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Assessment of post-war groundwater quality in urban areas of Mosul city /Iraq and surrounding areas for drinking and irrigation purposes by using the Canadian Environment Water Quality Index CCME-WQI and Heavy Metal Pollution Index HPI

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Abstract

The negative impact of war acts in the conflict area of the city of Mosul and its surroundings on groundwater quality and thus its use as drinking water, in domestic applications and for irrigation was addressed. Therefore, 8 wells were analyzed from January to September 2022 using the parameters pH, E.C., TDS, % salinity, COD, phosphate, nitrate, sulfate and the heavy metals Cd, Pb, Zn, Cr and Ni, and water quality was evaluated using a mathematical model based on the CCME WQI, the HPI and present salinity. Due to salinity, 6 of the 8 wells were moderately suitable for irrigation and 2 wells were difficult in use. According to the CCME WQI criteria, 4 wells were highly and 3 wells were moderately contaminated for drinking water supply and domestic use, and therefore unusable or limited usable, while 3 wells were unusable and 2 wells were moderately usable for irrigation purposes. For irrigation, only one well showed low and 2 wells showed marginal contamination. The HIP revealed good quality of 3 wells, poor quality of 2 wells and unsuitability of 3 wells (drinking water/ domestic use) or very poor quality (irrigation), respectively. According to all approaches, the wells located in the conflict area consistently showed poor water quality. Thus, war had a significant negative impact on groundwater quality in the conflict area, as the surface-near wells located here showed comparatively high levels of contaminations and heavy metals due to the infiltration of contaminated surface water, damaged sewage networks and infiltration of rainwater after passing through highly polluted soils. Cadmium, followed by lead, were the dominant water contaminants, which is why caution is advised before using this well water.

Keywords: Mosul; Groundwater Quality; Iraq; Heavy Metals; CCME WQI; Heavy Metals Pollution Index HPI; Water Use

1. Introduction

Groundwater is one of the most important source for drinking water supply and domestic water use, especially in times of war and disaster when existing water infrastructure is no longer available due to destruction and increasing war-related damages like cracks (Willig and Haeusler, 2012; Robins and Fergusson, 2014). In addition, groundwater is the most important source of water for agricultural irrigation, as agricultural irrigation accounts for nearly 70% of the global freshwater withdrawals and 90% of water consumption (Siebert et al., 2010).

The suitability of groundwater for various uses majorly depends on the quality of the groundwater. Hence, protecting the quality of groundwater is a important concern. This is especially true in case of environmental disasters and wars (Packialakshmi, 2015).

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In the city of Mosul, there are a large number of both shallow and deep wells. While most of the deep wells have been constructed recently due to hydrological projects built in riparian countries and climate change and the associated decrease in annual Tigris runoff from approximately 52.98 BCM in the 1970s to presently 16 BCM (Al-Ansari, 2021), some of the deep wells were dug hundreds of years ago and are an important source of agricultural irrigation, especially in the summer time (Jaradat, 2002).

Generally the ground water in Mosul city suffers from a high salinity and pollution with leakage of domestic wastewater, which leaks into the groundwater on a large scale (Abawi and Hashem, 2001) strongly supported by Mosul´s course texture of soil layers (Al-Abedeen Al-Ozeer and Ahmed, 2019). Sewage leakage is the primary source of water pollution in shallow wells, affecting the quality of drinking water there, especially by gastrointestinal microorganisms (Dobslaw, 2023; Dufner et al., 2024), causing a severe accumulation of diarrhea in summer 2017 (Al-Abedeen Al-Ozeer and Ahmed, 2019)..

During the occupation of Mosul city by ISIS (2014 -2017) and in the post-war years, people relied heavily on groundwater as a source of drinking water supply and domestic use after water treatment networks and facilities were destroyed, although most wells in the city were unsuitable for drinking water (UNEP, 2017). It is estimated that 90 percent of Mosul´s domestic and industrial water needs were met by groundwater sources during these years, reducing groundwater supplies to 40 % of the pre-war levels.. The heavy reliance on groundwater as the main source of water led to a further deterioration in its quality (Lafta et al., 2018; UNEP and OCHA, 2016; UNEP, 2017) .

Dependence on groundwater increased as ISIS deliberately contaminated surface waters like lakes, rivers and streams with contaminated soil products and toxic waste as well as wells by diesel discharges during their retreat battles, further exacerbating water availability on the right bank of Mosul, which has always struggled with water scarcity (Pax for peace, 2020). ,The expected long-term groundwater pollution is therefore a very serious problem, which is even exacerbated by the very limited self-purification capacity of the aquifer (UN-Habitat, 2016).

The severe oil contamination resulted from the leakage of oil or toxic pollutants, chemicals and heavy metals due to the burning of oil wells and sulfur fields, military activities, and the destruction of underground pipes (Pax for Pease. 2020), in addition to the destruction of the city's infrastructure (water supply, sewage pipes, decentralized septic tanks), agricultural chemicals, landfill waste and leachate, and other hazardous waste and air pollutants released.. This combination of factors has led to the deterioration of the groundwater quality, making it unsuitable for agricultural irrigation or other uses (UNEP, 2017; Raad and Margane, 2013).

Heavy metals are important environmental pollutants, particularly in areas with high anthropogenic sources inputs (ul Islam et al., 2007). These pollutants are extremely persistent in the environment, non-biodegradable and therefore can easily accumulate to toxic levels (Sharma et al., 2007; Micó et al., 2006), making them the third factor in description of irrigation water quality alongside the salinity and microbiological contamination levels already described (EPA, 2004).

Safawi et al. (2018) analyzed the quality of groundwater in some villages southeast of Mosul city. The results of the study indicated that, although the well waters there were suitable for irrigation purposes in terms of pH, sodium content and SAR, some problems related to salinity according to the international classifications were expected to emerge.

Similarily, the groundwater quality of wells in North-East of Mosul City was analyzed using chemical and physical parameters (EC, pH, TDS, levels of Na, K, Ca, Mg. HCO_3^-, CO_3^{2-}, SO_4^{2-}, Cl^- and NO_3^-) (Al-Salim, 2014). With a moderate water hardness and a SAR value of 0.07 to 0.62, which corresponds to a classification with a low sodium content, the water samples otherwise showed no abnormalities with otherwise good water quality, which meant that these wells could be used for irrigation without restrictions.

Al-Saffawi (2018 a) investigated application of the CCME WQI model to the water quality of twelve wells distributed in west of Mosul Al-Mahalibiyah sub district to assess the suitability for drinking purposes. Monthly water samples were collected from each well to track the concentrations of the following parameters: pH, total dissolved solids, total hardness, total alkalinity, anion and Cation concentrations. Experimental data indicated an increase in some parameters, especially in levels of total dissolved solid, calcium and sulfate ions, which reached concentrations of up to 3390 mg*L^{-1}, 9673 mg*L^{-1}, and 2271 mg*L^{-1}, respectively, negatively impacting the CCME WQI values (detected range 42.41 – 60). This deterioration in water quality reflected the nature of the geological formations of rocks through which water flew and strictly required pre-treatment prior to consumption.

The CCME WQI model was also applied by Al-Saffawi et al. (2018 b) for groundwater assessment on the Left side or east side of Mosul City, including the parameters pH, electrical conductivity, dissolved oxygen, total alkalinity, total hardness, concentration of calcium, magnesium, sodium, chloride, sulfate, nitrate as well as the total and selective bacterial count of faecal and coliform bacteria.At an index value of 24.49 to 31.90 (corresponding to as poor water quality), groundwater samples were unsuitable for drinking and domestic use. These low WQI values were mainly attributable to the higher values of EC, total hardness, level of sodium, sulfate and the bacterial contamination of the groundwater.

