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SEAWATER INTRUSION ALONG THE COASTAL AREA BETWEEN WADI LIBDA AND WADI-KAAM, NORTHWEST LIBYA

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ABSTRACT

Libya Arab Jamahiriya is considered as one of those countries having limited renewable water resources where most parts of the country are arid. The present study represents an attempt to evaluate the ground water quality along 20 km coastal stretch east of Al-Khums city, northwest Libya, which is bounded by Wadi Libda from the northwest, and Wadi Kaam from southeast. A total number of thirty ground water samples were analyzed for their chemical characteristics including pH, total dissolved solids (TDS), chloride, sulphate, bicarbonate, nitrate, sodium, potassium, magnesium and calcium content. Higher concentrations of some cations and anions were observed specialty in wells near the sea. An over-reliance on ground water to meet an ever-increasing water demand has resulted in an excessive depletion of the fresh ground water stock and the situation is being exacerbated by seawater intrusion. However, Wadi Kaam and Wadi libda play an important role in decreasing seawater intrusion around their basins.

KEYWORDS

Libya, ground water, seawater, intrusion.

INTRODUCTION

The intrusion of seawater to groundwater system has recently emerged as a serious problem damaging water ground systems, in Libya. This problem is triggered by the compulsive consumption of ground water in domestic, agricultural, and industrial applications, (Minas et al, 2005). Previous studies concluded that anthropogenic activities such as, groundwater pumping and land reclamation are believed to have significant physical and chemical impact on coastal groundwater flow systems (Stuyfzand, 1995; Jones et al., 1999; Park et al., 2005; Petalas and Lambrakis, 2006 and Guo and Jiao 2007). When seawater invades groundwater systems, it carries, beside salts, any pollutants contained by the seawater. Mediterranean Sea mass waters has an average of 3.85% TDS (Thurman, 1981). The pollution of shore waters has reached a critical level, due to charging of big amounts of domestic sewage and the lack of imposing regulations to control discharge of pollutants into the sea (Naeve, 1974). Shallowness, water discharge and tidal currents have a very significant effect on the nature of coastal water. Fresh water discharge has the TDS of the surface layer, while tidal currents have a considerable influence on the vertical mixing of shallow water near the coast (Nelson, 2004).

Land reclamation is expected to increase groundwater levels in the original coastal area. The filling material will decrease the flow of groundwater from the main land to the sea by acting, as a semi permeable barrier with thickness equals the distance between the previous and new interfaces. Therefore, the resistance to seawater fluxes increases causing a reduction in the groundwater seawater flux. The original coastal area and probably a portion of the reclaimed areas, which were soaked by saline water, will be gradually saturated by fresh groundwater as the interface moves slowly seaward. The chemical composition of groundwater is governed by the composition of materials it contacts and the contact duration. The longer the contact period, the more minerals transfer to the groundwater. Thermal water contains more minerals and materials that can deteriorate groundwater quality, if it comes to contact with it. During geothermal activities, ground thermal water is a serious threat, because it infiltrates groundwater-unconfined aquifers transferring minerals to these aquifers. Geological formations containing gypsum and calcium carbonate cover large areas in Libya (Christie, 1966). The groundwater in those formations has high concentrations of constituents. Therefore, chemical composition of groundwater is not acceptable.

In some groundwater basin, fresh water bearing formations and salty water layers are separated by impervious barriers. In such formations, if the wrong drilling method is used, salty water and fresh groundwater can be mixed.

Seawater intrusion (or salt-water intrusion) is the underground flow of seawater into freshwater wells and aquifers. Seawater intrusion is limited to aquifers where groundwater and seawater are in hydraulic continuity. Freshwater has lower density than Seawater and floats on top of it. The interface between the two bulks is not distinctive boarder; it is a mixture of fresh and salt water (saline water). The shape of the interface is established by the hydrodynamic balance along the contact plan. This interface has an inclination towards land and its toe intersects with the bottom of the aquifer (Fetter, 1972; Todd, 1974; Kallergis, 1986 and Jiao et al., 2006).

The higher groundwater levels inland causes the freshwater flow to be seaward. At the sea land borders, freshwater flows to the sea from the top part of the aquifer and sea water flows to the aquifer from the bottom. Seawater intrusion occurs when fresh water is withdrawn faster than it can be recharged near a coastline. As a result, the fresh water table and its hydrostatic pressure decreases allowing the salt water to enter the freshwater well (Fetter, 1972; Kallergis, 1986 and Bennetts et al., 2006). This intrusion is presented both as an advance of the whole interface towards land and an uplifting of the interface in the areas of overdraft, interface thickness being increased. However, when groundwater exploitation is significantly reduced, the aquifer will eventually recover, because the direction of the flow in this aquifer system will be reversed. The refreshing process of the costal aquifer will be controlled mainly by a natural topography-driven flow. Water from the land infiltrates through outcrops and the shallow soil will gradually recharge the aquifer

The goal of this study is to investigate the effect of seawater intrusion on the chemical characteristics of groundwater along the northwest Libya coastal stretch and evaluate its quality, class and possible uses.

