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Groundwater vulnerability map of Sulaymaniyah sub-basin using *SINTACS model*, Sulaymaniyah Governorate, Kurdistan Region, Iraq

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GIS

Abstract

The present work locates in the Complex and Unstable Platform of Arabian Plate within the Zagros Fold-Thrust Belt (ZFTB). It expands over an area of 523 Km^2 in the Sulaymaniyah Governorate. Lower Cretaceous and Holocene formations are the dominant stratigraphic units exposed in the area. The alluvium intergranular, karstic fissured, and complex aquifers are the principal water-bearing beds occur in the field of the question. The present study deals with the evaluation of groundwater vulnerability to pollution using SINTACS model in addition to the assessment of the validity of four scenarios applied in this work “Normal, Relevant, Drainage impacts and Nitrate scenarios” with the spatial distribution of nitrate “NO_3” map. Nitrate spatial map was constructed from 96 water samples collected from domestic and agriculture water wells, emergence from karezes and springs in benefit with the Geographic Information System (GIS). Although the SINTACS method gives good outputs in the evaluation of groundwater vulnerability to pollution, it cannot be used for reliable assessment of the groundwater pollution risk. Therefore, it is necessary to calibrate the original scenarios with nitrate distribution to obtain more accurate results.

I- Introduction

The protection and preservation of groundwater resources are compulsory, particularly in arid and semi-arid regions where the water resources are scarce. The area of study is located in the north-eastern part of Iraq within the Sulaymaniyah Governorate, between latitudes (3922182-3960119) North and longitudes (517289-545099) East, expanded over an area of (523 Km^2) *(Figure: 1)*. From the tectonic points of view, the area is located in complex and unstable platform of Arabian plate within the Zagros Fold-Thrust Belt (ZFTB). Geologically, the formations outcrops from old to recent appear as Lower Cretaceous to Holocene age *(Figure: 2)*. Climatically, the area locates under Mediterranean Sea impact that has warm and dry summer as well as cold, snowy and rainy winter. Based on the archives of the Sulaymaniyah and Bakrajo meteorological stations for the period of (1992-2014), the total average annual rate of precipitation is 668.5 mm. The average rate of humidity is % 46, and the average temperature is 21^{0}C. The average winds speed, the sunshine duration are 1.64 m/sec and 7.7 hours/day respectively. The result of the FAO - Penman Monteith method revealed the average annual evapotranspiration as 1481 mm/year. The dominant water bearing units are alluvium intergranular, karstic-fissured and complex aquifers. The main objective of the present work is to evaluate the groundwater vulnerability for contaminants by means of SINTACS model with the assistance of Geographic Information System (GIS).