An assessment of the groundwater quality of the Right side of Mosul city for drinking purposes based on the water quality index (WQI) , including pH, EC, total alkalinity, total hardness, sulfate ions, and total bacterial counts (TBC), yielded WQI values of 229 to 562, classifying the water samples as very poor to unsuitable for drinking water use (Al-Saffawi; Shihab, 2013).

Al-Ozeer et al. (2019) also applied the WQI model in 2014-2017 to assess the suitability of wells of Left Side Mosul city for irrigation purposes.. For the parameters pH, EC, TDS, TC and the ions of Na, K, Ca, Mg, B, , hydrogen carbonate, sulfate, chloride and nitrate, the results indicated that the water quality of the wells was suitable for irrigation. WQI values ranged from 66.6 to 74.0, meaning that the water quality was categorized as good to suitable for irrigation.

After the war, the central questions were, whether the groundwater in Mosul city was suitable for drinking and domestic use, whether was suitable for irrigation of vegetables and fruits, and whether the consumed was safe for humans, because increase in toxic substance levels and heavy metals levels in the soil severly affected the groundwater quality and thus had an impact on humans and agricultural crops (Kumar Sharma et al., 2007 ; Quaglia et al ,2022; Robins and Fergusson,2014)

To date, the answers have mostly remained elusive, as the available studies have mainly covered periods of investigation before the war.

The objective of this study was therefore to assess the groundwater quality in the conflict area within the city of Mosul and its surroundings after the war and thus its effects on groundwater quality. The assessment was based on the measurement parameters temperature, pH, EC, TDS, salinity, sulphate, nitrate and phosphate in accordance with the WHO guidelines (WHO, 2004; FAO; 1986) and also the heavy metal concentrations of Pb, Cd, Zn, Cr and Ni in order to test the suitability of the groundwater for drinking water and domestic use as well as for irrigation purposes. The CCME WQI and the Heavy Metal Pollution Index (HPI) in combination with the measured salinity were used as an evaluation model (EPA, 2004).

2. Methodology

2.1. Sampling

Data sets of this study were collected from groundwater samples from eight wells in the city of Mosul. Samples were taken from 4 wells within the inner city conflict zone on both sides of the Tigris (W5, W6, W7, W8) and from 4 wells in the outskirts of the city outside the conflict zone (W1, W2, W3, W4). In addition to the relative location to the conflict area, care was also taken to ensure that the wells were distributed as evenly as possible, so that one uncontaminated well and one contaminated well each were recorded in the north, east, south and west in order to do justice to existing groundwater infiltrations (see Fig. 1). Each well was sampled six times between January and September 2022 (see Table 1). The samples were collected in polyethylene bottles, which were first pre-rinsed with distilled water and subsequently with the groundwater sample before the actual sample aliquots were filled in (APHA, 2005). The temperature during the study period was between (0-35 °C), which is why the samples were cooled immediately after collection and subsequent in-field analysis (temperature, pH, electrical conductivity (EC), Total dissolved solids (TDS), salinity (in %). A sample series comprised the samples from each of the eight locations (see Table 1). The sample aliquots were analyzed for temperature, pH value, EC, TDS, salinity (all in-field analysis), COD, as well as the concentrations of the anions sulfate (SO_4^{2-}), nitrate (NO_3^-), phosphate (PO_4^{3-}) and the heavy metal cations cadmium (Cd), lead (Pb), zinc (Zn), chromium (Cr) and nickel (Ni), using standard methods for latter parameters (APHA-AWWA-WEF, 2005).

2.1.1. Chemical and physical analyses

Temperature ,pH value, EC, TDS and salinity of the water samples were directly analyzed in the field using a field measuring device Oumefar 5 in 1 Digital Water Quality Monitor Tester, type UPC 886108495111.

Laboratory parameters with associated methods were

PO_4^{3-} (in mg*L^{-1}): Phosphate was measured by a ultraviolet spectrophotometer screnning method using acidic ammonium molybdate – stannous chloride solution at a wavelength of 690 nm.

NO_3^{-} (in mg*L^{-1}): Nitrate was also measured by a photometric method after acidification with hydrochloric acid and subsequent addition of 1% solution of sulfanilic acid in 30% acetic acid, saturated solution of 1-napthylamine in 30% acetic acid and final addition of zinc powder to reduce nitrate to nitrite. Nitrite is detected by the formation of a red azo complex.

SO_4^{2-} (in mg*L^{-1}): Sulphate was quantified by turbidity analysis after addition of barium chloride and spectrophotometric analysis at 420 nm.

Chemical oxygen demand (COD; in mg*L^{-1}): The chemical oxygen demand was determined in accordance with DIN 38409-H41 after thermal digestion with potassium dichromate and back titration of the excess oxidizing agent with iron ammonium sulfate using a redox electrode to determine the end of titration.

Heavy metals (Cd, Pb, Cr, Ni, Zn): The heavy metals were quantified in accordance with APHA regulations (1985) using a Phenoix-986AAS atomic absorption spectrometer getting heavy metal levels in µg*L^{-1}. Each sample was analyzed in two variations: In variation 1, the sample was pretreated directly without filtration by acid digestion and then measured, whereby the total heavy metal concentration consisting of soluble and particulate heavy metal content could be determined. In the second variant, the respective sample was filtered through a 0.25 µm micro filter, whereby only the dissolved heavy metal components were present in the filtrate. The filtrate was digested and analyzed to calculate the HPI(see. 3.3). The analysis of the dissolved heavy metals was carried out as previously described (Mohan, 1996; Milivojević et al. 2016; Chiamsathit et al. 2020).

Table 1 Coordinates and depths of the study wells sites of Mosul city.

Site No.	Location	Latitude N	Longitude E	Describtion	used	Depth m
W1	Al-Shrykhn	36.402030	43.074644	Agricultur Area	Agriculture	45
W2	Gogjali	36.358306	43.257112	Res. +Commercial Area	Agruicultur	50
W3	Yarmja	36.304065	43.184903	Residential Area	Agricultur	55
W4	Rajem Hadeed	36.324916	43.064354	Reidentioal Area	Agricultur	62
W5	Almajmoa	36.369005	43.140040	Residentioal Area	Domestic	15
W6	Alfaysalia	36.345700	43.148470	Reidentioal Area	Domestic	13
W7	AlFaroq	36.342961	43.124260	Reidentioal Area	Domestic	15
W8	Old city	36.345019	43.131628	Reidentioal Area	Domestic	10

