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·l$^{-1}$                | Na$^+$                | 200 mg·l$^{-1}$                  | TDS                  | 10 000 mg·l$^{-1}$              |
| Mg$^{2+}$           | 100 mg·l$^{-1}$               | HCO$_3^-$             | 350 mg·l$^{-1}$                  | EC                   | 12 500 mg·l$^{-1}$              |
| Na$^+$              | 200 mg·l$^{-1}$               | SAR                   | 15 meq·l$^{-1}$                  | pH                   | 6.5–8.5                         |
| HCO$_3^-$           | 400 mg·l$^{-1}$               | Cl$^-$                | 250 mg·l$^{-1}$                  | NO$_3^-$             | 440 mg·l$^{-1}$                 |
| SO$_4^{2-}$         | 250 mg·l$^{-1}$               | B                     | 0.7 mg·l$^{-1}$                  | SO$_4^{2-}$          | 250 mg·l$^{-1}$                 |
| Cl$^-$              | 250 mg·l$^{-1}$               | TDS                   | 1 750 mg·l$^{-1}$                | ×                    | ×                               |
| NO$_3^-$            | 10 mg·l$^{-1}$                | pH                    | 6.5–8.5 mg·l$^{-1}$              | ×                    | ×                               |
| TDS                 | 500 mg·l$^{-1}$               | EC                    | 2 700 μhos·cm$^{-1}$             | ×                    | ×                               |
| pH                  | 6.5–8.5                       | ×                     | ×                                | ×                    | ×                               |
| EC                  | 2 000 μhos·cm$^{-1}$          | ×                     | ×                                | ×                    | ×                               |
### TABLE 2. Studied wells parameter’s data

| Well | Depth m | Ca mg·l⁻¹ | Mg meq·l⁻¹ | Cl mg·l⁻¹ | Na mg·l⁻¹ | SAR | SO₄ mg·l⁻¹ | HCO₃ | NO₃ | TDS | EC μhos·cm⁻¹ | pH |
|------|---------|------------|------------|-----------|-----------|-----|------------|------|----|-----|-------------|----|
| 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  | 2.6| 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: 
\[
Qr = \frac{Ci}{S}
\]
Summation of the sub-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  | SO4  | NO3  | Ca  | Mg  | Na  | HCO3  | Cl  | pH  |
| Row total | Relative importance | Scaled importance |
| 1 | TDS | 1 | 2 | 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 | SO4 | 1/3 | 1/2 | 1 | 2 | 1 | 2 | 3 | 4 | 3 | 5 | 28.83 | 16.45% | 4.03 |
| 4 | NO3 | 1/3 | 1/2 | 1 | 3 | 1 | 2 | 3 | 4 | 3 | 6 | 25.33 | 14.45% | 3.61 |
| 5 | Ca  | 1/4 | 1/3 | 1/3 | 1/2 | 2 | 2 | 2 | 3 | 5 | 6 | 15.42 | 8.80% | 2.43 |
| 6 | Mg  | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 2 | 0.5 | 3 | 4 | 12.03 | 6.87% | 2.02 |
| 7 | Na  | 1/5 | 1/4 | 1/5 | 1/5 | 1/4 | 1/4 | 1/4 | 1/4 | 1/4 | 8.45 | 4.82% | 1.60 |
| 8 | HCO3| 1/4 | 1/3 | 1/3 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 11.75 | 6.70% | 1.99 |
| 9 | Cl  | 1/5 | 1/4 | 1/5 | 1/5 | 1/4 | 1/4 | 1/4 | 1/4 | 1/4 | 5.52 | 3.15% | 1.25 |
| 10 | pH  | 1/5 | 1/4 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 3.45 | 1.97% | 1.00 |
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  | NO₃ | SO₄ | 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 | NO₃ | 1/3 | 1/2 | 2   | 1   | 0.5       | 4.33                | 12.65%           | 1.67             |
| 5 | SO₄ | 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
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.

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