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Groundwater assessment at east side of Mosul City during 2014–2017

Key word: groundwater quality (GWQ), attribute risk, weighted assessment, Epidemiological data

Introduction

The purity of drinking water is essential with no chemical and microbial contaminants like bacteria, viruses and protozoa which cause dangerous diseases like cholera, liver sag, Typhoid fever, dysentery (Cunningham, Daszak & Rodríguez, 2003). Groundwater quality is largely controlled by the range of human activities in addition to physical and biological properties (Kumar & Raj, 2018).

Wastewater is the primary source of water pollution in shallow wells which affects the drinking water. Most of harmful microorganisms live in digestive system; sewage, urban and domestic wastewater are widely discharged to groundwater (Tay & Kortatsi, 2008).

Abawi and Hashem (2001) studied the effect of wastewater leakage to groundwater through the study of 16 wells. The wells' depth ranged between 5 and 14 m near to the septic tanks distributed at Mosul city. Two wells far away from these septic tanks were used as a control. The results showed an increase of nitrate and phosphate for those near to contaminant sources.

Al-Hayali (2009) studied the groundwater which is situated within Mosul city for drinking and irrigation purposes for 16 wells. The results revealed that most of the wells are not suitable for drinking. The study showed that all samples were classified with high and very high salinity.

Al-Lela, Kharofa, Suheair Akrawi and Shatha (1993) studied using the groundwater at east side of Mosul city for irrigation purpose, and concluded that most of groundwater has high salinity while the other cations (Ca, Mg, Na, K) ranged between high to moderate.

Hussen (2002) assessed groundwater quality for 30 wells distributed within Mosul city. The results showed that using these wells was unsuitable for drinking and livestock purposes as they have high salinity.

This study assesses groundwater quality for 18 shallow wells in the east side of Mosul city for different purposes due to lack of availability of tap water during 2014–2017. Epidemiological analysis shows a risk in using this water based on epidemiological data about diarrhea cases that had been occurred at this period.

This study aims at studying the impacts of wastewater disposal practice on the groundwater quality through studying biological, physical, and chemical properties of groundwater. Also, the study reviews the texture of sub-layers of the studied area by the help of groundwater modelling system – GMS 10.1.

Materials and methods

Studied area

The studied area is located between (36°25′11.0125″ N, 36°16′29.2338″ N) latitude and (43°04′43.1214″ E, 43°14′ 21.5791″ E) longitude within municipal boundaries at the east of Mosul city. Figure 1 shows the locations of wells within this area which has 93.40719 km^2.

