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# Groundwater Suitability for Agriculture using GIS Techniques in the Lower Part of Lesser Zab River Basin

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**Abstract**

Suitability of groundwater for irrigation depends upon many constrains factors, these factors depend upon the dissolved salts during the flow of the recharge of the groundwater beside the aquifer constituents itself, from these factors (EC, $SO_4^{-2}$, $Cl^-$, Na%, and SAR) .The spatial distribution of each constrain factor may show discrepancy from the another, so it is not possible to depend upon one factor. The aim of this work is to present a classification of the groundwater quality for agriculture including all the mentioned five factors, by using Arc GIS which provides tools to serve a purpose to create conceptual model for solving spatial problems. A set of conceptual steps used to build a model for suitability map of groundwater for irrigation. 3D spatial analyst can interpolate the data of each constrain factor into raster. The rasters are reclassified by grouping ranges of values into single value. New output raster represents the value of the rasters after making weighted overlay and after calculating the influence of each constrain factor by using Analytical Hierarchy Process (AHP), the final raster shows spatial extent of groundwater quality and its suitability for agriculture. The lower part of Lesser Zab River Basin was chosen to know the suitability of groundwater for irrigation. The final raster shows that there are 4 classes (Excellent-Doubtful), the excellent suitability scattered in a small areas, while the good, permissible, and doubtful distributed on the most parts of the area.

**Keywords:** Groundwater, Suitability, Agriculture, Model, GIS

# ملائمة المياه الجوفية للزراعة باستخدام تقنية نظم المعلومات الجغرافية في الجزء الأسفل من حوض نـهر الزاب السفل

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**الخلاصة**

تعتمد الزراعة على عوامل عديدة يبرز في مقدمتها المياه والتربة والانحدارالطوبوغرافي والمناخ وغيرها. ان معظم المياه تحتوي على املاح ذائبة وعناصر نادرة ينتج قسم منها عن التجوية الكيميائية حين ملامسة المياه لسطح الارض وتزيد الاملاح في المياه الجوفية بالاعتماد على ملامستها للصخور ونوعها وسرعة حركتها ومسامية الصخور وحجم التغذية السنوي واسباب اخرى عديدة. سبق وان وضعت تصنيفات عديدة لصلاحية المياه للاغراض الزراعية اعتمدت على التوصيلية الكهربائية أومجموع الاملاح الذائبة ، النسبة المئوية للصوديوم ،الكلور والكبريتات وقد وضعت حدودا دنيا وعليا لكل من هذه المحددات مما جعل عدد الاصناف خمسا تتراوح مابين ممتاز الى غير ملائم، على ان التصنيفات السابقة واجهت انتقادات وجدلا تركز على عدم

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وجود فواصل او حدود بين الاصناف المختلفة . ان التصنيف الحالي والذي يخص صلاحية المياه الجوفية للاغراض الزراعية في الجزء الجنوبي من حوض الزاب الأسفل يستند على دمج العوامل الخمسة المؤثرة على الاصناف الزراعية وهو يعطي صورة نهائية لصلاحية المياه للاغراض الزراعية دون الاعتماد على محدد واحد .هذا التصنيف يعتمد استخدام نظم المعلومات الجغرافية حيث التحليل الموقعي ثلاثي الابعاد يحول القيم النقطية لكل محدد من المحددات المستخدمة في هذا التصنيف الى مجموعة من الخلايا التي تتشارك بنفس القيمة لتمثل مايدعى المظهر الجغرافي (Geographic Feature). وباعادة اعطاء قيمة بديلة لمدى كل صنف لكل محدد من خلال استخدام نفس الاداة تراوحت مابين (1 – 5 ) بدلا عن المديات العالية للصنف الواحد ضمن كل محدد امكن الحصول على خمسة اشكال ذات خلايا بقيم متساوية (Raster).ولغرض تحديد مؤثرية كل من المحددات الخمسة استخدمت عملية التدرج التحليلي لحساب تاثير كل عنصر (محدد) وبعد التعرف على مؤثرية كل عنصر استخدمت اداة التحليل الموقعي وتحديدا (Weighted Overlay) وصولا لشكل واحد (Raster) يعطي قيما تتراوح حتما مابين (1– 5) اي خمسة اصناف تتراوح مابين ممتاز وغير ملائم اعتمادا على المحتوى الكمي لكل عنصر وقد لا يكون الشكل النهائي متراوحا بين هاتين القيمتين بل محصورا بينهما . لقد اتضح ان تصنيف المياه الجوفية في المنطقة المدروسة تقع ضمن الأصناف ( 1– 4 ) اي مابين ممتاز الى مشكوك فيه بالأعتماد على دمج المحددات الخمسة المذكورة .