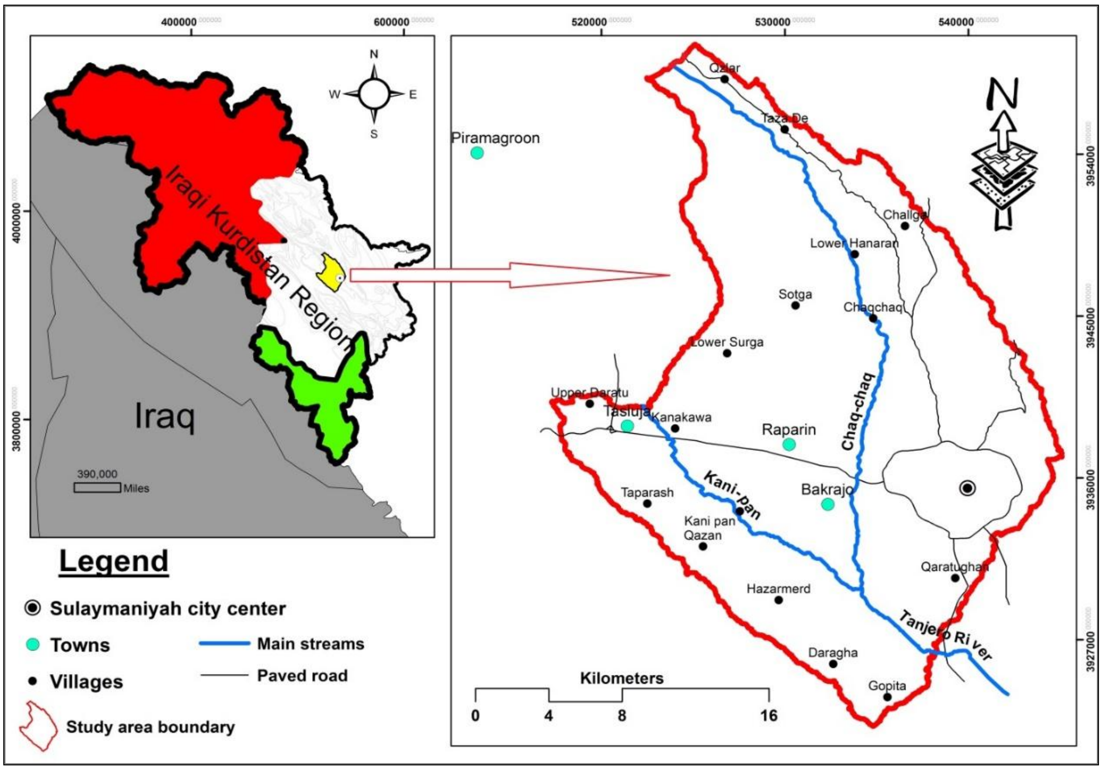

Figure- 1: Location map of the study area

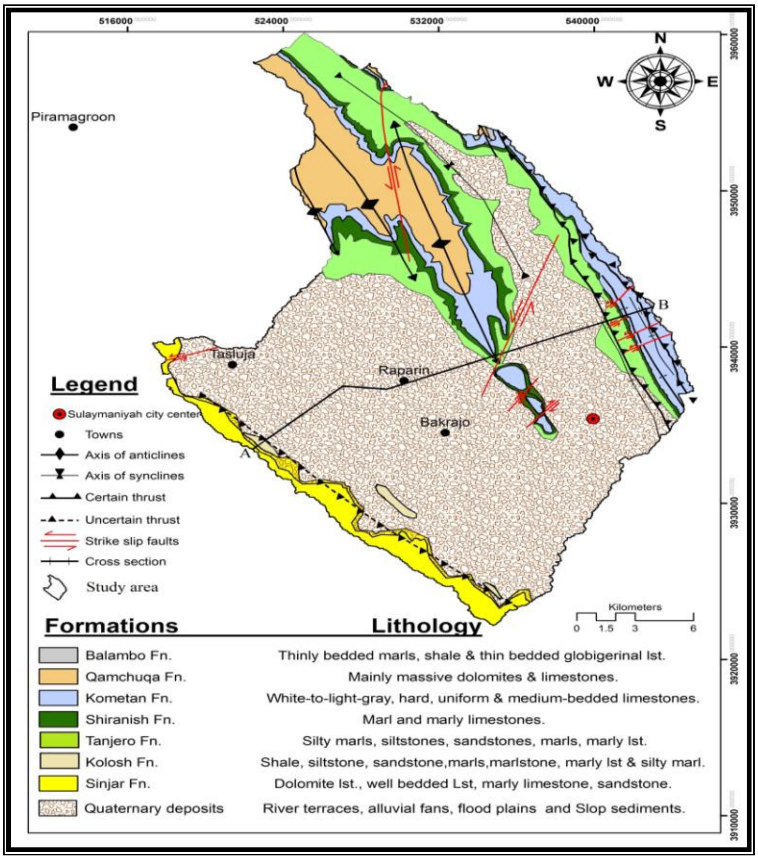

Figure- 2: Geological map of the area of interest (after Ali, 2007; Al-Hakari, 2011 and Bety, 2013)

II- Background

The SINTACS model was proposed and arises in Italy by Civita in (1994). It is partially derived from DRASTIC, after that the enhancement is continuing until the final release 5 is reached by Civita and De Maio, in (2000). It is widely applied worldwide, examples are Longo et al., (2001); Janza and Prestor, (2002); Corniello et al., (2004); Mali and Janza, (2005); Uhan et al., (2008); Polemio et al., (2009); Khemiri et al, (2013); Hemmati et al., (2014); AL-Qurnawi, (2014), etc. The groundwater vulnerability map is a useful, feasible and crucial way to protect and manage the groundwater particularly in a region where the natural climatic conditions, high population growth, and industrial activity through the groundwater resource become crisis (Ducci and Sellerino, 2013; Antonakos and Lambrakis, 2007). In the last decades, vulnerability maps used as a predictive tool for groundwater management, land-use planning, and risk assessment. From the late 1980s, there were various attempts to formalize the definition of the expression and to develop related mapping systems. Recently, different methods have been developed to evaluate aquifer vulnerability and applied to groundwater protection in karstic and intergranular media *(Table-1)*.

Table-1: Qualitative intrinsic vulnerability methods based on origin

Origin	***Vulnerability methods***
Aller et al., 1987	DRASTIC
Foster, 1987	GOD
Civita and De Maio, 1997	SINTACS
Doerflinger et al., 1999	EPIK
Goldscheider et al., 2000	PI
Vías et al., 2006	COP

The first attempt in creating groundwater vulnerability map by using DRASTIC model for Iraq was done by Hamamin (2011). Manhi (2012) used GOD method to the Upper part of the Dibdibba aquifer in Safwan area (Southern Iraq). Later, Al-Qurnawi (2014) used DRASTIC, SINTACS and GOD methods collectively in assessing the Alton Kopry basin in Kirkuk Governorate.

III- Methodology

Basically, this model takes into consideration the same seven DRASTIC parameters applied in this field but, it is more flexible and implement various ratings (**R**) and weights (**W**) indexes as shown in (Appendix-1) & (Appendix-2). It provides six weight classifications or scenarios, namely: *normal* impact, *relevant* impact, *drainage* (by streams), *karstic* (aquifers), *fissured* (aquifers) and the pesticides by *nitrates* (Civita and De Maio, 1997). The SINTACS index (or contamination potential) is a summation of the rating of each parameter multiplied by the associated weight score for each scenario based on the expression (1);

$$\boldsymbol{I_{SINTACS}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{7}} \boldsymbol{P_i} \ \boldsymbol{x} \, \boldsymbol{W_i} \ldots\ldots\ldots..(1)$$

Where:

I $_{SINTACS}$: SINTACS index

P$_i$: The score of parameters that the method considers

W$_i$: The relative weight

The intrinsic vulnerability index (**I**) is divided into six vulnerability classes as shown in *(Table-2)*.

Table-2: Classes of intrinsic vulnerability index as proposed by (Civita and De Maio, 2000)

Ranges ***I*** *SINTACS*	***Vulnerability Classes***
less than 80	Very low
80 – 105	Low
105 – 140	Medium
140 – 186	High
186 – 210	Very high
210 – 260	Extremely high

The following seven parameters are considered by SINTACS, each with a score ranging from 1 to 10 where the higher value denotes greater aquifer vulnerability. A numerical value called a weight parameter ranged between 1 and 5 is assigned to each parameter and reflects its influence degree and related to hydrogeological, environmental, and local anthropogenic conditions. The SINTACS comes from the Italian names of the factors that are used:

i. **S**oggiacenza (depth to water table),
ii. **I**nfiltrazione efficace (effective infiltration).
iii. Azione del **N**on saturo (unsaturated zone attenuation capacity).
iv. **T**ipologia della copertura (Soil/overburden attenuation capacity).
v. Caratteri Idrogeologici dell'**A**cquifero (Aquifer hydrogeologic features).
vi. **C**onducibilità idraulica (Hydraulic conductivity).
vii. Acclività della **S**uperficie topografica (Topographic surface average slope).