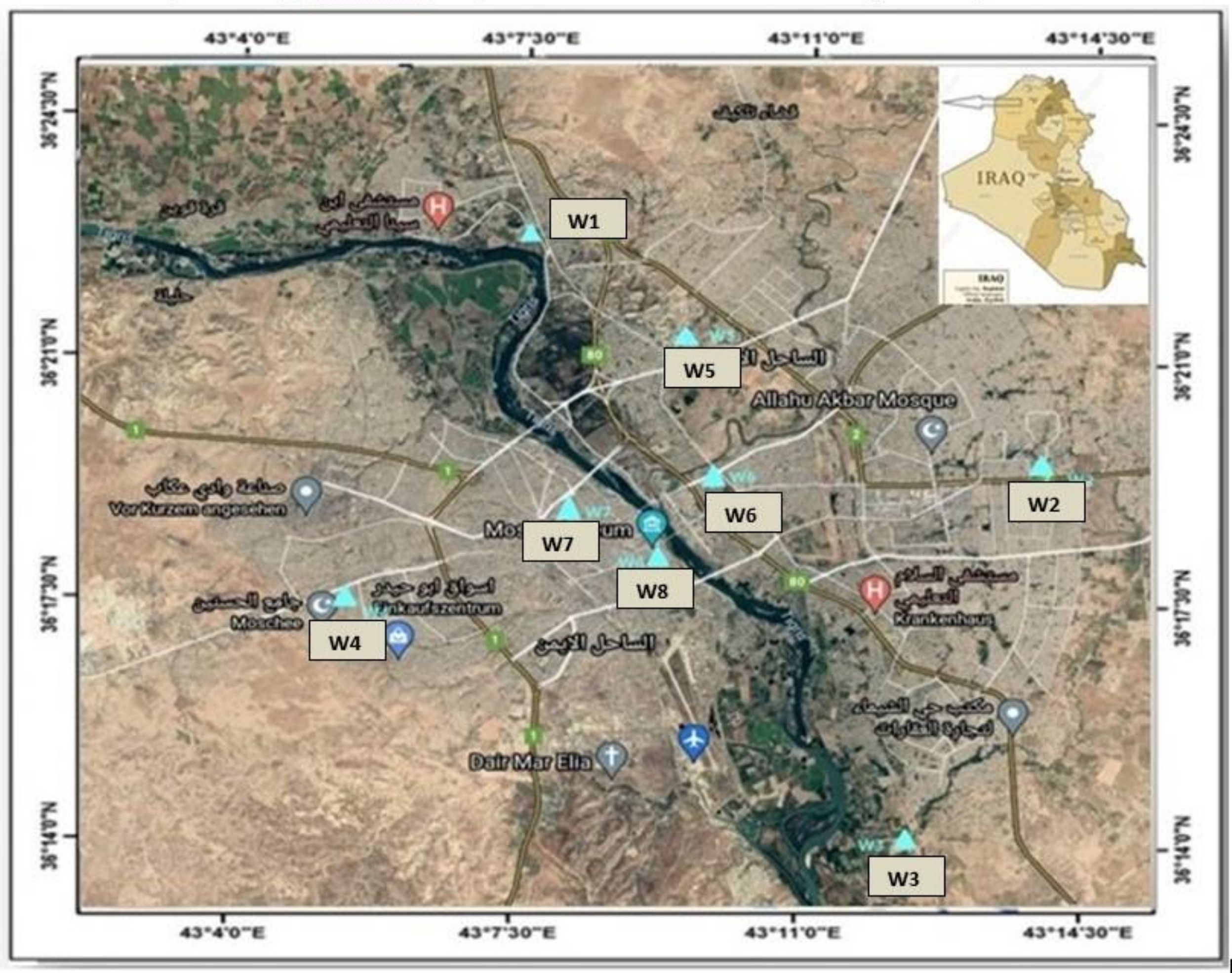

Figure 1 Sampling sites map

2.2. Assessment of ground water pollution

The assessment of pollution-related groundwater suitability depends on the factors salinity, specific ion toxicity, and degree of microbial contamination (EPA, 2004). In the current study, the suitability assessment of groundwater is therefore based on these criteria:

2.2.1. Salinity (in percent)

A high salt content in irrigation water has a negative effect on the root cells and thus on plant growth, as the osmotic pressure gradient virtually dehydrates the plant and thus severely restricts growth. There is an inverse proportion in saline irrigation water-root cells relationship due to osmotic pressure gradient which results in reduction of plant growth (van der Leeden, 1990). Tables 2 shows a severe impact of increased salinity, represented by EC, TDS, and the percentage of Salinity according to the classification previously introduced by EPA (EPA, 2004).

Table 2 Irrigation salinity impacts (EPA, 2004)

Parameters	**Unite**	**Salinity impact range**		
		none	Moderate	Severe
E.C	mS/cm	<0.7	o.7-3	> 3
TDS	mg/l	<450	450-2000	>2000
% Salinity		<0.7	o.7-3	>3

2.2.2. Calculation of the CCME-WQI

The CCME-WQI equation is computed using three factors (CCME-WQI, 2001) as follows:

$$\text{CWQI} = \mathbf{100} - \{\frac{\sqrt{\mathbf{F1+F2+F3}}}{\mathbf{1.732}}\}$$

Factor 1 (F1): The percentage of the variables that exceed the guideline:

$$\mathbf{F1} = \{\frac{\textbf{Number of Faild Variables}}{\textbf{Total Number of Variables}}\} *100$$

Factor 2 (F2): This factor, equivalent to a frequency, represented the percentage of individual tests that do not meet the guidelines (failed tests):

$$\text{F2} = \{ \frac{\textbf{Number of Faild Test}}{\textbf{Total Number of Variables}} \} *100$$

Factor 3 (F3) Represents the number of readings that exceeded the standards, and therefore the amplitude of the signal, and according to the following steps:

1-Calculation of the deviation excursion, when the values of readings are higher than the values of the standards criteria are calculated from the following equation:

$$\text{Excursion} = \{ \frac{\textbf{Faild Value i}}{\textbf{Objective j}} \} -1$$

2-The sum of the standard deviations nse and the sum of the readings not meeting the standards is calculated by the sum of the deviations divided by the total sum of the tests:

$$\text{Nse} = \frac{\sum_{i=1}^{n} \textbf{Excursion}}{\textbf{Number of Tests}}$$

F3 is then computed from the following equation:

$$\text{F3} = \frac{\textbf{nse}}{\textbf{0.01 nse+0.01}}$$

CCME-WQI categorization was presented in Table 3.

Table 3 CCME-WQI water classified and suitability for use

Suitability	class	CCME WQI Value
Excellent	1	95-100
Good	2	94-80
Moderate	3	79-65
Marginal	4	64-50
Poor	5	49-0

2.2.3. Heavy metal pollution Index (HPI)

The HPI is an evaluation index that reflects the composite influence of dissolved heavy metals in water with regard to the suitability of the water for human consumption. It reflects the relative importance of the individual quality aspects and is inversely proportional to the recommended standard (Si) for each parameter, i.e. low values represent high water quality. The quality and suitability of the water as drinking water can be derived from this quality index. The calculation of the HPI comprises the following steps (Mohan, 1996; Milivojević et al. 2016; Chiamsathit et al. 2020):

Based on a weightage Wi of the individual parameters (Eq. 1) and a heavy metal-specific quality factor Qi, which is calculated from the monitoring value Mi, ideal value Ii and standard value Si (Eq. 2), the HPI can be determined using both auxiliary parameters according to Equation 3.

The calculation of weightage of the parameter,

Wi =K/Si ……………………Q1
Eq. 1

The quality rating for each of the heavy metal Qi.

$$Qi = \sum_{i=1}^{n} \frac{Mi-Ii}{Si-Ii} \times \mathbf{100} \quad \text{…………………Q2} \quad \text{Eq. 2}$$

$$HPI = \sum_{i=1}^{n}(\mathbf{Wi} \times \mathbf{Qi}) / \sum_{i=1}^{n} \boldsymbol{Wi} \quad \text{…………………………………Q3}$$
Eq. 3

HPI for each element = (Wi ×Qi) $/\sum_{i=1}^{n} \boldsymbol{Wi}$

Wi : is the unit weight age for the parameter
K: constant =1
Mi : Monitoring value of heavy metal parameters
Ii : Ideal value of heavy metal parameters
*S*i: Standard value of heavy metal parameters
N : is the number of parameters considered

The classification and suitability of the HPI as an evaluation parameter is shown in Table (4).

