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Mohammed Fakhraldeen AHMED, Raid Mahmood FAISAL
Mosul University, Collage of Environmental Sciences and Technology

GIS based modeling of GWQ assessment at Al-Shekhan area using AHP and SAW techniques

Key words: AHP, SAW, GWQ, Al-Shekhan area, GIS based model

Introduction

Groundwater Quality (GWQ) determination of human consumption is necessary for a healthy living (Ishaku, 2011). There is a shortage of papers published in regard of GWQ at Nineveh governorate, Iraq, nevertheless a rapid review of research concerning similar cases studying GWQ in other areas.

Al-Hayali (2010) studied GWQ of 16 wells distributed in Mosul city, Iraq during 2008 along four months. The results show that GWQ of the wells were unsuitable for drinking purposes but it was suitable only for plants resistant to saline water.

Mukheef, Al-Kubaisi and Rasool (2019) assessed the GWQ in Baghdad Province for irrigation purposes by using WQI. The results show that there is an increase of Cl, K, and Ca ions in water samples, and that GWQ is very poor in the middle part of the studied area while it is moderate in the western part for the irrigation purpose.

Gorgij, Kisi, Moghaddam and Taghipour (2017) assessed GWQ of 21 samples at Azarshahr Plain, Iran for drinking purposes by using the entropy technique which extracts the weights needed in determining the Water Quality Index (WQI). The results show that the GW samples are classified as good to poor, and bicarbonate ion is the most effective parameter.

Rao, Venkatesch and Ahmed (2018) studied GWQ of 30 wells in Guntur District Andhra Pradesh-India. Inverse Distance Weighted IDA technique was used to determine the spatial distribution of the GW parameters. The results show that most of GWQ which is located in the western parts of the district is not suitable for drinking purposes, while the eastern part of the district had the most suitability zones for different purposes.

Al-Ozeer and Ahmed (2019) assessed 18 shallow wells for different purposes at east side of Mosul city using SAW technique. The research included an application of Groundwater Modeling System (GMS 10.1) to create the studied area sub-layers as three dimension map. The results show that GWQ is suitable for livestock purposes.

Ochungo, Ouma, Obiero and Odero (2019) studied samples of 39 wells to assess their suitability for drinking purpose in Langata, Kenya. The research concluded that there is no indication of surface water percolation due to low concentrations of SO_4 and Cl ions.

Minh et al. (2019) developed WQI by founding the weight of parameters depends on fuzzy-AHP techniques of shallow wells during 10 years in Giang Province, Vietnam. The research concluded that GWQ in areas located in the Northeast of Giang had very bad quality because of both human activities and natural reasons.

Ibe, Aigbedion, Marcellinus, Okoli and Sola (2019) studied the physical and chemical properties of GW samples from 45 wells for drinking purposes at Ado-Ekiti State, Nigeria, using WQI and Arc GIS. The results show that 34 wells were suitable, while the rest were unsuitable. The research ranked WQ in the studied area as best in the north-west, fair in south east, and very poor in the south.

This study aims to assess GWQ of Al--Shekhan area by the help of AHP, SAW techniques and Arc GIS version 10.5 to build a model which serves this aim, and can be a raw model to be applied to assess GWQ in any other area after inserting the values of their parameters.

Material and techniques

The studied area

Al-Shekhan area is located in the north eastern of Mosul city, Iraq between 36°44′57″ to 36°29′6″ N latitudes and between 43°12′28″ to 43°31′10″ E longitude with 30 wells to be examined, as in Figure 1.

Data analysis

Eleven parameters are experimentally analyzed based on APHA, AWWA, WEF (2005) measurements and compared with international standards (WHO, 2003; EPA, 2004), as in Table 1. Data of parameters is tabulated in Table 2.

The used techniques

Analytical Hierarchical Process

AHP technique was firstly developed by (Saaty, 1980, 2008). This technique can be used in different applications (Faisal & Ahmed, 2018). This technique uses pair wise comparison to derive the relative weights of parameters. Three steps are used in this technique; the extracted parameters are organized and given certain importance degree in the first step. Then, a matrix of the selected relative weights is adopted in the second step. At last, the consistency ratio (CR) is applied to check the importance degree. If CR $\leq$ 0.1, there is no need for reweighting. The scale of relative importance for pair wise comparison is arranged as a scale from 1 to 9, where 1 represents equal importance while 9 represents extreme importance.