The "***S***" or (depth to water table) can be defined as the distance from the ground surface to the water table (Al-Kuisi et al., 2006). It impacts the required time for contaminants to reach the water table (Garcia-Barbon, 2004). As the depth to water table increases, the probability of groundwater pollution is decreased and vice versa. The effective infiltration ***"I"*** indicates the amount of water which penetrates the ground surface and reaches the water table (Fitts, 2013). The ***"N"*** parameter refers to the unsaturated zone material properties, which controls the pollutant attenuation processes (Hemmati et al., 2014). The unsaturated zones are necessary for attenuation processes such as biodegradation, chemical reaction, volatilization, and dispersion. The ***"T"*** factor represents the uppermost weathered portion of the unsaturated zone and controls the amount of recharge that can infiltrate downward (Babiker et al., 2005). The type and size of the soil media directly affects the rate of infiltration of pollution (Aller et al., 1987). The ***"A"*** refers to the hydrogeologic characteristics of the aquifer, being either porous medium, fractured or karst are fundamental to determine the groundwater flow and consequently contaminant dispersion through it (Civita et al., 2009). The Hydraulic conductivity ***"C"*** refers to the rate at which the aquifer materials transmit water. It is important because it determines the rate of movement through the aquifer of a contaminant from the point of contact (Klug, 2009). The ***"S"*** parameter refers to topography of the land which has a great impact on groundwater vulnerability. The slope of the land has an important role in determining whether the contaminant released will become run-off or infiltrate to the aquifer (Abdullahi, 2009). However, topography influence soil development and therefore has an impact on contaminant attenuation (Piscopo, 2001).

IV- Results

To demonstrate an application of the SINTACS model in a Geographic Information System and prior to analysis of the SINTACS model, a GIS database was setting up. The required data and procedure for constructing thematic layer of each parameter is described briefly in the following sections:

i- “S” (depth to water table)

In the present work, depth to water table was collected from 585 water wells taken from the archives of the Sulaymaniyah Groundwater Directorate. These data were georeferenced in the GIS environment to construct the depth to water table or (**S** map). The rating of *“S”* parameter varies from 1“low vulnerability” to 9 “high vulnerability” as shown in (Appendix-1) and (Figure: 3).

ii- “I” (effective infiltration)

The effective infiltration was calculated based on the simple water balance method. The output divides the study area into three recharge zones with rating values of (1, 4, and 8) as shown in *(Figure: 4)*.

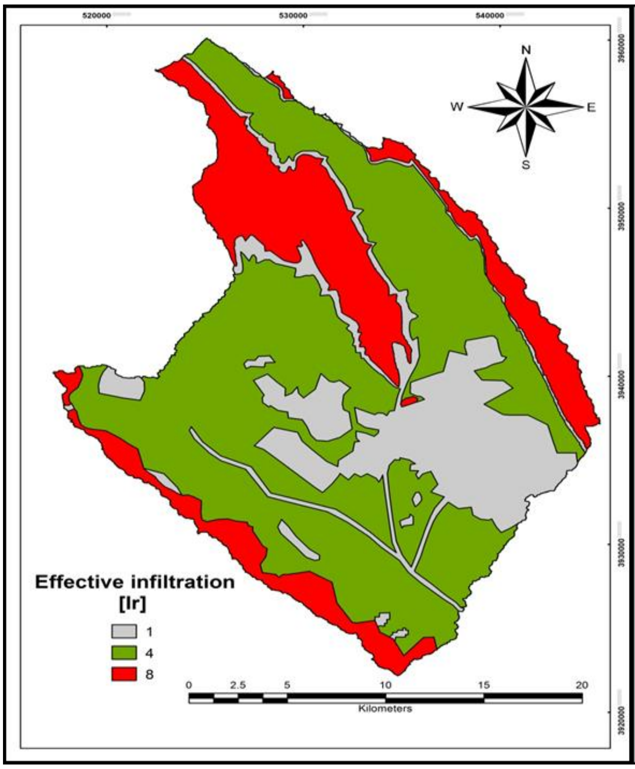

Figure- 3: Rating Map of ‘S’ (depth to water table)

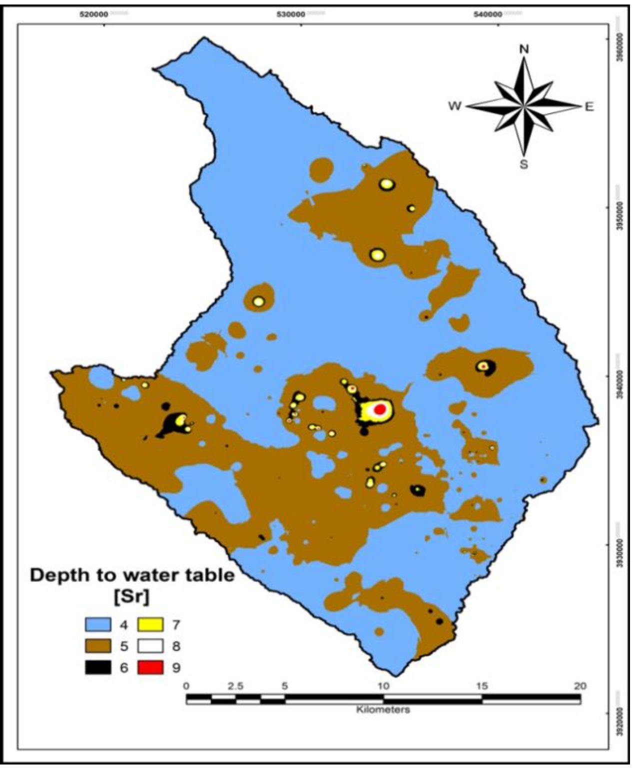

Figure- 4: Rating map of ‘I’ (effective infiltration)

iii- “N” (Unsaturated zone attenuation capacity)

The information about the unsaturated zone is mainly derived from the recorded profiles of almost 500 water wells in addition to geoelectrical investigations conducted inside the study area. The ratings of the unsaturated zone materials and the spatial distribution of this parameter are illustrated in both *(Appendix-1)* and *(Figure: 5)* respectively.