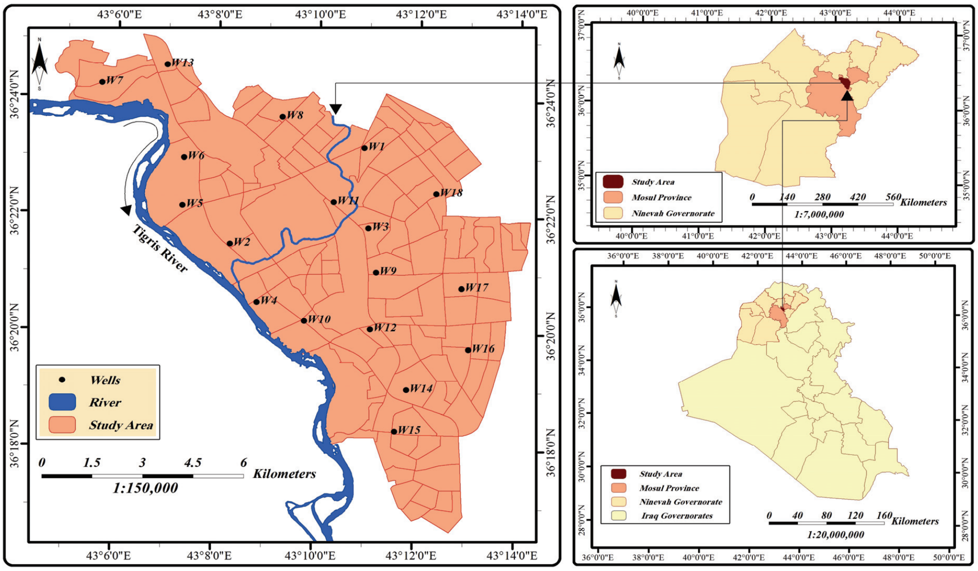

FIGURE 1. The studied area

The studied parameters

Eighteen shallow wells are selected within the studied area to assess their groundwater suitability for different purposes. Many depended parameters are tested for physical, chemical and biological analyses according to international standards (APHA, AWWA, WEF 2005). Parameters pH, Ca, Mg, *TDS*, *EC*, SO_4, CL, NO_3, B, K, Na, HCO_3, and *TC* are as in Tables 1 and 2. Incubation of positive tubes is used to exam the existence of *Escherichia coli*.

TABLE 1. Physical and chemical properties

No	pH	*TDS* [mg·l^{-1}]	*EC* [mhos·cm^{-1}]	HCO_3 [mg·l^{-1}]	SO_4 [mg·l^{-1}]	NO_3 [mg·l^{-1}]	Cl [mg·l^{-1}]	B [mg·l^{-1}]	K [mg·l^{-1}]	Na [mg·l^{-1}]	Mg [mg·l^{-1}]	Ca [mg·l^{-1}]	*SAR**
1	7.9	1 971	2.4	500	176	34	87	2.8	6.2	54	76	120	0.9
2	7.6	3 153	3.5	975	387	27	75	3.3	7.5	78	98	418	0.9
3	7.8	3 841	5.0	895	189	29	110	2.2	8	65	89	286	0.9
4	8.1	2 747	2.9	760	462	43	85	3.1	11	97	107	356	1.2
5	7.9	1 823	1.7	650	221	34	113	2.9	8.5	65	69	388	0.8
6	7.7	3 577	4.7	677	266	59	84	3.8	13	59	93	230	0.8
7	8.2	4 867	6.2	742	550	47	90	3.2	7	90	187	561	0.8
8	7.6	3 471	4.2	1050	230	38	82	3.1	5.5	60	105	358	0.7
9	7.8	4 140	5.5	740	314	21	100	3.0	8.3	71	63.4	294	1.0
10	7.5	2 781	3.2	820	189	35	88	3.2	29	68	144	389	0.7
11	8	3 279	3.9	890	278	32	94	3.6	2.2	82	127	374	0.9
12	8.2	1 977	2.0	730	329	19	59.9	2.7	1.6	74	82	268	1.0
13	7.7	6 665	9.3	810	420	46	74	3.9	8.3	94	112	523	1.0
14	8.1	3 226	3.9	795	345	25	97	4.0	7.5	123	96	315	1.6
15	7.6	3 298	4.1	755	220	51	90	3.1	9	77	134	400	0.8
16	7.5	3 134	3.1	860	365	13	130	3.4	7.8	98	115	387	1.1
17	7.7	2 120	2.3	690	144	22	98	3.1	2.4	68	51	235	1.0
18	7.6	2 679	2.8	578	490	61	129	3.2	11	91	78	310	1.2

*sodium adsorption ratio = Na / SQR(Ca+Mg) / 2, units in epm.

TABLE 2. Total Coliform and bacteria type

No	MPN·100 ml^{-1}	Bacteria type
1	240	*E. coli*
2	75	*E. coli*
3	3	Fecal coliform
4	4	Fecal coliform
5	5	Fecal coliform
6	8	*E. coli*
7	10	*E. coli*
8	200	*E. coli*
9	195	*E. coli*
10	80	*E. coli*
11	77	*E. coli*
12	65	*E. coli*
13	198	*E. coli*
14	87	*E. coli*
15	68	*E. coli*
16	265	*E. coli*
17	310	*E. coli*
18	300	*E. coli*

MPN – most potable number.

Parameters' impacts on groundwater quality

A brief summary of the parameters' impacts that are considered in assessing groundwater quality for different purposes are shown in Table 3.

Drinking groundwater assessment

Physical and chemical standards

Physical and chemical standards of the groundwater quality (GWQ) parameters for drinking purposes are listed in Table 4.

