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Geochemistry of the Ground Water in the Sinkhole Area at Ghor El Haditha, Southeast Dead Sea, Jordan

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Abstract
Twenty water geochemical samples collected from the sinkhole, spring at Ghor Al Haditha area and from the upstream running in Wadi Ibin Hammad area. The samples analyzed by Atomic Absorption Spectrometer (AAS) to determine their major cation (Na, K, Mg, Ca,), and anion (HCO_3, Cl, SO_4) and TDS. The results of the analyses water samples shows high concentration of all the elements for the samples spring after the sinkhole area at along eastern shoreline of the Dead Sea caver the study area, TDS range between 3170 to 419519 mg/l. The samples sinkhole shows high concentration of major cation and anion elements, TDS range between 4844 to 31275mg/l. The high concentration of Na, K, Mg, Ca, Cl, HCO_3, SO_4, and TDS as a result to dissolve the salt, evaporate halite and gypsum layers under the sinkhole area, and the sinkhole body as indication to the sinkhole sudden within dissolved the salt. It is reflects the motion and movement of the ground water by affected the decline the Dead Sea Level at the last 30 years ago.
Keywords: Geochemistry, Groundwater, Sinkhole, Ghor Al Haditha, Jordan.

1. Introduction

The sinkholes formed at the Southeast Edge of the Dead Sea (DS) Coast at Ghor Al Haditha during the past thirty years ago (Arkin Y. 1993; EL-Isa et al. 1995). The Sinkholes distribution in the two sides of Dead Sea, Eastern side from Jordan (Ghor Al Haditha) and Western side from Israel (Taqieddin et al. 2000; Amos et al., 2011). The Sinkhole dimensions reach up to about 12 meters in depth and 27meters in diameter. They represented to dangers to both life and properties disrupt life in the area, and adversely affect building and development. The formation of the sinkholes is a dynamic process continuing to the present day, and which their resultant development at unexpected sites (Yechieli et. al., 2002). Sinkholes are produced by 1) Ingression of fresh water in the lowering of the Dead Sea level and tectonic movement have a sound role in triggering the failure of these cavities (EL-Isa et al. 1995); 2) limestone karsts, terrains commonly develop and modify during for a long periods associated with collapse or subsidence cavities. 3) Sudden and collapse of the ground surfaces caused by washing out of loose materials cover into underlying solution cavities (Diabat A. 2005).

4) Solubility and dissolution rates of the salt (halite, NaCl) or a common mineral and rock at the subsurface (Amos et al. 2011).

The sinkholes phenomena have been evaluate within 35 years, due to increasing decline of the Dead Sea level, because interception of the freshwater flow to the Dead Sea upstream by domestic, agricultural, industrial needs of surrounding countries.

Brief studies have reported after the major sinkholes suddenly appeared in 1992 in an access road to the west of Lisan Peninsula (Diabat A. 2005). This study focused to the sinkholes is collapse due to fresh water ingress along former flood channels. Diabat A. 2005 studies the tectonic factor affected at Ghor Al Haditha Area and reported the active tectonics presence of salty groundwater conditions and underground shallow salt bodies by Fluctuation of the subsurface water with time, which caused at least partial dissolution of salt bodies leading to creation of subsurface cavities. In addition, cavities triggered to form collapse or cracks accelerated by tectonic Movements or earthquakes, and hence forming the surface cavities or the sinkholes. Geophysical methods are widely used such as GPR, microgravity and Geoelectric to explain the sinkholes produced for detection in carbonate karst (Crawford et al. 1999; Thomas and Roth, 1999; Erchul, 1993, Zhou et al. 1999; Benson and Yuhr, 1993). This method detection of the cavities and other karst features in carbonate rocks (mostly limestone) (Amos et al. 2011). Seismic method are used to developed for investigating salt environments such as the evaporate deposits along the Dead Sea coast in Jordan and Israel. Some of the main peculiarities of the unconsolidated, salty sediments in the Dead Sea region are high salinity groundwater and the rapid subsurface dissolution of the salt in response to human-induced changes in environmental (hydrogeological) conditions. Low electrical resistivity of the Dead Sea aquifers in the coastal area creates a contrast with surrounding sediments (Beck and Herring, 2001; Beck, 2003; Al-Zoubi et al. 2007; Ezersky, 2006 and 2008). The objective of this study is to investigate the Hydro Geochemistry method was used to explanation of the sinkhole phenomena by using analysis of the water Geochemistry samples for sinkholes, spring and stream. The water geochemistry method was used to obtained good results and helped in explanation and evaluation of these phenomena.