Table 4 Heavy metal pollution Index suitability classifications

HPI	Classification
<25	Excellent
26-50	Good
51-75	Poor
76-100	Very poor
>100	Unsuitable

The study used the mathematical methods of CCME-WQI and HPI to assess the water quality of wells for drinking and domestic use. The same methods were also used to assess the suitability of wells for irrigation based on irrigation standard limits (WHO,2004 ; FAO ,1986).

3. Result and Discussion

3.1. Ground water properties

3.1.1. pH

The pH value enables an assessment of the degree of contamination of the tested water and thus a classification of the suitability of the water for various purposes. The results show that the pH values of all wells were within the range specified in the WHO guidelines (WHO, 1996) for drinking and domestic use and for irrigation (WHO, 1996; FAO, 1986). In fact, the samples were at pH values between 6.5-7.8, but mostly in the slightly acidic range. The acidification results on the one hand from the passage of the aquifer through geological formations with water-soluble salts, whereby the groundwater is enriched in anions such as sulphate, nitrate and chloride as well as metals as cations; on the other hand from the biological degradation of organic matter under oxygen-deficient conditions (Al-Saffawi, 2018b). The resulting pH reduction leads to a shift in the lime-carbonic acid balance and thus decreasing acid capacity, which reduces the water quality both for use as irrigation water and drinking water (Al-Saffawi, 2018a ; ;Shihab et al ,2013). Furthermore, increased acidification in particular leads not only to a higher availability of macronutrients such as nitrogen, potassium, calcium, magnesium, and sulphur (Ferrarezi et al., 2022) but also to an increased mobilization of toxic metals such as aluminium (Al-Mashhadany, 2021; Li et al. 2022) and organic impurities (Bidleman et al., 2012; Dobslaw et al., 2021).

3.1.2. Electrical conductivity E.C

Electrical conductivity is an indicator representing the concentration of water-soluble salts such as calcium, magnesium, sodium, sulphate and chloride ions, etc. (Karroum et al., 2019). The average electrical conductivity values of all groundwater samples were between 1530.9-3654.8 µS/cm (see Table 6), which shows that all values in all wells were generally elevated and exceeded the limit value for drinking water use. In addition, the limit values for use as irrigation water were also exceeded at wells W4 and W8. The high conductivities detected at these wells are due to the high porosity of the soil, which, in addition to the nature of the geological formations of the study areas (gypsum, anhydrite, and dolomite rocks) and a climatically induced near-surface salt accumulation due to increased water evaporation (Al-Jawadi et al, 2018; Al-Saffawi et al, 2018a,) also favored increased soil transfer and accumulation of pollutants released during the war. In the case of use as irrigation water, salt-tolerant plants should be selected in these two cases or technical desalination strategies should be pursued in order to avoid salt accumulation in agricultural areas.

3.1.3. Total dissolved solids TDS

Total dissolved solids (TDS) as a water quality parameter comprises the content of dissolved organic and inorganic components. While components such as calcium, magnesium, carbonate, sulphate etc. are typical dissolved water ingredients after soil passages and do not lead to any significant negative health effects on their own, dissolved heavy metals and non-volatile organic water contaminants such as herbicides, pesticides or flame retardants have a considerable impact on water quality. According to the EPA secondary drinking water regulations the recommended maximum of TDS for drinking water application is 500 ppm, while levels beyond 1000 ppm show unsafe levels (EPA, 2020). The average values in all wells were between 787-3427 mg/l, with the lowest average value measured at well W1 and thus on the river entrance side of the city and the highest average value at well W6 within the former conflict zone. With the exception of wells W1 and W2, the water samples from the other wells consistently exceeded the limits for drinking water use. In addition, the limit values for irrigation use were also not complied at wells W6, W7 and W8 (see Table 6). In addition to medical aspects, the TDS levels should be as low as possible, as high TDS values have a negative impact on water hardness and thus the service life of technical devices due to deposits. Furthermore, high TDS levels lead to discolored water and a bitter, salty to metallic taste (Rana et al., 2024; Devesa and Dietrich, 2018).

The main reasons for the high TDS values are particularly geological, as minerals are leached out when water penetrates (Othman et al., 2021; Al-Saffawi, 2013). In the case of wells W1, W2, W3 and W4, which are designed as deep wells, this natural influence is the main factor. On the other hand, wells W5, W6, W7 and W8 are designed as shallow wells, whereby pollutants can quickly penetrate through layers close to the surface, especially during the rainy season, and enter the water catchment of the aforementioned wells. On the other hand, these four wells are located in residential areas in the former conflict zones, where soil is heavily contaminated with heavy metals, particularly as a result of the fighting (and here by the munitions). Therefore, especially during the rainy season, these metals are increasingly absorbed by the water phase and enter the groundwater through direct percolation or through war-related damage to the wastewater networks.

3.1.4. Salinity

Salinity describes the concentration of dissolved salts such as Na^+, Ca^{2+}, Mg^{2+} in the water phase and showed average values of 2.10-3.20 % for the present samples. The values thus also exceeded the limit values for drinking water use, but were below the limit values for irrigation use, with the exception of wells W4 and W8. According to the EPA salinity classification (EPA, 2004), the suitability of the well water for irrigation purposes can be classified as 'moderate' for wells W1, W2, W3, W5 and W6 and as 'severe' for wells W4 and W8 (see Tables 6, 7 and 8).

3.1.5. Chemical Oxygen demand (COD)

The COD is considered as an important criteria for determining the quality of water according to the degree of pollution as well as its role in preventing the formation of harmful compounds and bad odors (Al-Saffawi, 2018 b). Available samples showed concentrations of 15-104 mg/l, with the highest values detectable at well W8, which could not comply with the specified limits (see Tables 6 and 7). Like W8, wells W6 and W7 are in the former, heavily polluted conflict area, but the COD contamination in the latter wells was below the limits restricting application.

3.1.6. Phosphate PO_4^{3-}

Water-soluble orthophosphates are predominantly introduced into the environment anthropogenically via fertilizers as well as faeces and wastewater (Sichler et al., 2022), in decreasing relevance as additives in detergents (as pentasodium triphosphate, degreasers, cleaners and in food (so-called E451)). As a specific case in Mosul, the use of phosphorus bombs during the liberation of Mosul in the summer of 2017 is another source of phosphate (Aljazeera, 2017). The main natural source of ortho-phosphate is the biogenic degradation of amino acids (NLWKN, 2020). High phosphate concentrations (more than 10 µg/l) in drinking water lead to vomiting and diarrhea in humans and animals (UNEP, 2008). The average concentration of ortho-phosphate ions in the available water samples was between 0.29 and 0.73 mg/l and increased by approx. 30-40 % over the urban watercourse. In addition to damages in the wastewater infrastructure, the increase can therefore also be attributed to infiltration of war-related phosphate deposits in the urban area. Compared to the other anions measured, the phosphate concentration is always low, as phosphate is efficiently precipitated or adsorbed in the present pH range and is only mobile under acidic conditions (Al-Mashhadany, 2019; do Nascimento et al., 2018). Nevertheless, the detected values exceeded the limit values in all wells except W2. Well W8 had the highest average values, as it is located both within the former conflict zone and in a densely populated residential area, where damages to the wastewater infrastructure have an increased impact. The situation is further exacerbated during the winter rainfall season by infiltration of contaminated rainwater runoff (war residues, agricultural runoff).

