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Adjustment of Original DRASTIC model by means of Lineament Density to Map Groundwater Vulnerability: Case Study in Rania Basin, Kurdistan Region, Iraq

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Abstract

Groundwater has never been heavily relied on as a water source in Northern Iraq as it has been in the last two decades due to the rapid and often unplanned urbanization, industrial and agricultural projects. This paper attempts to present a concise groundwater vulnerability assessment of Rania basin to the local and regional planning authorities to ensure a more sustainable development in the area. The focus of the study is the Rania basin, which is a part of Dokan sub-basin in North East Iraq. The initial groundwater vulnerability assessment is mapped with standard DRASTIC model. It is then modified by adding “Lineament Density Index” to the original seven DRASTIC parameters due to the previously established close relationship between flow and yield of groundwater with lineament. The area is categorized into five vulnerability index zones of; very low (26%), low (32%), medium (31%), high (11%) and very high (0.012%). The modified model offeres a slightly different vulnerability classification of; very low (16.61%), low (35.45%), medium (30.32), high (17.57) and very high (0.05%). Measured Nitrate concentration is used to validate the assessment results. A progressive increase in nitrate concentration somehow reflects the different vulnerability zones identified by the DRASTIC models in the area. Samples of wet season show 15.96 mg/l, 17.68 mg/l and 20.1 mg/l for very low vulnerability, low vulnerability and medium vulnerability zones when classified by modified DRASTIC model.

Keywords: Groundwater; Vulnerability; DRASTIC model; Lineament; Validation; Kurdistan

Abbreviations: m.a.s.l**,** meter above sea level**;** SGD, Sulaimani Groundwater Directorate; GIS, Geographic Information Service; DEM, Digital Elevation Model; ETM+, Enhanced Thematic Mapper Plus;

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1. Introduction

In the last two decades and since lifting the UN economic blockade on Iraq, a progressive process of multilateral development and urbanization has got on the way in the Kurdistan Region in particular. Groundwater as the leading source of water supply to most of the newly built industrial, urbanisation and agricultural projects is exploited to its maximum potential. The conversion of arable lands in almost everywhere and in the Rania Basin specifically, to residential, commercial, industrial, and recreational purposes took place. This resulted in substantial change in the land use structure. Thus, the environmental implication of these activities to water sources and to groundwater in particular, has been a major concern as it has caused degradation to groundwater quality.

Data from Rania Water Directorate and Sulaimani Groundwater Directorate shows a sharp increase in the number of deep wells in the studied basin. This surge in groundwater use in the last 18 years has caused an enormous burden on this vital resource in terms of quantity and quality. Hence, a detailed assessment study into the quality of groundwater and its vulnerability in this area is considered as vital to minimise the adverse effect of possible pollution.

Any assessment of groundwater vulnerability should address the measurement of potential risk to both anthropogenic and natural contaminants and their movement in the unsaturated and saturated zones as well (Yang et al., 2012). Approaches that are taken to assess vulnerability of groundwater include statistical, process-based, index and overlay techniques (Brindha and Elango, 2015). There has been a rapid development to the previously existed models of vulnerability evaluation in the last two decades and various new approaches and methods have been invented that serve the same purpose (Sener and Davraz, 2013). DRASTIC, GOD, AVI and SINTACS Many other conventional models such as SINTACS, DRASTIC, AVI and GOD also exist. These models can separate different vulnerability

categories in various lithology on a large scale (Vias et al., 2005). However, DRASTIC as a standard assessment model is the most widely used method globally and considered the most effective and suitable one. As the acronym suggests, DRASTIC model uses a combination of seven hydro-geological parameters. These are depth to groundwater (D), net recharge (R), aquifer media (A), type of soil (S), topography (T), zone of unsaturation (I), and hydraulic conductivity (C). Explicit rate and weight values are given to each parameter. The vulnerability of groundwater to pollution categorises an index function of hydrogeological elements, anthropogenic effects and pollution sources in any specified area (Abdullah et al., 2015). Regardless of its popularity, various limitations have made some researchers to link DRASTIC with other pollution parameters, adding extra or ignoring existing parameters and/or control the evaluation with sensitivity analysis (Javid et al., 2011a) The Vulnerability Index is made according to the equation below:

$$DI = V = \sum_{i=1}^{7}(wi \times Ri) \quad (1)$$

In a way that V is index value, Wi and Ri are both weighting and rating coefficients for I parameter. Depending on their relative importance towards the pollution potential, these parameters are weighted from 1 to 5 (Aller et al., 1987).

Lineaments are referred to features that are linear in shape seen on satellite imageries, aerial photos or Digital elevation model (DEM). These lineaments are most likely originated or related to a geological feature and an interconnection is recognised between existence and density of these features with the yield and flow of groundwater in previous studies (Al-Rawabdeh et al., 2014; Fernandes and Rudolph, 2001). Greater values of lineament density might point out to a higher potential of groundwater pollution (Abdullah, 2015).

This paper aims to organise a map of lineament density of the Rania Basin and utilize it as an extra parameter on the standard DRASTIC model to assess the pollution vulnerability of

groundwater. Various techniques in GIS and Remote Sensing were utilized to extract lineament maps from satellite imagery of Enhanced Thematic Mapper plus (ETM+).

2. Study area

Rania basin is located in the northeastern part of Iraq. It extends from northeast to the northwest of Sulaimani province between latitudes (36.05.15, 36.28.13) and longitudes (44.25.38, 44.58.51). The approximate area of interest is (1269.3) km^2. Rania district center is situated to the north of Sulaimani city by 131 km is 10 km away from Dokan Lake. In terms of topography, the area is mountainous in the north, with altitudes higher than 2400 meters above sea level, while the elevations reduces to nearly 500 meters above sea level near Dokan lake **(Fig. 1).** Snow and rain are regular and make it very cold in winter, while hot and dry in the summer. The popular farming products in the area are, barley, wheat, sunflower and tobacco. The basin engulfs Chwarqurrna, Hajiwawa and Betwata sub districts plus 114 villages in addition to the Rania district center (Al Manmi 2008).