2. Study Area

The study area of Ghor Al Haditha is located on the eastern side of the Dead Sea to the west of Wadi Ibn Hammad, Wadi Ed Dhira, Wadi El Madba΄a and Wadi El Karak mouths (Figure 1). The area in which the sinkholes have occurred is a gently inclined wave-eroded platform about 3 km wide east of the Lisan Peninsula (Diabat A. 2005). This area formed the bed of the Dead Sea, when it has submerged during a period of higher sea levels. The underlying geological materials boreholes data shows consist of laminated calcareous, silt interbedded with salt (halites) and gypsum. Sinkholes appear and located with deferent materials, composed mainly sand, silt, clay and gravel, and evaporate minerals such as salt and gypsum Figure 2. According with Knill 1993; Knight, 1993 and Tapponniers, 1993 was reported the sinkhole after suddenly in October 1992, at southern end of the Dead Sea west of Lisan Peninsula and access road west of Lisan Peninsula. After that at Ghor Al Haditha area the sinkhole subsidence appears. The lowering of the Dead Sea level and the movement of ground water under the area (Ghor Al Haditha) and tectonic movement has a role to failure of cavities and subsidence of the sinkhole risk (El-Isa et al. 1995).

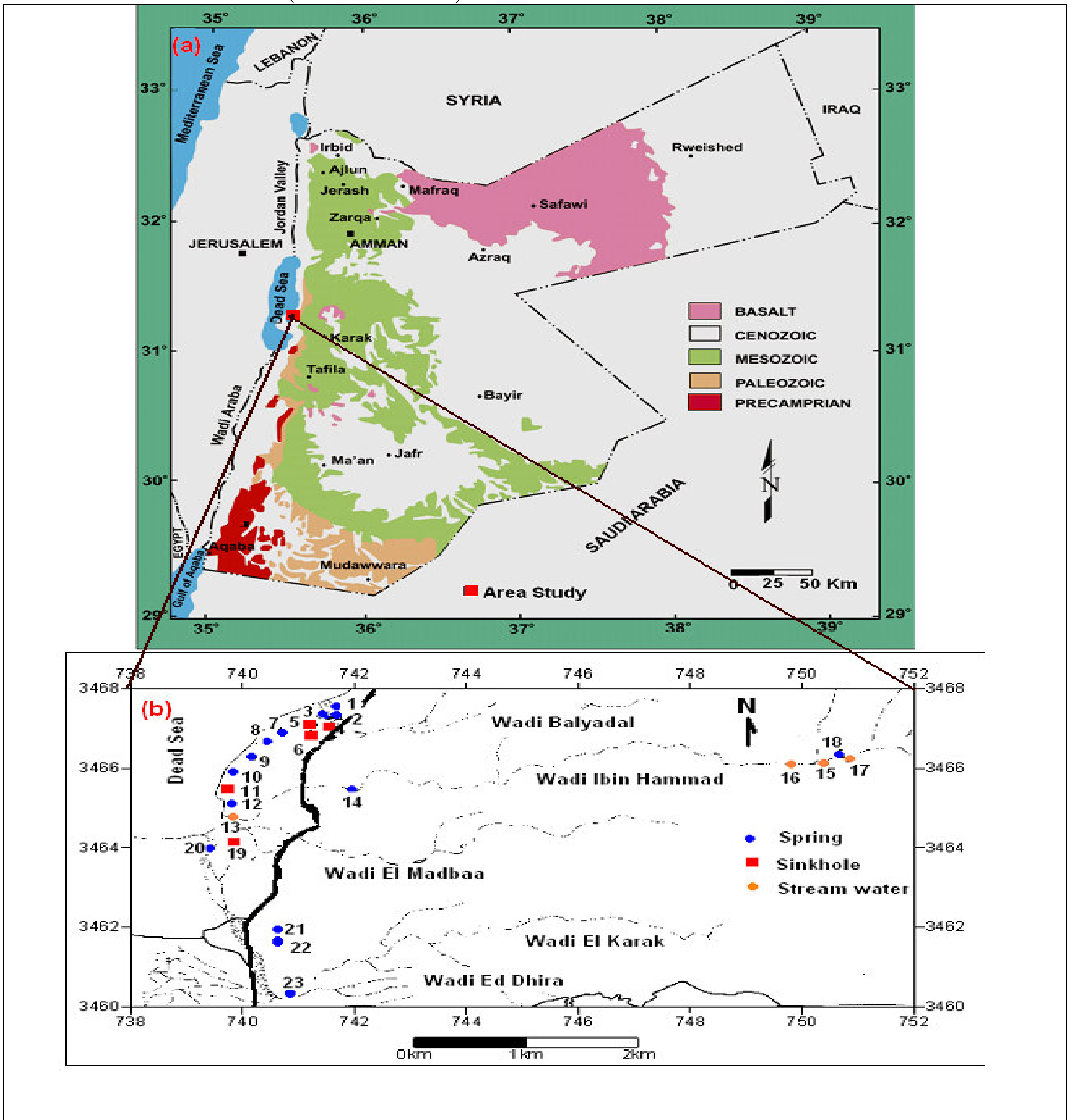

Figure 1: (a) Location map of the study area, (b) Water geochemical samples location (spring, sinkhole and stream water)

Figure 2: Photographs shows the Ghor Al Haditha Study area, (a) Sinkhole filling water. (b) Spring, (c) Sinkhole and spring, (d and e) Sinkhole within the farmers, (f) Sinkhole filling water and spring.

