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Assessment and analysis of groundwater reservoir suitability for drinking purpose using GIS based multi criteria decision approach, a case study of Faisalabad City

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Abstract

Industrialization is the major phenomenon due to high trend of urbanization in many developing and under developed countries. Growing demands of the population in urban areas lead to settle out the various industries. So, these industries not only improve the socio economic development in the area on one side but also have a lot of adverse environmental impacts by degrading its quality. This study also focuses on these adverse impacts of such industries on our groundwater reservoirs. For the purpose, land suitability analysis was performed for drinking purpose in an industrialized City Faisalabad. GIS based Multi Criteria Decision Approach was applied and various criteria were set as EC, pH, TDS, TH, CA, Mg, Bicarbonates, Na and chlorides for analyzing the drinking quality. An Analytical Hierarchical Process was used for ranking the suitability factors. Suitability map layers were constructed using resulting weights. Weighted sum overlay in ARC GIS 10.2 was used to construct the land suitability maps for drinking quality of groundwater reservoir. Only 2.91 % of total area was found highly suitable, 36% in moderately suitable, 35% marginally suitable and 26% not suitable for drinking purposes which indicate that groundwater reservoir of the study area has highly been contaminated by the hazardous waste released by these industries.

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Introduction

Water is the constituent part in many industrial procedures and products and is used in heating, cooling and specially steam generation (WWAP, 2006).Basically heavy metals are present in the natural state of water but they are harmful and considered toxic when exceeded in body from the prescribed limit. So there are many physiochemical parameters that are useful to determine the quality of water (Siddiqui and Sharma, 2009). Nature of industrial discharges and effluents consists of toxic and dangerous material that is unhealthy and harmful for human beings (Ogunfowokan *et al.*, 2005; Gana *et al.*,2008). These chemicals may be in form of heavy metals like mercury, chromium, lead etc., organic chemicals of toxic in nature as pesticide, hydrocarbons, dioxins, phenolic compounds and petrochemicals (Rao *et al.*, 1998; Njoku *et al.*, 2009; Gbadebo *et al.*, 2010). This polluted water causes harmful effects even death toll is increasing in poor and developing countries. 30,000 people/ day are dying due to water related diseases. WHO survey shows that almost 80% of all illnesses are due to poor water quality in poor countries. Moreover, ¼ of born children die due to water related diseases in poor and developing countries (Taj *et al.* 2013). Estimation shows that almost 80% diseases of all are caused by poor water quality and unhygienic situation(Olajire and Imeokparia, 2001; Vasanthavigar *et al.*, 2012).

In exploring and solving the complicated problems, MCE is considered the useful tool that can be utilized. (Jeong *et al.*, 2013). To generate the common output of various alternatives in relation with the various perspectives and priorities, MCE is capable to evaluate these alternatives quantitatively by representing decision making analysis based on decision science theory (Barfod *et al.*, 2011; Convertino *et al.*, 2013). Various studies (Koschke *et al.*, 2012; Convertino *et al.*, 2013) have used MCA to assess the spatial distribution of environmental problems, whereas others have combined the MCA with cost-benefit analysis (Barfod *et al.*, 2011; Gühnemann *et al.*, 2012). All MCA analyses have a common pattern: define the alternatives to be ranked, identify the criteria that will influence the outcome, assign "weights" to the criteria and normalize them, and determine the final values (Convertino *et al.*, 2013). Uncertainties exist with respect to the impact levels and weights, but in most cases, neither the time nor resources exist to follow the full construction of the model (Gühnemann *et al.*, 2012). The assessment criteria are chosen to a greater or lesser extent by how well they relate to the functional and livable dimensions of land uses (Gühnemann *et al.*, 2012; Sze and Sovacool, 2013). The MCA is employed in land-use conflicts analysis to classify the risk levels of significant impacts on the affected area (Helbron *et al.*, 2011) inthe establishment of public policy contexts (Kowalski *et al.,* 2009) or as applied to conflict resolution (Kamruzzaman and Baker, 2013).