**Introduction:**

Lesser Zab River Basin is situated between latitudes 43° 21′ 41" – 46º 17′ 55" N and 35° 1′ 29" – 36º 54′ 41" E, the larger part of Lesser Zab River lies in the NE part of Iraq while the smaller part lies in Iran, it means the river originates in Iran Figure-1. The total area of the basin is 19700.845 $Km^2$, 74.77% is located inside Iraq which represents 14729.690 $Km^2$ and 25.23 % is located inside Iran which represents 4970.310 $Km^2$.

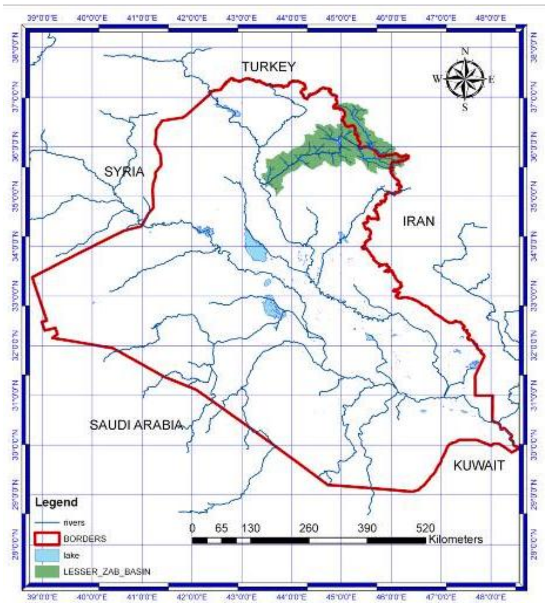


**Figure 1-** Location map

Lesser Zab River Basin and according to establish two main and effective hydrologic structures which were represented by Dokan and Dibis dams could be divided into 3 parts, upper, middle ,and lower Figure-2.