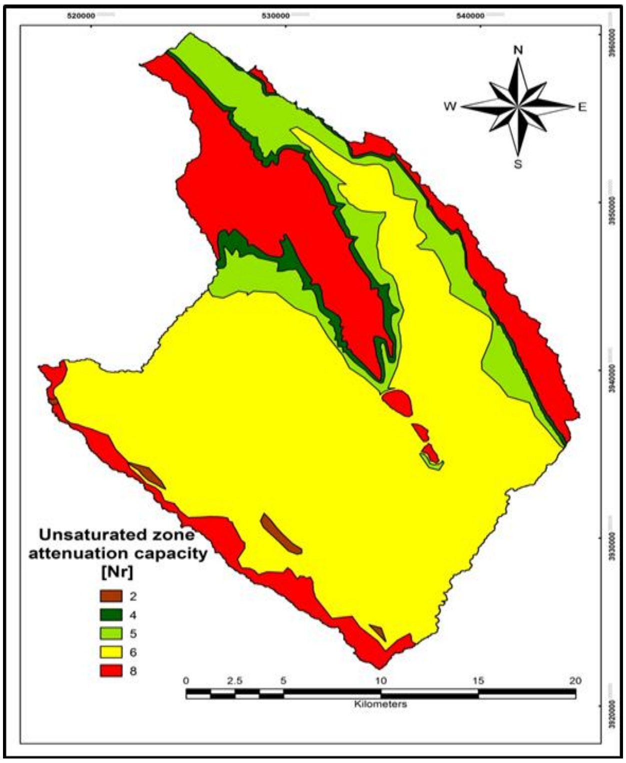

Figure- 5: Rating map of ‘N’ (Unsaturated zone attenuation capacity)

iv- “<u>T</u>” (Soil / overburden attenuation capacity)

Soil type and land use maps that prepared previously by (Berding, 2003) were used and reclassified to construct the map of this parameter *(Figure: 6)*. The soil media was then assigned ratings from (4 to 10) according to the description of soil permeability and texture as proposed by Civita and De Maio, (1997). The soil polygon feature was converted to a raster format to meet the requirement of the model, *(Figure: 7)*.

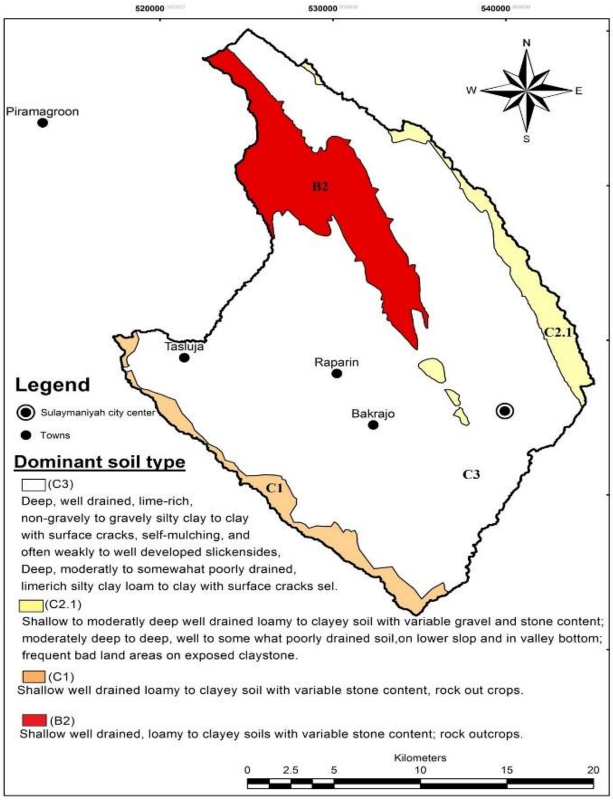

Figure- 6: Soil type of the area (after Berding, 2003)

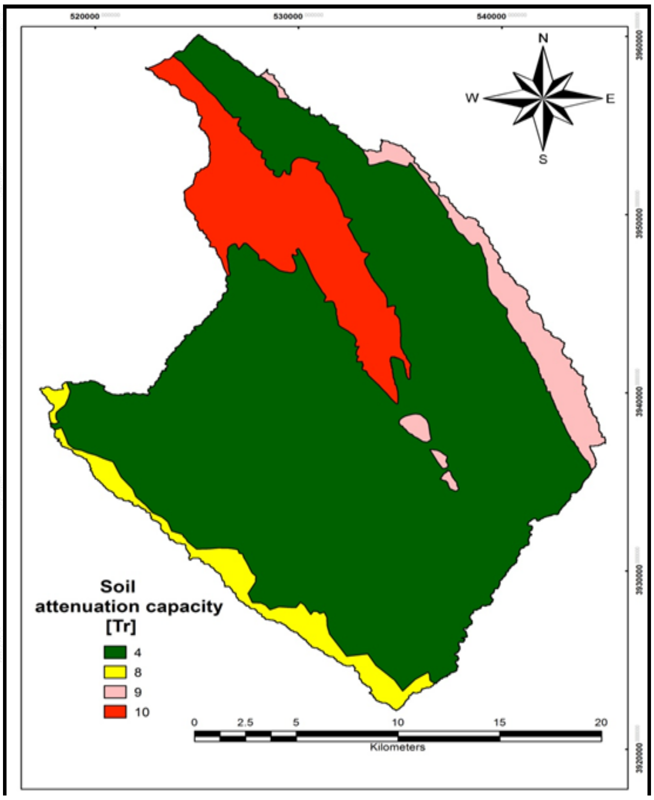

Figure- 7: Rating map of ‘T’ (Soil/overburden attenuation capacity)

v- “A” (Aquifer Hydrogeologic features)

This layer was prepared in benefit with the description of previous reports and profiles from geophysical investigations and lithology from tenth of drilling water wells in the area of interest, such as Aziz, (2001); Ali, (2007) and SGI, (2011). The resulted thematic “***A*** map” is presented in *(Figure: 8).*

vi- “C” (Hydraulic conductivity)

The aquifer parameters, such as transmissivity and hydraulic conductivity obtained by pumping test using AQTESOLVE version 4.5 software program. This program is capable of computing parameters even in the case of a single well and partially penetration situations. For the current study, hydraulic conductivity “C” was determined from the calculation of the aquifer transmissivity (T) obtained from pumping test analysis of 84 single wells divided by the aquifer saturated thickness (b) using (Eq. 2). Thematic map of “C” parameter is then constructed and presented in *(Figure: 9).*

$$\boldsymbol{C} = \frac{\boldsymbol{T}}{\boldsymbol{b}} \dots\dots\dots\dots (2)$$

Where; C is hydraulic conductivity in (m/day)
T is transmissivity in (m^2/day)
b is aquifer saturated thickness in (m).

