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Delineation of groundwater recharge potential zones using weighted linear combination method (case study: Kuhdasht plain, Iran)

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Abstract

Extracting groundwater resources in Kuhdasht plain in west of Lorestan province as a suitable and available resources of water for agricultural usage, has been led to decline in groundwater level and reservoir storage, changes in water quality, land subsidence and etc. Artificial recharge plans are one of the alternatives to deal with aforementioned challenges. Present study has been reached with the aim of locating prone areas for artificial recharge plans in Kuhdasht plain. Accordingly, seven layers including lithology, slope, elevation, fault density, stream density, land use, and alluvial thickness were weighted using a weighted linear combination (WLC) method. Finally, extracted map of overlapping these layers using WLC method was classified to five potential classes including 'very high' (31.45% of the area), 'high' (38.94%), 'moderate' (18.43%), 'low' (6.08%) and 'very low' (5.1%).

Keyword: Groundwater, Artificial Recharge, Artificial Neural Network, KuhdashtPlain

1. Introduction

In the past, extraction of groundwater resources was limited to springs, qanats and hand-digging wells. Today, with the access to technology of digging deep wells, withdrawal of groundwater resources has been increased, so that easy access to the groundwater resources has been led to some problems such as water table drawdown, decrease in storage, degradation of groundwater quality or aquifer contamination. For dealing with such problems, artificial recharge methods can be applied to decrease drawdown and revitalize the aquifer storage (Ebrahimi et al. 2011).

In recent years, decreasing in groundwater level of Kuhdasht aquifer (about 12 meters) reveals the need for present study. Therefore, the main aim of this study is locating the suitable areas where is prone to artificial groundwater recharge of Kuhdasht aquifer using a weighted linear combination (WLC) method. So far many studies have been done in this field in Iran and other parts of the world, including:

Mousavi et al. (2008) studied the suitable areas for groundwater recharge using remote sensing and GIS in the southern part of Izeh plain in southern of Iran. Results showed that the areas with fractures in the limestone formations had the greatest potential. Ataeezadeh and Chitsazan (2008) investigated the feasibility of artificial recharge using GIS techniques in Maydavod-Daloon plain in Khuzestan province. In this study, map of recharge potential zones extracted and a weighted index overlay method has been applied. Mahdavi et al. (2011) investigated locating of prone areas for groundwater artificial recharge by applying a fuzzy logic method in Shahrekord catchment. The results of combination of layers such as slope, soil permeability, aquifer thickness, chemical water quality, land use, and drainage network showed that about 5 percent of the area lies in suitable for artificial recharge of aquifer.

Shankar Mohan (2005) studied the prone artificial recharge areas using parameters such as drainage pattern, slope, drainage density, lineament, water table fluctuation, and land use in Dakan in western Douglas County, Colorado, United States. Yeh et al. (2008) delineated the groundwater artificial recharge zones using remote sensing and GIS in Chih-Pen catchment in Taiwan. Chowdhury et al. (2010) applied GIS and remote sensing data for locating artificial recharge zones in West Medinipur district, West Bengal. They used 5 factors (geomorphology, stream density, slope, and transmissivity) to extract the recharge potential map of the area and results showed that 46 percent of the area had the suitable potential for groundwater artificial recharge plans. Radhakrishnan and Ramamoorthy (2014) presented