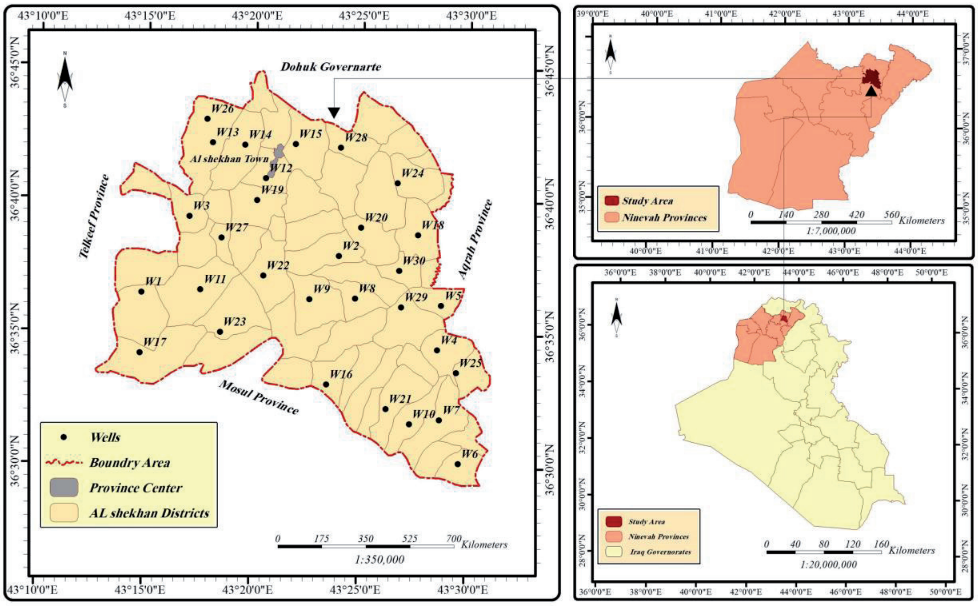

FIGURE 1. Location of the studied area

TABLE 1. Parameters international standards

Drinking parameters	Drinking standards (EPA, 2004)	Irrigation parameters	Irrigation standards (EPA, 2004)	Livestock parameters	Livestock standards (WHO, 2003)
Ca^{2+}	75 $mg \cdot l^{-1}$	Na^{+}	200 $mg \cdot l^{-1}$	TDS	10 000 $mg \cdot l^{-1}$
Mg^{2+}	100 $mg \cdot l^{-1}$	HCO_3^{-}	350 $mg \cdot l^{-1}$	EC	12 500 $mg \cdot l^{-1}$
Na^{+}	200 $mg \cdot l^{-1}$	SAR	15 $meq \cdot l^{-1}$	pH	6.5–8.5
HCO_3^{-}	400 $mg \cdot l^{-1}$	Cl^{-}	250 $mg \cdot l^{-1}$	NO_3^{-}	440 $mg \cdot l^{-1}$
SO_4^{2-}	250 $mg \cdot l^{-1}$	B	0.7 $mg \cdot l^{-1}$	SO_4^{2-}	250 $mg \cdot l^{-1}$
Cl^{-}	250 $mg \cdot l^{-1}$	TDS	1 750 $mg \cdot l^{-1}$	×	×
NO_3^{-}	10 $mg \cdot l^{-1}$	pH	6.5–8.5 $mg \cdot l^{-1}$	×	×
TDS	500 $mg \cdot l^{-1}$	EC	2 700 $\mu hos \cdot cm^{-1}$	×	×
pH	6.5–8.5	×	×	×	×
EC	2 000 $\mu hos \cdot cm^{-1}$	×	×	×	×