3.1.7. Nitrate NO_3^-

A high nitrate concentration in drinking water has serious effects on the health of consumers and can lead to blue baby syndrome, various cancers (stomach, pancreatic and rectal cancer) and an increased miscarriage rate in vulnerable groups of people (Schullehner, 2018). The average values varied between the wells in the range of 27.9 -39.7 mg/l and were at a higher level at wells W1, W6, W7 and W8 in direct comparison. While W1 had the highest average value due to its location in an agricultural area, the nitrate content of wells W6, W7 and W8 was influenced by their location in the former conflict zone. Nevertheless, the nitrate contamination of all wells is below the WHO limits for drinking water and irrigation (WHO, 2003; WHO, 2004; FAO, 1986), which means that there is no restriction on use based on these parameters (see Table 7).

3.1.8. Sulphate SO_4^{2-}

The concentration of sulphate ions in natural waters depends on the percolation behavior of the water through geological formations and thus their sulphate content. Accordingly, high water concentrations can occur in rock layers containing sulphate (e.g. gypsum) and thus exceed the limit values. High sulphate concentrations have a negative impact on the quality of drinking water and the health of the user, as high sulphate concentrations have a laxative effect on humans and animals and can lead to irritation of the digestive system. In the available samples, all wells except well W3 exceeded the limit values for drinking water on average and reached concentrations of 359-1072 mg/L. These concentrations exceed the Iraqi standard for sulphate content in drinking water (250 mg/L) by a factor of 1.4-4.3. In the area of well W4, which reached the highest average values, the geological formation caused high sulphate levels as this formation consists of gypsum and calcite (Altamir, 2005; Al-Saffawi and Shihab, 2013). The petrographic inhomogeneity of the geological layers is the reason for the wide range of sulphate concentrations in the various wells. Contrary to the local petrography, however, high sulphate concentrations also occurred within the conflict zone at wells W6, W7 and W8, reaching average values of 502 mg/L (W6). The main reason for this is the heavy soil contamination with sulphate, which was caused by the burning of the sulphate fields south of Moshul during the war and the atmospheric wet deposition and oxidation of SO_2 as sulphate. Infiltration of surface water introduced near-surface sulphate into the aquifer (UNEP & OCHA, 2016; UNEP, 2017).

3.1.9. Heavy metals

High levels of heavy metal contamination in groundwater and thus in well water result primarily from the percolation of surface water through contaminated soils, as heavy metals themselves have a low natural mobility in the soil. Oral ingestion of high doses of heavy metals can lead to acute and chronic toxicity, damage to the liver, kidneys and intestines, anemia and cancer (EPA, 2022). Known phytotoxic effects of elevated heavy metal concentrations are shown in Table 5.

In case of cadmium (Cd) the results revealed that all wells, with the exception of wells W1 and W2, exceeded the limits for drinking water use with average concentrations of 2.8-18.2 µg Cd/L. Wells W3 and W4 also proved to be suitable for irrigation purposes, while wells W5, W6, W7 and W8, located in the conflict area, did not meet the limits for either drinking water or irrigation (WHO; 2004; FAO, 1986). At 18.2 µg/L, well W8 showed a 3.6-fold exceedance of the drinking water limit and a 1.8-fold exceedance of the irrigation limit (see Tables 6 and 7).

For lead (Pb), the limits for irrigation were met at all wells, but wells W5, W6, W7 and W8, which are located in the former conflict area, again exceeded the drinking water limits, as lead is usually used as a core for full metal jacket bullets (Mariussen et al., 2021; Deese, 2021 Tan et al,2022).

All wells complied with the limit values for zinc (Zn) for both drinking water and irrigation water at average concentrations of 208.8-856.9 µg/L. The maximum value was again detected at well W8.

For chromium (Cr), the analyses showed compliance with the drinking water limits for wells W1-W6 and compliance with the irrigation limits for W7 and W8, whereby the average concentrations were almost identical at 61.0 and 63.5 µg/L, respectively. As chromium-containing alloys are used as passivation alloys for ammunition (Jovanovic et al., 2018;sharma et al ,2020, there is again a causal relationship with the conflict zone and the infiltration of chromium-containing surface runoff into the groundwater. The detected concentration range was between 8.90-63.5 µg/L.

Equivalent to chromium, the nickel contamination (Ni) with concentrations of 3.40-25.70 µg/L was also below the limit values for drinking water use for wells W1-W6 and below the irrigation limit values for wells W7 and W8. Similar nickel concentrations of 23.7 and 25.7 µg/L were again detected on average for W7 and W8. Here too, the use of CuNi alloys as a building metal in the outer jaket means that there is a direct causal link with the combat operations. (Shweti & verna,2018)

In summary, it can therefore be stated that the increased heavy metal concentrations in the wells W5, W6, W7 and W8 located in the conflict area compared to the remote wells W1-W4 are due to the past hostilities and the resulting heavy soil contamination. Through the infiltration of contaminated surface waters such as infiltration and rainwater, particularly during the winter and spring seasons, these contaminants, which were initially localized on the surface, were introduced into the aquifer and thus the wells. The four wells localized in the conflict area were constructed during the conflict on the basis of the introductory explanations. Due to the lack of availability of heavy construction equipment, these are shallow wells, which are significantly more susceptible to infiltration from surface runoff and thus meteorological conditions than deeper wells (W1-W4). This aspect has already been addressed by Temaugee et al (2020), Kamble et al (2016) and Kumar et al (2010). In addition, the heavy metal concentrations can be influenced by the existing geological formations in the region, as higher pH values in particular lead to the immobilization of heavy metals (Kicinska et al., 2021)

Table 5 The impacts of high concentration of the selected parameters on the Plants (EPA, 2001)

Parameter	Impacts
pH	High pH causes an increase in Na cautions which are toxic in both soil and plants; low pH: causes an increase of (Al) and (Mn) cautions which are toxic to the crops.
Electrical conductivity EC	High EC increasing the osmotic pressure of the nutrient solution, wastes nutrients, and the increases discharged of nutrients into the environment
% Salinity	Salinity stress , leading to reduced growth and development. It disrupts the balance of essential ions within plant cells, causing ionic imbalance, osmotic stress, oxidative stress, and nutritional imbalance.
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.
Sulfate	High concentration causes unlikable odor of hydrogen sulfide , cause an increase in salts. This can accumulate and cause the plants to become stunted and dark in color
Nitrate	High levels can In waterways stimulate overgrowth of algae – called eutrophication.
Phosphat	High concentration can cause increased growth of algae and large aquatic plants, which can result in decreased levels of dissolved oxygen– a process called eutrophication.
Cadmium Cd	High concentration reduces uptake and translocation of nutrients and water, increases oxidative damage, disrupts plant metabolism, and inhibits plant morphology and physiology
Lead Pb	High concentration damages to plants during disturbs the plant water and nutritional relations and causes oxidative damages to plants

Zinc Zn	High concentration reduced growth, photosynthetic and respiratory rate, imbalanced mineral nutrition and enhanced generation of reactive oxygen species.
Chrome Cr	High concentration due to deterioration of the chlorophyll content in many plants
Nickel Ni	High concentration due to severely retards seed germ inability of many crops and mobilization of food reserves in germinating seeds.