This study develops and identifies those areas of FSD City that are prone to groundwater contamination for local population due to industrial adverse impacts. Main objective of the current project was to develop a tool for drinking water quality parameters into comprehensive strategies for industrial panning. Objectives of the present study has been categorized as follows, i) to set the indicators/parameters that defines the drinking water quality that remains useful for evaluating the groundwater contamination due to industrial impacts. ii) Integration of these indicators/parameters into multi criteria assessment. iii) To identify high incidence of groundwater contamination due to industrial adverse impacts on the groundwater natural resource.

Materials and methods

Study area

Faisalabad geographical location lies between 30°42' and 31°47' North latitudes and 72°40' and 73°40' East longitudes(Cheema *et al.*, 2006).Its relative location bounds Faisalabad by Nankana Sahib in the East, Jhang in the West, Okara in South East, Sahiwal and Toba Tek Singh in the South and Hafizabad and Chiniot in the North. Here the sun rays do not slant much, especially in the summer therefore high temperature prevails during the summer months. Many scientists have predicted that rising global temperatures are making our weather and climate not only warmer, wetter and windier but also more unpredictable and violent (Rajindra and achauri, 2005). In Faisalabad, rainfall does not occur throughout the year, most of the rainfall occurs in two seasons namely summer, from July to September and winter, from December to March. Winter rainfall accompanies the western disturbances. A small quantity of rainfall occurs during thunderstorms (dry summer & calm interval) (Cheema *et al.*, 2006) (Fig. 1).