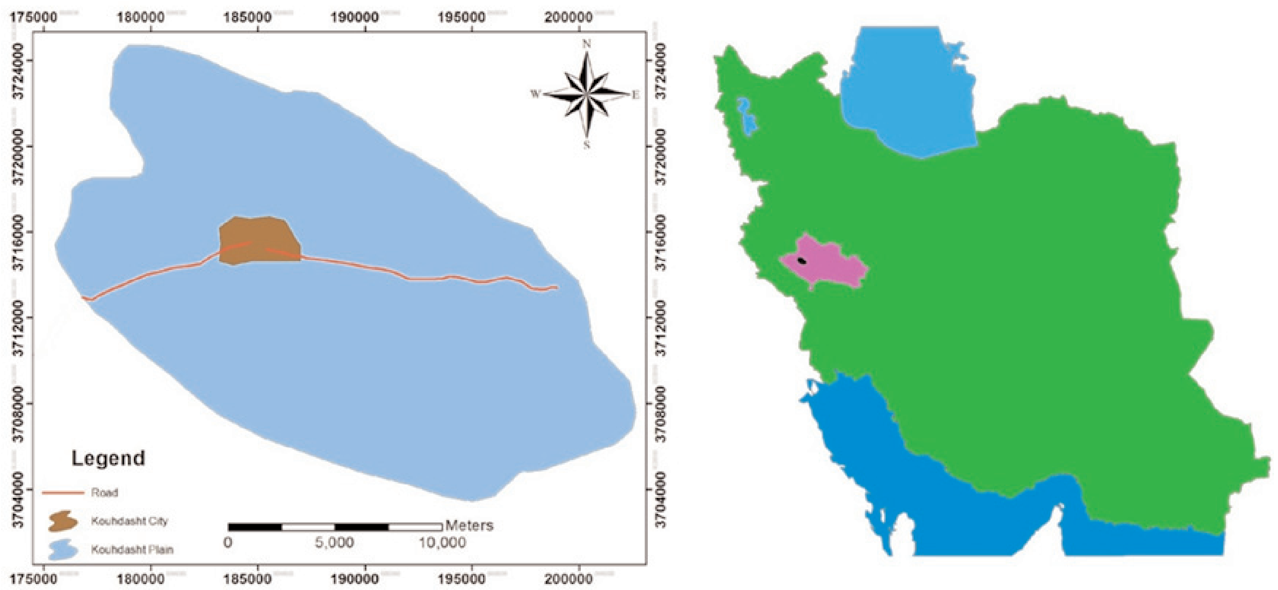

Figure 1. Geographical location of Kuhdasht plain

the prone zones for groundwater artificial recharge using remote sensing data and GIS in Mailam Block, Villupuram district in India.

2. Study area

Kuhdasht plain, one of sub-basin areas ofKashkan river, is located 80 km west of Khorramabad with an average height of 1362 m above sea level. The main roads of the study area in clude Khorramabad-Kuhdasht road in the eastern parts of area and another road that enters the plain and connects Kuhdasht city to Eslamabad-Poldokhtarroad (Fig. 1).

3. Materials and methods

3.1. Effective factors in choosing suitable zones for artificial recharge

In this study, the map of each effective factor in locating appropriate zones for artificial recharge based on hints such as target, regional conditions, the impact of each factor and the availability of adequate information has been prepared as follows:

Aquifer thickness: Aquifer thickness map has been obtained using interpolation between 31 points of vertical electrical sounding data.

Lithology: Rock type and properties of each type including texture and purity play important roles in changing hydraulic properties of rocks such as porosity, initial permeability, and groundwater flow into the lower layers. In this study, lithological units have been prepared using geological map of Khorramabad (1: 250,000), Landsat ETM + images and field surveys.

Land use: Land use map has been extracted using TM satellite data and interpretation of NDVI Index. This map has been verified by field surveys.

Faults: Acting of faults on geological units and formations can increase secondary porosity and makes the units permeable for water flow through the units towards the lower parts, leading to facilitate aquifer recharge. In order to prepare the fault layer geological maps, aerial photos and filtered band 7 of ETM + sensor were used.

Slope: Smoother slopes result in slower runoff or greater percolation, concluding greater recharge (Sabery et al. 1391). The slope map extracted from digital elevation map (DEM) of topographic map using Arc GIS.

Stream: In order to provide map of distance from streams, stream networks have been extracted from topographic map and digitized in Arc GIS environment.

Elevation: Elevation is one the topographic factors that plays an important role in producing runoff and infiltration rate into the ground. The classified elevation map is provided from digital elevation map (DEM).

3.2. Weighted linear combination (WLC) method

In present study, the weighted linear combination (WLC) method has been applied for investigating prone areas of artificial groundwater recharge. First each layer is standardized using a fuzzy method. Then, a weight is given to each layer using analytic hierarchy process and pair-wise comparison methods. Finally, all weighted layers integrate to extract the potential map of artificial recharge zones in interest area.