2.1 Geology of the study area

According to Jassim and Goff (2006), Rania basin, is located in the Sulaimaniyahya-Zakho subzone of high-folded zone, in the unstable platform in terms of tecto-struactural condition. The structure of the area has strong orogeny-induced uplifted units that are very complex,

Though relatively uniform, ones (Jassim and Goff, 2006). Formations of Jurassic- lower Cretaceous make up the crests of the anticlines while late Cretaceous and more rarely Paleogene beds makes the synclines and the flanks (Al Manmi, 2008). The main structures in the area are Rania, Makook, Pelewan, Karookh, and Handreen anticlines (Jassim and Goff, 2006).

Geological rock units from lower Jurassic up to recent ages are visible in the area (**Fig. 2 A&B).** Based on findings by Jassim and Goff, 2006; Buday 1980 and 1987; Bellen et al., 1959;

Bolton, 1956 and 1958d the oldest rocks are of Sarki (mainly limestone and dolomite) and Sehkanian formations from lower Jurassic followed by Sargallu, Naokelekan (bituminous limestone), Barsarin (limestone and dolomitic limestone) and Chiagara formations of middle to upper Jurassic. The cretaceous rock units include, Sarmord, Balambo, Qamchugha, Bekhma, Shiranish and Tanjero formations. Sarmord (Valanginian-Aptian) which has a thickness of (403 m) at (Hanjeera village) in Rania and its lithology is only regular repetition between marl and marly limestone. Shiranish Formation of the upper Campanian or Kometan Formation of the Upper Turranian overlies Ballambo (Valanginian – Turanian) while its lower boundary is with Chiagara formation in Rania area (Mohyadin, 2007). The Qamchuqa Formation (Hawlerivian – Albian) in the studied basin, is mainly composed of calcitic dolomite, dolomite and limestone (Al Manmi, 2008). Bekhme (Late Campanian) is characterized by existence of benthonic and planktonic Foraminifera in its thick and massive beds of limestone in the Rania area (Jassim and Goff, 2006). Shiranish formation (Late Campanian) is composed of thin-bedded argillaceous limestone (locally dolomitic) (Bellen et al., 1959). Tanjero (Late Campanian – Maastrichtian) according to (Bolton, 1958d) overlies the Shiranish Formation in a conformable and gradational contact while it is unconformable in its lower boundary.

Quaternary (Alluvial fan, River terraces, and Flood Plain) deposits are the most significant units in the studied basin in terms of water supply and hydrogeological characteristics. Conglomerate, sand, silt, loam and clay plus poorly sorted weathered products of the previously mentioned formations make up these deposits (Al Manmi 2008). Slope sediments have formed along the flanks of the structures. The synclines are filled with gravel and clay while the structure flanks are made with slop deposits. Alluvial fans of Rania and Chwarqurrna are resulted from streams starting from the anticlines (Al Manmi 2008). Accumulation of often poorly cemented boulders, gravels, sands and clays exist beside the streams. Expanse of run-off sand, silt and clay cover flat areas between anticlines. Flood plain sediments fill the valleys that are locally developed and they make up good quality aquifers in the basin. The thickness

of Quaternary deposits ranges from 10 meters and rises in the direction of the west and south of the basin where it reaches around 150 meters.

2.2 Hydrogeology

According to Jawad (2008), Rania is located in the sub basin of Dokan that is a part of the lower Zab basin. The basin has a high potential of groundwater resource, which can be used for medium to large-scale irrigation projects. Springs, Wells and streams are the main sources of potable water in the area. Shawre and Qashan are the two main streams that flow from the north to the south of the basin, ultimately discharging into Dokan Lake. Several springs and thousands of deep wells in the area tap the groundwater resource.

Four aquifer systems of various ages are recognised in the basin and they are Quaternary, Late Cretaceous limestone, Early-late Cretaceous and Jurassic systems (Al Manmi, 2008) **(Fig. 3**). The flow of groundwater is from northwest to southeast, i.e. from, Pelewan, Handreen and Makok anticlines as well as Rania plain to the Dokan Lake. Quaternary deposit is considered as the main aquifer in the area.

3. Methodology

3.1 Materials and data

Shape files were created using Geographic Information Systems (GIS: Arc Map 10.5) software for geological, hydrogeological and soil maps of the Rania basin. Static water level recorded with electrical sounder in 368 deep wells in the wet season were considered to determine the distance to groundwater in the basin and prepare D-map. Saturated zone thickness and some other related data were taken from the Sulaimani Groundwater Directorate. Results of 11 single well pumping test from the area were entered into AQTESOLVE software to establish hydraulic conductivity. PCI Geomatica and GIS software were used to prepare lineament

distribution and lineament density maps from satellite images of the basin. Universal parameters were used in making the standard DRASTIC model. The modified DRASTIC on the other hand, was prepared by combining the standard model with the map of lineament density.

3. 2 Standard DRASTIC model

To assess the groundwater vulnerability of the basin, the first model to consider, was standard DRASTIC. The model is a combination of seven parameters with specific weights (1 to 5) and rates (1 to 10) assigned to each parameter as explained in (**Table 1**). Abbreviations from each parameter are taken to make the short form of "DRASTIC". Geological and hydrogeological characters are the fundamental criteria used to assign the label unit of the map.

The equation below is a linear representation of all factors involved to find the vulnerability index by standard DRASTIC model:

$$DI = DwDr + RwRr + AwAr + SwSr + TwTr + IwIr + CwCr \quad (2)$$

In a way that, DI is the DRASTIC Index, w = weighting coefficient and r= rating coefficient.

D is the depth to water table, R is recharge, A is the aquifer media, S is the soil media, T is the basin topography, I is the impact of unsaturated zone and C represents the basin hydraulic conductivity.

The basin was mapped and classified into several categories in terms of groundwater vulnerability with Geographic Information System (GIS Arc Map 10.5). All the rates and weights were reached at through Delphi technique, i.e. employing the professional's academic and field-based insight to evaluate the risk in the area under certain circumstances (Rahman, 2008).