MATERIALS AND METHODS

Study Area:

The study area is a 20 km coastal stretch on the south shoreline of the Mediterranean sea, It is bounded by Wadi Libda from the northwest, and Wadi Kaam from southeast, and lies between latitudes 32^{O} 28` and $32^{O}$ 38` N and longitudes 14^{O} 14` and $14^{O}$ 27` E. The study free groundwater aquifer is mainly recharged by rainfall, which is relatively high along the coastal area, and subsurface from Jabal Nafusa in the southwest. Surface runoff across the study area is mainly affected by the main water divides and is represented mainly by Wadi Kaam, and Wadi Libda (Fig.1). Two dams were constructed on Wadi Kaam and Wadi Libda for water conservation, which is relatively high along Wadi Kaam.

Fig (1): Location map showing the sites of studied wells

Climate:

The climate of the area is described as hot and dry, in summer, and warm and rainy, in winter. It is characterized by low precipitation rates, high evaporation and wide range annual temperatures. Rainfall is seasonal with maximum precipitation in winter months and little or no precipitation during other seasons. The variation in temperatures is due to hot summers and cold winters when the temperature rarely drops below the freezing point. Reverse northwest winds are frequent and responsible for the rainy winters. In summer, hot winds known, locally, as Alghibli from the southern Sahara Desert (Al-Ghiblis), are common.

Geology:

The Cenomanian rocks, which represented by Sidi As-Said Formation is clearly exposed at the lower part from the stratigraphic sequence of Kaam valley. Hinaway (1974) divided the formation into two members: the Lower Ain Tobi Member, which is dominantly composed of dolomitic sediments, and the upper Yafrin Member, which is composed of limestone and dolomite containing lutite admixture and marls. Sidi As-Said Formation unconformable underlies the carbonate sediments of middle Miocene.

The middle Miocene sediments has been recognized in the studied area, and named by Mann, (1975) as Al-Khums Formation, reflect carbonatic development of the succession marl, marlstone, calcilutite, and cacarenite. Quaternary sediments lie disconformably on Sidi As Said Formation and Al-Khums Formation, classified lithostratigraphically and genetically into; pliestocene sediments which includes Gargaresh Formation, forming low ridges that exending especially along the coastline of the Mediterranean sea, divided by Minas (2003) into an upper Kaam Member (eolian) shoreline dune and lower Karrot Memper (backshore-foreshore environment), the Formation mainly consis cross bedded calcarenite sediments, red soil, and cliche sediments, 2) Holocene sediment characterized by sediments of recent wadi, Aeolian, fluvio-aeolin, and sabkha.

Experimental work:

Thirty samples of ground water were collected in March 2009, after a rainy winter season. As shown in Fig. 1, the samples were distributed along a horizontal line to cover the chosen strip. Water temperatures were recorded in the field and the pH were measured using pH-meter type HANNA model HI8014, and electric conductivity E C values were measuresd using E C meter model 4520. The total dissolved solids (TDS) were weighted after sample evaporation. Chloride, carbonate, bicarbonate, calcium and magnesium were determined according to Adams (1990), while sodium and potassium were measured by using flame photometer type JENWAY model PFP7. Nitrates were measured by Ultraviolet Spectrophotometer Screening.

RESULTS AND DISCUSSION

Total Dissolved Solids (TDS) Distribution:

Figure 2 shows the total dissolved solids (TDS) content in the area's Ground water. Total dissolved solids (TDS) concentration varied between 4276 ppm, near the Mediterranean Sea, and 3124 ppm landward northwest and southeast of the study area. The distribution of TDS content indicates a gradual decrease in TDS concentration landward. Low TDS concentrations are more toward the northwestern and southeastern boundaries, which may reflect a local recharge from surface runoff along the main water divides (W. Kaam and W. Libda) northwest and southeast of the study area, respectively (Fig. 2).

Comparing the present TDS values with that reported by the Ministry of Agriculture (1973 and 1978), TDS content increased significantly through the last thirty-five years (Table 1). This increase could be a result of seawater intrusion that is triggered by the increased consumption of ground water.