3.2.1. Standardization

It is necessary that each criterion be saved as a separate map in GIS database by defining the set of criteria for evaluating decision options. For measuring qualities, a variety of scales can be used. Accordingly, it is necessary that values in different layers of the map fit together and become comparable units. By doing this operation, we will have comparable standard maps. Fuzzy method is one of the standardization methods. Fuzzy operations take the inputs and give a relevant grade to each of them by the relative membership functions.

Membership function can be defined as the degree of elements belonging of the reference set to its subsets, showed as c (X)μ . There is no a specific algorithm to obtain the membership function but experience, innovation, and even personal opinion can be effective in forming and defining the membership function. In present study, maps of effective factors in groundwater artificial recharge of Kuhdasht plain have been converted to fuzzy map using three membership operation functions, including Linear, Gaussian and User defined.

3.2.2. Weighting factors using Analytical Hierarchy Process (AHP)

In AHP method, oral judgments (expert opinion) based onpair-wise comparisons are used to determine the priority of factors and convert them into quantities. So that the decision maker can investigate preference of a factor than other, as it has shown in Table 1 and converts theses judgments into quantities between 1 to 9 values. Finally, the results of these comparisons import to Expert Choice software to calculate the incompatibility index. If the calculated index is less than 0.1, the results are acceptable; otherwise weighting should be reinvestigated.

4. Results and discussion

In order to prepare the potential map of prone sites for artificial recharge in the study area, schematic maps of each of the contributing factors has been prepared and classified. The results of review of each layer are as follows:

The aquifer thickness map shows that north western and western parts of the region can act as a good storage for artificial recharge plans due to having high thickness (Fig. 2).

Table 1. Fundamental scale for pair-wise comparisons (Saaty and Vargas, 2001)

Description	Dominant value
Equal importance	1
Moderate prevalence of one over another	3
Strong or essential prevalence	5
Very strong or demonstrated prevalence	7
Extreme high prevalence	9
intermediate values	2,4,6,8

From geological point of view, Kuhdasht plain has a variable lithological units (Table 2). Distribution of geological units in this area (Fig 3). shows that a large part of the area is covered by recent alluvial deposits which could create the potential for storage of water. In addition, Kashkan formation with lithology of conglomerate and sandstone covering eastern and north-western parts of the area could also help to transport water to the lower layers. It should also be noted that hard formations including fine particle size and high density with lithology of marl and shale, such as Gurpi and Gachsaran formations have a low hydraulic properties and lie in category of regions

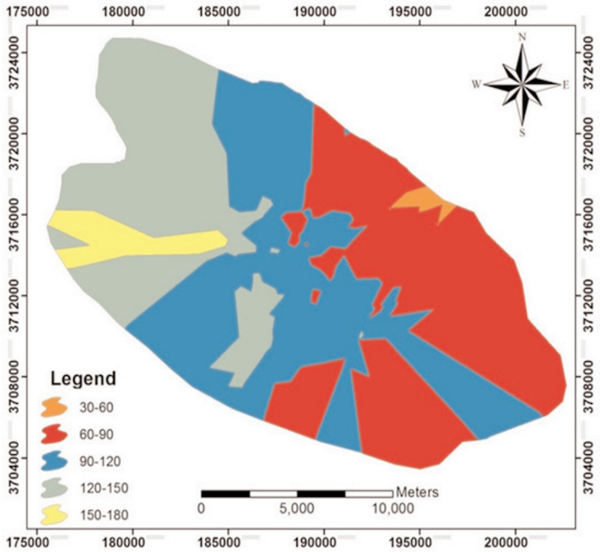

Figure 2. Alluvial thickness in Kuhdasht plain

Table 2. Geological formation properties in Kuhdasht plain

Formation	Lithology
Gurpi	Gray marl, Shale and Marly limestone
Amiran	Siltstone, Sandstone, Conglomerate and Shale
Talezang	Gray to brown limestone with layering
Kashkan	Conglomerate, Sandstone and red siltstone
Asmari-Shahbazan	Cream to brown limestone, Dolomitic limestone and Sugary dolomite
Gachsaran	Alternation of gypsum, anhydrite, marl and salt
Alluvial	Gravel, sand and clay