TABLE 2. Studied wells parameter's data

Well	Depth	Ca	Mg	Cl	Na	SAR	SO_4	HCO_3	NO_3	TDS	EC	pH
	m	$mg \cdot l^{-1}$				$meq \cdot l^{-1}$	$mg \cdot l^{-1}$				$\mu hos \cdot cm^{-1}$	-
1	100	18.0	4.0	37.0	20.0	1.11	10.0	50	0.3	226	550	8.6
2	203	135.0	73.0	280.0	175.0	3.02	160.0	370	2.4	1 890	3 270	8.0
3	144	28.0	8.0	60.0	30.0	1.29	23.0	70	0.3	276	475	8.6
4	200	24.0	28.2	17.0	94.0	3.1	285.0	147	176.0	494	761	8.9
5	120	19.2	25.3	15.0	13.0	0.46	225.0	288	152.0	228	305	8.8
6	183	30.9	3.9	19.9	200.0	9.05	76.9	319	6.6	450	603	7.2
7	156	48.0	23.0	5.0	22.0	0.64	28.0	280	2.0	260	425	8.1
8	185	24.0	42.9	31.0	92.0	2.59	97.5	241	1.2	356	571	8.2
9	200	19.3	38.0	17.0	66.0	2.00	76.0	292	1.9	592	703	7.5
10	156	27.3	32.2	5.0	7.8	0.24	21.8	226	3.1	355	468	7.0
11	156	32.1	24.3	18.9	52.0	1.68	35.4	273	2.7	455	577	7.8
12	168	90.0	52.6	40.0	26.0	0.53	44.2	478	3.14	769	863	7.1
13	160	46.5	12.6	2.0	14.0	0.46	6.0	219	3.89	334	353	6.9
14	150	62.6	4.87	3.0	15.0	0.48	10.3	224	2.75	326	335	7.1
15	150	27.3	34.1	3.0	21.0	0.63	11.7	258	2.19	368	393	7.2
16	150	57.8	21.4	3.0	6.0	0.17	21.2	258	1.50	387	446	8.1
17	180	59.4	61.4	20.0	17.0	0.32	157.0	253	1.10	610	945	7.3
18	149	321.0	117.0	26.0	17.0	0.20	954.0	219	0.36	1 663	1 890	7.6
19	152	35.3	41.4	12.0	11.0	0.29	55.7	248	1.59	405	527	7.8
20	123	32.0	28.0	18.0	34.0	5.01	40.0	170	50.0	335	608	8.1
21	49	40.0	28.0	11.0	56.0	7.62	48.0	246	10.0	285	480	7.1
22	134	44.0	33.0	15.0	48.0	0.00	43.0	322	0.0	376	620	8.1
23	47	19.0	11.0	66.0	100.0	20.20	24.0	290	0.0	334	650	8.0
24	75	47.0	38.0	20.0	46.0	5.66	91.0	251	2.0	424	677	8.2
25	61	52.0	23.0	9.0	21.0	2.63	34.0	254	2.0	272	377	7.8
26	104	28.0	29.0	4.0	2.0	0.30	19.0	159	18.0	199	294	8.3
27	55	48.0	29.0	15.0	58.0	7.33	99.0	230	8.0	392	597	8.0
28	104	132.0	76.0	19.0	35.0	2.68	238.0	299	34.0	769	1 450	6.8
29	73	24.0	34.0	23.0	18.0	2.81	10.0	250	0.0	221	430	7.6
30	76	44.0	34.0	14.0	28.0	3.58	38.0	311	19.0	331	490	7.7

Tripych worksheet

Tripych is an Excel add-in tool that is part of the Statistical Design Institute (StatDesign, 2018) which is used to prioritize items by performing AHP matrix of the parameters. The yielded results are tabulated in Tables 3, 4, and 5.

Simple Additive Weighting technique

Simple Additive Weighting technique is used firstly by McDuffie and Haney in 1973 to summarize the huge data into one index. In this simple technique, relative weights which are extracted from AHP are multiplied by quality rating scale to calculate the sub-index for each parameter. The following equation illustrates the calculation of quality rating (Qr) which is computed by dividing the concentration of each parameter (Ci) to its standard value (S), as follows: $Qr = Ci / S$. Summation of the sun-indices gives the final index. This final index classifies water quality into five categories: 0–25 excellent, 26–50 good, 51–75 poor, 76–100 very poor, and unsuitable if the index is more than 100. The indices' results of the three purposes are tabulated in Table 6.