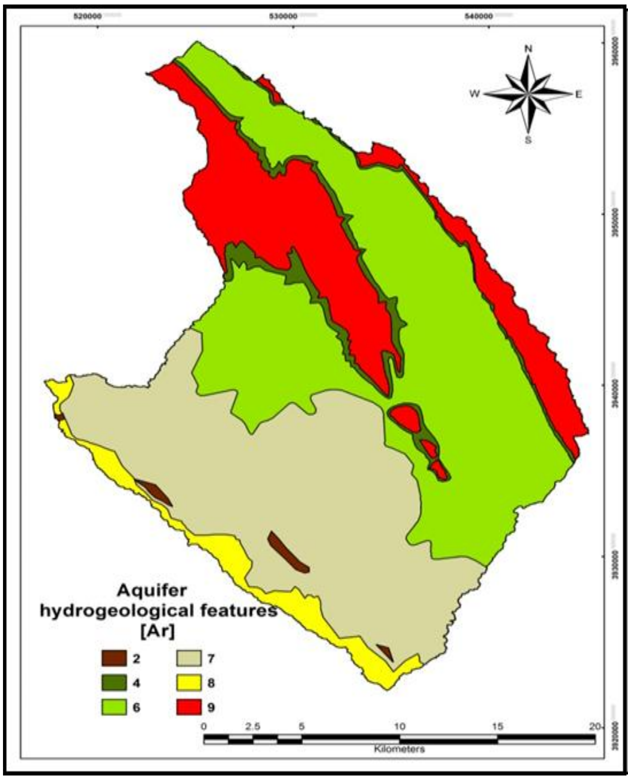

Figure- 8: Rating Map of ‘A’ (Aquifer features)

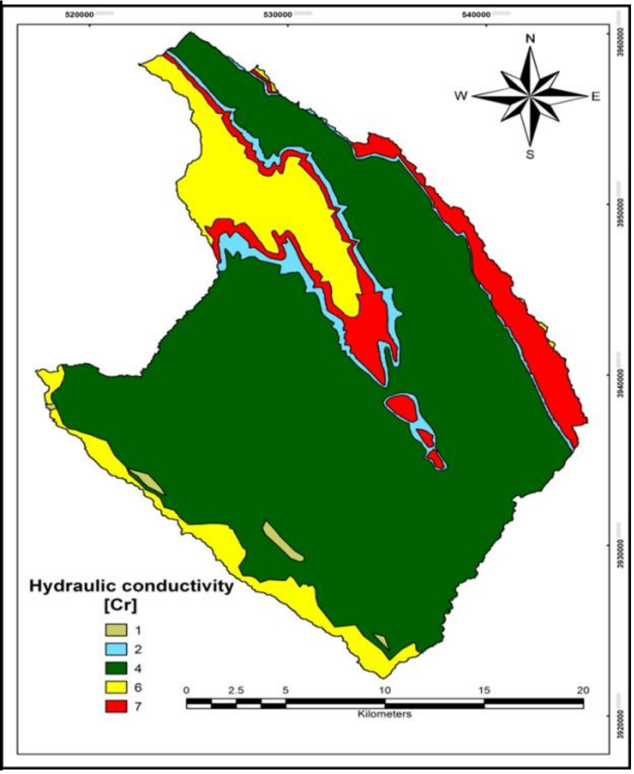

Figure- 9: Rating Map of ‘C’ (Hydraulic conductivity)

vi- “S” (Topographic surface average slope)

The “S” map was constructed by interpolation from the slope percent of the land surface using the digital elevation model “DEM”. The DEM was taken from NASA srtm satellite image with a resolution of 15 m. 10 classes of slope were determined, then it was sliced and reclassified to rating values according to the percent ranges proposed in the SINTACS model. The output is shown in *(Figure: 10).*

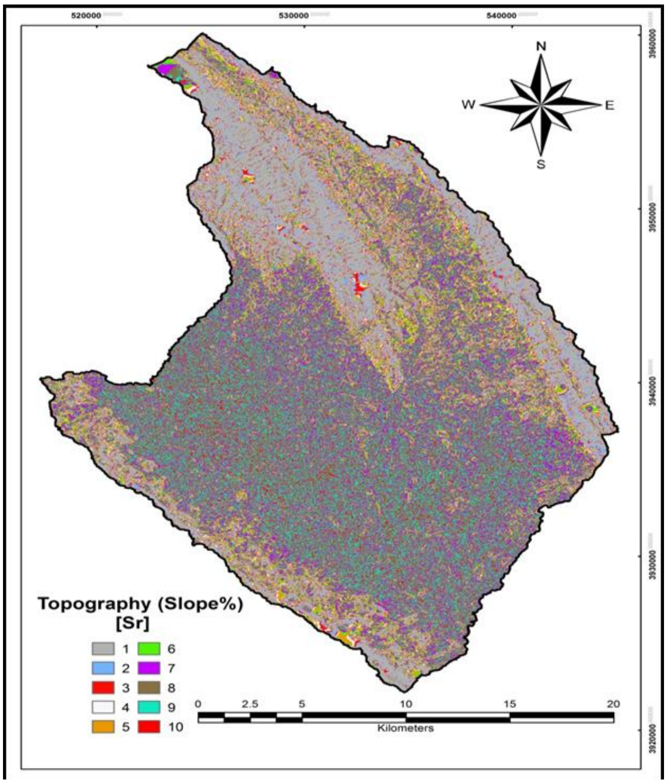

Figure- 10: Rating Map of 'S' (Topographic surface average slope)

V- Discussion

After preparations of the previous seven parameters, thematic map layers were converted into the raster grid format with a cell resolution of 15 m. The SINTACS vulnerability index (SVI) were obtained by overlaying the layer maps. Each layer was multiplied by their significant weights and ratings by mapping algebra in GIS toolbox using the (*Eq. 3*). Four scenarios namely; the Normal, Relevant, Drainage impacts and Nitrate were applied *(Figures: 11 - 14)*. The "Karstic and Fissured" scenarios have been neglected in the current work because carbonate rocks in the area of interest are mostly behave as Karstic - Fissure aquifers rather than Karstic or Fissure alone.

$$\boldsymbol{SVI = Sr * Sw + Ir * Iw + Nr * Nw + Tr * Tw + Ar * Aw + Cr * Cw + Sr * Sw} \ldots\ldots (\mathbf{3})$$

Where; ***S, I, N, T, A, C***, and ***S*** are the seven required parameters

w; The weight of the factor based on (Appendix 2), and ***r***; is the rating associated (Appendix 1).