As all the process of degradation and natural attenuations of the contaminants are time consuming, the greater depth of the water table, often plays a positive role to delay the contaminant to reach the aquifer, hence providing more chance for attenuation. All the measurements of depth to water table used to construct (D_Map) for this research have been

collected in wet season, since water table is at its shallowest depth which is crucial in groundwater vulnerability to contamination. The data was partly collected by the researcher using electrical sounder and mainly from the archives of the Sulaimani Groundwater Directorate (SGD). The data set ranges from 2.5m, the shallowest, to 104m the deepest. The Depth layer in raster format was created using an ArcMap tool of Inverse Distance Weighted (IDW) and divided the basin into nine zones according to the recommended rates given in **(Table 1)**.

The nine classes were (less than 4.5m, 4.5 – 7.5, 7.5 – 10, 10 – 12.5, 12.5 – 15, 15 – 19, 19 - 23, 23 – 30 and more than 30m). Class 1 or the lowest vulnerability class is designated to the deepest water table, more than 30m mostly in the north, east and center of the area. Over exploitation in the villages scattered over the mountainous area having a higher altitude may explain the deeper water table. In contrast, shallower water table of less than 4.5 having a higher vulnerability index rating of 9 is seen in the southern and western area closer to the Dokan Lake.

(R) is the net recharge (NR). The amount of water that reaches the saturated zone in a year is defined as the net recharge (Mohammadi et al 2008). The higher the recharge rate, the easier the pollutant can move and hence the greater contamination risk. To find out the extent of the aquifer net recharge in the studied basin, Metha et al., (2006) has recommended an equation, which is also known as, equation of simple groundwater balance:

$$NR = P - ET - R_o \qquad (3)$$

In a way that; NR: is the net recharge, P: is the amount of precipitation figured out from meteorological data of Dokan Station between 1984 and 2019. ET is the amount evapotranspiration found through FAO Penman Monteith method as recommended by (Allen et al, 2006) and R_o is the bulk amount of runoff. All the parameters used in the equation are measured in millimeters and on annual basis. The soil conservation service – curve number (SCS – CN) was used to calculate the total runoff for each month after dividing the basin into 9 sub subzones using reference tables provided by the (USDA - NRCS, 2004)

$$S = \frac{25400}{CN} - 254 \quad (4)$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \text{ for } P > 0.2S \quad (5)$$

Q is the runoff total in (mm) of depth; P is the precipitation total using average monthly records in (mm).

Thus, the total runoff in a year was 167.9 mm per annum, which is about 24.6 % of the total precipitation, and the projected net recharge is estimated as 220.2 mm in a year or 32 % of the precipitation. The figures obtained values of net recharge percentages distributed over the basin were used to draw the recharge (R – map) which was later categorized based on the recommended rates by Aller et al (1987) and transformed from polygon format to raster through GIS.

(A) is the saturated media or the auifer. The identified aquifers of the study basin have been regrouped and four different rates of (3, 6, 8 and 9) were given to them according to the rates of standard DRASTIC (**Table 1)**.

(S) is the soil media. Soil cover (texture and type) has a considerable influence on the infiltrated water and the contaminant's ability to percolate through the materials to reach the vadoze zone (Lee, 2003). The previously prepared soil map modified from FAO (2001) and Berding (2003), was redrawn. In accordance to the recommended rates by Aller et al (1987), 4, 7, 9 and 10 were given to the four different soil types of (silty loamy to clayey, silty clay to clayey, excessively well drained and thin or absent soil) respectively.

(T) is the topographic parameter. Topography which takes a weighting value of 1 in DRASTIC model, dictates the pollutant's extent of runoff and controls the likelihood of it to settle in a place and stay long enough to enable infiltration to reach groundwater (Aller et al, 1987). The topographic map (T_Map) was constructed in Arc Map GIS 10.5 using a 30m pixel sized digital elevation model (DEM) of the basin. The basin was categorized into five zones based on the

gradient value (Maqsoom et al, 2020). The mountainous areas with the very steep slope (>40°) is given the lowest rate of 2 while the shallower area in the south of the basin that has a very gentle slope (<5°) is assigned the highest rate of 9. The other parts with steep slope (20°-40°), moderate slope (10°-20°) and gentle slope (5°-10°) are given the rates of 4, 6 and 8.

(I) impact of Vadoze zone: The presence and the nature of the unsaturated zone plays an influential role on the natural attenuation processes of contaminants before reaching the groundwater. Five regions (3, 4, 5, 6 and 8) were classified according the rates recommended for standard DRASTIC model **(Table 1).**

(C) Hydraulic Conductivity: Is the media's ability to let water pass through it, hence dictates the movement of the contaminant traveling through the saturated medium. To find (C) value of the hydrogeological units of the basin, results of 31 single well tests from the area were considered. AQTESOL 4 software and equation (6) were employed to calculate hydraulic conductivity.

$$C = \frac{T}{b} \quad (6)$$

The rate value of 1 (very low) was assigned to aquifers of lower hydraulic conductivity or less than 4m/day and rate of 2 (low) was given to aquifers with hydraulic conductivity higher than 4m/day.

3.3 Maps of lineament and density of lineaments

Linear features that imitate a general surface expression of underground fractures on the ground surface are called lineaments (Pradhan and Youssef, 2010). According to Devi et al., (2001), there is a close relationship between lineament and groundwater in terms of storing and movement since fractures enable percolation of exterior runoff into the subsurface. Greater density values of lineament may indicate more potential groundwater contamination. The Rania basin map of lineament distribution was prepared using images from The Landsat

8 Thematic Mapper Plus of 5th Nov. 2020 with cell size of (30 x 30) meters and the grey scale Operational Land Imager (OLI) spectral band. The lineament distribution over the basin was extracted with the help of PCI Geomatica technique. **Figures. 4A** and 4**B** show the thematic and the lineament distribution maps of the study area respectively. Spatial analysis tool from ArcMap 10.5 was used to build the lineament density map. The chances of moving a pollutant towards the groundwater increases with higher intensity of lineament features in the studied area.