3. Geological Setting

The geological formation of the study area represented by the Quaternary Pliocene to Holocene marine and continental sediments deposit. This formation penetrated and exposed in the sinkhole area. The formation from older to younger are follows (Basem K, 1988); 1) Usdom Evaporate Formation; this formation composed mainly of rock salt (Halite) with some horizons of carnalite and shale or clay and silt. Its thickness is about 4 000 m as penetrated in the El-Lisan-l wildcat well. The Geophysical studies indicated that the salt is at least 6 000 m thick (Diabat A. 2005). 2) Lisan Formation; is a horizontally bedded sequence of laminated deposit with bands of silty clay, clayey silts and sands. This formation is composed of alternating grey-green to white laminate; the grey lamina are dominated by calcite with gypsum and quartz, whereas the white lamina are dominated by aragonite with smaller amounts of gypsum and traces of Quartz and Calcite. 3) Superficial deposits; composed of fluviatile and lacustrine gravels of Pleistocene age in addition to Holocene and Recent sediments (e.g. alluvium and alluvial fan deposits of Wadi Ibn Hammad and other wadi (Basem K, 1988).

Structurally, the study area located within the Dead Sea Transform Fault (DSTF), it exposed at the surface and covered by the Lisan Formation and by alluvial fans. The fault zone trending the eastern of the shoreline of the Dead Sea, North of Wadi Assail it swings NNW-SSE along the topographic low between the Ed Dhira plain and the Lisan Peninsula (Powell, 1988, Basem K, 1988, Diabat A. 2005). Many faults trending NE-SW and N-S trending parallel to the main structure and exposed along the adjacent to the Dead Sea basin.

4. Sampling and Analytical Techniques

A total of (23) geochemical water samples collected from the study area Figure 1. The samples represented three-type of water sources stream, spring, sinkhole, caver the eastern and western part of the study area, these samples are:

- 14 Geochemical water samples collected from the spring before and after the sinkhole area
- 5 Geochemical water samples collected from sinkholes body (within study area).
- 4 Geochemical water samples collected from the stream running in Wadi Ibin Hammad, eastern side of the sinkhole area. PH, EC and Temperature measured in the field. The samples transported to the laboratory by polyethylene bottles.

The chemical analysis determined by using Atomic Absorption Spectrophotometer (AAS.) PERKIN ELMER- 2280 Model for Na^+ , K^+, Titration method for analysis Ca^{2+} and HCO_3^-, Ion Chromatograph method analysis for Cl^- and $SO4^{2-}$ and Ion Exchange Resin to determine Mg^{2+}. The analysis carried out of major cation (Na^+, K^+, Mg^{2+}, Ca^{2+},), major anion (HCO_3^-, Cl^-, $SO4^{2-}$) at Natural Resources Authority laboratories. Total Dissolved Solids (TDS) measured by Instrumental measurement, PH by PH-meter, Electrical Conductivity (EC) by Conductivity meter. The chemical analysis data list in Table 1.

Table 1: Chemical analysis of the spring, sinkholes and stream Geochemical water samples.