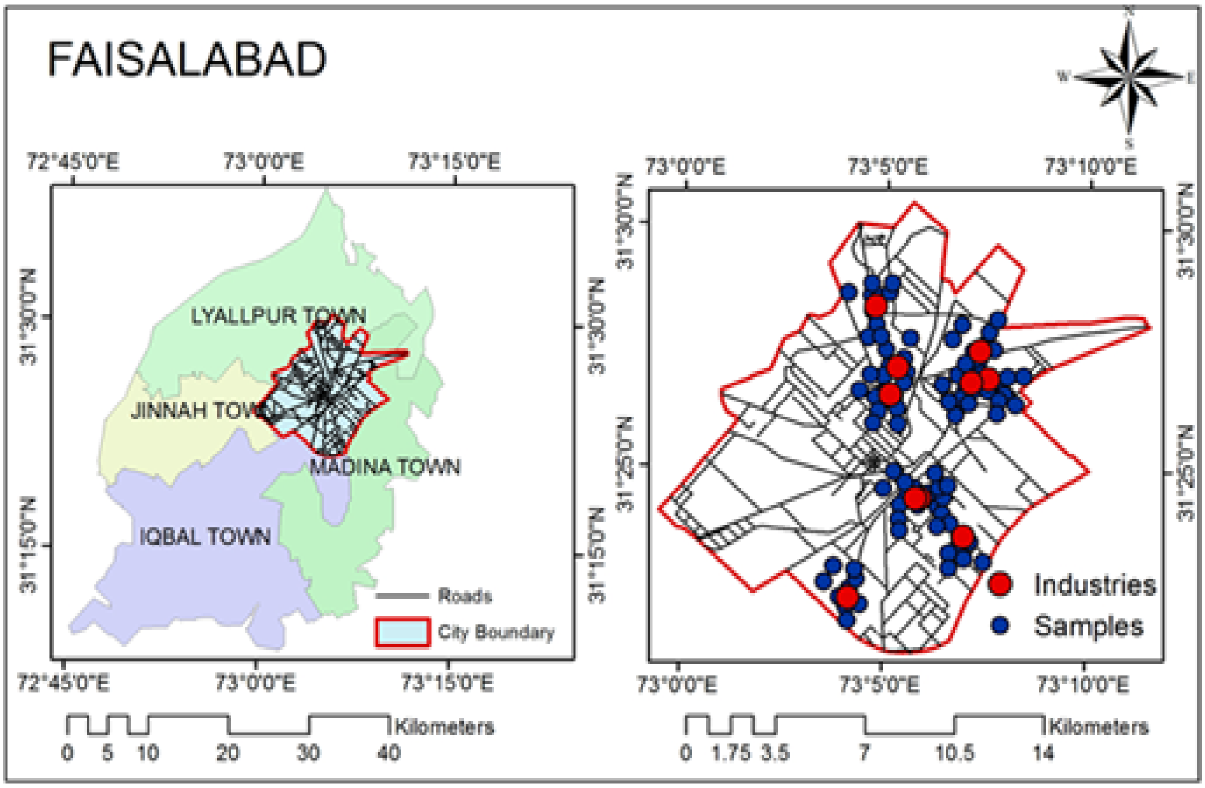

Fig. 1. Map of study area showing the location of industries and all collected water samples.

Methodology

Multi criteria analysis

Decision making through MCDM helps us to relate and transmutes a set of geographical data input into an output resultant decision (Drobne and Lisec, 2009).The type of decision making problem with geographical nature is to consider different alternatives and number of incompatible and unequal criteria. Numbers of real life spatial problems make Multi criteria decision making (MCDM) and geographic information system (GIS) more important. In the process of MCDM each criteria is given a specific weight and that specific weight represent the genuine and real importance of that criteria. (Chow & Sadler, 2010) The importance of criteria under study depends on, how criteria are compared with their alternative and the weight that is given to that criteria (Al-Mashreki *et al.*, 2011). The criteria under study in this MCDM approach are EC, PH, TDS, TH, Ca, Mg, Na, Cl and bicarbonates. Which we used to find out the ground water suitability for drinking purpose.

Data collection

Ten industries of the city were selected to be analyzed and judged for ground water contamination. By using random sampling, required industries were selected for each relative industrial sector by getting the list of all industrial units from "Chamber of Commerce and Industry FSD". After the final selection of industries, work on the collection of groundwater samples was initiated via field survey. Convenient sampling was applied and these samples were collected by conveniently available electric pumps as well as hand pumps. Sample size was'100' allotted equally to each industry i.e. 10 samples for each industry. Locations of all the places were noted using GPS in the process of data collection. Analyzing and checking of these samples were done in WASA laboratory. They used different chemical test for the quality inspection of drinking water by quantifying number of chemical parameters like EC, TDS, Ca, Cl, Ph and bicarbonates.