3.4 Map of lineament rating and lineament index

The alluvial deposits in the Rania basin shows many linear features that represent higher potential of increased porosity and permeability. Furthermore, the movement of groundwater in the Rania basin is mostly through the fractures due to their abundance in greater portion of the aquifers in the area. Therefore, the most effective parameter to be added to the DRASTIC model in assessing the basin's groundwater vulnerability more precisely is lineament density. The lineament density maps with ranges and rating **(Fig. 6A and 6B)** made in GIS according to values taken from **Table 2**. The value of (5) was given to the lineament density as a weight coefficient based on its valuable importance (Al-Rawabdeh, 2014) and finally the index map was constructed by multiplying the rated lineament map to the mentioned weight, using the map algebra tool in ArcMap 10.5.

3.5 Modification of standard DRASTIC model with lineament index map

To make the DRASTIC model represent a more realistic vulnerability assessment of groundwater, the lineament index is added to the generic model. This is because a strong relationship of lineament with groundwater occurrence, flow and production has been established in previous studies (Lattman and Parizek, 1964). When the lineament index is

introduced to the generic DRASTIC model (equation 7), its influence is can be easily noticed on the groundwater vulnerability assessment (Al-Rawabdeh, 2014).

$$DL(i) = Di + Li \qquad (7)$$

DL (i): DRASTIC index modified with lineament; Di: index of generic DRASTIC, Li: index of lineament.

3.6 Index validation with nitrate

The obtained vulnerability maps from both standard as well as modified DRASTIC models were validated using actual nitrate concentration recorded in 39 water samples. The dry season sampling took place in October 2018 and the wet season round was in May 2019. Pre-cleaned 500 ml bottles of polyethylene were used to collect the water samples. They were first filtered using 0.2µm filter to get rid of colloids and transported to the laboratory in a cool box at 4°C. All the samples were analysed in the laboratories of Sulaimania Health Protection Directorate according to the standard procedures recommended by APHA (2005).

4. Results and discussion

4.1 Standard vulnerability mapping assessment

As shown in **Fig. 5**, Rania basin is categorized into five vulnerability zones of very low (<100), low (100 – 125), medium (125 – 150), high (150 – 200) and very high (>200) based on the the assessment produced by standard DRASTIC model. All the classified vulnerability sections together with the area they cover in km^2 and percentage of the whole basin are represented in **Table 3**. Vulnerability zones of very low and low classes correspond mainly with Quaternary Intergranular Aquifers of clastic fine-grained materials (Alluvial fan and Slope deposits) that help natural attenuation. They are both situated in the southern, central and the western parts of the area. Medium, high and very high vulnerable sections are found in areas where karstic

and fissured karstic aquifers exist and rightly, so, the higher amount of recharge and hydraulic conductivity increase the speed of the contaminant to reach groundwater and hence, decrease the natural attenuation.

In general terms, 58% which is greater than the half of the studied area are assessed to have very low and low vulnerability to pollution, while only 10.64% of the area is assessed as highly and very highly vulnerable **(Table 3).**

4.2 Lineament assessment

Landsat 8 images (ETM+, 2020) was used to extract lineament distribution map and hence the lineament density map. Five classes of lineament density were identified in Rania basin (**Fig. 6C).** The lineament density classes and their covered area percentages are demonstrated in **Table 2.** It can be noticed that most of the studied basin (1164.19) km2 which is (91.72%) of the total area is covered by the lowest lineament range (Class V). The highest lineament density range (Class – I) on the other hand, covers only 1.09 Km2 or (0.09%) of the whole basin. This higher lineament density coincides with major subsurface structural features situated in the north along Makok anticline near the sub district of Bezwada and far west parts of the basin along the Bane-Bowe anticline. The rest (Class – IV, Class – III and Class - II) occupy an area of 66.28km^2, 23.75 km^2 and 13.98km^2 or 5.22%, 1.87%, and 1.1% of the total area correspondingly. The map of lineament ratings (**Fig. 6B**) shows the basin divided according to density ratings from 1 – 5. A small portion of about 1.09% in the basin having the highest lineament intensity (Class – 1) was given a high rating value of 5 whereas rating value of 1 was given to areas having the lowest lineament density (Class-V). Ratings of 2, 3 and 4 were given to areas with lineament density classes of (IV, III and II) correspondingly.

The final lineament index map was prepared by multiplying the lineament rating map in raster format designated weight of lineament parameter (5) through map algebra in GIS **(Fig. 6C).** The produced index map was then divided to five zones of (5, 10, 15, 20 and 25), occupying area already demonstrated with map of lineament ratings.

4.3 Modified DRASTIC model assessment

The produced map from Modified DRASTIC assessment (**Fig. 6D)** was categorised into five zones of vulnerability from very high to very low. The dividing benchmarks were derived from the lineament index values **(Table 2)** that ranges from (56.19 – 226. 2). As represented on **Table 3** and shown on **Fig. 6D**, Areas with highest vulnerability to pollution (very high class) with index value (200.01 – 226.2) accounts for a tiny amount (0.05%) of the studied basin whilst the largest portion of the area (35.45%) has a low vulnerability which ranges from (100.01 – 125).

The second dominant vulnerability class in the basin is (medium) with ranges (125.01 – 150) and the high and very low class covers (17.57%) and (16.61%) respectively. When compared to the vulnerability classification and values obtained by the standard DRASTIC model, the modified DRASTIC values do not differ substantially (Table 3). There is about 10% decrease in the area covered by the very low vulnerability class and 6% increase with regard to the class of high vulnerability compared to the results offered by the standard DRASTIC evaluation. However, the variation in the areas covered by other classes of high, medium and low vulnerability is less than 5%. The low variation between the two models suggests the marginal influence of lineament density index on the assessment of groundwater vulnerability in the area. This is because 91.72% of the basin has the lowest lineament distribution ranging (0 – 1.05) as represented on **(Table 2)** and **(Fig. 6A).**

4.4 Validation of the modified DRASTIC method with concentration of Nitrate (NO_3^-)

To validate the vulnerability models, Nitrate (NO_3^-) is considered as a reality check for the DRASTIC model in both generic and modified phases. Nitrate does not enter the water supply

through dissolved minerals but comes from nitrogen cycle. Therefore, it can be used as an indicator for pollution of water resource (Secunda et al, 1998).