Each applied scenario for the present study is briefly explained in the following sections:

i. *Normal scenario*

The vulnerability index of normal scenario was classified into five classes, and it ranged from 58 to 205. The medium intrinsic vulnerability class is predominant, and it occupied (333 km^2) or 63%. High and very high classes occupied about 32% collectively from the whole area of study as shown in both *(Figure: 11)* and *(Appendix-3)*. The zones with high vulnerability are distributed mainly in the mountain regions that constituted by karstic fissured outcrops of Balambo, Qamchuqa, Kometan and Sinjar Formations. Accordingly, the impact of aquifer media, soil texture, and the high permeability of the vadose zone are believed to be the most useful parameters in this scenario.

ii. *Relevant scenario*

In this scenario, the vulnerability index ranged from 63 to 208. The medium class increased by 8% in comparison to the normal scenario *(Figure: 12)*. The relative weight of soil texture and recharge zone are probably the main factors beyond this increment. The medium and high classes occupies (374 km^2) or 71% and (81 km^2) or 15% of the whole area respectively *(Appendix-3)*.

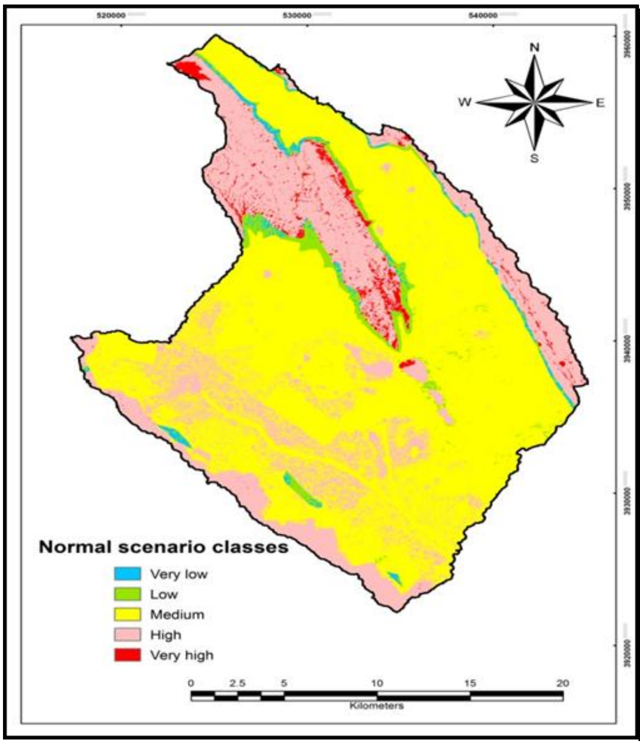

Figure- 11: Normal scenario of the study area

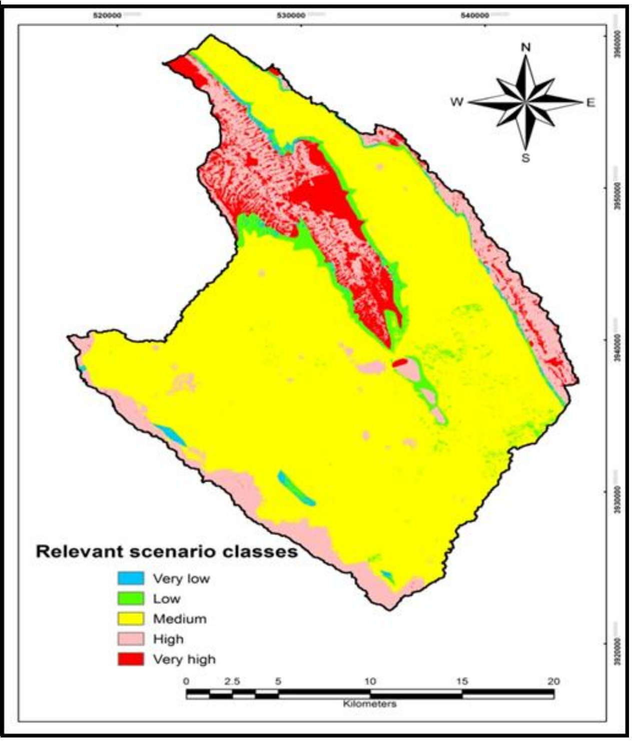

Figure- 12: Relevant scenario of the study area

iii. Drainage scenario

The vulnerability index of drainage scenario ranged from 53 to 204. Again, the medium vulnerability class is predominant the most area of study that occupied (342 km^2) or 65% of the total area *(Figure: 13)*. In this scenario, the medium class is increased by 2% than the normal scenario due to the proper weight for aquifer media and hydraulic conductivity.

iv. Nitrate scenario

The thematic rating map of this scenario was multiplied by nitrate weight as shown in *(Appendix-2)*. The index was classified into five categories as the previous scenarios. This scenario considered to determine intrinsic vulnerability if the agricultural activities expand in the future that contain NO_3, may deteriorate the quality of water in the area. The index values ranged from 62 to 209. The most dominant classes are represented by a medium vulnerability that occupied an area of about 357 km^2 or (68%) of the whole area. Urban and agricultural area mainly cover it. Very low and low vulnerability classes comprise small amounts of this rate (1.2%) and (5.5%) from the whole area respectively *(Figure: 14)*.