Geographic Information System

ARC GIS 10.5 is used to create all the suitability maps for each purpose, then building a model through applying multiple tools and finally extracting the final map (Esri, 2016). Maps of each purpose were created by ArcGIS, as in Figures 2, 3 and 4.

TABLE 3. Tripych drinking water results, CR = 0.0479

		TDS	EC	SO_4	NO_3	Ca	Mg	Na	HCO_3	Cl	pH	Row total	Relative importance	Scaled importance
1	TDS	1	2	3	3	4	5	5	4	5	5	37.00	21.11%	5.00
2	EC	1/2	1	2	2	3	4	4	3	4	4	27.50	15.69%	3.87
3	SO_4	1/3	1/2	1	2	3	4	4	3	5	6	28.83	16.45%	4.03
4	NO_3	1/3	1/2	1/2	1	2	3	4	3	5	6	25.33	14.45%	3.61
5	Ca	1/4	1/3	1/3	1/2	1	2	2	2	3	4	15.42	8.80%	2.43
6	Mg	1/5	1/4	1/4	1/3	1/2	1	2	0.5	3	4	12.03	6.87%	2.02
7	Na	1/5	1/4	1/4	1/4	1/2	1/2	1	0.5	2	3	8.45	4.82%	1.60
8	HCO_3	1/4	1/3	1/3	1/3	1/2	2	2	1	2	3	11.75	6.70%	1.99
9	Cl	1/5	1/4	1/5	1/5	1/3	1/3	1/2	1/2	1	2	5.52	3.15%	1.25
10	pH	1/5	1/4	1/6	1/6	1/4	1/4	1/3	1/3	1/2	1	3.45	1.97%	1.00

TABLE 4. Tripych irrigation results, CR = 0.0763

		TDS	EC	Na	HCO_3	Cl	pH	B	SAR	Row total	Relative importance	Scaled importance
1	TDS	1	2	4	4	3	4	3	2	23.00	24.78%	5.00
2	EC	1/2	1	3	4	3	3	2	2	18.50	19.93%	4.07
3	Na	1/4	1/3	1	2	2	3	2	1	11.58	12.48%	2.65
4	HCO_3	1/4	1/4	1/2	1	2	3	2	0.5	9.50	10.23%	2.22
5	Cl	1/3	1/3	1/2	1/2	1	2	2	3	9.67	10.41%	2.25
6	pH	1/4	1/3	1/3	1/3	1/2	1	0.5	0.33	3.58	3.86%	1.00
7	B	1/3	1/2	1/2	1/2	1/2	2	1	0.33	5.67	6.10%	1.43
8	SAR	1/2	1/2	1	2	1/3	3	3	1	11.33	12.21%	2.60

The results

Figure 2 illustrates the suitability of drinking water purpose where the higher class ranges between 19.27 and 25, which is located in the north western part of the studied area, and lower class is 87.5–100, which is located in the north eastern part of the studied area. Figure 3 shows the suitability of irrigation purpose where the higher class ranges between 16 and 20, which is located in the north western part of the studied area and lower class is 40–45, which is located in the south eastern part of the studied area. Figure 4 illustrates the suitability of livestock purpose where the higher class ranges between 9.2 and 15 including the whole studied area except the eastern part which is considered as the lower class with 25–30. All relative weights and indices extracted from AHP and SAW respectively, in addition to Figures 2, 3, and 4 are utilized to build a model.

Model building

A model is built using ArcGIS and its primary tools as “Add field”, “Calculated field”, and “Kernel”; while the secondary tools are: “Reclassify”, “Raster to vector”, “Clip”, “Union overlay”, and “Select by attribute”, as in Figure 5. This model utilizes the importance scale of parameters, the relative weights indices, and area suitability maps to create the final map which represents an overall reference combining the suitability of water for the three purposes.

Final map

The final map is created by using union tool within GIS overlay mapping tools, as clarified in Figures 5 and 6.