Collected samples of water from 39 wells were analysed for this study. They were taken in October 2018 and May 2019 to represent the variations in Nitrate concentration that may exist between dry and wet seasons **(Table 3**). The nitrate concentration in the dry season reads 15.18 mg/l, 16.77 mg/l and 18.55 mg/l for the very low, low and medium vulnerability classes assessed by the modified DRASTIC model **(Fig. 7A)**. It is a generally a medium level of contamination. The identified concentration values for the wet season though, are 15.96 mg/l for very low vulnerability class, 17.68 mg/l for low vulnerability and 20.1 mg/l for medium vulnerability **(Fig. 7B**) which represent a slight increase in the three vulnerability classes. The increase is attributed to anthropogenic factors such as application of different chemicals that include nitrogen as well as naturals factors like fluctuating the water table and finally the considerable role that rainfall can play in nitrate transportation.

5. Conclusions

The main purpose of carrying out this research is to evaluate the groundwater in the Rania basin in terms of its vulnerability to pollution. Drastic model as the most widely used and its easy-to-use approach was considered for the assessment. However, it was soon realized that despite its good performance for intrinsic vulnerability on a larger scale, the standard DRASTIC model comes short to offer, an accurate and a closer to reality, assessment of the groundwater pollution on a smaller and detailed scale. Therefore, the generic model was modified through adding an extra parameter of Lineament Density to its original seven.

The vulnerability index values that produced through the final modified DRASTIC model (DI+DL) ranged between 56.19 and 226.2.

According to the index values and the maps produced by both models, the Rania basin is divided into five vulnerability ranks of (very high, high, medium, low and very low). Although

no major and decisive discrepancies appear between the intensity and the classifications of the intrinsic vulnerability classes produced by each model, never the less, slight deviations can be noticed between the areas covered by each vulnerability classes. Areas ranked as very highly vulnerable accounts for the smallest section of the studied basin while the low vulnerability class covers the largest portion of the basin.

To validate the results offered by the DRASTIC models, Nitrate concentration level measured in samples of groundwater taken in 39 water wells from the basin were assessed. Variations in nitrate concentrations form wet season somehow reflected the different vulnerability classes branded by the modified DRASTIC model. The Nitrate concentration of 23 samples from the very low vulnerability area showed an average of 15.96 mg/l. Samples from 10 wells in the low vulnerability areas given 17.68 mg/l as an average nitrate concentration and two wells located in the medium vulnerability parts of the basin showed averaged nitrate concentration of 20.1 mg/l.

Declarations:

- **Ethics approval and consent to participate**: Not applicable
- **Consent for publication**: Not applicable
- **Availability of data and materials**: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.
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Figures