3.2. Calculations of CCME-WQI

The suitability test of the analysed well samples for drinking and domestic use according to the CCME-WQI approach showed that wells W1, W2, and W3 had moderate water quality (class 3), while well W4 showed low water quality (class 4) and the remaining wells W5-W8 revealed poor water quality (class 5) during the study period (see Table 9). The high levels of sulphate and salts that were dissolved from the regional geological rock formation during the passage of water in the aquifer were the main reason for the heavy pollution in W4. This mechanism was previously described by Altamir et al. (2005) and Al-Saffawi et al. (2018a). In turn, the very low suitability of the water samples from wells W5-W8 was mainly due to the input of pollutants as a result of the previous armed conflicts. These samples revealed high levels of E.C., salts, TDS, SO_4^{2-}, PO_4^{3-}, and the heavy metals Cd, Pb, Cr and Ni.

The CCME-WQI suitability test for use as irrigation water showed that wells W1 and W3 can be assigned to class 3 (moderate quality for irrigation), while W2 is assigned to class 2 (good quality), wells W4 and W5 to class 4 (low quality) and W6-W8 to class 5 (poor quality and not suitable for irrigation). The unsuitability of wells W7 and W8 based on the high contents / values of electrical conductivity, salts, sulphate, phosphate and the heavy metals Cd and Ni, while unsuitability of W6 relates to exceedances of TDS, salinity, sulfate, and Pb and Cd as heavy metals.

3.3. Calculation of the HPI

The Heavy Metal Pollution Index (HPI) classifies the wells according to the concentration of dissolved heavy metals in the water and the suitability of the corresponding water as drinking water or for irrigation. The HPI was calculated on the basis of the average concentrations of dissolved heavy metals shown in Table 10.

The results demonstrate that wells W2, W3 and W4 could be classified as "good" and therefore "suitable" in terms of their suitability for drinking water and domestic use, while the water quality of the other wells shows clear deficiencies due to high heavy metal contents and therefore wells W1 and W5 must be classified as poor for drinking water and domestic use and W6-W8 as unsuitable in accordance with the WHO guidelines (WHO, 2004).

If, according to Table 11, use as irrigation water is assumed, the water extracted from wells W2-W4 can be classified as "good", while the water quality of wells W1 and W5 can still be categorized as poor. Wells W6-W8 improve to the classification "very poor" in the case of irrigation application.

If the HPI value is calculated for the individual heavy metals, Cd shows the highest specific HPI value compared to the other dissolved heavy metals, which means that it can be regarded as the most relevant groundwater contaminant of heavy metals. Following closely behind, Pb can be considered the second most important contaminant. The comparison of the specific HPI values according to Table 12 allows the heavy metals to be ranked as follows: Cd > Pb > Ni > Cr > Zn.

Due to the comparatively very high limit value of Pb in irrigation water and the associated significant undercutting of the limit value, the HPI value specific to Pb is irrelevant. Accordingly, the heavy metal sequence according to Table 13 changes in the case of irrigation application to: Cd > Ni > Cr > Zn > Pb. The limit values for Cd are exceeded on average by the wells W5-W8 and for Ni by the two wells W7 and W8.

Table 6 Characteristics of Groundwater in all wells and standard limits for Drinking and Irrigation , (WHO,2004) ; FAO ,1986)

WHO drinking		**PH**	**E.c µS/cm**	**TDS mg/l**	**% Sal.**	**COD mg/l**	**PO4 mg/l**	**NO3 mg/l**	**SO4 mg/l**	**Cd µg/l**	**Pb µg/l**	**Zn µg/l**	**Cr µg/l**	**Ni µg/l**
		6.5-8.5	1400	1000	1	100	0.4	50	250	5	10	5000	50	20
WHO& FAO		6.5-9	3000	2000	3	100	0.4	50	400	10	5000	2000	100	20
W1	Mean	7.2	2943.7	787.1	2.3	15.6	0.50	39.7	471.8	2.8	4.6	299.9	20.1	4.2
	Max	7.5	3280.0	1023.0	3.2	18.0	0.67	41.0	566.0	4.5	5.4	322.0	28.0	6.2
	Min	6.9	1100.0	405.3	1.9	12.0	0.24	13.0	240.0	14.0	2.8	168.0	17.0	3.1
W2	Mean	7.2	2888.9	945.4	2.6	50.6	0.29	29.5	466.2	4.0	3.0	307.1	8.9	3.4
	Max	7.6	3480.0	2030.0	2.8	45.0	0.38	38.0	530.0	4.8	4.2	405.0	12.0	4.2
	Min	6.8	2360.0	754.0	1.5	13.0	0.04	12.0	143.0	2.7	2.4	223.0	6.9	2.6
W3	Mean	7.1	1530.9	1403.8	2.4	46.5	0.67	27.9	359.7	5.4	6.9	360.1	10.4	4.2
	Max	7.8	2180.0	2008.0	2.8	55.0	0.82	32	406.0	7.5	7.4	423.0	13.7	5.7
	Min	6.5	1290.0	1045.0	1.7	44.0	0.47	8	232.0	3.2	3.8	298.0	8.0	2.4
W4	Mean	7.3	3475.9	1973.9	3.3	44.7	0.50	32.7	1072.7	8.6	5.9	208.8	17.5	4.0
	Max	7.8	3806.0	2365.0	3.9	60.0	0.64	36.0	1289.0	10.6	7.1	312.0	19.0	6.0
	Min	6.8	2860.0	890.0	2.4	34.0	0.28	12.0	830.0	5.9	4.6	178.0	11.0	2.8
W5	Mean	6.8	2479.8	1124.9	2.1	54.8	0.63	32.2	454.2	11.4	28.3	664.0	35.8	6.2
	Max	7.3	3080.0	1590.0	3.0	77.0	0.76	43.0	562.0	15.4	32.2	544.0	39.0	7.0
	Min	6.5	2060.0	976.0	1.8	40.0	0.40	21.0	302.0	6.6	23.0	411.0	26.0	4.7
W6	Mean	7.1	2427.8	3427.8	3.2	98.5	0.60	37.6	458.2	15.9	21.9	538.8	36.0	11.2
	Max	7.3	3300.0	3900.0	3.8	116.0	1.28	42.0	554.0	16.9	23.0	623.0	41.0	13.3
	Min	6.8	2023.0	1088.0	2.1	88.0	0.24	26.0	312.0	11.5	16.0	433.0	28.0	9.3
W7	Mean	7.0	2315.7	2179.6	2.9	94.8	0.68	32.3	502.3	16.8	30.8	732.7	61.0	23.7
	Max	7.3	2988.0	3087.0	3.8	112.0	0.78	46.0	678.0	18.2	34.0	833.0	66.0	24.3
	Min	6.9	1677.0	1030.0	1.8	89.0	0.35	17.0	322.0	8.4	26.0	643.0	49.0	21.0
W8	Mean	7.2	3654.8	2540.9	2.8	104.0	0.73	33.9	435.5	18.2	25.2	856.9	63.5	25.7
	Max	7.7	4060.0	3906.0	3.9	144.0	0.80	49.0	671.0	21.3	28.0	907.0	69.0	27.0
	Min	7.0	3061.0	1045.0	2.0	58.0	0.40	13.0	365.0	14.8	21.0	621.0	45.0	22.9

Table 7 Average values of wells characteristics classification according to standard limits for Drinking and Irrigation (WHO,2004 ; FAO ,1986)