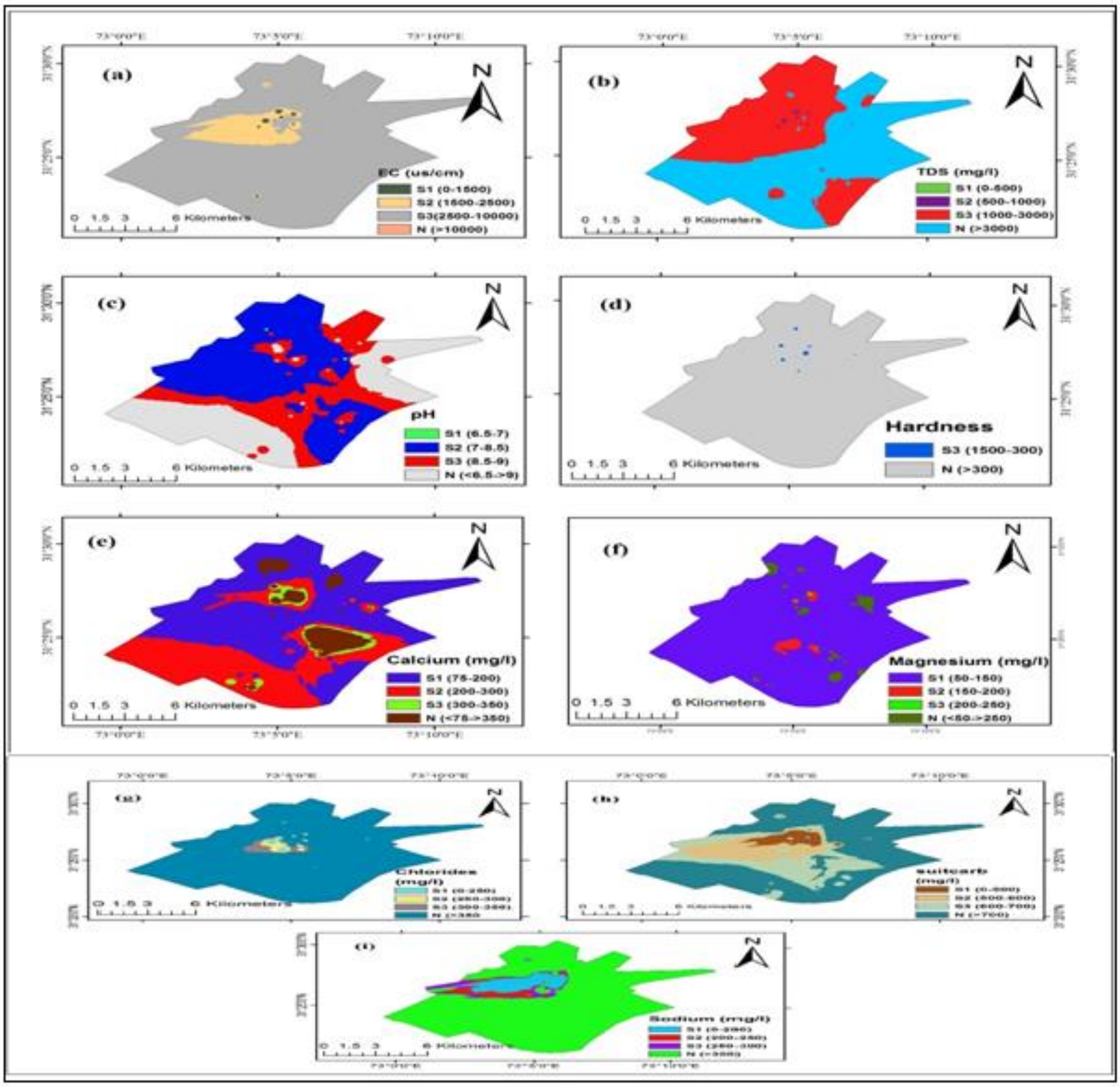

Fig. 2. Maps of all criteria's showing the suitability levels.

GIS layer development

GIS layer is created after spatial and non-spatial data collection. Layer for each criteria is created using IDW in Arc GIS 10.2. On the basis of literature, experts knowledge and authors experience, suitability levels were assigned to each criteria (Table 1).

After applying the IDW the layer is reclassified using Reclassify tool in Arc GIS 10.2 in accordance with the suitability orders which is the base for the creation of the criteria maps.

The suitability levels for each factor were ranked as: Highly suitable-S1, Moderately suitable-S2, Marginally suitable- S3, Not suitable-N (Fig. 2).

Analytical hierarchy process (AHP)

The most reliable MCDM method is AHP which is widely accepted and used by researchers in real and ideal mode(Triantaphyllou and Mann, 1995).What makes decision making methods more significant than other is the precise judgment of the relevant data.

The weights of alternatives are determined in most of the decision making method in term of criteria which is under study in given decision making problem. Most of the researchers get attracted by the pair wise comparison introduced by Saaty, 1980.