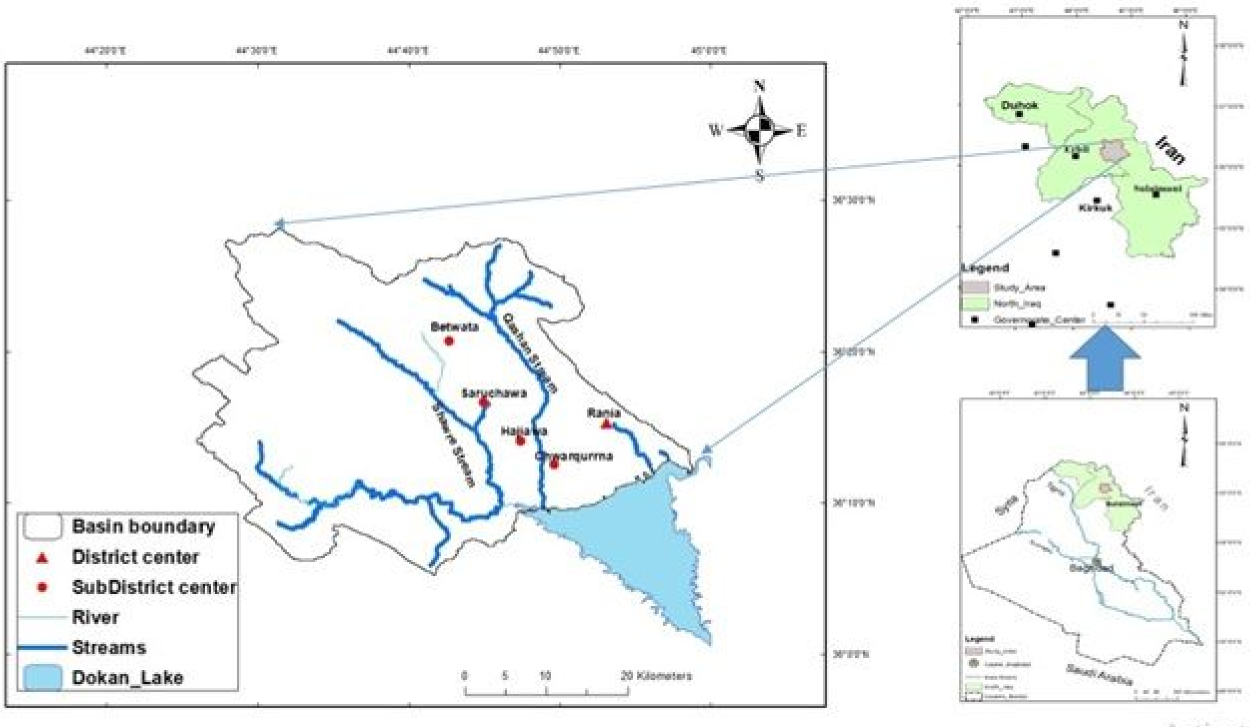

Figure 1

Study area

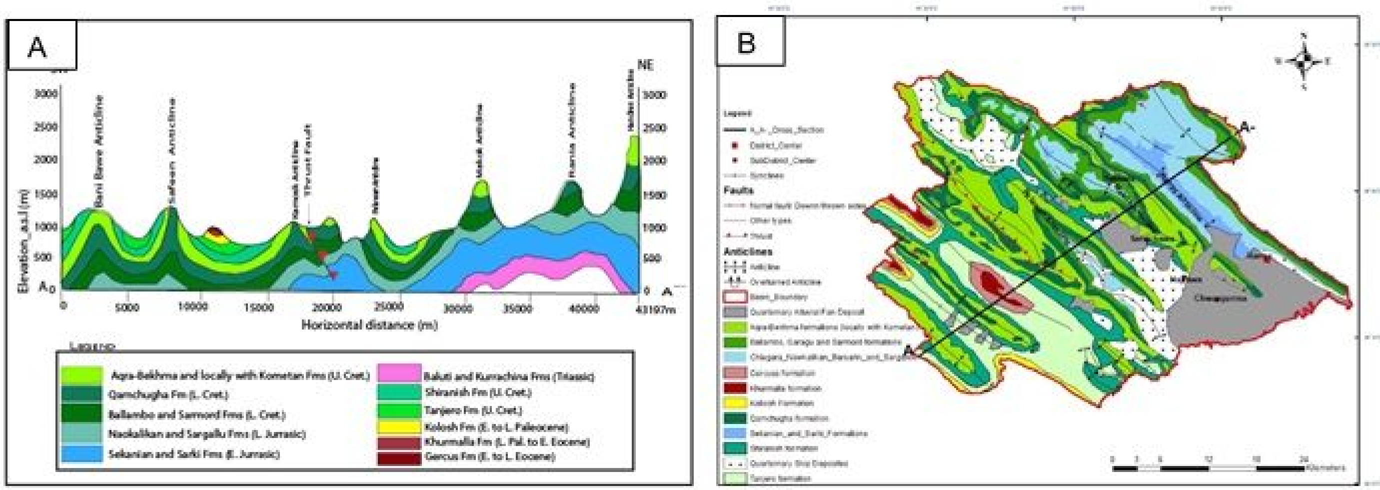

Figure 2

(A) Geological map of the Rania basin (B) Geological cross section through line (A–A—) adopted from (Sissakian, 1997)

