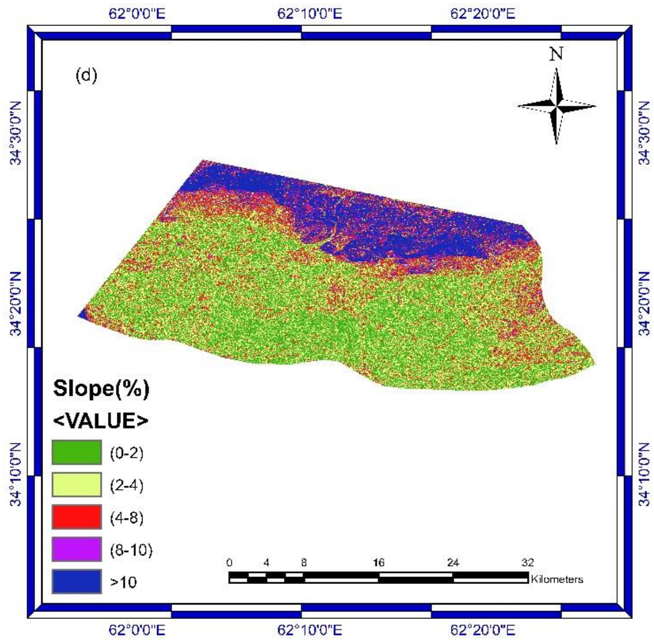


Fig. 3 thematic layers (a) electric Conductivity, (b) infiltration rate, (c) depth to groundwater, (d) slope

To validate the model, a comparison between mean of water level points which located in suitable zone of Fig.4g and water level classes of Fig.3c done [22]. The average of water level points which located in suitable zone is 10.84*m* and since non-accepted range of water level is just first class of Fig.3c where depth to groundwater is less than 4*m* as its membership degree illustrated 0.01 in Table.2. Thus, it can be inferred that the artificial recharge zones delineated by remote sensing and GIS techniques are reliable.

VII. Conclusion

Groundwater resources provide the most important amount of water resources, and many agricultural units have been subjected to negative balance of water due to overharvesting of wells in Afghanistan [7]. Hence proper management of groundwater resources is necessary and artificial recharge of groundwater can be helpful in management of groundwater and increasing the groundwater level. One of the most important factors in successful recharge of groundwater resources is locating suitable areas for these projects. Therefore, site selection of artificial recharge suitable areas is very important.

Four factors namely, depth to groundwater, electric conductivity, slope, and infiltration rate parameters were explored, classified, weighted and overlaid. To overlay these layers, fuzzy logic was used, and the study areas were divided into two suitable and unsuitable classes for artificial recharge. Results showed that based on overlay fuzzy logic 17.74% of study area was suitable for artificial recharge. In this matter, it can be said that suitable areas have been decreased from 20.08 % to 17.74 % using land use filtering. In fact, land use is one of the major factors of water resources management restriction. This artificial recharge zone map can serve as a guideline for the planners/decision-makers as well as practicing hydrogeologists for the sustainable management of groundwater resources in the study area.