Groundwater modelling system

Groundwater Modelling System (GMS 10.1) is an extension of GIS which can be used to create a three dimensional profile of underground layers (Anderson & Woessner, 1992; Kresic, 2007). Input data of cross sections of sub-layers texture of each well is processed. A profile is created to speculate whether an infiltration might occur within the studied area, as in Figure 2.

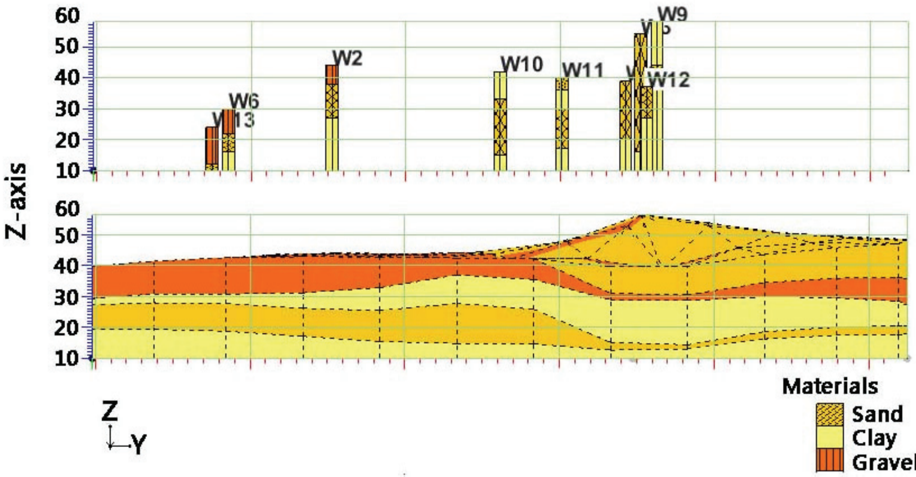

FIGURE 2. Profile of sub-layers

TABLE 3. The impacts of the selected parameters (EPA, 2001)

Parameter	Impacts
Chloride	High concentration of Cl indicates water pollution by sewage; high chloride levels may render pure water unsuitable for irrigation
pH	High pH causes an increase in Na cations which are toxic in both soil and plants; low pH: causes an increase of (Al) and (Mn) cations which are toxic to the crops
Sulfate	High concentration causes unlikable odor of hydrogen sulfide
Total dissolved solids – *TDS*	The high concentration of TDS increases the density of water
Sodium	High concentrations of sodium can cause cardiovascular diseases, and is toxic to plants
Nitrate	High concentrations are hazardous to infants as they stimulate the "blue baby" disease
Total hardness – *TH*	High concentrations can cause heart cardiovascular disease
Sodium adsorption ratio – *SAR*	High value is unsuitable for irrigation
Hydro carbonate	The presence of this anion in groundwater indicates that there is high concentration of soluble CO_2 in water and less of dissolved O_2
Total coliform – *TC*	Indicates the presence of wastewater in the analyzed water samples
Boron	It is considered dangerous to crops in irrigation at 1–2 $mg \cdot l^{-1}$ concentration
Calcium and Magnesium	High concentration is related to heart diseases
Electrical conductivity – *EC*	Indicator of hardness and alkalinity values

TABLE 4. Standards for drinking groundwater quality – DGWQ (EPA, 2001)

Parameter	Maximum permissible concentration	Unit
Calcium ($Ca^{2+)}$	75	$mg \cdot l^{-1}$
Magnesium (Mg^{2+})	100	$mg \cdot l^{-1}$
Sodium (Na^{+})	200	$mg \cdot l^{-1}$
Potassium (K^{+})	12	$mg \cdot l^{-1}$
Bicarbonate (HCO_3^{-})	400	$mg \cdot l^{-1}$
Sulphate (SO_4^{2-})	250	$mg \cdot l^{-1}$
Chloride (Cl^{-})	250	$mg \cdot l^{-1}$
Nitrate (NO_3^{-})	10	$mg \cdot l^{-1}$
pH	6.5–8.5	–
Total hardness – *TH*	300	$mg \cdot l^{-1}$ as $CaCO_3$
Total dissolved solis – *TDS*	500	$mg \cdot l^{-1}$
Total coliform – *TC*	0	$MPN \cdot 100\ ml^{-1}$

Relative, odd and attributed risk

Epidemiological data of the diarrhea cases that had been occurred at the period 2014–2017, are shown in Table 5.