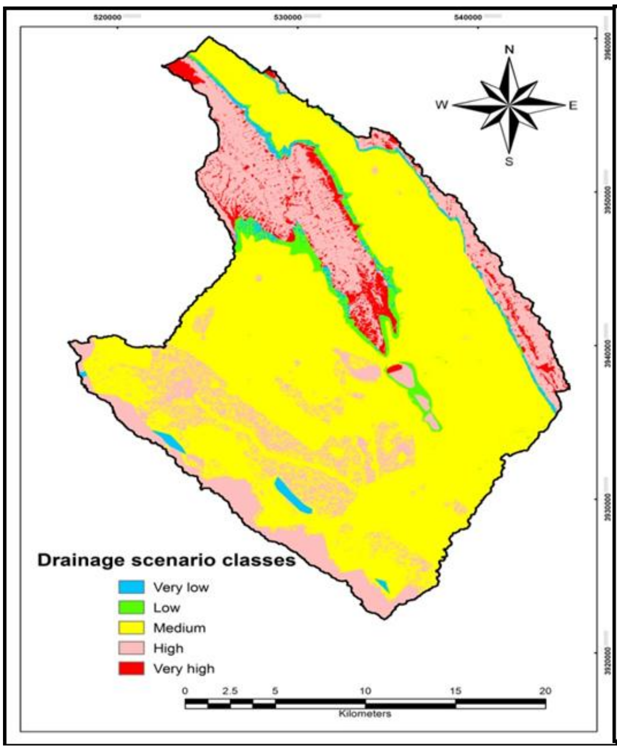

Figure- 13: Drainage scenario of the study area

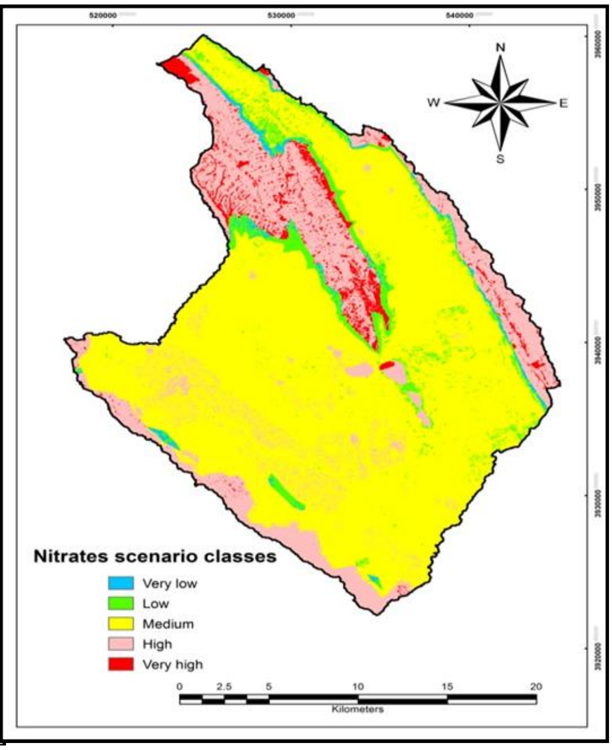

Figure- 14 Nitrate scenario of the study area

VI- Validity of SINTACS maps

To evaluate the validity of vulnerability maps, the spatial distribution of nitrate concentration was selected as the primary contamination to correlate with the SINTACS model *(Figure: 15)*. The total amount of 96 water samples were collected from domestic and agriculture water wells, emergence from karezes and springs during the periods from April to May 2014 *(Figure: 16).* As can be depicted from the nitrate map, the concentration varies from (0.5 to 70 mg/l). This result is close to those detected previously by Mustafa and Ahmad (2008) for water wells in the area. Some of the samples are exceding the standard permissible limits recommended by Iraqi (2001) and World Health Organization "WHO 2006 and 2011". The primary source of groundwater contamination by Nitrate (NO_3) in the area was likely to be related to sewage and wastewater leakage from Sulaymaniyah city. The industrial activities, and agricultural practices especially in the southern and western parts of the city are the other resources of the high nitrate concentration. Al-Manmi (2002) and Mustafa (2006) in their previous works refereed the primary source of high NO_3 concentration in the groundwater of Sulaymaniyah city to the leakage from sewages system.

As a whole, the nitrate concentration is increased diagonally from north-west and western part to south-east, in addition to the observed trace of higher concentration within the Chaq Chaq stream in the northern and central parts too. Accordingly, the Kani pan stream has a great impact on transporting and spreading NO_3 pollution which probably comes from urban sewage water that used for crop irrigation inside and out of the area. The correlation analysis between SINTACS vulnerability scenarios with the spatial distribution of nitrate map showed that, Drainage scenario is more compatible with nitrate in comparison to the other three scenarios.