S. No.	Na mg/l	K mg/l	Mg mg/l	Ca mg/l	Cl mg/l	HCO_3 mg/l	SO_4 mg/l	TDS mg/l	EC Ms/Cm	T/C^0	PH
Spring Geochemical water samples after sinkhole area along the eastern shoreline of the Dead Sea											
1	**4700**	**10500**	**38640**	**12800**	**194380**	**91**	**954**	**419519**	**481760**	**24.2**	**5.25**
2	**3600**	**740**	**2256**	**1080**	**14683**	**256**	**271**	**22758**	**33820**	**24.0**	**6.6**
3	**2550**	**530**	**1776**	**1040**	**12180**	**256**	**271**	**29245**	**29595**	**24.2**	**6.72**
7	**860**	**204**	**694**	**452**	**4155**	**256**	**191**	**6684**	**12561**	**24.2**	**7.05**
8	**1510**	**362**	**1150**	**588**	**6490**	**342**	**413**	**10684**	**18680**	**24.2**	**6.61**
9	**1210**	**259**	**832**	**494**	**5339**	**256**	**185**	**8447**	**13280**	**24.3**	**7.0**
10	**910**	**198**	**520**	**332**	**3504**	**256**	**195**	**5787**	**8280**	**24.3**	**7.05**
12	**420**	**123**	**315.6**	**200**	**1527**	**512**	**329**	**3170**	**5140**	**24.3**	**6.70**
20	**2500**	**460**	**1600**	**760**	**10252**	**341**	**218**	**15960.5**	**23500**	**24.4**	**6.50**
Spring Geochemical water samples before the sinkhole study area											
14	**100**	**10**	**41**	**58**	**192**	**183**	**79**	**663**	**930**	**24.2**	**7.16**
18	**64**	**6.2**	**18**	**43**	**120**	**195**	**96**	**444.7**	**730**	**35.2**	**7.0**
21	**160**	**13.6**	**45**	**70**	**270**	**305**	**162**	**873.1**	**1203**	**24.5**	**6.50**
22	**160**	**12.2**	**39**	**62**	**236**	**281**	**200**	**849.9**	**1138**	**24.8**	**6.50**
23	**640**	**43**	**270**	**240**	**1686**	**268**	**835**	**3848**	**5670**	**24.6**	**6.50**
Sinkholes Geochemical water samples											
4	**910**	**26**	**816**	**444**	**5005**	**268**	**387**	**7722**	**13140**	**24.2**	**7.80**
5	**2820**	**640**	**1128**	**800**	**13014**	**232**	**332**	**18850**	**31932**	**24.2**	**7.50**
6	**700**	**177**	**444**	**316**	**2786**	**305**	**269**	**4844**	**8790**	**24.2**	**7.30**
11	**520**	**115**	**360**	**90**	**1710**	**305**	**174**	**31275**	**5230**	**24.3**	**7.05**
19	**470**	**101**	**200**	**422**	**1551**	**446.5**	**416**	**3383.2**	**5240**	**25.2**	**7.0**
Stream Geochemical water samples at Wadi Ibin Hammad											
13	**259**	**4.3**	**155**	**104**	**792**	**183**	**169**	**1624**	**2720**	**24.3**	**7.69**
15	**67**	**5.5**	**24**	**48**	**122**	**189**	**105**	**466**	**772**	**24.5**	**7.0**
16	**64**	**5.4**	**25**	**44**	**122**	**195**	**105**	**462.9**	**772**	**24.8**	**7.0**
17	**54**	**5.5**	**29**	**54**	**110**	**220**	**15**	**467.5**	**796**	**25.8**	**7.0**

5. Result

The ground water in the study area (Ghor Al Haditha) is located and caver by shallow aquifer within Alluvium deposits. The perennial Wades are the source of the spring in the upper elevation in eastern part, usually covered by rocks of cretaceous age and it is basic flow to recharging the shallow aquifer. The source of the spring geochemical samples No. (2, 3, 7, 8, 9, 10, 12, and 20) from Wadi fan gravel in contact between gravel and Dead Sea sediments, near the east shore line of the Dead Sea. The discharge of spring geochemical sample No. 14 from the Purge dolomite limestone formation, it is location about one (1km) east of the sinkholes area (within Wadi Ibn Hammad). The discharge of the spring geochemical samples No.(21, 22, 23) from gravel's, and spring

No. (18) from kurnub sandstone (Figure 1).

5.1. Geochemistry of the spring water samples:
The water samples from spring were collected from two sites, first spring location in the west side (after) of sinkhole area and second spring location before the sinkhole area in the East side Figure (1). The chemical analysis shows high concentration of the major cations and anions (Na, K, Mg, Ca, Cl, HCO_3, SO_4, and TDS) for the west side spring (after) of sinkhole area samples No. (2, 3, 7, 8, 9, 10, 12, 20) (Table 1). Nevertheless, the other spring in the East Side location shows a normal concentration samples No. (14, 18, 21, 22, 23) (Figure1). The groundwater PH is generally low, in the range of 5.25 to 7.05 with average 5.25, this reflection to rich dissolution SO_4 sources. The values of the electrical conductivity (EC) are 5140 µs/cm to 481760 µs/cm with average 69624 µs/cm, it is indication to high cation and anion concentration and Total dissolved Solid (TDS) with average 58028.28 mg/l (**Amadi, M and Amadi A. 1990)** Table 1. The order of abundances of cations and anions as measured in the sinkhole area is Na+ > Ca^{2+} > Mg^{2+} > K^+ and Cl^- > $SO_4{}^{2-}$ > HCO_3 respectively. The Isosalinity contour line for spring (Figure 3) shows the salinity increasing from east to west direction. The high chemical concentration of the spring in west side of the study area explains the source of salt layer under the sinkholes area. The fresh ground water flow dissolved the salt under the sinkholes area from east to west direction flows. The salt layer may be represented as simple salt evaporate, halite (NaCl), anhydrite ($CaSO_4$), potassium chloride (KC1), and polyhalite (K_2SO_4 $MgSO_4$. $_2CaSO_4$. $_2H_2O$), this type of salt is good origin because it is easy to be dissolved by motion of ground water flow, this motion increase by fluctuations of the Dead sea water level in the last year.