TABLE 5. Number of diarrhea cases during 2014–2017 (Al-Salam Mosul Hospital, 2018)

No of month	2014	2015	2016	2017
1	33	163	68	21
2	48	96	94	59
3	61	124	113	89
4	89	120	126	65
5	111	67	135	83
6	nil	136	224	89
7	nil	121	332	155
8	106	183	410	135
9	112	127	253	177
10	67	58	nil	123
11	53	45	nil	110
12	39	65	nil	21
Total	719	1 305	1 755	1 127

Preliminary data analysis involves setting up a simple matrix with two rows and two columns, the columns divide the subjects according to those who were not diseased, and those who weren't diseased. The rows divide the subjects according to those who were exposed, and those who were not exposed (Masters & Ela, 1998). The symbols of values (a, b, c and d) used in 2 × 2 matrix are extracted from Table 5 and tabulated in Table 6.

In the following a brief of the equations that considered to extract the relative, attribute, and odd risk from the used matrix:

TABLE 6. Preliminary data analysis

Subjects	Diseased	Not Diseased
Exposed	$a = 41\%$	$b = 59\%$
Not exposed	$c = 10.6\%$	$d = 89.4\%$

Explanations in the text.

relative risk = $a / (a + b) / c / (c + d)$.

The relative risk must be equal to 1. If the relative risk, above 1.0, there is a direct exposure-risk proportion:

odd risk = $a \cdot b / c \cdot d$.

The odds ratio suggests a exposure--risk relationship.

attributed risk = $a / (a + b) – c / (c + d)$.

An attributed risk of 0 suggests no exposure-risk relationship.

Irrigation groundwater Assessment

Irrigation groundwater standards

Parameters under study which are used for irrigation and their depended standards are listed in Table 7.

TABLE 7. Standards of parameters used for irrigation (EPA, 2001)

Parameter	Unit	Standards
TDS	$mg \cdot l^{-1}$	1 750
EC	mhos·cm–1	2.7
pH	–	6.5–8.5
Na	$mg \cdot l^{-1}$	200
Cl	$mg \cdot l^{-1}$	250
B	$mg \cdot l^{-1}$	0.7
Coli form for food plants	$MPN \cdot 100\ ml^{-1}$	$23\ cell \cdot 100\ ml^{-1}$
Coli form for non-food plants	$MPN \cdot 100\ ml^{-1}$	$240\ cell \cdot 100\ ml^{-1}$

Problem associated with using groundwater quality

There are many problems associated with using IGW purpose. They are, salinity, specific ion toxicity, and microbial effects (EPA, 2004).

There is an inverse proportion in saline irrigation water-root cells relationship due to osmotic pressure gradient which results in reduction of plant growth. Tables 1 and 8 show a severe impact of salinity represented by *EC* and *TDS*.

TABLE 8. Irrigation salinity impacts (EPA, 2004)

Parameter	Unit	Salinity impacts range		
		none	slight to moderate	severe
EC	$mhos \cdot cm^{-1}$	< 0.7	0.7–3	> 0.3
TDS	$mg \cdot l^{-1}$	< 450	450–2000	> 2 000

Three specific ions which must be considered in irrigation, they are boron (B), sodium (Na), and chloride (Cl). The source of boron is usually comes from household detergents or discharges from industrial plants. The quantities of chloride ions increases as a result of domestic usage. Tables 1 and 9 show that boron has a severe impact while chloride has slight to moderate impact in some wells while the other wells show no impact. Finally, sodium impact expressed as *SAR* which has no effect due to high existence of dictations causing low sodium adsorption ratio *SAR*.