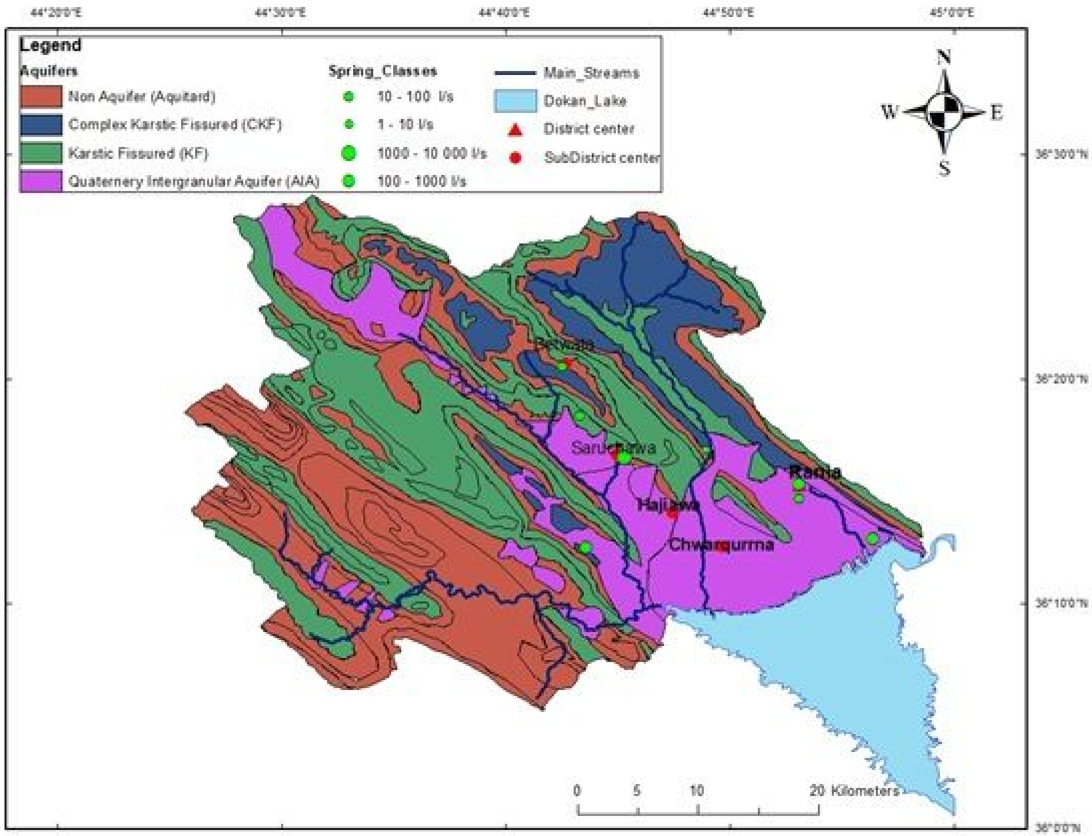

Figure 3

Map of hydrostratigraphic units in the Rania basin

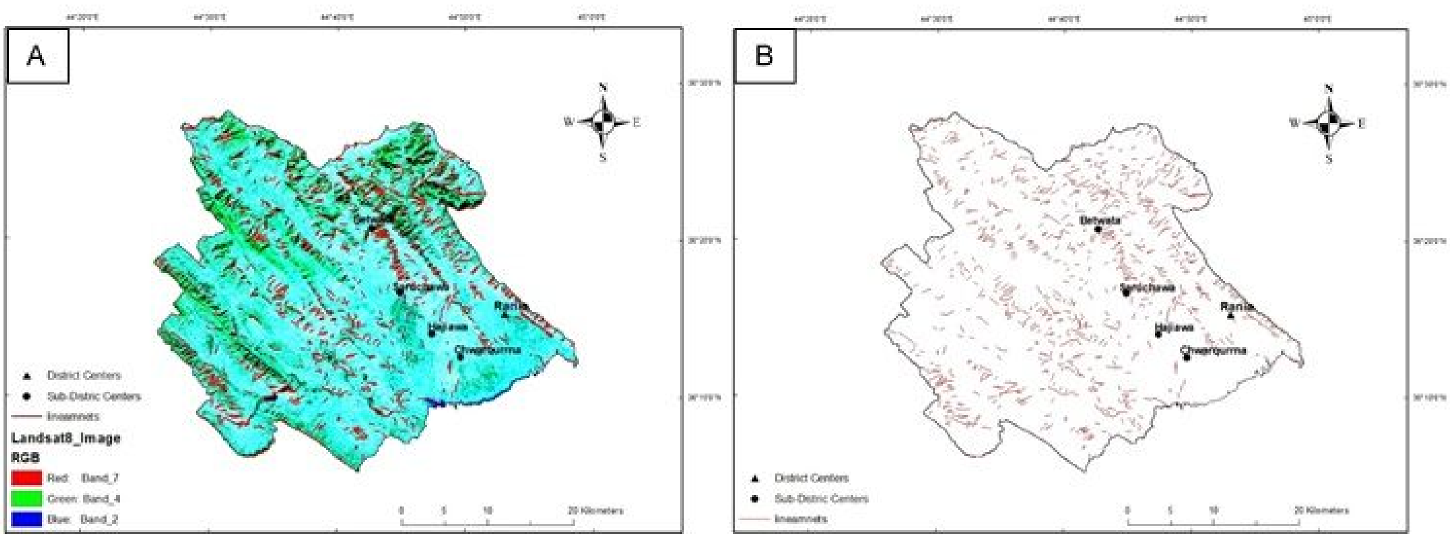

Figure 4

(A) Thematic map of the Rania basin (B) lineament distribution map of the basin

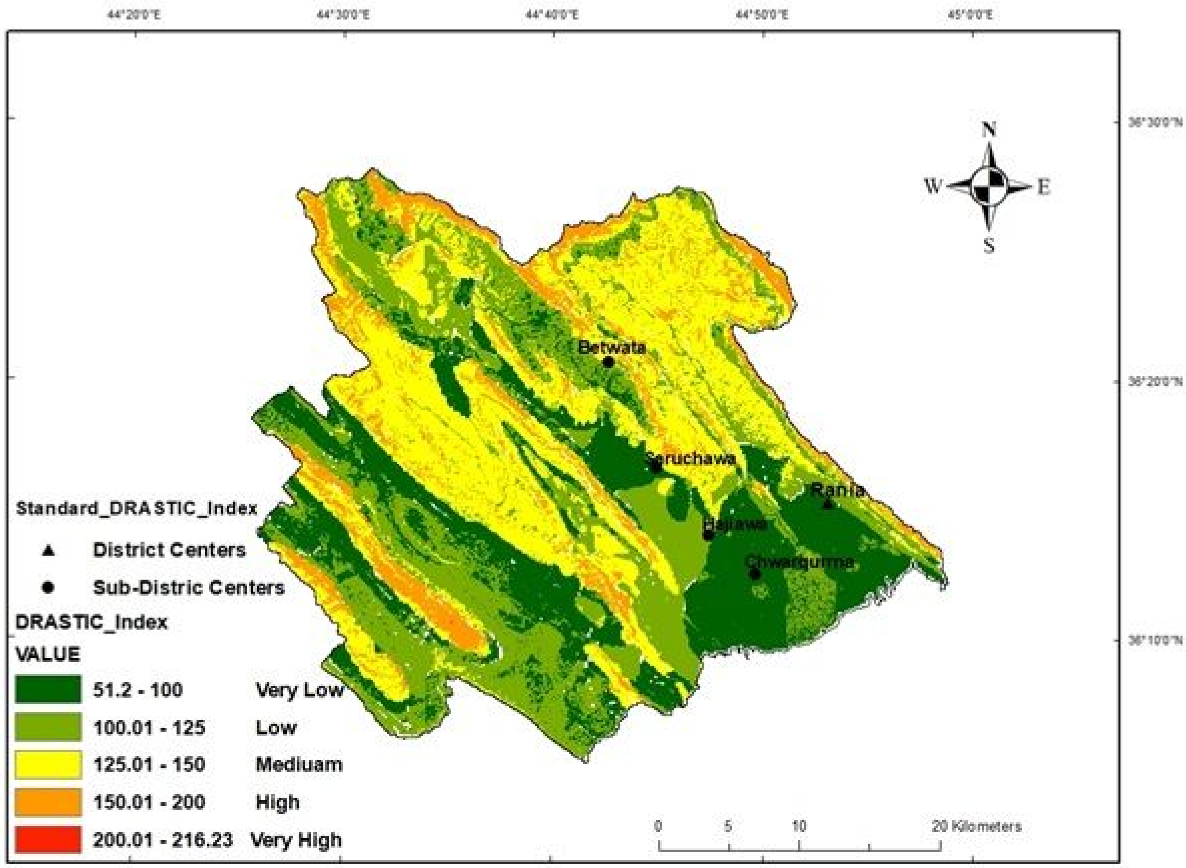

Figure 5

Standard DRASTIC index map for the Rania basin