Drinking WHO limits	**PH**	**E.c µS/cm**	**TDS mg/l**	**% Sal.**	**COD mg/l**	**PO4 mg/l**	**NO3 mg/l**	**SO4 mg/l**	**Cd µg/l**	**Pb µg/l**	**Zn µg/l**	**Cr µg/l**	**Ni µg/l**
	6.5-8.5	1400	1000	1	100	0.4	50	250	5	10	5000	50	20
Irrigation WHO & FAO	6.5-9	3000	2000	3	100	0.4	50	400	10	5000	2000	100	20
W1	7.2	2943.7	787.1	2.3	15.6	0.50	39.7	471.8	2.8	4.6	299.9	20.1	4.2
W2	7.2	2888.9	945.4	2.6	50.6	0.29	29.5	466.2	4.0	3.0	307.1	8.9	3.4
W3	7.1	1530.9	1403.8	2.4	46.5	0.67	27.9	359.7	5.4	6.9	360.1	10.4	4.2
W4	7.3	3475.9	973.9	3.3	44.7	0.50	32.7	1072.7	8.6	5.9	208.8	17.5	4.0
W5	6.8	2479.8	1124.9	2.1	54.8	0.63	32.2	454.2	11.4	28.3	664.0	35.8	6.2
W6	7.1	2427.8	3427.8	3.2	98.5	0.58	37.6	458.2	15.9	21.9	538.8	36.0	11.2
W7	7.0	2315.7	2179.6	2.9	94.8	0.68	32.3	502.3	16.8	30.8	732.7	61.0	23.7
W8	7.2	3654.8	2540.9	2.8	104	0.73	33.9	435.5	18.2	25.2	856.9	63.5	25.7
suitable for Drinking and Irrigation				Unsuitable for Drinking and Irrigation					unsuitable for Drinking suitable for Irrigation				

Table 8 Salinity impact suitability for irrigation (EPA,2004)

Wells	**Suitability**
W1	Moderate
W2	Moderate
W3	Moderate
W4	Severe
W5	Moderate
W6	Severe
W7	Moderate
W8	Moderate

Table 9 CCMWQI classification and suitability of wells for Drinking and Irrigation ,(WHO,2004) ; FAO ,1986)

	CCMWQI for Drinking			**CCMWQI for Irrigation**		
Wells	CCMWQI	Classe	Sutability	CCMWQI	Classe	Sutability
W1	72.187	3	Moderate	77.53	3	Moderate
W2	75.891	3	Moderate	94.80	2	Good
W3	67.907	3	Moderate	79.51	3	Moderate
W4	57.169	4	Marginal	64.0	4	Marginal
W5	44.065	5	poor	60.903	4	Marginal
W6	49.752	5	poor	47.254	5	Poor
W7	47.970	5	poor	45.365	5	Poor
W8	48.155	5	poor	46.372	5	Poor

Table 10 Average values of dissolved heavy metals in (μg/l) in all wells

Wells	**Cd μg/l**	**Pb μg/l**	**Zn μg/l**	**Cr μg/l**	**Ni μg/l**
W1	1.014	1.665	108.564	7.276	1.520
W2	1.448	1.086	111.170	3.222	1.231
W3	1.955	2.498	130.350	3.765	1.520
W4	3.113	2.136	75.586	6.335	1.448
W5	4.127	10.245	240.368	12.960	2.244
W6	5.756	7.928	195.046	13.032	4.054
W7	6.082	11.150	265.237	22.082	8.579
W8	6.588	9.122	310.198	22.987	9.303

Table 11 HPI classification suitability of wells for Drinking and Irrigation ,(WHO,2004) ; FAO ,1986)

HPI for Drinking			**HPI for Irrigation**		
Sites	HPI	Sutabilty	Sites	HPI	Sutabilty
W1	60.047	poor	W1	50.802	poor
W2	46.114	good	W2	44.326	good
W3	36.492	good	W3	26.131	good
W4	46.114	good	W4	40.227	good
W5	61.101	poor	W5	54.840	poor
W6	100.078	unsuitable	W6	76.635	very poor
W7	121.613	unsuitable	W7	89.219	very poor
W8	130.412	unsuitable	W8	96.440	very poor

Table 12 HPI for Drinking for each elements in all wells

	W1	W2	W3	W4	W5	W6	W7	W8
Cd	53.6574	41.9232	28.2333	30.572	50.4376	74.4408	83.2414	96.9313
Pb	4.49810	2.93354	6.74716	5.769314	17.6731	21.4149	30.1177	24.6418
Zn	0.07810	0.07803	0.07751	0.078996	0.07454	0.07576	0.07387	0.07265
Cr	0.78619	0.34811	0.40678	0.684495	1.40028	1.40810	2.38595	2.48373
Ni	1.026742	0.831172	1.02674	0.97785	1.515667	2.737979	5.79376	6.282685

Table 13 HPI for Irrigation for each elements in wells

	W1	W2	W3	W4	W5	W6	W7	W8
Cd	46.789	41.69014	22.943662	36.53991	48.43662	67.55634	71.38028	77.32864
Pb	0.0002	0.00021	0.00017646	0.000185	5.75667	4.87843	2.76443	2.066781
Zn	0.074	0.073898	0.0731475	0.07529	0.068843	0.070616	0.06787	0.066111
Cr	0.708	0.1756291	0.3883755	0.487089	1.04216	1.059155	1.183568	1.396009
Ni	0.231	0.805751	0.93688	0.124413	1.29284	1.948357	4.587148	5.649354

3.4. Mapping of the spatial distribution of heavy metals in groundwater

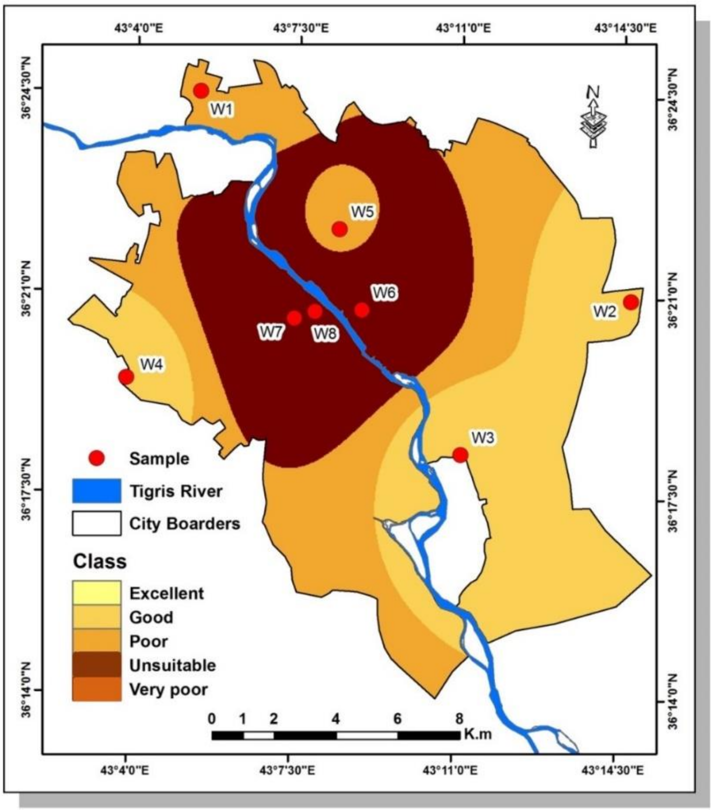

Figure 2 The spatial distribution of heavy metals pollution index according to suitability for drinking (WHO,2004)

Based on the eight wells sampled and with the help of geostatistical analyses in ArcGIS software 10.4 (Johnston et al., 2005; ; Simsek & Gunduz, 2006), the heavy metal distribution in the urban area of Mosul was mapped using the HPI as an indicator variable. From this mapping it can be deduced that around 33.9 % of the wells in the city area are actually located within the former combat zone, which is why they are heavily contaminated with heavy metals and the water obtained here is not suitable for drinking. Subsequently, 33.5 % of the total number of wells are located in a larger radius of the conflict area, which continue to be affected by the conflict zone and only have poor water quality for drinking water use. And 32.5 % of the wells have good water quality (see Figure 2 and Table 13).