TABLE 9. Irrigation specific ion toxicity impacts

Parameter	Unit	Specific ion toxicity range		
		none	slight to moderate	severe
Na	–	*SAR* < 3.0	*SAR* (3.0–9.0)	*SAR* > 9.0
Cl	$mg \cdot l^{-1}$	Cl < 140	Cl (140–350)	Cl > 350
B	$mg \cdot l^{-1}$	B < 0.7	B (0.7–3.0)	B > 3.0

There is an inverse proportion between total coliform and groundwater quality, especially on crops. The maximum number of total coliform is 23 and 240 cell per 100 ml for food and non-food crops respectively (EPA, 2004). Most of wells show huge impact of microbial on food crops, as in Table 2.

Methods used in groundwater classification

Three methods are used to classify the groundwater for irrigation purpose (US-SL, 1954). US-SL classifies water quality for irrigation purpose according to the concentration of salinity into four classless ranking from little salt ($100–250\ \mu hos \cdot cm^{-1}$) which is suitable for most of plants to very high salt which is suitable for plants with high resistance to salinity with both good drainage and high permeability soil ($2,250–5,000\ \mu hos \cdot cm^{-1}$).

Richard (1954) classified water quality for irrigation based on *SAR* and *EC* and ranked water quality into 16 classes from excellent (low sodium and low salinity) to poor (very high sodium and very high salinity).

Todd, Leaden and Trosise (1990) classified water quality for irrigation which includes five classes of water quality from excellent to unsuitable based on percentage of sodium ion and *EC*. A comparison among the three classifications in illustrated in Table 10.

TABLE 10. A comparison among three groundwater classifications

No	(Richard, 1954)	(US-SL, 1954)	(Todd, Leaden &Trosise, 1990)
1	very poor	#	suitable
2	very poor	#	doubtful to unsuitable
3	very poor	#	unsuitable
4	very poor	#	unsuitable
5	admissible	#	doubtful to unsuitable
6	very poor	#	good to permissible
7	very poor	#	unsuitable
8	very poor	#	unsuitable
9	very poor	#	unsuitable
10	very poor	#	unsuitable
11	very poor	#	unsuitable
12	admissible	#	unsuitable
13	very poor	#	doubtful to unsuitable
14	very poor	#	unsuitable
15	very poor	#	unsuitable
16	very poor	#	unsuitable
17	very poor	#	unsuitable
18	very poor	#	doubtful to unsuitable

Suitable for plants with high resistance to saline water if there is good drainage system for soils with high permeability.

Groundwater standards for livestock

Higher levels of suspended solids and salinity may be tolerated by certain livestock showing a flexibility with higher ranges than human. Standards for livestock groundwater are tabulated in Table 11.

TABLE 11. Livestock groundwater suitability standards (WHO, 2003)

Parameter	Unit	Standards
TDS	$mg{\cdot}l^{-1}$	10 000
SO_4	$mg{\cdot}l^{-1}$	1 000
pH	–	6.5–8.5
NO_3	$mg{\cdot}l^{-1}$	440
EC	$mhos{\cdot}cm^{-1}$	12.5
Total coliform – *TC*	$cell{\cdot}100\ ml^{-1}$	$100\ cell{\cdot}100\ ml^{-1}$

Groundwater quality index (weighted assessment)

Groundwater quality index (*GWQI*) gives the weight of the groundwater for each well. The used procedure for extracting indices is used by many researchers such as Abdul Hameed, Alobaidy, Maulood and Kadhem (2010), and Reza and Singh (2010). The procedure is summarized as follows: Each parameter is given a weight according to its importance where number one is the least important and number five is the highest one. The relative weight (wi) is calculated by dividing the estimated importance of each parameter by the summation of total weights of parameters. The quality rating scale (qi) is computed by using the following equation: $qi = (Ci / Si) \cdot 100$, where Ci represents the concentration of