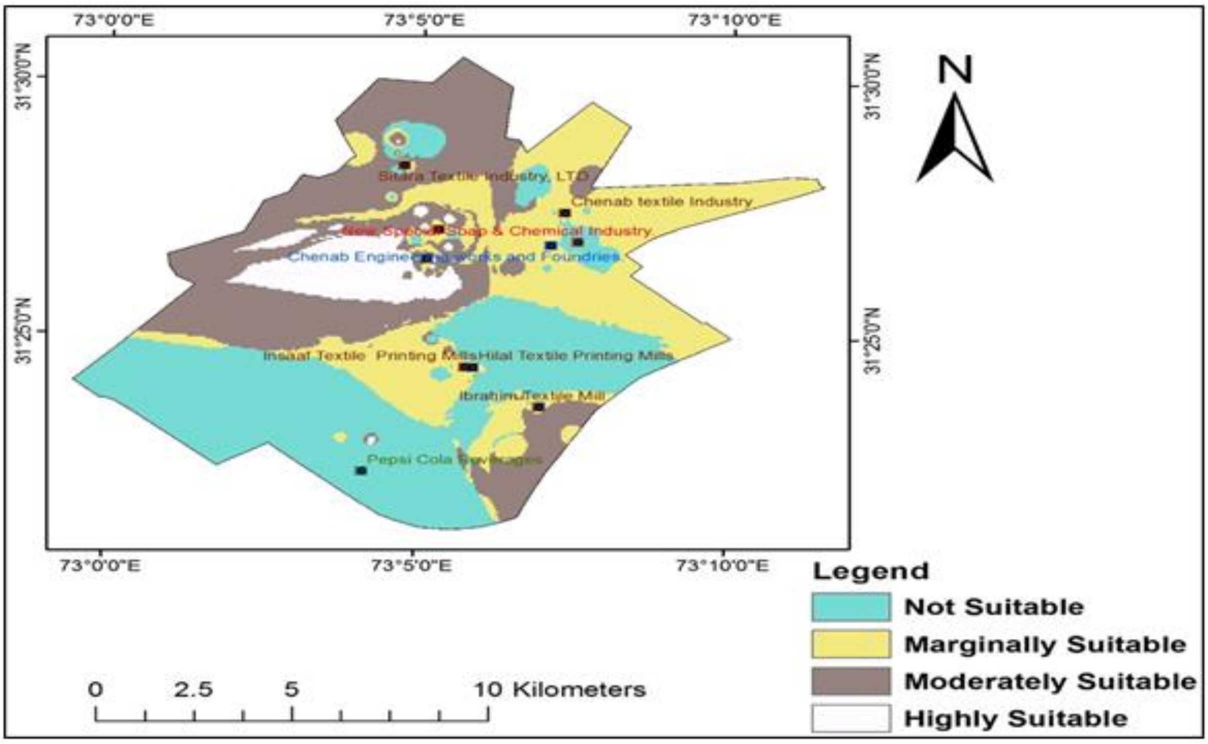

Fig. 3. Final land Suitability map of groundwater reservoir for drinking purpose.

The weights are calculated by comparing factors at a time with help of pair wise comparison matrix (PCM). A scale was introduced according to which values of Pair wise comparison in AHP are determined according to that scale. If we focus on scale, available values for comparison are members of set (9, 8, 7, 6, 5, 4, 3, 2, 1, ½, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9)(Saaty, 1980)(Table 2).

The nine indicate that row factor is more important than column factor and a rating of 1/9 shows column factor is more important than the row factor (Mustafa *et al.*, 2011).

1' is given when both the factors are equal importance. Using PCM, AHP calculate weight for each criterion and then normalized the sum equal to unity using Eigen vector which indicates the largest Eigen value of matrix (Table. 2).

Standardization of criteria using AHP

The general ordinal scale as (S1, S2, S3 and N) is being used to show criteria map in land suitability. Keeping in view the necessities of drinking purpose, these ordinal scale has been used to show suitability of one attribute class from other according to the requirements of water drinking quality (Sehgal, 2014).

For more analysis, we rate all the classes to show importance to particular criteria for the final goal.

Importance of one class from other is compared within single criteria.