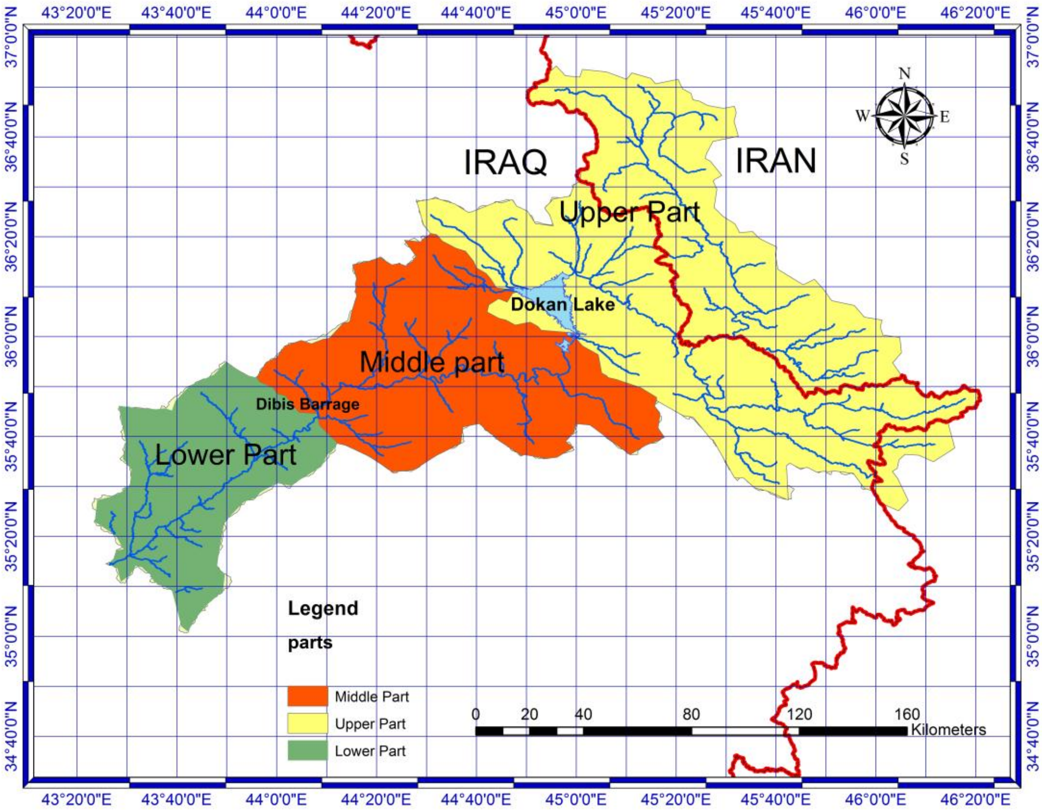


**Figure 2 -** Lesser zab river basin parts

**Objective:**

The main objective of this study is to classify the groundwater suitability for agriculture in the lower part of the basin which was represent by Quaternary Deposits representing the unconfined aquifer in this part, depending on the most constrains factors influencing the agricultural practices; an output raster shows potential areas to suitability of groundwater for agriculture after statistically treating the multiple data, to tell us the overall quality of groundwater bodies and its suitability for agricultural uses.

**Method of Study:**

**A.** Hydrogeological data bank which is available in Groundwater studies center in addition to 10 samples of groundwater were collected from the area under study and analyzed in the National Center for Water Resources Management.

**B.** GIS (V. 10) was used to produce maps using 3D spatial analysis; surface interpolation functions create a continuous surface from sampled point values. The continuous surface of a raster dataset represents concentration of EC, SAR, Na%,$SO_4^{-2}$ and $Cl^-$.

**C.** Reclassifying data means replacing input cell values with new output cell values based on groundwater quality for irrigation in a suitability analysis or for creating new raster's.

**D.** Analytical Hierarchy Process (AHP) method was used for computation the factors weights.

**E.** The cell values of each input raster are multiplied by the raster's weights to produce the final suitability map.

**Hydrogeology:**

Groundwater are mostly used in the lower part especially at the areas outside the boundaries of the irrigation projects due to existence of vast plains which are mostly suitable for agriculture .The area under study could be divided into many Hydrogeologic basin, all of these basins are covered by Quaternary Deposits with its two parts (Older and Younger Alluvium), its thickness ranged between 50-130 m ,the lithology characterizes by its good to high permeability. The Quaternary Sediments cover vast areas mostly within the broad synclinal valleys .They consist of river terraces ,flood plain sediments .These sediments are tapped by some drilled wells either individually or in combination with older formations [1]. More than 200 wells were drilled in the area. The chemical analyses of 63 groundwater samples were used in this study.

**Quality Criteria for Irrigation Purpose**

According to the different previous classification of groundwater for agriculture, the most constrain factors are $Cl^-$ and $SO_4^{2-}$ Scofield [2]. Wilcox [3] used percentage sodium and electrical conductance in evaluating the suitability of groundwater for irrigation. Christiansen et al. [4] have proposed to use a somewhat newer approach to assess irrigation water quality, they defined 6 different classes of irrigation water considering total salt concentration, sodium ratio, SAR value, sodium carbonate, chloride, effective salinity and boron concentration of the irrigation water.. Many other classifications were put after 1977 the famous one was that of Ayers [5] which was adopted by FAO, while Todd [6] focused on SAR. It is well noticed that all the classifications were contributed in many factors that have influence on agricultural species. These factors are EC, SAR, Na %, $Cl^-$ and $SO_4^{2-}$. Jawad [7] classified the suitability of groundwater for agriculture after determination the weight of each factor, these factors are EC, SAR, Na%, $Cl^-$,and $SO4^{2-}$, after using GIS Model Builder and making a combination between different factors. The importance of these constrains factors for suitability of groundwater are described below:

**1. Electrical conductivity:**

EC plays a vital role in suitability of water for irrigation. Higher salt content in irrigation water causes an increase in soil solution osmotic pressure [8]. The salts apart from affecting the growth of plants also affect the soil structure, permeability and aeration which indirectly affect plant growth. Most of the salts in water are present in their ionic forms and capable of conducting current and conductivity is a good indicator to assess groundwater salinity. Electrical conductivity is an indication of the concentration of total dissolved solids and major ions in a given water body [9]. The concentrations of EC ranged between (400 to 7909 µmhos/cm) in the studied area Figure-3.