5.2. Geochemistry of the sinkholes water samples:
Five geochemical samples collected from the sinkholes, Numbers (4, 5, 6, 11, and 19). The chemical analysis show high concentration of major cation and anion (Na, K, Mg, Ca, Cl, HCO_3, SO_4 and TDS) from sample 4, 5, 6 (Table 1). The PH value range 7.0 to 7.8 with average 7.33, however PH within the natural water (Langmuir, 1997). The values of the electrical conductivity (EC) range between 5230 µs/cm to 31932 µs/cm with average 12866 µs/cm, it is a high cation, anion concentration, and (TDS) with average 13214.84mg/l. The isosalinity contour line of the sinkholes water samples show increasing in chemical concentration form east to west direction throughout the sinkholes area (Figure 4). The data explain the good origin of the salt layer under the sinkholes areas.

5.3. Geochemistry of the stream water samples
Four-stream geochemical water samples collected from Wadi Ibin Hammad, samples No. (15, 16, 17) it is location about 15km east side of the sinkholes study area. This sample represent running stream water, and one sample No (13) located in the end side of wadi Ibn Hammad. Chemical analysis of these sample (Table 1), the sample No (13) shows relatively high concentration of major cations, anions and TDS = 1624 mg/l. However, the other samples shows normal chemical analysis, TDS Average = 464 ppm. The average PH value equal 7.17. The isosalinity contour line of the stream water samples shows increasing chemical concentration from East to West direction throughout of the sinkhole area (Figure 4).

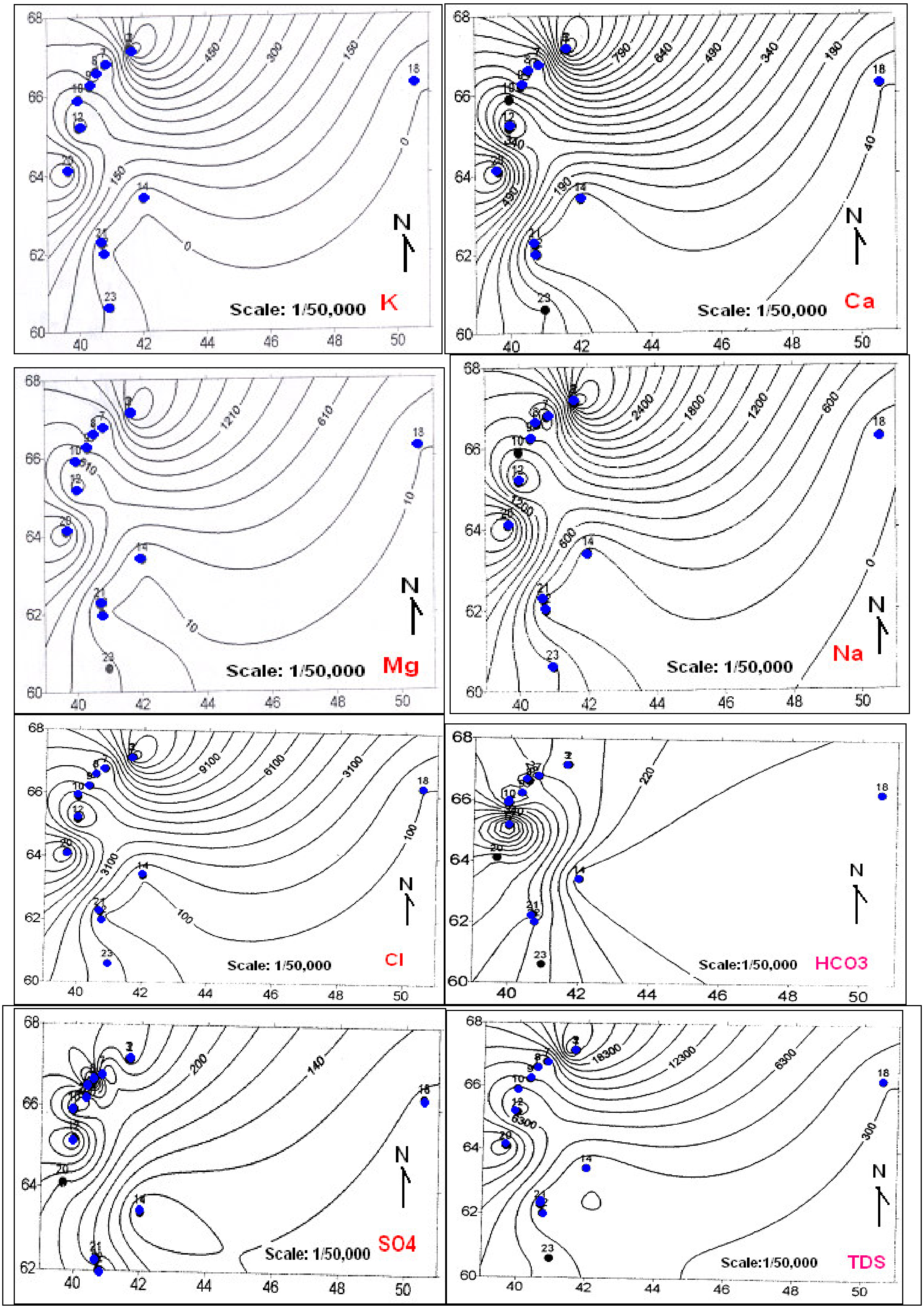

Figure 3: Isosalinity map (K, Ca, Na, Mg, Cl, HCO_3, SO_4 and TDS (mg/l)) for spring geochemical water samples.