TABLE 5. Tripych livestock results, CR = 0.0204

		TDS	EC	pH	NO_3	SO_4	Row total	Relative importance	Scaled importance
1	TDS	1	2	4	3	3	13.00	37.96%	5.00
2	EC	1/2	1	3	2	2	8.50	24.82%	3.27
3	PH	1/4	1/3	1	0.5	0.5	2.58	7.54%	1.00
4	NO_3	1/3	1/2	2	1	0.5	4.33	12.65%	1.67
5	SO_4	1/3	1/2	2	2	1	5.83	17.03%	2.25

TABLE 6. GWQIs of each purpose

Well	Drinking Index	DGWQ	Irrigation Index	IGWQ	Livestock Index	LGWQ
1	19.2	excellent	18	excellent	10.7	excellent
2	137.3	unsuitable	92.7	very poor	25	excellent
3	22.7	excellent	21.7	excellent	11	excellent
4	50	good	32	good	22.2	excellent
5	36	good	21.2	excellent	18.5	excellent
6	39.6	good	45.3	good	11.6	excellent
7	26.5	good	23.5	excellent	10.5	excellent
8	36.2	good	30.7	good	12.4	excellent
9	45.1	good	32.3	good	12.5	excellent
10	28	good	19.8	excellent	9.7	excellent
11	36.3	good	29	good	11.4	excellent
12	59.1	poor	38	good	12.6	excellent
13	26.6	good	19.8	excellent	9.2	excellent
14	26.5	good	18.9	excellent	9.2	excellent
15	29.1	good	22.4	excellent	9.6	excellent
16	31.2	good	21.1	excellent	10.9	excellent
17	50.6	good	29	good	14.2	excellent
18	150	unsuitable	51.5	poor	33.6	good
19	34	good	24.3	excellent	11.4	excellent
20	32.6	good	25	good	12.7	excellent
21	34.6	good	28.7	good	10.2	excellent
22	34.6	good	27.8	good	11.5	excellent
23	31.3	good	34.5	good	11	excellent
24	38.8	good	30.6	good	12.8	excellent
25	26.5	good	20.7	excellent	10.2	excellent
26	23.4	excellent	16	excellent	10.5	excellent

TABLE 6 cont.

Well	Drinking Index	DGWQ	Irrigation Index	IGWQ	Livestock Index	LGWQ
27	38.3	good	26.4	good	12.6	excellent
28	80.4	very poor	38.8	good	17.6	excellent
29	22.5	excellent	22	excellent	9.5	excellent
30	36.6	good	27.4	good	11.1	excellent