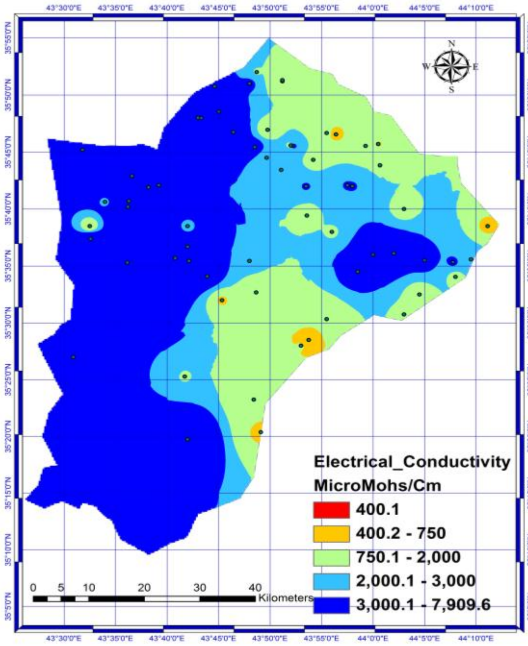


**Figure 3-** Spatial distribution of EC

**2. Sodium (Na %):**

Na+ is an important cation which in excess deteriorates the soil structure and reduces crop yield [9].When the concentration of $Na^+$ is high in irrigation water; $Na^+$ tends to be absorbed by clay particles displacing $Mg^{2+}$ and $Ca^{2+}$ ions. This exchange process of $Na^+$ in water for $Ca^{2+}$ and $Mg^{2+}$ in soil reduces the permeability and eventually results in soil with poor internal drainage. The Na% is calculated using the formula given as:

$$Na\% = \{(Na^+ + K^{+)}/Ca^{2+} + Mg^{2+} + Na^+ + K^+)\} \text{ X } 100 \quad (1)$$

Where, the concentrations are reported in meq/L. According to Wilcox, [3] classification, the water is classified based on the Na% with respect to the other cations present in water. Sodium concentration is an important factor in classifying water for irrigation because it is a measure of alkali/sodium hazard to crops. Because sodium reacts with soils and reduce its permeability which makes cultivation difficult. Figure-4 shows the spatial distribution of Na%.

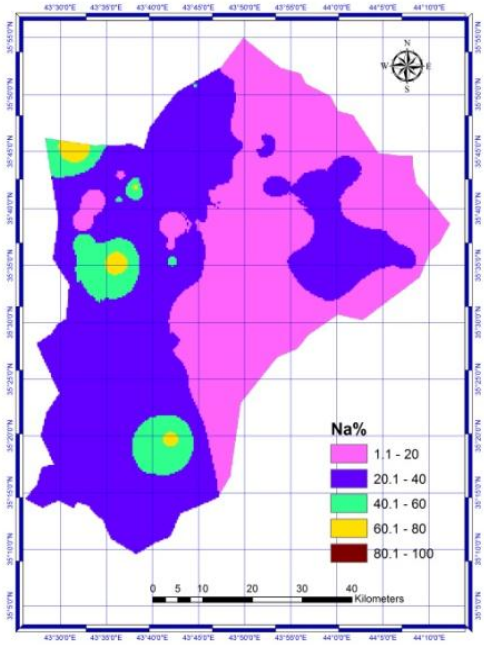


**Figure 4-** Spatial distribution of Na%

**3. Sodium Adsorption Ratio (SAR):**

It is defined according to Todd [6] through the following formula:

$$SAR = [Na+] / \{([Ca^{2+}] + [Mg^{2+}]) / 2\}^{1/2} \quad (2)$$

Where the concentrations of the constituents are expressed in meq /L[6].Sodium Adsorption Ratio (SAR) is the most commonly used for evaluating groundwater suitability for irrigation purposes [5].SAR values in irrigation waters have a close relationship with the extent to which Na+ is absorbed by soils. If water used for irrigation is high in Na+ and low in Ca2+, the ion exchange complex may become saturated with Na+, which destroys soil structure because of dispersion of clay particles. As a result, the soil tends to become deflocculated and relatively impermeable. Such soils become very difficult to cultivate. The potential for a sodium hazard increases in waters with higher sodium adsorption ration (SAR) .SAR ranged between 0.5-37, the spatial distribution of SAR is shown in Figure-5.