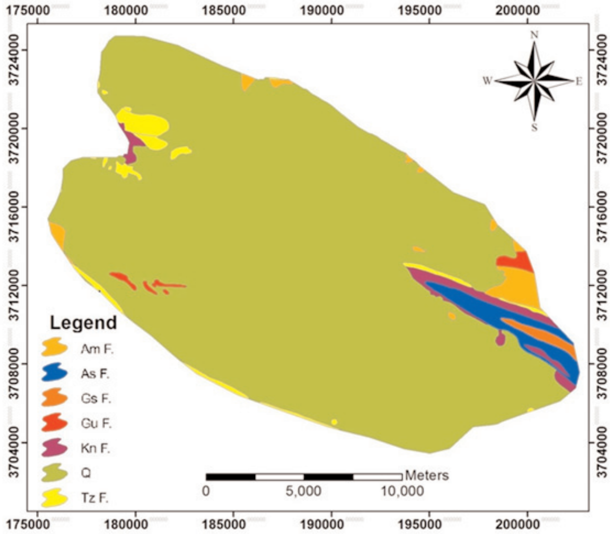

Figure 3. Geological units in Kuhdasht plain

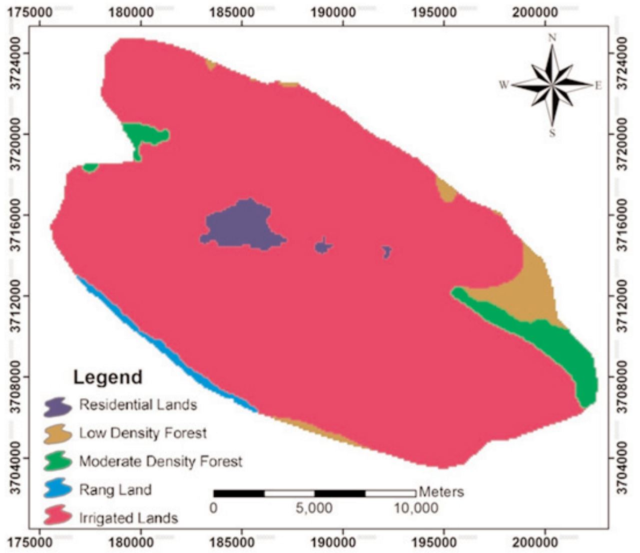

Figure 5. Land use map of Kuhdasht plain

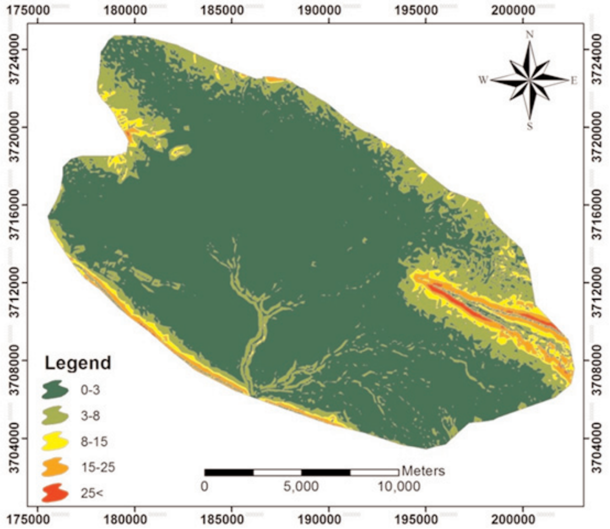

Figure 4. Slope map of Kuhdasht plain

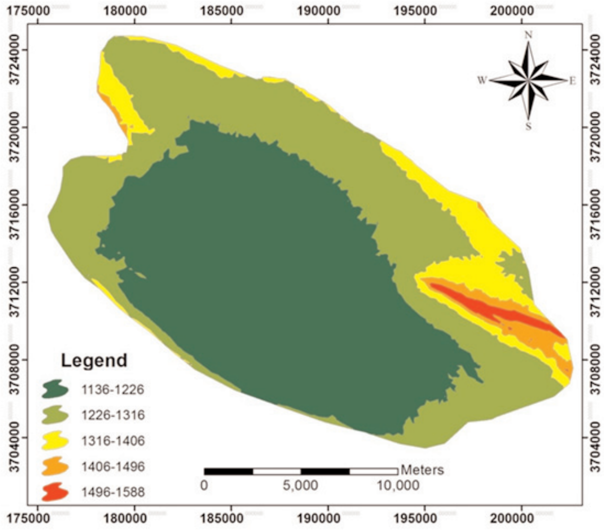

Figure 6. Classified topography map of study area

with least hydraulic parameters for yielding and storage of water.

Smoother slopes result in slower runoff or greater percolation; nevertheless, the higher percentage of slope engenders rapid runoff with feeble recharge potential. Based on Fig. 4, the most parts of the area have been covered by a slope of lower than three degrees and have a high potential for artificial recharge plans.

The land use map shows that a large part of the area is covered by agricultural land. Because of high permeability, this part can provide a large area for artificial recharge plans in Kuhdasht aquifer (Fig. 5).

The elevation map of study area (Fig. 6). shows that the elevation range of 1226 m to 1316 m makes a belt that form the outer parts of the plain. By inserting the artificial recharge zones in this area, water can flow along the hydraulic gradient towards the center of the plain.

As shown in Fig. 7., it is clear that the surface flow and stream networks finally concentrate in the center of plain that has the lowest elevation. It means that closer and denser streams recharge groundwater more and produce higher potential groundwater zones.