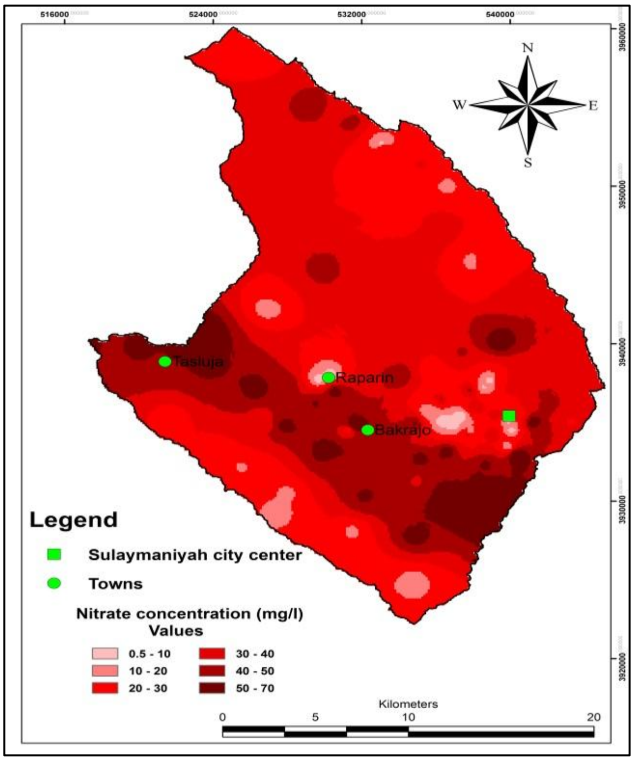

Figure- 15: Spatial distribution of nitrate concentration

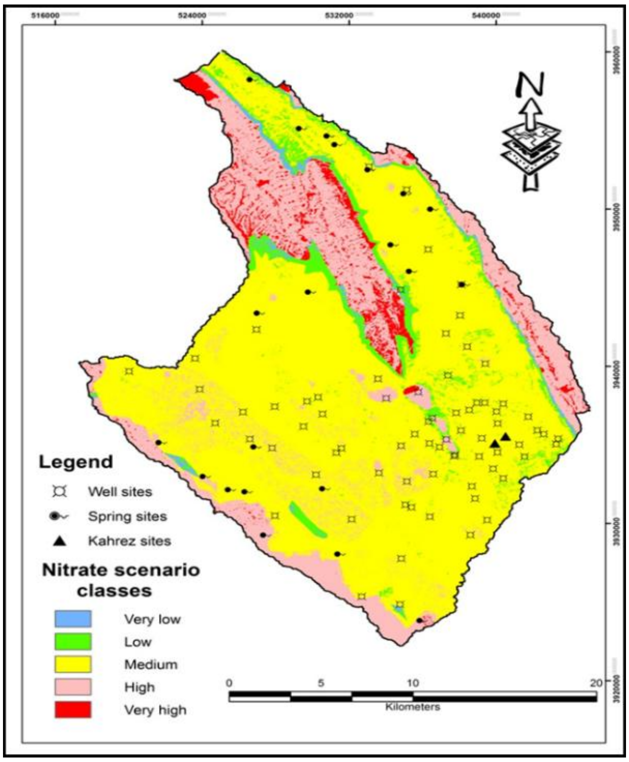

Figure-16: Collected water samples from wells and springs

VI- Conclusions

The aims of the present work were to create groundwater vulnerability maps using SINTACS model, and to assess the validity of four scenarios applied in this manner namely “Normal, Relevant, Drainage impacts and Nitrate” with the spatial distribution of nitrate “NO_3” map. Although the SINTACS method gives useful outputs in the evaluation of groundwater vulnerability to pollution, it cannot be used for reliable assessment of the groundwater pollution risk. Therefore, it is necessary to calibrate the original scenarios with nitrate distribution to obtain more accurate results. Outcomes of this work reveal a great similarity in the distribution of the vulnerable zones recognized by indexes. The most common vulnerability zone is a medium for the all the constructed four scenarios particularly in areas where Quaternary deposits and Tanjero Formation are cropping out. The high vulnerability class is diffuse, especially where Karstic-Fissured aquifers represent the aquifer. In contrast, the very low and low vulnerability index is dominant in the foothill of mountains. The correlation analysis between SINTACS scenarios with the nitrate distribution showed that Drainage scenario is more compatible with nitrate in comparison to the other three scenarios. The Kani pan stream has a great impact in increasing the high vulnerable zone particularly in the central and western parts of the area. The urban sewage water that used for crop irrigation and the nature of soil texture could be the probable possibility of the relatively high nitrate concentrations in these fields.

Appendix-1: Original SINTACS weights and rating systems, (Civita and De Maio, 1997)

Depth to water table "S" in (m)		**Effective infiltration "I" in (mm)**		**Hydraulic conduct. "C" in (m/ day)**		**Topographic surface "S" in %**		**Soil / overburden atten. Capacity "T"**		**Unsaturated zone attenuation "N" & Aquifer Hydrogeologic features "A."**		
Range	*Rating*	***Range***	*Rating*	***Range***	*Rating*	***Range***	*Rating*	***Range***	*Rating*	***Range***	*Rating "N."*	*Rating "A"*
> 20	***4***	< 50	***1***	< 0.1	*1*	0 – 2	***10***	Clay	***1 – 1.5***	Coarse alluvial deposits	***6 – 9***	***8 – 9***
10 - 20	***5***	50 – 60	***2***	0.1 – 0.43	*2*	3 – 4	***9***	Silty – clay	***1.5 – 2***	Karstified limestone	***8 – 10***	***9 – 10***
8 – 10	***6***	60 – 75	***3***	0.43 – 0.86	*4*	5 – 6	***8***	Clay loam	***2 – 3***	Fractured limestone	***4 – 8***	***6 – 9***
6 - 8	***7***	75 – 100	***4***	0.86 – 4.32	*5*	7 - 9	***7***	Silty clay loam	***3 – 4***	Fissured dolomite	***2 – 5***	***4 – 7***
4 – 6	***8***	100 – 125	***5***	4.32 – 8.64	*6*	10 – 12	***6***	Silt loam	***3.5 – 4***	Medium-fine alluvial deposits	***3 – 6***	***6 – 8***
1 - 4	***9***	125 – 150	***6***	8.64 – 43.2	*7*	13 – 15	***5***	Loam	***4 – 5***	Sand complex	***4 – 7***	***7 – 9***
0 - 1	***10***	150 – 175	***7***	43.2 – 86.4	*8*	16 – 18	***4***	Sandy clay loam	***4.5 – 5***	Sandstone, conglomerate	***5 – 8***	***4 – 9***
		175 - 250	***8***	86.4 - 432	*9*	19 – 21	***3***	Sandy loam	***5.5 – 6***	Turbidtic sequences	***2 – 5***	***5 – 8***
		250 – 325	***9***	432 – 864	*10*	22 – 25	***2***	Sandy clay	***6.3 – 7***	Fissured volcanic rocks	***5 – 10***	***8 – 10***
						> 26	***1***	Peat	***7.5 – 8***	Marl, clay stone	***1 – 3***	***1 – 3***
								Sandy	***8 – 8.5***	Clay, silt, peat	***1 – 2***	***1 – 3***
								Clean sand	***9 – 9.5***	Pyro-clastic rock	***2 – 5***	***4 – 8***
								Clean gravel	***9.5 - 10***	Fissured metamorphic rocks	***2 - 6***	***2 - 8***
								Thin or absent	***10***			

Appendix-2: Strings of weights and hydrogeological scenario in SINTACS model (Civita and De Maio, 1997)

Weights of hydrogeological and potential impact scenarios

Parameter	*Normal*	*Relevant*	*Karstic*	*Fissured*	*Drainage*	*Nitrate*
S	5	5	2	3	4	5
I	4	5	5	3	4	5
N	5	4	1	3	4	4
T	3	5	3	4	2	5
A	3	3	5	4	5	2
C	3	2	5	5	5	2
S	3	2	5	4	2	3

Appendix-3: Total exposed and percentage of surface area occupied by four different SINTACS model scenarios

Classes	***Normal scenario***		***Relevant scenario***		***Drainage scenario***		***Nitrate scenario***	
	Extended area (Km^2)	Percent area (%)	Extended area (Km^2)	Percent area (%)	Extended area (Km^2)	Percent area (%)	Extended area (Km^2)	Percent area (%)
Very low	6.71	1.28	5.54	1.06	9.88	1.89	6.35	1.21
Low	16.00	3.06	22.77	4.35	14.45	2.76	28.66	5.48
Medium	333.85	63.80	374.58	71.59	342.06	65.37	356.87	68.20
High	154.09	29.45	81.35	15.55	136.65	26.12	111.66	21.34
Very high	12.6	2.41	39.00	7.45	20.20	3.86	19.69	3.76
Extremely high	0	0	0	0	0	0	0	0

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