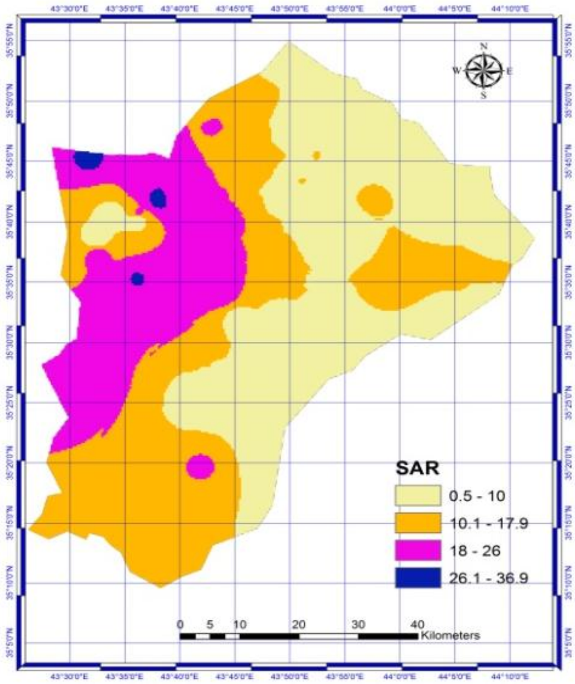


**Figure 5-** Spatial distribution of SAR

**4. Chloride:**

It is one of the most important parameter in assessing the water quality and higher concentration of chloride indicates higher degree of organic pollution [11], Figure-6 shows the spatial distribution of $Cl^-$ which ranges between 8-1864 ppm.

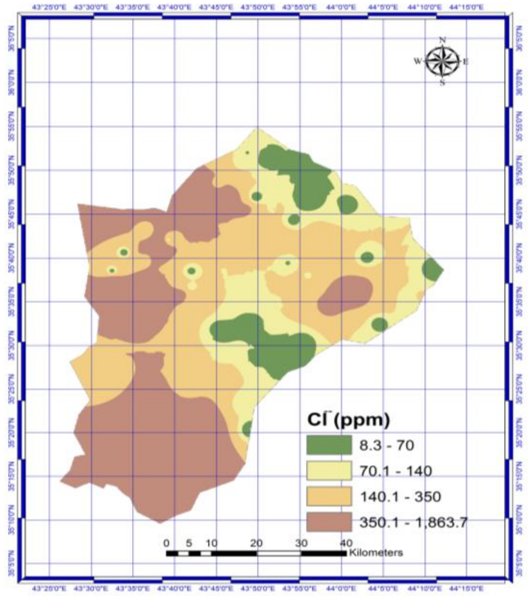


**Figure 6-** Spatial distribution of $Cl^-$

**5. Sulphate:**

The sulfate ion is a major contributor to salinity in irrigation water. However, toxicity usually is not an issue, except at very high concentrations where high sulfate can interfere with uptake of other nutrients. As with boron, sulfate in irrigation water has fertility benefits, the Figure-6 shows the distribution of $SO_4^{2-}$ in the studied area which ranged between (8-3290) ppm.