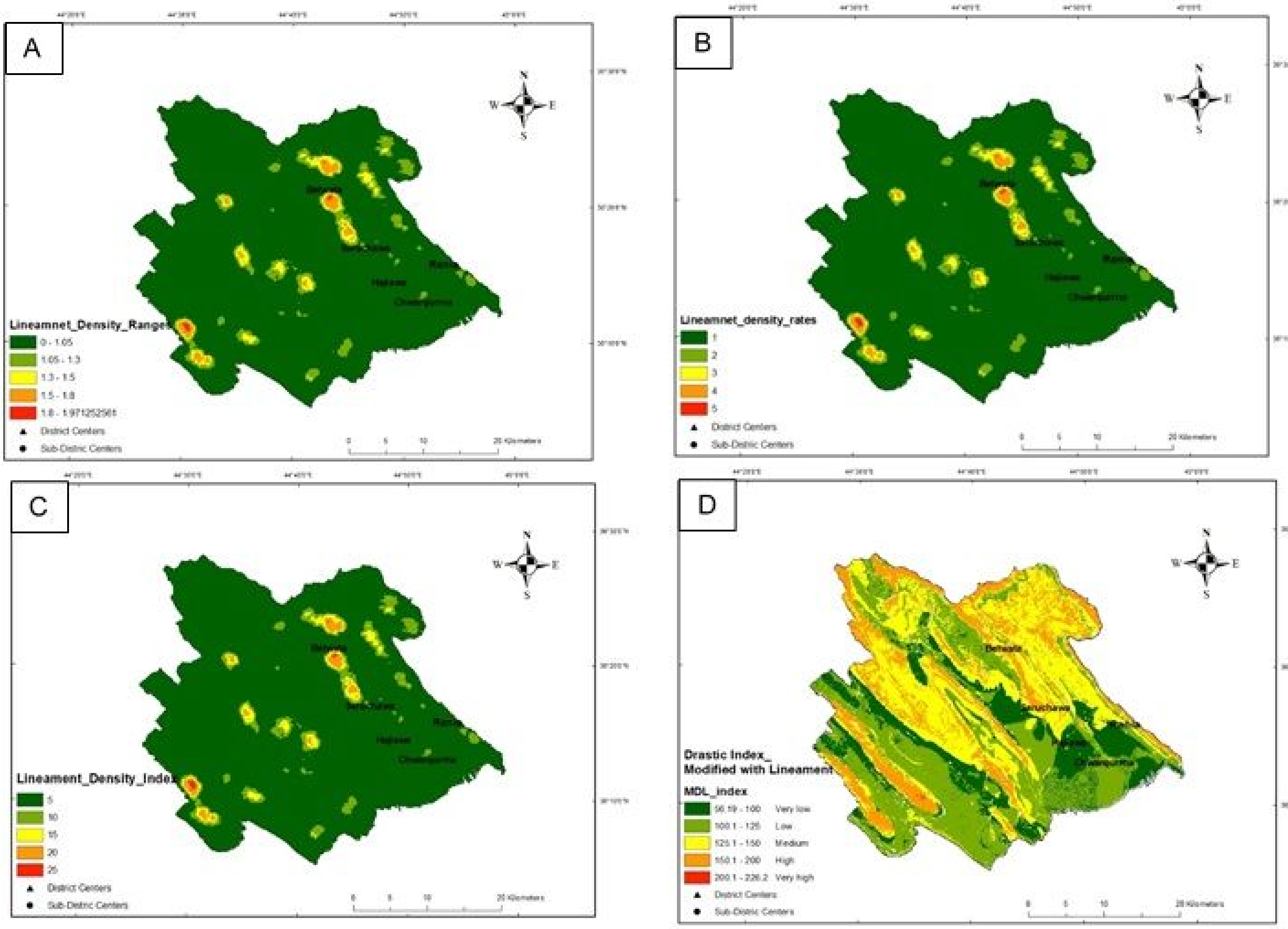

Figure 6

(A) Lineament density ranges map (B) lineament density rating map (C) Lineament density index map (D) Modified with lineament DRASTIC map

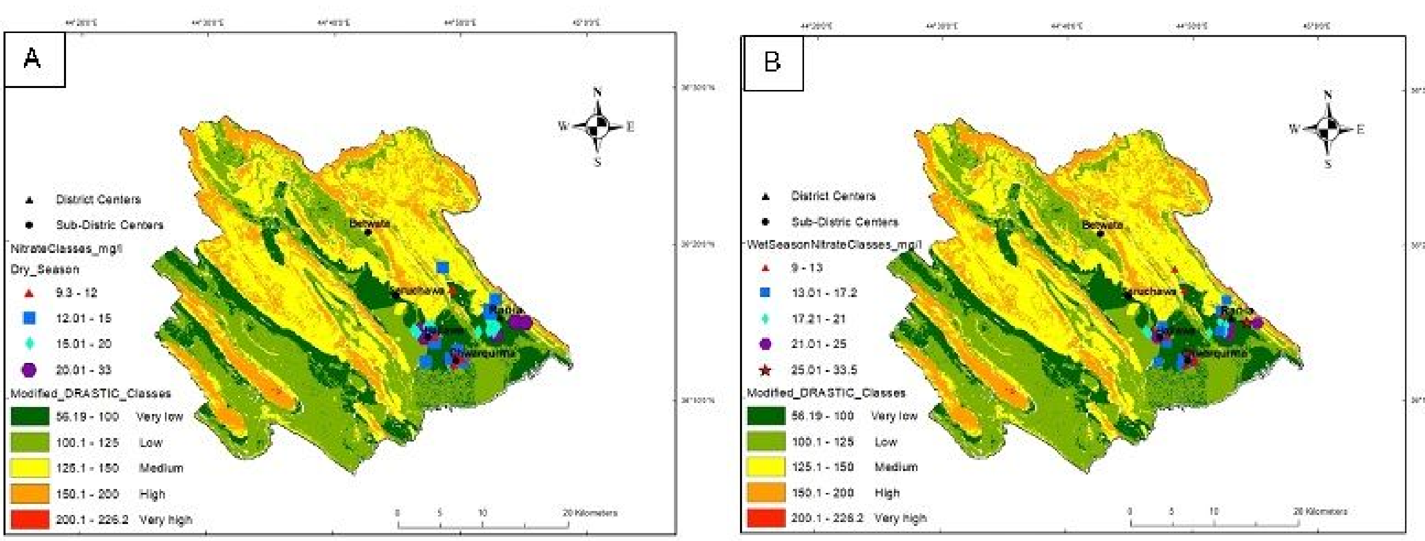

Figure 7

Modified DRASTIC maps (A) with nitrate (no3-) concentrations in dry season (B) with nitrate (no3-) concentrations in wet season