TABLE 12. Groundwater quality index – *GWQI*

No	*DGWQI*		*IGWQI*		*LGWQI*	
	drinking	suitability	irrigation	suitability	livestock	suitability
1	4 262	unfit	194	unfit	63	poor
2	1 512	unfit	96	very poor	45	good
3	268	unfit	50	good	33	good
4	273	unfit	49	good	34	good
5	264	unfit	42	good	26	good
6	364	unfit	25	excellent	35	good
7	488	unfit	67	poor	45	good
8	3 667	unfit	177	unfit	66	poor
9	370	unfit	175	unfit	69	poor
10	1 577	unfit	97	very poor	41	good
11	1 544	unfit	102	unfit	45	good
12	1 270	unfit	79	very poor	39	good
13	3 775	unfit	564	unfit	82	very poor
14	1 706	unfit	113	unfit	48	good
15	1 395	unfit	93	very poor	46	good
16	4 781	unfit	221	unfit	76	very poor
17	5 486	unfit	240	unfit	78	very poor
18	5 371	unfit	241	unfit	85	very poor

0–25 excellent, 25–50 good, 51–75 poor, 76–100 very poor >100 units. *DGWQI* – drinking groundwater quality index; *IGWQI* – irrigation groundwater quality index; *LGWQI* – livestock groundwater quality index

the given parameter, *Si* represents international standards. Then, the sub index *Sli* of a given parameter computed by multiplying the relative weight by the quality rating using the equation: $SIi = wi \cdot qi$. Then, *GWQI* is computed by summation of sub-indices as in the equation: $GWQI = \sum SIi$. This index has four ranges (excellent to unfit). The results appear in Table 12.

Representation of groundwater quality index by GIS

Arc GIS 10.2 with its geostatical analyst is used to represent *GWQIs* data from Table 12 for all purposes using Kernal interpolation tool, as in Figures 14a, b and 14 c. Overlay-union tool is used to create spatial fitting for *IGWQI* and *LGWQI* except *DGWQI* which is unfit.