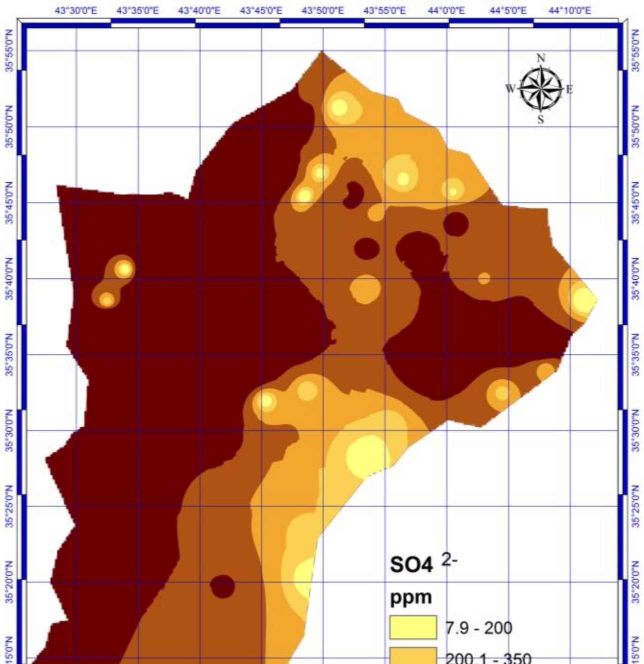


**Figure 7-** Spatial distribution of $SO_4^{2-}$

**Values Reclassification:**

The raster's are reclassified by grouping ranges of values into single value.3D spatial analyst reclassifies a range of values to an alternative value. All values on the original raster that fall within the specified range of values will receive the alternative value assigned to that range. Since the input criteria layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion must be reclassified into a common preference scale such as 1 to 10, with 1 being the most favorable, the lowest value ( low concentration of each factor will have an alternative value equal to 1) the alternative value will be increased gradually to 5 which is equivalent to the highest concentration of each constrain factor .the alternative values between 1-5 will be changed to excellent to unsuitable,(Table-1).

**Table 1-** Proposed suitability alternative values

| Suitability value<br>------------<br>Factor | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
|---|---|---|---|---|---|
| EC (µmohs/cm) | 0 -250<br>Excellent | 250-750<br>Good | 750-2000<br>Permissible | 2000-3000<br>Doubtful | >3000<br>Unsuitable |
| Na % | 0 - 20<br>Excellent | 20-40<br>Good | 40-60<br>Permissible | 60-80<br>Doubtful | >80<br>Unsuitable |
| Cl- (ppm )<br>---------------<br>SO4-2 (epm) | < 70<br>Excellent<br>-----------<br>< 4<br>Excellent | 70-140<br>Good<br>--------------<br>4_7<br>Good | 140-350<br>Permissible<br>---------------<br>7_12<br>Permissible | 350_500<br>Doubtful<br>---------------<br>12_20<br>Doubtfull | >500<br>Unsuitable<br>--------------<br>>20<br>Unsuitable |
| SAR(unitless) | 0 –10<br>Excellent | 10-18<br>Good | 18-26<br>Permissible | | >26<br>Unsuitable |

**Computation of the Factors Weights:**

Analytical Hierarchy Process (AHP) method was used for computation of the factors weights. Saaty [12] proposes a simple method for this task that involves different steps to compute the weight of each constrain factor. The weights of the factors, these steps are explained in the following Table-2:

**Table 2-** Steps for computing the weight of each constrain factors

| Step 1 | SAR | Na% | EC | SO4 | CL | | |
|---|---|---|---|---|---|---|---|
| SAR | 1 | 0.43 | 0.12 | 0.130384 | 0.08 | | |
| Na% | 0.932 | 1 | 0.24 | 0.032 | 0.031 | | |
| EC | 5.4 | 4.2 | 1 | 0.87 | 0.54 | | |
| SO4-2 | 7.3 | 27.4 | 1.03 | 1 | 0.49 | | |
| CL- | 9.2 | 39.7 | 1.32 | 1.83 | 1 | | |
| | 23.832 | 72.73 | 3.71 | 3.862384 | 2.141 | | |
| Step 2 | SAR | Na% | EC | SO4 | CL | TOTAL | |
| SAR | 0.0419604 | 0.0059123 | 0.032345 | 0.0337574 | 0.0373657 | 0.1513408 | |
| Na% | 0.0391071 | 0.0137495 | 0.06469 | 0.008285 | 0.0144792 | 0.1403108 | |
| EC | 0.2265861 | 0.0577478 | 0.2695418 | 0.2252495 | 0.2522186 | 1.0313438 | |
| SO4-2 | 0.3063108 | 0.3767359 | 0.277628 | 0.2589074 | 0.228865 | 1.4484472 | |
| CL- | 0.3860356 | 0.5458545 | 0.3557951 | 0.4738006 | 0.4670715 | 2.2285574 | |
| Step 3 | SAR | Na% | EC | SO4 | CL | | Weight |
| SAR | 0.0420 | 0.0059 | 0.0323 | 0.0338 | 0.0374 | 0.1513 | 0.2772576 |
| Na% | 0.0391 | 0.0137495 | 0.06469 | 0.008285 | 0.0144792 | 0.1403 | 0.2787175 |
| EC | 0.2266 | 0.0577478 | 0.2695418 | 0.2252495 | 0.2522186 | 1.0313 | 0.2116999 |
| SO4-2 | 0.3063 | 0.3767359 | 0.277628 | 0.2589074 | 0.228865 | 1.4484 | 0.2114753 |
| CL- | 0.3860 | 0.5458545 | 0.3557951 | 0.4738006 | 0.4670715 | 2.2286 | 0.1332222 |
| | 1 | 1 | 1 | 1 | 1 | | 1.1003725 |