The process of relative importance for all the criteria is the "Standardization of Criteria" (Prakash, 2003). This process of standardization uses different scale .i.e. 0-1 or 0-10 or 0-100. To standardize the ordinal values, PCM (pair wise comparison) technique is usually applied. In our case of study, pair wise comparison using ideal AHP was applied for rating the ordinal values of suitability classes (Table 3) (Prakash, 2003).

Assessing weights using AHP

Not all the factors are equally important for any analysis; same is the cause with drinking suitability analysis. There is a need to compare the importance of factors with each other .i.e. how much pH is important than calcium? So we need collection of events and algorithms which will organize decisional hurdles and will design, evaluate and rank the alternative results. MCDM is the process which provides us all these things. AHP (analytical Hierarchical Process) is a common and well known technique for various types of MCDM processes that has been assimilated to suitability procedures in GIS (Marinoni, 2004).

Then each factor was compared and given specific value. Scale introduce by Saaty is used for the determination the values of pair wise comparison.

In this cause of study given weights are based on local expert opinion and other researchers work. PCM (pair wise comparison) matrix has been shown in Table 5.

Factors with value "1" are those which are compared with it. After normalization of PCM matrix (Table 5), the weights for each criterion were determined (Table 7).

The consistencies are very important of these factors derived from PCM method. To indicate the probability of matrix judgments about the randomly creation, CR is used (Saaty, 1977; Park *et al.*, 2011).For this, consistency ratio (CR) is checked after normalization of PCM.

CR= CI/RI

CI=λ-n/n-1

Where: Lambda (λ) is the Maximum Eigen Value

CI: Consistency Index

CR: Consistency Ratio

RI: Random Index, which is the average of the resulting consistency index depending on the order of the matrix given by Saaty.

n: The numbers of criteria or sub-criteria in each pairwise comparison matrix.

A CR of "0.10" or less points to the sensible levels of consistency showing that the weights are properly chosen. In our study, the CR is 0.03 which tells comparison of water characteristics are consistent and chosen weights were properly derived (Table 4,5,6& 7).

Overlay analysis

To produce the final suitability map of groundwater reservoir for drinking purpose, weighted sum overlay was utilized in Arc GIS 10.2. Weighted Overlay is a technique that is used for putting the dissimilar and miscellaneous datasets into one common scale for the purpose of integrated analysis (Kuria *et al.*, 2011). Illustrating the water suitability, various map layers were assigned the weights by using AHP process. A decision matrix was established after that.

Basic function of the Weighted Sum Overlay is that the cell values of each input raster dataset get multiplication with the weight of raster (criteria weight). As a result of it, a final output raster (suitability map) is generated by adding the resulting cell values. Results can be examined in Table 9 and final suitability map for groundwater suitability for drinking purpose has been presented in Figure 3.

This suitability map can be considered as the best product in context of suitability of groundwater reservoir in FSD city. This final map has been classified in four suitability classes of groundwater reservoir for drinking purpose that are Highly

Suitable for drinking, Moderate Suitable for drinking, Marginal Suitable for drinking and Not Suitable for drinking (Table 8 & 9) (Fig.3).

Results and discussion

MCDM has been proved as an adequate and important tool to identify the suitability zones for groundwater in terms of its suitability levels by quantifying various parameters under consideration.

Table 1. Suitability classes of all criteria for drinking purpose.

Criteria	Suitability Classes			
	S1	S2	S3	N
EC (us/cm)	0-1500	1500-2500	2500-10000	>10000
TDS (mg/l)	0-500	500-1000	1000-3000	>3000
pH	6.5-7	7-8.5	8.5-9	<6.5->9
Hardness (mg/l)	0-75	75-150	150-300	>300
Ca (mg/l)	75-200	200-300	300-350	<75->350
Mg (mg/l)	50-150	150-200	200-250	<50->250
Cl (mg/l)	0-250	250-300	300-350	>350
Bi-car (mg/l)	0-500	500-600	600-700	>700
Na (mg/l)	0-200	200-250	250-300	>300

Table 2. Scales for AHP pairwise comparison. Source: Saaty (1980).