a

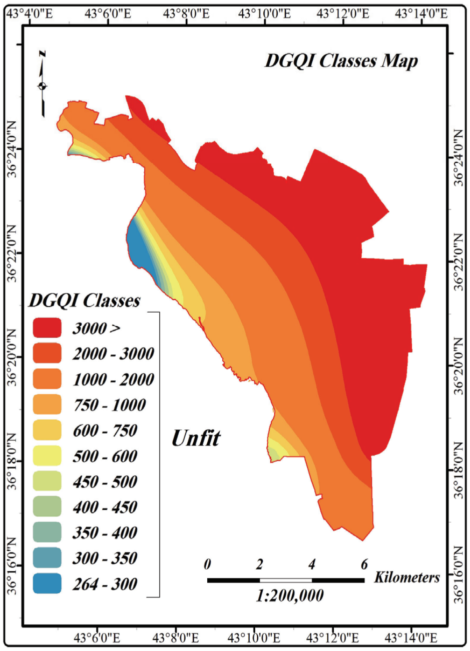

FIGURE 4a. Drinking groundwater suitability areas based on drinking index

c

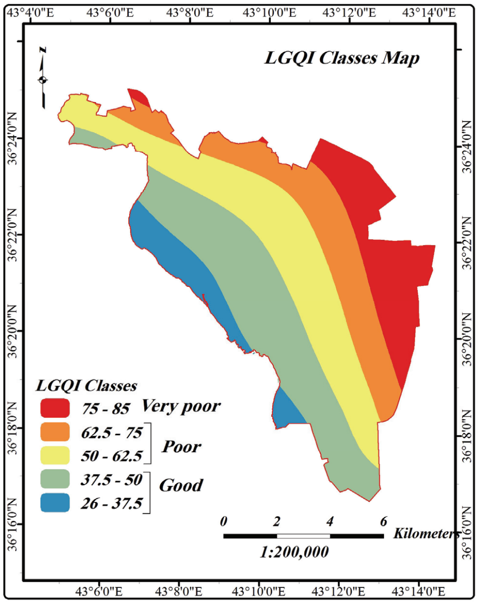

FIGURE 4c. Live stock groundwater suitability areas

b

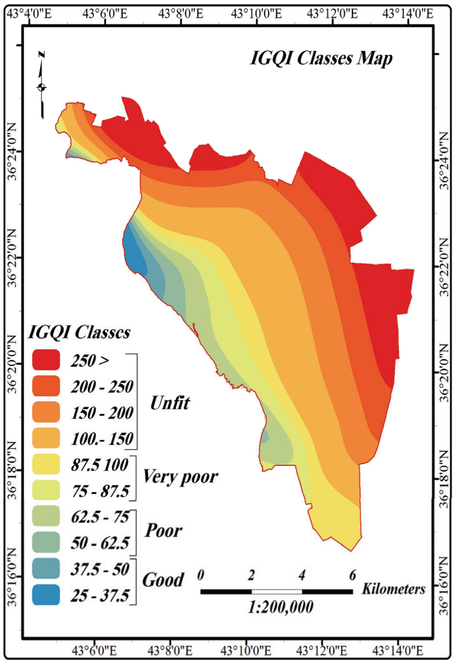

FIGURE 4b. Irrigation groundwater suitability areas

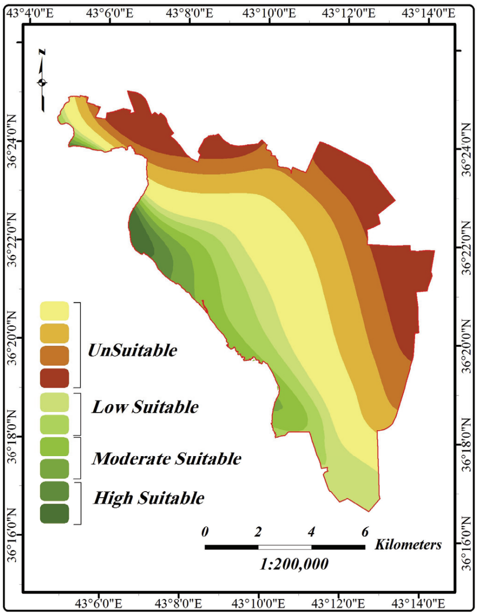

FIGURE 5. Suitability classes areas or irrigation and livestock

Suitable areas for Figures 4b, and c are overlaid with select by attribute tool. The output areas rank from high suitable to unsuitable. As in Figure 15, the suitability classes increases in areas nearby the river due to dilution of raw water which decrease the impacts of the polluted groundwater.

The process of ranking assessment of parameters has been done according to their degree of effect and marked by a number of increasing stars (from low to very high effect), or different shades. These stars and shades can point out the most effective parameter that decrease GWQ. Groundwater ranking assessment is tabulated in Table 13.

TABLE 13. Groundwater ranking assessment

Drinking ranking assessment									Irrigation ranking assessment				Livestock ranking assessment		
										ions toxicity					
No	TC_1	NO_3	*TH*	Mg	Ca	HCO_3	SO_4	*TDS*	*Sal.*	Cl	Na	B	TC_2	*TDS*, *EC*, SO^4, NO^3	TC_3
1	****	***	**	N	**	**	N	***	***	*	N	**	***	N	**
2	****	**	***	N	***	***	**	****	****	*	N	***	***	N	N
3	***	**	***	N	***	***	**	****	****	*	N	**	N	N	N
4	***	****	***	*	***	***	**	****	***	*	N	***	N	N	N
5	***	***	***	N	****	***	N	****	***	*	N	**	N	N	N
6	****	****	**	N	***	***	**	****	****	*	N	***	***	N	N
7	****	****	****	**	****	***	***	****	****	*	N	***	***	N	N
8	****	***	***	**	***	****	N	****	****	*	N	***	***	N	N
9	****	*	***	****	***	***	**	****	****	*	N	***	***	N	N
10	****	***	****	**	****	***	N	****	****	*	N	***	***	N	*
11	****	***	***	**	****	***	**	****	****	*	N	***	***	N	**
12	****	*	***	N	***	***	**	****	***	*	N	**	***	N	*
13	****	****	***	**	****	***	**	****	****	*	N	***	***	N	**
14	****	**	***	N	****	***	**	****	****	*	N	***	***	N	N
15	****	****	***	**	****	***	N	****	****	*	N	***	***	N	**
16	****	*	***	**	****	***	**	****	****	*	N	***	***	N	***
17	****	**	**	N	***	***	N	****	***	*	N	***	***	N	**
18	****	****	***	N	****	**	***	****	***	*	N	***	***	N	***