**Weighted Overlay Tool:**

The Weighted Overlay tool applies one of the most used approaches for overlay analysis to solve multi-criteria problems such as on and suitability models. In a weighted overlay analysis, each of the general overlay analysis steps are followed. As with all overlay analysis, in weighted overlay analysis, after defining the problem, break the model into submodels, and identify the input layers.The weighted overlay table allows the calculation of a multiple criteria analysis between several rasters (Arc GIS, V10). The cell values for each input raster in the analysis are assigned values from the evaluation scale and reclassified to these values. This makes it possible to perform arithmetic operations on the rasters that originally held dissimilar types of values. Each input raster is weighted, or assigned a percent influence, based on its importance to the model model. The total influence for all rasters equals 100 percent. The cell values of each input raster are multiplied by the rasters' weights. The resulting cell values are added together to produce the output raster.

$$\text{Output Raster} = R_{EC} \times Inf_{EC} + R_{Na\%} \times Inf_{Na\%} + R_{Cl} \times Inf_{Cl} + R_{SAR} \times Inf_{SAR} + R_{SO4} \times Inf_{SO4}$$

R = Raster

Inf = Influence (Weight)

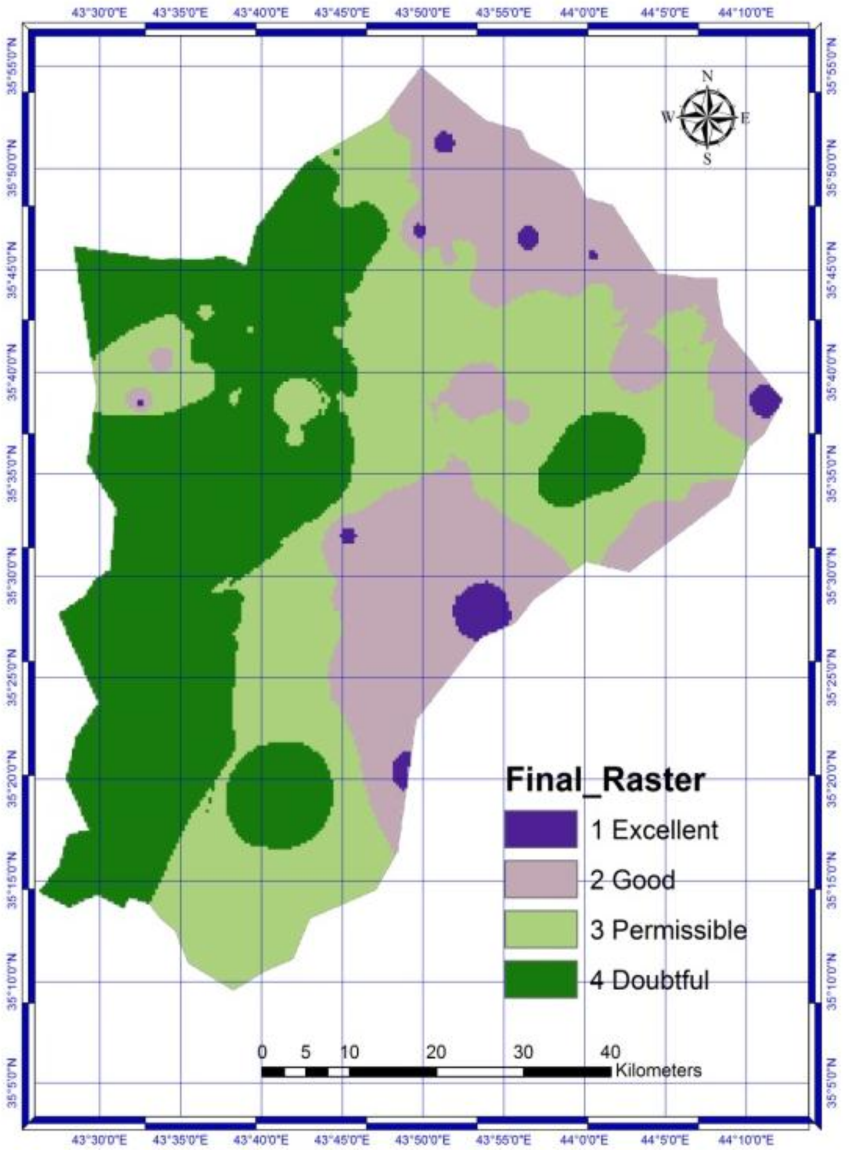


**Figure 8-** Suitability raster

**Using the Conceptual Model to Create a Suitability Map:**

A set of conceptual steps can be used to build a model. These steps are shown in the following Figure-9.

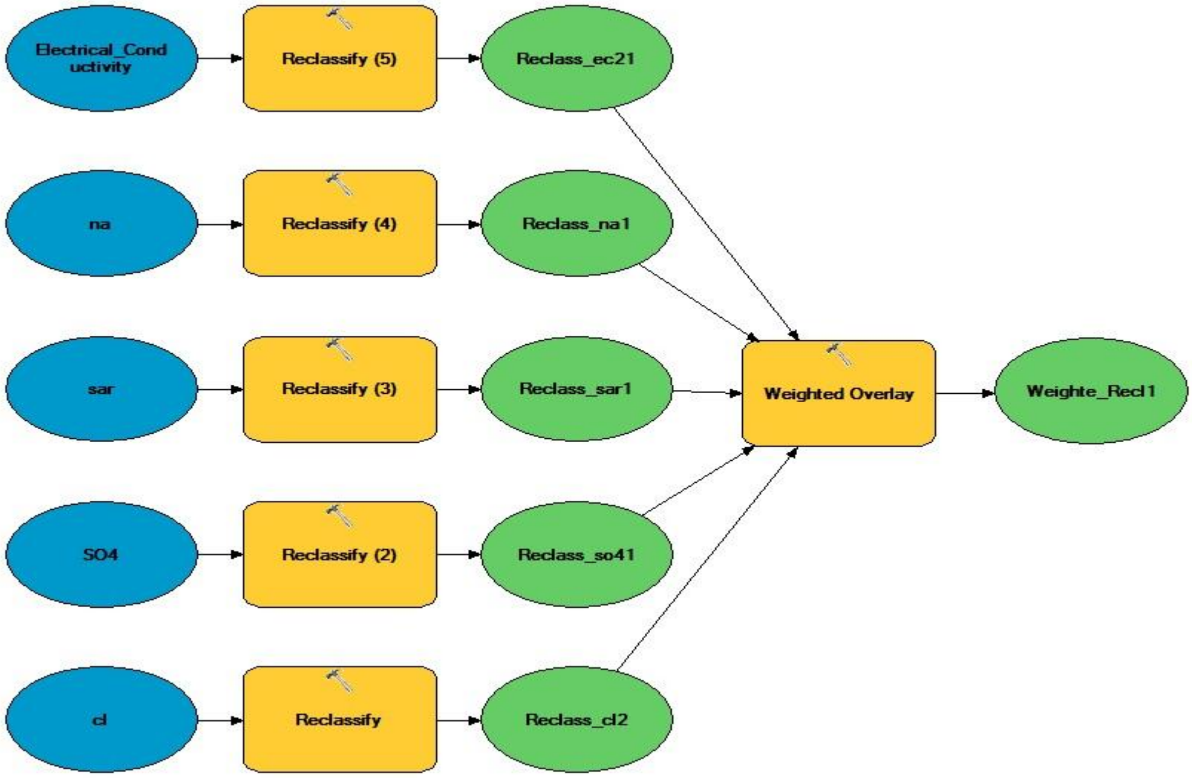


**Figure 9-** Model builder to implement the method of study

## Conclusion:

It is concluded that the groundwater of Unconfined aquifer for Quaternary Deposits in the area under study could be divided into four suitability classes for agriculture ranged between Excellent to Doubtful, the excellent class occupied a small dispersed area ,while GOOD class occupied the northeastern and southeastern parts of the area. The doubtful area is mostly situated in the western parts of the area, which should be excluded from new well drilling to keep groundwater out of deterioration.

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