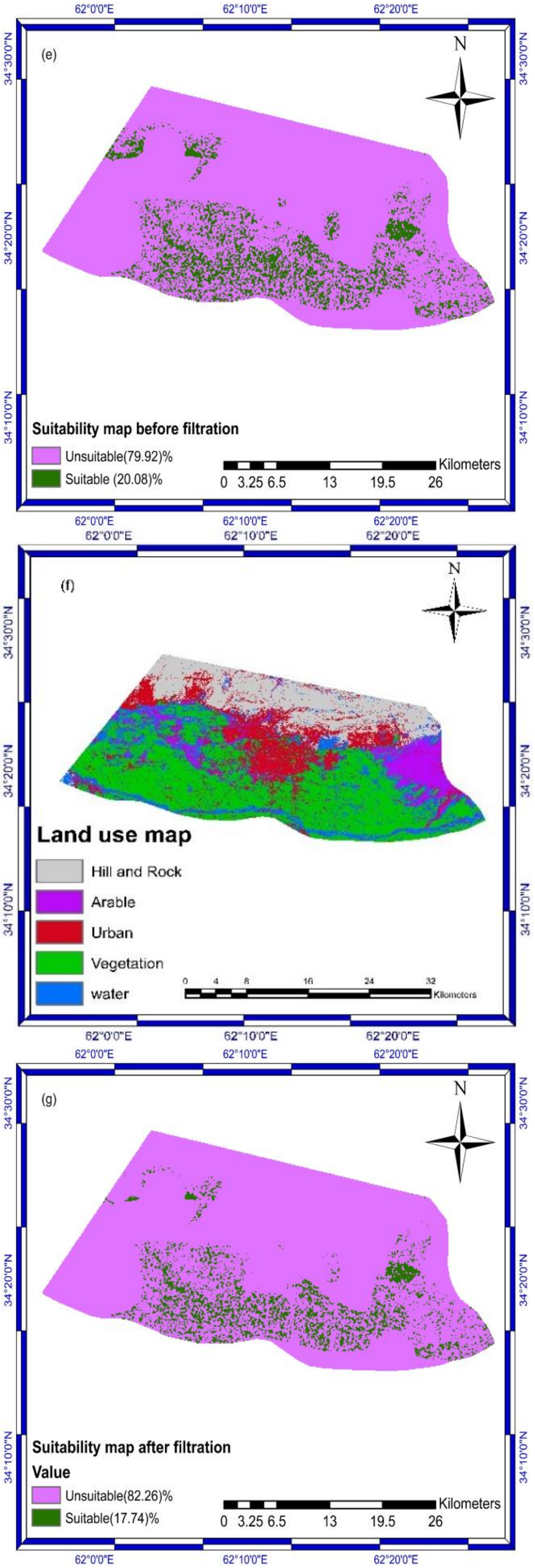


Fig.4 (e) Suitability map of AR before filtration, (f) land use map, (g) suitability map of AR after Filtration

References

[1] V. B. M. Sayana, E. Arunbabu, L. Mahesh Kumar, S. Ravichandran and K. Karunakaran, "Groundwater Responses to Artificial Recharge of Rainwater in Chennai, India: A Case Study in an Educational Institution Cam- pus," Indian Journal of Science and Technology, Vol. 3, No. 2, 2010, pp. 124-130.

[2] G. Berndes, "Water Demand for Global Bioenergy Production: Trends, Risks and Opportunities," Wissenschaftlicher Beirat Der Bundesregierung Globale Umweltveränderungen (WBGU), 2008.

[3] M. W. Rosegrant, X. Cai and S. A. Cline, "Global Water Outlook to 2025, Averting an Impending Crisis," International Water Management Institute (IWMI), 2002.

[4] E. H. Hofkes and J. T. Visscher, "Artificial Groundwater Recharge for Water Supply of Medium-Size Communities in Developing Countries," International Reference Center for Community Water Supply and Sanitation, Hague, 1986.

[5] M. M. Kheirkhah Zarkesh, A. M. J. Meijerink and M. Goodarzi, "Decision Support System (DSS) for Site Selection Floodwater Spreading Schemes Using Remote Sensing (RS) and Geographical Information Systems (GIS)," DESERT 12, 2008, pp. 149-164.

[6] JICA. (2011). Needs assessment survey for water resources management and development in Afghanistan. Japan International Cooperation Agency, Final Report.

[7] Ehsanullah Hayat & Alper Baba, "Quality of groundwater resources in Afghanistan" Environ Monit Assess,2017, pp 189: 318

[8] Gale, M.I, "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",2005.

[9] R. Nirmala, M. Shankara and D. Nagaraju, "Artificial Groundwater Recharge Studies in Sathyamangalam and Melur Villages of Kulathur Taluk, Pudukottai District, Chennai, Using GIS Techniques," International Journal of Environmental Sciences, Vol. 1, No. 7, 2011, p. 1592- 1608.

[10] Kwang-Hoon Chi,No-Wook Park,Chang-JoChung,"Fuzzylogic integration for landslides Hazard mapping Using spatial data from BOEUN, KOREA" National GeoscienceInformation Center, Korea Institute of Geoscience and Mineral Resources, Daejon,2004, 305-350.