Intensity of Importance	Description
1	Equal importance
3	Moderate importance
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Extreme importance
Reciprocals	Values for inverse comparison

Table 2. Rating of criteria classes using PCM (ideal AHP).

Criteria	Suitability classes			
	S1	S2	S3	N
EC	1	0.5	0.35	0.15
TDS	1	0.4	0.25	0.09
pH	1	0.2	0.17	0.08
Hardness	1	0.4	0.25	0.05
Ca	1	0.3	0.2	0.12
Mg	1	0.3	0.2	0.06
Cl	1	0.5	0.39	0.17
Bi-car	1	0.7	0.3	0.15
Na	1	0.5	0.2	0.05

Suitability map for drinking purpose of groundwater reservoir in the case study area generated by weighted sum overlay in ARCGIS 10.2 has been presented in Fig. 3. Four Suitability classes of reservoir have been presented in final map. Results shows very clearly that highly suitable drinking water covers an area of 9.96 ha that is only 2.91 % of the total.

Table 3. Random Index (RI).

Order Matrix	RI	Order Matrix	RI
1	0	6	0.24
2	0	7	0.32
3	0.58	8	0.41
4	0.9	9	0.45
5	0.12	10	0.49

Table 5. Pairwise comparison matrix (PCM) of selected criteria.

	EC	TDs	pH	Hardness	Ca	Mg	Cl	Bi-car	Na
EC	1	3	4	4	5	6	6	7	9
TDS	1/3	1	2	2	3	4	4	5	7
pH	1/4	1/2	1	1	2	3	3	4	6
Hardness	1/4	1/2	1	1	2	3	3	4	6
Ca	1/5	1/3	1/2	1/2	1	2	2	3	5
Mg	1/6	1/4	1/3	1/3	1/2	1	1	2	4
Cl	1/6	1/4	1/3	1/3	1/2	1	1	2	4
Bi-car	1/7	1/5	1/4	1/4	1/3	1/2	1/2	1	3
Na	1/9	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1

Table 6. Conversion of value from fraction to decimals.

	EC	TDS	pH	Hardness	Ca	Mg	Cl	Bi-car	Na
Ec	1.00	3.00	4.00	4.00	5.00	6.00	6.00	7.00	9.00
TDS	0.33	1.00	2.00	2.00	3.00	4.00	4.00	5.00	7.00
pH	0.25	0.50	1.00	1.00	2.00	3.00	3.00	4.00	6.00
Hardness	0.25	0.50	1.00	1.00	2.00	3.00	3.00	4.00	6.00
Ca	0.20	0.33	0.50	0.50	1.00	2.00	2.00	3.00	5.00
Mg	0.17	0.33	0.33	0.33	0.50	1.00	1.00	2.00	4.00
Cl	0.17	0.25	0.33	0.33	0.50	1.00	1.00	2.00	4.00
Bi-car	0.14	0.20	0.25	0.25	0.33	0.50	0.50	1.00	3.00
Na	0.11	0.14	0.17	0.17	0.20	0.25	0.25	0.33	1.00
	2.62	6.26	9.58	9.58	14.53	20.75	20.75	28.33	45.00

This area is in proximity of Chenab Engineering works and Foundry that indicates that machinery sector has the lowest proportion of pollution in the natural resource. Highly suitability class (S1) was identified by : EC 0-1500, TDS 0-500, pH 6.5-8.5, Hardness 0-75, Calcium 75-200, Magnesium 50-150, Chlorides 0-250, Bicarbonates 0-500 and Sodium 0-200 (Fig.2).These values for highly suitability were set by experts and literature. Table '9' clearly indicates that majority of the area is in under the category of S2 (Moderately Suitable) for drinking. This class covers an area of 123.83 ha that is 36% of the total.S2 class was characterized by: EC1500-2500, TDS 500-1000, pH 7-8.5, Hardness 75-150, Calcium200-300, Magnesium 150-200, Chlorides 250-300, bicarbonates 500-600 and Sodium 200-250(Fig. 2).Approximately similar part covers the suitability class of S3 (Marginal Suitable) that occupied the area about 121.67 ha i.e. 35.56% of the total(Table 9). Last suitability class N (Not Suitable) covers an area of 25 % of the total i.e. 87.29 ha of the study area is completely unsuitable and unhygienic for drinking purpose.