N – no effect (no shade); *light effect (light shade), **moderate effect (moderate shade), ***high effect (high shade), ****extreme effect (extreme shade); *TH* – total hardness, *EC* – electrical conductivity, *TC* – total coliform, *Sal.* – sensitive crops salinity; All parameter units in $mg \cdot l^{-1}$ except *TH* – in $mg \cdot l^{-1}$ as $CaCO_3$, *EC* in $mhos \cdot cm^{-1}$, *TC* in $MPN \cdot 100\ ml^{-1}$; TC_1 – total coliform ranking in drinking water, TC_2 – total coliform ranking for irrigation (for food crops), TC_3 – total coliform ranking for livestock.

Results and discussion

Most of wells are classified as unfit for drinking as in Table 11 due to high permissible infiltration of waste and grey water (upper layer mostly course texture), as in Figure 4. The main parameters affecting *DGWQ* are: *TC*, *TDS*, NO_3, HCO_3 and SO_4 in sequence as in Table 13. There is a range of values for unsuitability representing unfit for using the studied ground water for drinking purpose, as in Figure 4a. The epidemiological data show that relative risk is 3.8, and odd risk is 5.8, and attribute risk is 0.34.

A number of wells are unfit for irrigation except those nearby the river 3, 4, 5 and 6 which they are unsuitable for crops with sensitivity for high salinity as in Figure 4b. The main parameters affecting *IGWQ* are salinity, *TC*, Boron (B) and Chloride in sequence as in Table 13.

For livestock purpose, the majority of wells are classified as suitable except those far away from the river (wells 16, 17 and 18, as in Figure 4b). The main parameter affecting *LGWQ* are the presence of in their watering, as in Table 13.

Final map in Figure 5 shows classes of areas having combined suitability between irrigation and livestock watering ranked from high suitability nearby the river to the unsuitable for those far away.

Epidemiological data of relative and odd risk of diarrhea analysis indicate exposure-disease relationship due to the fact that both of their values are higher than one. The result of the attributed risk of those who were exposed is higher than non exposed by three folds.The *IGWQ* is classified as very poor and unsuitable according to Richard (1954) and Todd, Leaden and Trosise (1990), while *IGWQ* is classified according to US-SL (1954) as suitable for plants with high resistance to saline water if there is good drainage system for soils with high permeability.

Conclusions

The importance of this study comes from developing GIS model with GMS extension to draw geological layers of the studied area . Also, it conducts an analysis of spatial and epidemiological data to assess the degree of hazard of the water samples.

The groundwater which was used during 2014–2017 is unsuitable for drinking with a attributed huge risk. Most of the diarrhea cases especially in summer of 2016 indicates the polluted of water used for drinking purposes represented by the existence of *TC* as the main cause with high concentrations of salinity and nitrate. One of the main causes of groundwater pollution is the course texture of soil layers with high permissible infiltration of wastewater and grey water.

The studied samples are suitable only for plants having high resistance to saline water, if and only if, there is good drainage system for soils having high permeability. Most of the wells are suitable for live stock purpose, except (wells 16 and 17) due to the existence of high coliform values.

The study data analysis indicates that more far the well's location from the river relates to less suitability. It is vital to say that, although the studied water was used for a limited duration only during war processes but its risk was very high represented by the increase of pathological cases.

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Summary

Groundwater assessment at east side of Mosul City during 2014–2017. This study assesses groundwater quality GWQ at the east side of Mosul city for different purposes during 2014–2017. Eighteen shallow wells distributed in residential areas are selected and assessed by analyzing their physical, chemical and biological properties. This study reviews the textures of sub-layers by using groundwater modelling system (GMS) to show the probability of infiltration of nearby wastewater and gray water. This study analyzes epidemiological data about diarrhea cases that were increased during that period and calculating the relative, attributed and odd risk. There are three types of assessment are conducted including ranking assessment, weighted assessment and geographical information systems (GIS) assessment. A final map is created to show the most suitable area for live stock and irrigation purposes. The results show that the studied groundwater samples are unsuitable for drinking. High damage can happen for crops with sensitivity for salinity. Most wells are acceptable for live stock purpose.

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