[11] J. Ghayoumian, M. Mohseni Saravi, S. Feiznia,B.Nouri,A.Malekian ,"Application of GIS techniques to determine areas most suitable for artificial groundwater recharge in a coastal aquifer in southern Iran", Journal of Asian Earth Sciences 30 ,2007,pp 364–374.

[12] B. Nouri, J. Ghayoumian, M. Mohseni Saravi, A. Darvish Sefat and S. Feiznia, "Identification of Suitable Sites for Groundwater Artificial Recharge by Basins Method Using GIS," Iranian Journal. Natural Resources, Vol. 57, No. 3, 2005, pp. 635-647.

[13] ASCE Standard, Environmental and Water Resources Institute, American Society of Civil Engineers. Standard Guidelines for Artificial Recharge of Groundwater, ASCE Standards, EWRI/ASCE 34-01, 2001, p. 106.

[14] A. Kordi and A. Moussavi, "On Fuzzy of BCI-Algebras," PUMA, Vol. 18, No. 3-4, 2006, pp. 301-310.

[15] P. An, W. M. Moon and A. Rencz, "Application of Fuzzy Set Theory for Integration of Geological, Geophysical and Remote Sensing Data," Canadian Journal of Explo- ration Geophysics, Vol. 27, No. 1, 1991, pp. 1-11.

[16] M. Karimi, M. B. Menhaj and M. S. Mesgari, "Preparing Mineral Potential Map Using Fuzzy Logic in GIS Environment," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8, Beijing, 2008.

[17] Sameena Naaz, Afshar Alam and Ranjit Biswas, "Effect of different de-fuzzification methods in a fuzzy based load balancing application", International Journal of Computer Science Issues,2011, Vol. 8, Issue 5, No 1.

[18] A. Mahdavia, S.H. Tabatabaeia, R. Mahdavib and M.R. Nouri Emamzadeia, "Application of digital techniques to identify aquifer artificial recharge sites in GIS environment", International Journal of Digital Earth, 2013, Vol. 6, No. 6, 589-609.

[19] Martin P. Wanielista, Yousef A. Yousef, Stormwater Management,1993.

[20] Martin P. Wanielista, Yousef A. Yousef John Wiley & Sons, "Storm water Management", 1993, page 264.

[21] Alivia Chowdhury, Madan K. Jha and V. M. Chowdary, "Delineation of groundwater recharge zones and identification of artificial recharge sites in West Medinipur district, West Bengal, using RS, GIS and MCDM techniques", Environmental earth science,2010, 59:1209–1222.

[22] S Lee, JH Ryu, IS Kim, "Landslide susceptibility analysis and its verification using likelihood ratio, logistic regression, and artificial neural network models: case study of Youngin, Korea", Landslides, 2007, Volume 4, Issue 4, pp 327–338.
[23] Bahram Malekmohammadi, Majid Ramezani Mehrian and Hamid Reza Jafari, "Site selection for managed aquifer recharge using fuzzy rules: integrating geographical information system (GIS) tools and multi-criteria decision making", Hydrogeology Journal, 2012, volume 20, Issue 7, pp 1393–1405.
[24] Mercedes Arauzo, "Vulnerability of groundwater resources to nitrate pollution: A simple and effective procedure for delimiting Nitrate Vulnerable Zones", Science of the Total Environment, 2017, volume 575, pp 799-812.
[25] Ismail Chenini, Abdallah Ben Mammou and Moufida El May, "Groundwater Recharge Zone Mapping Using GIS-Based Multi-criteria Analysis: A Case Study in Central Tunisia", Water Resour Manage, 2010, Volume 24, pp 921–939.
[26] Jafar Ghayoumian , B. Ghermezcheshme , S. Feiznia, A. A. Noroozi, "Integrating GIS and DSS for identification of suitable areas for artificial recharge, case study Meimeh Basin, Isfahan, Iran", Environ Geol ,2005,Volume 47,pp 493–500.

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