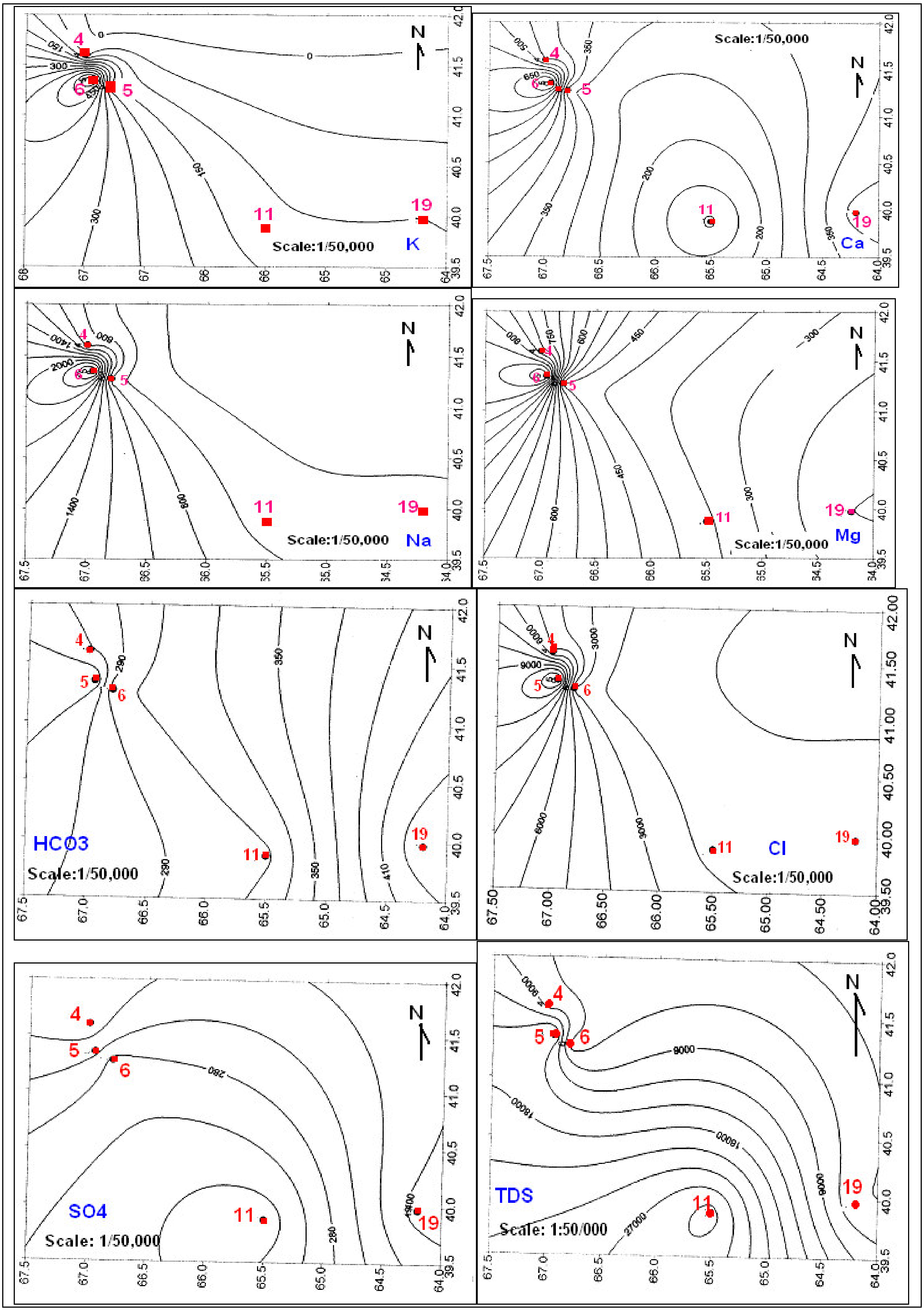

Figure 4: Isosalinity map (K, Ca, Na, Mg, Cl, HCO_3, SO_4 and TDS (mg/l)) for Sinkhole geochemical water samples.