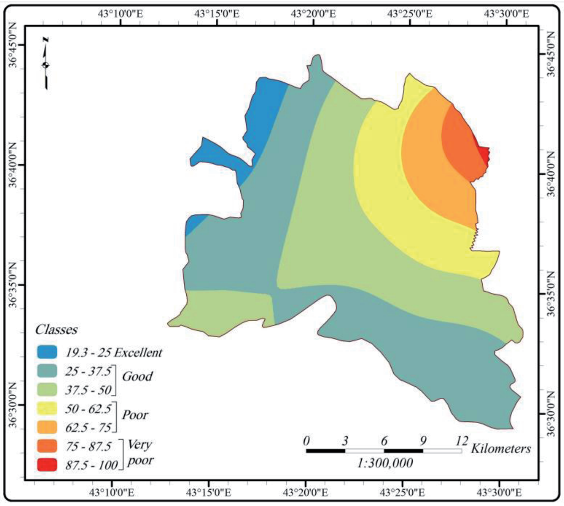

FIGURE 2. Drinking water suitability classes

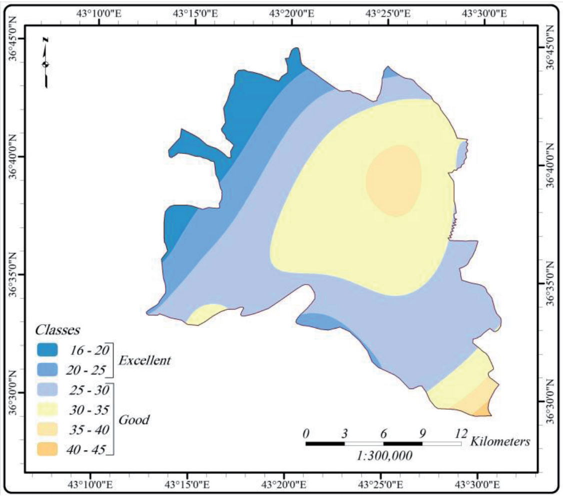

FIGURE 3. Irrigation water suitability classes

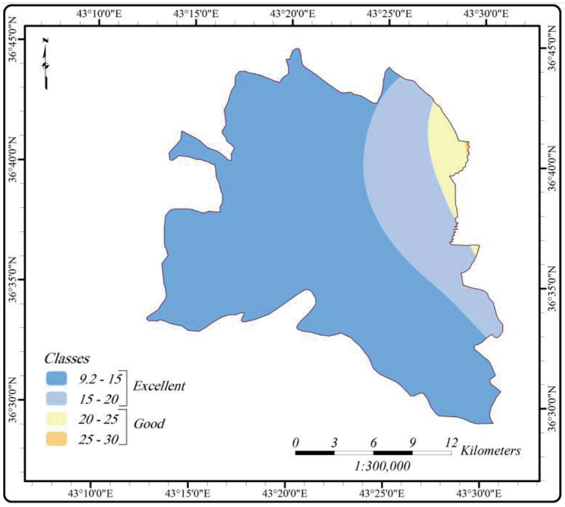

FIGURE 4. Livestock suitability classes

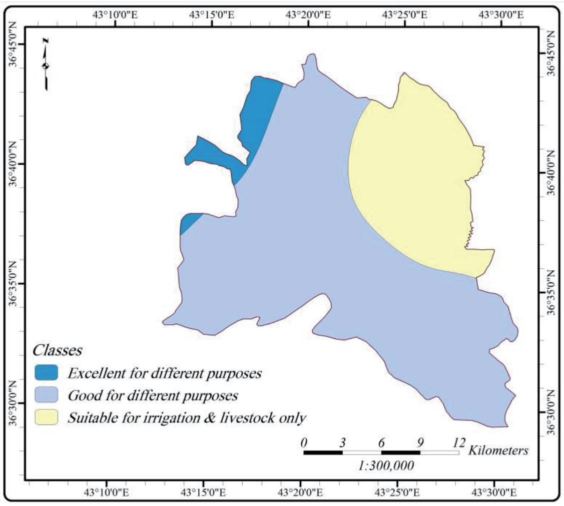

FIGURE 6. The final map

This map shows that the first part 4.6% of the study area which is located in the western part is excellent for the three purposes. The central large part which represents 70% of the study area is good for the three purposes. The eastern part of the studied area occupies the last class which represents 25.4% of the study area which is only suitable for irrigation and livestock purposes.

The discussion

To the best of the knowledge of the authors of this study, there is no previous work that build a model based on both