The pollution mapping in Figure 3 shows that, in light of irrigation use, 26.5 % of the areas and thus the wells located there had very poor water quality, 32.7 % had poor water quality, 40.723 % had good water quality (see Table 14).

Table 14 Spatial distribution area (Square meter))and percentage of heavy metals pollution Index in all wells according to suitability for drinking and domestic use

Class	Area (M2)	Percentage
Good	65.635	32.537
Poor	67.683	33.552
unsuitable	68.405	33.9104

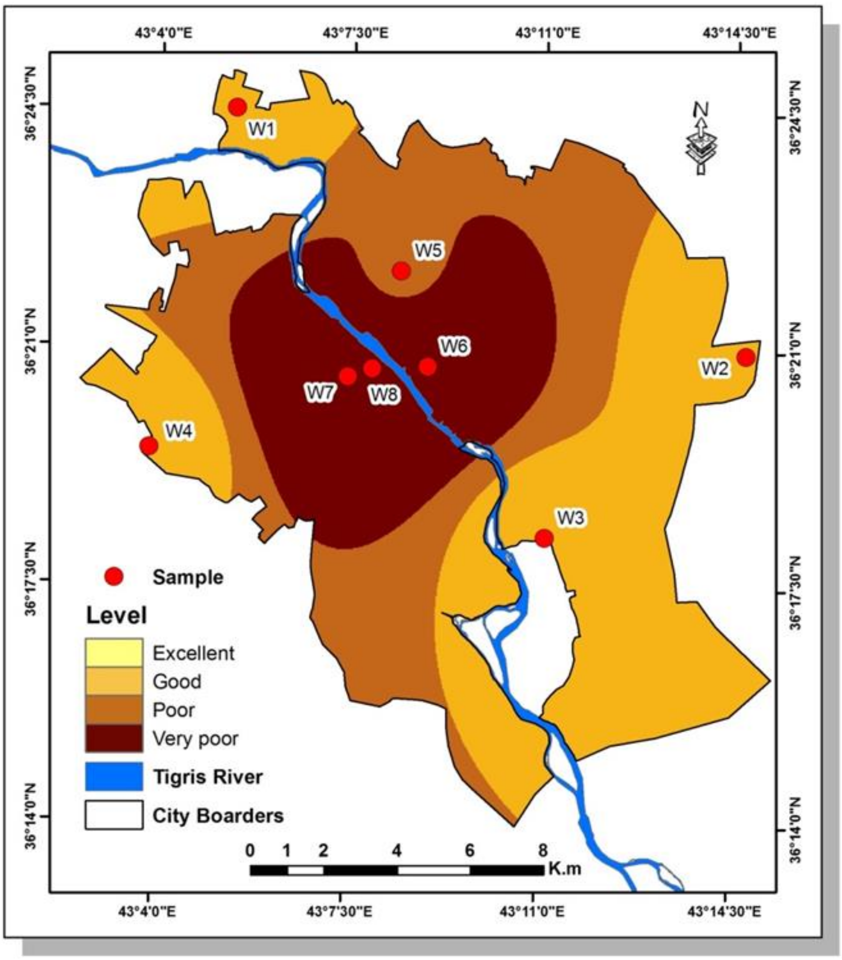

Figure 3 The Spatial distribution of heavy metals pollution index according to suitability of Irrigation (WHO,2004)

Table 14 Spatial distribution area (Square meter) and percentage of heavy metals pollution Index in all wells according to suitability for Irrigation use

Class	Area (M2)	Percentage
Good	82.124	40.723
Poor	66.005	32.720
Very poor	53.570	26.556

4. Conclusion

The values of EC,TDS , Salinity ,SO4 ,PO4,COD and heavy metals, Cd, Pb ,Cr ,Ni exceeded the limits according to,(WHO 2003)(WHO,2004 ;FAO,1986) for the drinking and domestic use and for Irrigation use , in the wells in the conflict zone and surrounding. while Zn values were within limits in all wells ,they were as follows:

W1 was according to Salinity impact for Irrigation classified as class3 (moderate) , and according to CCMWQI suitability for drinking and for Irrigation was (Moderate). And according to HPI classification and suitability for drinking and irrigation classified (poor) for drinking and irrigation.

W2 was according to Salinity impact for Irrigation classified as (moderate) and it's suitability for drinking was class 3 (Moderate) and for Irrigation use classified as class 2 (Good) ,and according to heavy metal content HPI classification, it was classified (good) and suitable for drinking and domestic use and for irrigation.

W3 was according to Salinity impact for Irrigation classified as (moderate) and class 3(Moderate) according to CCMWQI for drinking and domestic use, but for irrigation it was classified as class 3 (Moderatel). Based on its heavy metal content and according to HPI classification, it was (Good) for drinking and domestic use, and for irrigation. But only for crops that tolerate this degree of heavy metal and salinity concentration.

W4 was according to Salinity impact for Irrigation classified as (Severe) and class 4 (Marginal) according to CCMWQI for drinking and domestic use ,but for irrigation it was class 4 (Marginal), because of the high SO4 ,Salinity values. But based on its heavy metal content and according to HPI classification, it was (Good) for drinking and domestic use, and classified as (Good) for irrigation.

W5 was according to Salinity impact for Irrigation classified as (Moderate) and classified class 5 (Poor) for drinking and domestic use and class 4 (Marginal) for irrigation according to CCMWQI. According to HPI classification and suitability and its heavy metal content , it was (Poor) for drinking and domestic use, and it was(Poor) for irrigation.

W6 was according to Salinity impact for Irrigation classified as (Severe) and it was class 5 (poor) for drinking and domestic use and for irrigation according to CCMWQI. According to HPI classification and suitability and its heavy metal content , it was (unsuitable) for drinking and domestic use, and it was(very poor) for irrigation. because the increase of the salinity wert and heavy metal content.

W7,W8 were according to Salinity impact for Irrigation classified as (Moderate) and class 5 (poor) for drinking and domestic use and for irrigation according to CCMWQI. According to HPI classification and suitability and their heavy metal content, they were (unsuitable) for drinking and domestic use, and they were (very poor) for irrigation., because the increase of the salinity wert and heavy metal content.

The negative impact of wars in the long term appears clearly in the pollution of groundwater in the conflict zone and surrounding (W5,W6,W7,W8) compared with other wells (W1,W2,W3,W4) and this is shown by the high concentrations of heavy metals ,Cd,Pb, Cr,Ni , COD,PO4 ,SO4 E.C ,TDS ,Salinity . Cadmium, followed by lead, were the dominant water contaminants heavy metals. Due to the heavy soil contamination through the infiltration of contaminated surface waters such as infiltration and rainwater, particularly during the winter and spring seasons, these contaminants, which were initially localized on the surface, were introduced into the aquifer and thus the wells.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

- Zena Fakhri Altahaan: Sampling, material preparation, data collection and analysis, literature research, writing.
- Daniel Dobslaw: Study conception, sampling plan, literature screening, writing.

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