5.4. Sources of Major Ions

The relationship between Na^+ and Cl^-, indication to the origin of salinity in the sinkhole area, the salinity of the spring water samples have $Na^+/(Na^+ + Cl^-)$ ratio (Gibbs, 1970) within the range of 0.242 to 0.268 or plot along line of the Na^+ vs. Cl^- , sinkhole water samples have range from 0.219 to 0.319 within average 0.268 respectively Figure (5a and b). It is implying that halite dissolution is responsible for Na^+ and Cl^- in the groundwater. However, halite is a known to be associated with the geology of the sinkhole area, and it is likely to be source of Na^+ and Cl^-. The graph of Na^+/ (Na^+ + Ca^{2+}) varies of TDS (Gibbs, 1970; Ahialey et al. 2010) Figure 6 as indication sources of dissolved ions as broadly by plotting graph, this suggest chemical weathering of the rock forming minerals of evaporate. The relationship between Ca + Mg (meq/l) and HCO_3 + SO_4 (meq/l) for spring samples after the sinkhole area should be an indication of potassium chloride (KC1), and polyhalite (K_2SO_4 $MgSO_4$. $_2CaSO_4$. $_2H_2O$), gypsum ($CaSO_{4}.{}_2H_2O$), anhydrite ($CaSO_4$), aragonite and clay minerals such as brucite ($Mg(OH)_2$) as the predominant processes controlling solution composition and groundwater falling below the signifies ion exchange which involves the enrichment of Ca + Mg for samples 2, 3, 20 and depletion HCO_3 + SO_4 compared samples 8 and12 (James D. 1997; Mclean and Jankowski, 2000): Figure 7. The enrichment of (Ca + Mg) relative to (HCO3 + SO4) as result dissolution sources of Ca and Mg (Figure 7), and Na^+ must be excess the HCO_3 + SO_4. Sulphate in the groundwater is derived principally from the evaporate minerals gypsum, hydrous calcium sulphate ($CaSO_4 \cdot {}_2H_2O$), and minerals like anhydride ($CaSO_4$), Epsom salt ($MgSO_4 \cdot {}_7H2O$) and Glauber's salt ($Na_2SO_4 \cdot {}_{10}H_2O$). The high percentage salinity of the spring water samples in the sinkhole area indication to dissolution of salt layer by increasing movement of groundwater as a result to fluctuation of the Dead Sea Level.