Fault density of an area indirectly reveals the groundwater recharge potential of that area since the presence of faults usually denotes a permeable zone. Areas with higher fault density are good for potential of groundwater artificial recharge. However, numbers of faults in Kuhdasht plain are limited and have been located in the fine and low permeability sediments. So, fault density map of Kuhdasht plain has a lower role in locating zones of groundwater artificial recharge (Fig. 8).

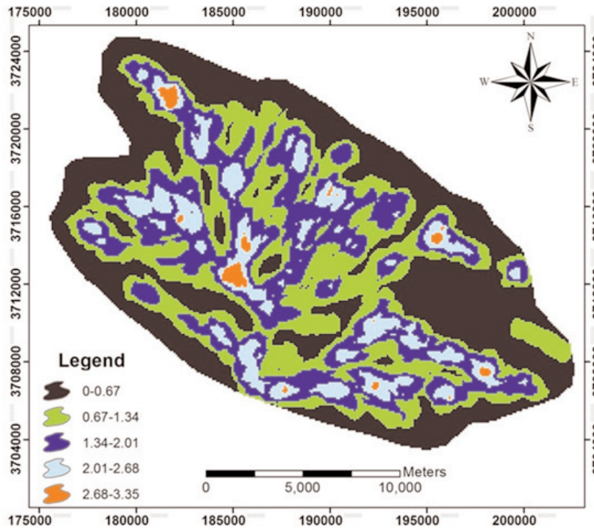

Figure 7. Stream density map of study area

After preparing different maps, layers will be standardized using fuzzy method. Notice should be given in the selection of fuzzy function types to standardize the layers. For example, increasing (ascending) or decreasing (descending) function type can be used. In this study, layers of alluvium thickness, fault density and stream density standardized by increasing linear function. Slope layer and topographic layer standardized by decreasing linear function and user defined function, respectively. After standardization, to each layer should give a proper weight because of different effects of different layer on the final map of artificial recharge areas. For weighting, the hierarchical analysis method is used. First layers are mutually compared (table 3) by pair-wise comparison method (table 1), then the results are imported to Expert choice software for calculating the weights of each factor. The results of incompatibility coefficient showed that the compar-