Table 7. Normalized pairwise comparison matrix determination and computation of criteria weights.

	EC	TDS	pH	Hardness	Ca	Mg	Cl	Bi-car	Na	Total	Weight
Ec	0.38	0.48	0.42	0.42	0.34	0.29	0.29	0.25	0.20	3.06	0.34
TDS	0.13	0.16	0.21	0.21	0.21	0.19	0.19	0.18	0.16	1.63	0.18
pH	0.10	0.08	0.10	0.10	0.14	0.14	0.14	0.14	0.13	1.09	0.12
Hardness	0.10	0.08	0.10	0.10	0.14	0.14	0.14	0.14	0.13	1.09	0.12
Ca	0.08	0.05	0.05	0.05	0.07	0.10	0.10	0.11	0.11	0.71	0.08
Mg	0.06	0.05	0.03	0.03	0.03	0.05	0.05	0.07	0.09	0.48	0.05
Cl	0.06	0.04	0.03	0.03	0.03	0.05	0.05	0.07	0.09	0.46	0.05
Bi-car	0.05	0.03	0.03	0.03	0.02	0.02	0.02	0.04	0.07	0.31	0.03
Na	0.04	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.17	0.02
											1.00
										λmax	9.30
										CI	0.04
										CR	0.02

Table 8. Decision matrix of criteria weights and rating of suitability classes.

		Rating of Suitability classes			
Criteria's	Weight of Criteria's	S1	S2	S3	N
EC	0.34	1	0.5	0.35	0.15
TDS	0.18	1	0.4	0.25	0.09
pH	0.12	1	0.2	0.17	0.08
Hardness	0.12	1	0.4	0.25	0.05
Ca	0.08	1	0.3	0.2	0.12
Mg	0.05	1	0.3	0.2	0.06
Cl	0.05	1	0.5	0.39	0.17
Bi-car	0.03	1	0.7	0.3	0.15
Na	0.02	1	0.5	0.2	0.05

Table 9. Computation of overall areas for each suitability class.

Suitability Class	Area (hectares)	Coverage
Not Suitable	87.29	25.51593
Marginally Suitable	121.67	35.56562
Moderately Suitable	123.18	36.00702
Highly Suitable	9.96	2.911429
	342.10	100

This class is the most nearer part of industries (excluding machinery sector). As we take a closer look at the suitability map (Fig. 3), it depicts evidently the role of industries in pollution the groundwater resource of FSD city. It can be examined on the map that suitability classes and distance from industries have direct relationship with one another. As distance decreases from the industry, suitability level also decreases. N suitability class is in extremely nearer to the industries. Then S3 class (Marginal Suitable) exists and then S2 class (Moderate Suitable) covers the area. It can easily be examined that Chemical sector and Food & Beverage sector are responsible for N class while Textile sector is taking the S2 and S3 classes (Fig. 3).

Conclusion

Weighted Sum Overlay of spatial analysis technique adequately located all suitable classes of groundwater suitability for drinking purpose. Integration of GIS technology with MCDM using AHP can provide full guideline regarding identification of groundwater natural resource actual condition and for sustainability of this valuable resource. On the basis of above mentioned results, it can easily be concluded that Faisalabad city is facing the grave threats for the environment due to industrialization. Industries of the city are destroying the natural groundwater resource making it unsuitable for drinking purpose to community and local population as only 2.9% area was found suitable for drinking. So on the basis of current study, MCDM can be considered as quite suitable method for identification of such problems.

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