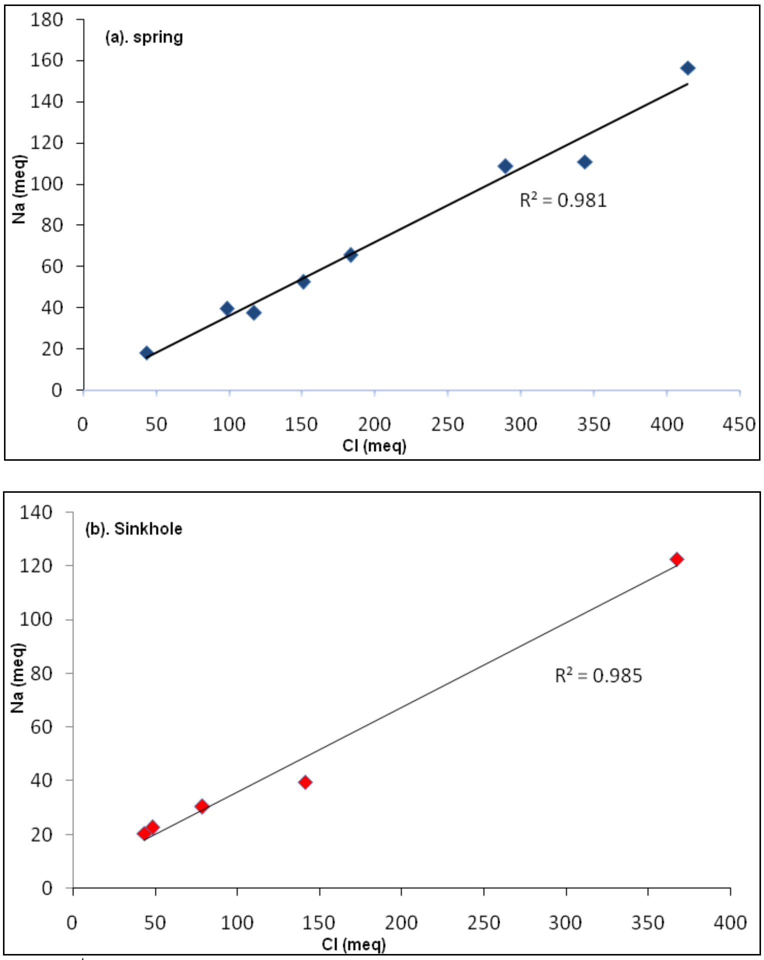

Figure 5: Na^+ and Cl^- relationship for (a) Spring and (b) Sinkhole

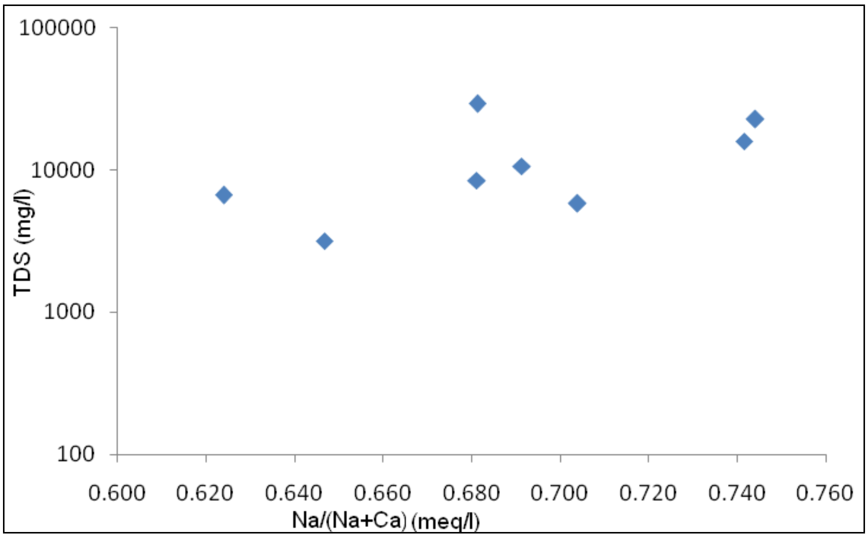

Figure 6: Mechanism governing groundwater chemistry

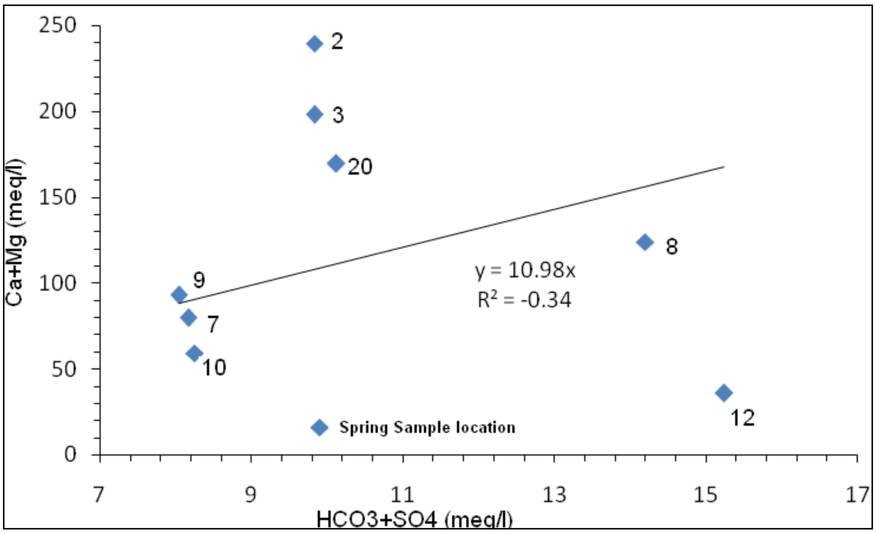

Figure 7: Relationship between Ca + Mg (meq/l) and $HCO_3 + SO_4$ (meq/l).

6. Discussion

The chemical analysis of the geochemical water samples study shows the variable concentration of the major cations and anions for different sources of the sample. The spring water sample is different concentration with samples in east and west side of the sinkhole study area. This result reflects the motion and movement of the ground water by affected the decline the Dead Sea Level at the last 30 years ago. The high concentration of Na, K, Mg, Ca, Cl, HCO_3, SO_4, and TDS as a result to dissolve the salt, evaporate halite, aragonite, clay minerals (brucite) and gypsum layers under the sinkhole area. The other hand the high concentration of these elements in the sinkhole body as indication to the sinkhole sudden within dissolved the salt. This result documented by different geophysical, geological and structural study of the phenomena in two side of the Dead Sea by many others such as (Swarieh et al. 2000; Beck, 2003; Diabat A. 2005; Al-Zoubi et al. 2007; Ezersky, 2006 and 2008; Amos et al. 2011). This study explain by the sinkholes produced for detection in carbonate karst and dissolved of evaporate and peculiarities of the unconsolidated material.

7. Conclusion

Various geochemical water samples methods has been applied in this study in order to provide an important tool for better understanding of the sinkhole phenomena and ground water dynamics to explain why the sinkhole produced at Ghor Al Haditha area. The following is the conclusions of present study:

- The chemical analysis of geochemistry samples shows: High concentration of chemical composition of the water samples in the west side (after) of the study sinkhole area, and Low concentration of chemical composition of the water samples in the East side (before) of the study sinkhole area. it is documented by TDS for the spring, average TDS= 1335.74 mg/l before sinkhole area and the average TDS = 58028.28

mg/l after sinkhole area.

- The high chemical composition of the water spring in west side (after) of the sinkhole area, explain the mean source of the salt layer dissolved by groundwater flow under the sinkhole area.
- The sources of major ions such as Na^+ and Cl^- implying halite dissolution, Ca^{2+} and K^+ dissolution polyhalite, gypsum and potassium chloride and aragonite, Mg^{2+} by brucite and Epsom salt, SO_4 by calcium sulphate and anhydrite.
- The decline of the Dead Sea level in the last 30 years is due to increasing the motion of the ground water flow; it affected to dissolve the salt layer under the sinkhole area.

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