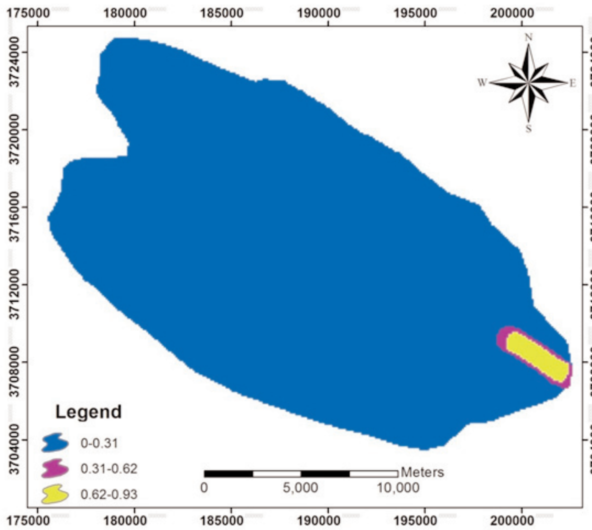

Figure 8. Fault density map of Kuhdasht plain

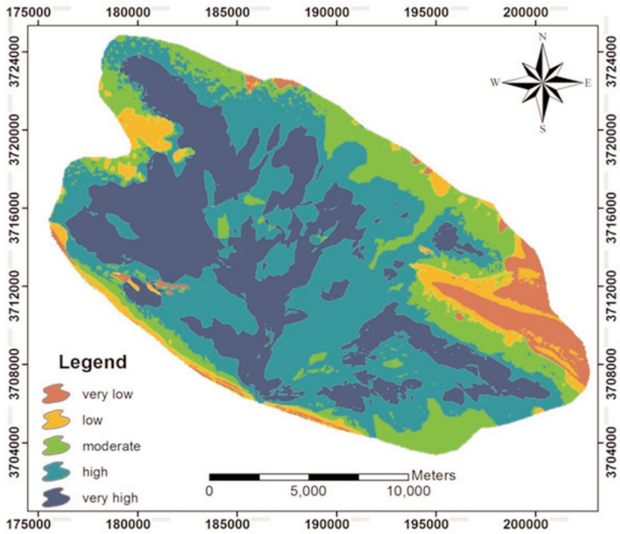

Figure 9. Suitable areas for groundwater artificial recharge in Kuhdashtplain

Table 3. Pair-wise comparisons of factors affecting on locatingsuitable areas for artificial recharge inKuhdasht plain

	Litology	Slope	Drainage density	Thick alluvium	Landuse	Elevation	Fault density	weighte	Inconsistency
Litology	1	2	2	3	4	4	**5**	0.311	
Slope		1	1	2	3	3	4	0.193	
Drainage density			1	2	3	3	4	0.193	
Thick alluvium				1	2	3	3	0.125	
Landuse					1	1	2	0.069	
Elevation						1	2	0.066	**0.01**
Fault density							1	0.044	

isons have been done correctly (Table 3).

In order to preparing final map of suitable area for artificial groundwater recharge in Kuhdasht plain, the WLC method has been applied and fuzzy map of each layer multiplied by the weights which obtained from AHP method. Finally, maps of all factors have been overlapped. Final map of locating artificial recharge areas (Fig. 9). was classified to five potential classes including 'very high' (31.45% of the area), 'high' (38.94%), 'moderate' (18.43%), 'low' (6.08%) and 'very low' (5.1%).

5. Conclusion

Artificial recharge plans can be used as an alternative to deal with groundwater level drawdown, subsidence, changes in water quality and etc. Therefore, this study has been done with the aim of locating prone areas for groundwater artificial recharge plans in Kuhdasht plain using seven layers including lithology, slope, elevation, fault density, stream density, land use, and alluvium thickness. Finally, extracted map of overlapping these layers using WLC method was classified to five potential classes including 'very high' (31.45% of the area), 'high' (38.94%), 'moderate' (18.43%), 'low' (6.08%) and 'very low' (5.1%). Based on the results, area with very low potential lies in Asmary, Amiran, Talezang and Gurpi formations with low hydraulic parameters because of their practical sizes and no appropriate for artificial recharge plans. Also, area with very high potential locates in recent deposits with high hydraulic parameters and having high weights of other parameters (slope, alluvium thickness, land use and …) make this area suitable for applying artificial recharge plans.

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