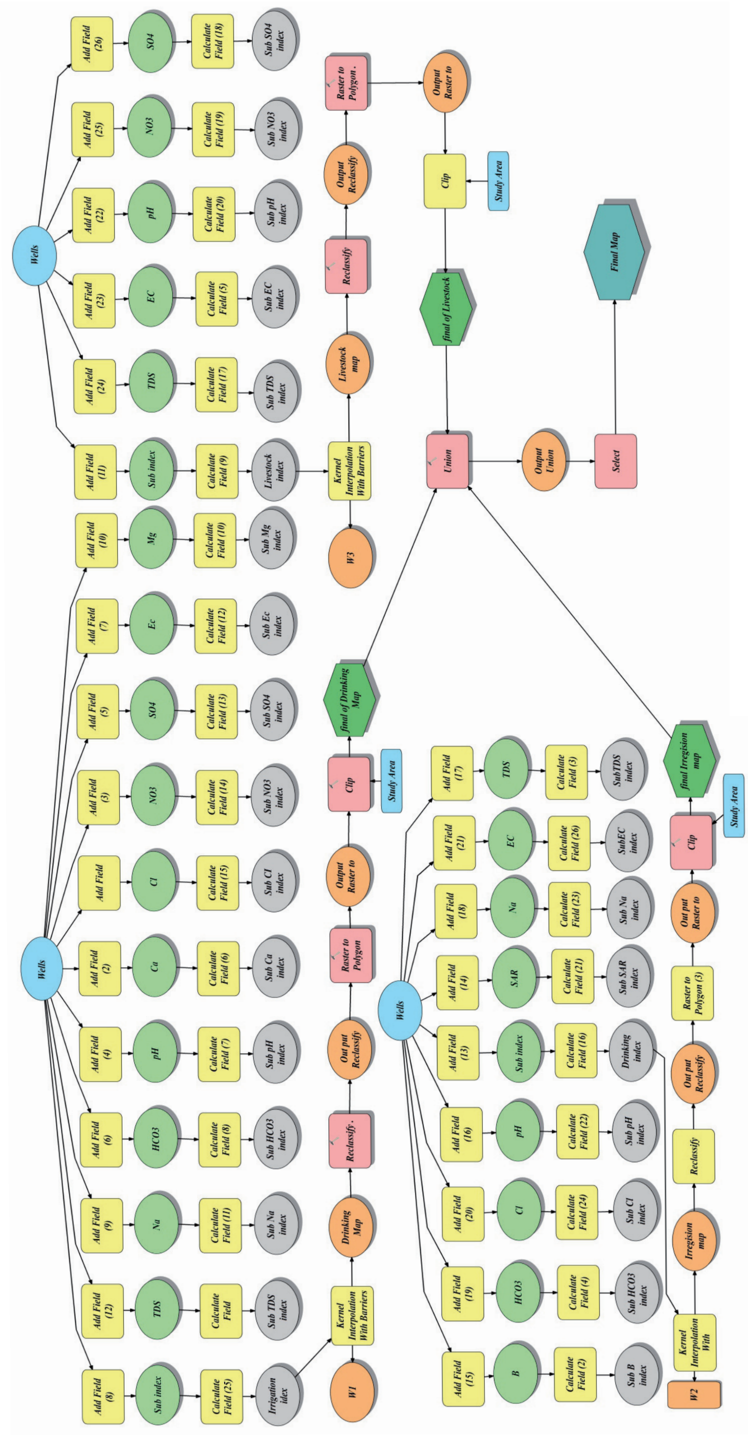

FIGURE 5. The model building

ArcGIS and AHP to assess groundwater quality. Therefore, the concluded model can be conducted to create a detailed map of classes of water suitability after applying the relevant parameters.

Conclusions

The use of AHP and SAW are useful to determine the relative weights and indices of the parameters. ArcGIS utilizes the combination of the relative weights and indices in addition to water suitability maps to create a model. The model identifies water quality in the study area and is considered as a database for future agricultural and developmental projects. The final map illustrates that GWQ can be classified according to its indices, where all wells are suitable for multi-purposes except wells (18, 24, and 28), as in Figure 1, which are appropriate for irrigation and livestock only.

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Summary

GIS based modeling of GWQ assessment at Al-Shekhan area using AHP and SAW techniques. There is a continuous need to assess Groundwater Quality (GWQ) for human beneficial uses especially in areas suffering a shortage of nearby surface water. This study aims to assess GWQ of 56 wells located at Al-Shekhan area for drinking, irrigation, and livestock purposes. Analytical Hierarchical Process (AHP) technique is used to extract weights of parameters that are needed in the calculation of Simple Additive Weighting (SAW) technique. Maps are created using Geographical Information Systems (GIS), and these maps shows the classes of suitable areas for each purpose depending upon the calculated indices which are extracted from SAW technique. The results show that the final map classifies the suitable parts according to the drinking, irrigation and livestock purposes, and it shows that the north eastern part of the studied area is suitable for irrigation and livestock only. A model of GIS and AHP is built to assess the suitability of GWQ in Al-Shekhan area, and can be a raw model to be applied to assess GWQ in any other area after inserting the values of their parameters.

Authors' address:
Mohammed Fakhraldeen Ahmed
(https://orcid.org/0000-0003-0414-0509)
Raid Mahmood Faisal al-Moula
Mosul University
Collage of Environmental Sciences
and Technology
Department of Environmental Technology
42001, Mosul, Iraq
e-mail: mfakher1962@gmail.com
raidalfaisal2017@yahoo.com