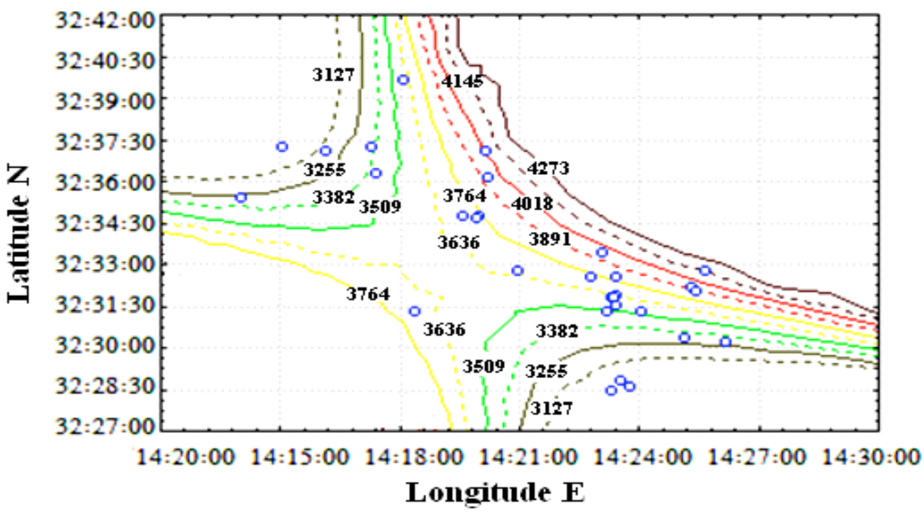

Fig (2): Variation of TDS content (ppm) along the study area

Table (1): Chemical characteristics of the ground water along the study area

		Ministry of Agriculture		This work (2009)		
	Unit	1973	1978	Maximum	Minimum	Mean
TDS	ppm	1196-2926	1500-3000	4276	3124	3554
Cl^-	ppm	489-935	568-1136	1424.2	829.4	1064
SO_4^{--}	ppm	457.2-604.8	542-988	1089	762.7	890.19
NO_3^-	ppm	Traces -38	13.2-36.6	44.58	12.13	23.57
HCO_3^-	ppm	-	-	498.00	405.00	449.54
Na^+	ppm	322-602	371-682	923.25	606.33	730.25
K^+	ppm	10.53-21.84	4-19	27.30	9.71	19.93
Mg^{++}	ppm	96-144	103.2-182.4	256.00	124.80	174.41
Ca^{++}	ppm	116-296	184-272	269.33	153.30	200.08
Temp.	^oC	-	-	26.9	20.00	24.14
pH	----	-	-	7.61	6.67	7.14
E. C.	mmohs/cm	-	-	6.60	4.51	5.36

Chloride Content Distribution:

The variation of chloride content is represented in Fig. 3. It has a similar profile to that of TDS. It shows that, chloride concentration varies between 1424.2 ppm near the Mediterranean Sea and 829.4 ppm landward northwest and southeast of the study area. The gradual increase of chloride content seaward is due to saltwater intrusion. However, the decreasing in chloride toward the northwest and southeast might be attributed to the local surface recharging through the main water divides represented by W. Libda and W. Kaam, respectively. Local concentration in chloride content at the southwestern part of the study area may attribute to local surface evaporates and subsurface environments related to lithology of water bearing rocks.

The present chloride content (829.4 -1424.2) is much higher than that reported by the Ministry of Agriculture, in 1978 (568-1136) which, in part, is higher than that reported by the same ministry in 1973 (489-935).

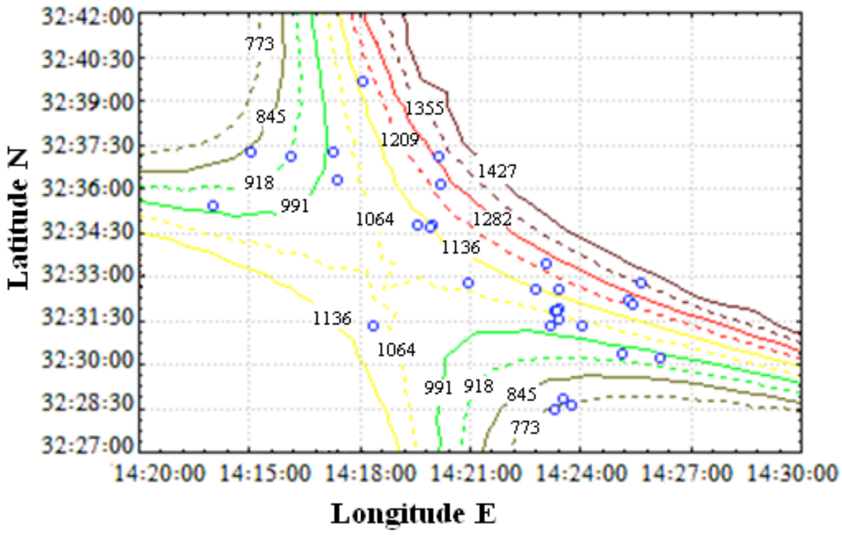

Fig (3): Variation of chloride content (ppm) along the study area

Sulphate Content Distribution:
Sulphate constitutes the second predominant anion after chloride and varies in content between 1089 ppm near the Mediterranean Sea and 762.7 ppm landward northwest and southeast of the study area (Table 1 & Fig. 4). Generally, the sulphate distribution pattern is similar to that of chloride and TDS content indicating that, sulphate enrichment is associated with TDS rise (Figs 2, 3 & 4). The present sulphate content (762.7-1089 ppm) is much higher than that reported by the Ministry of Agriculture, in 1973 (542-988 ppm) and 1978 (542-988).

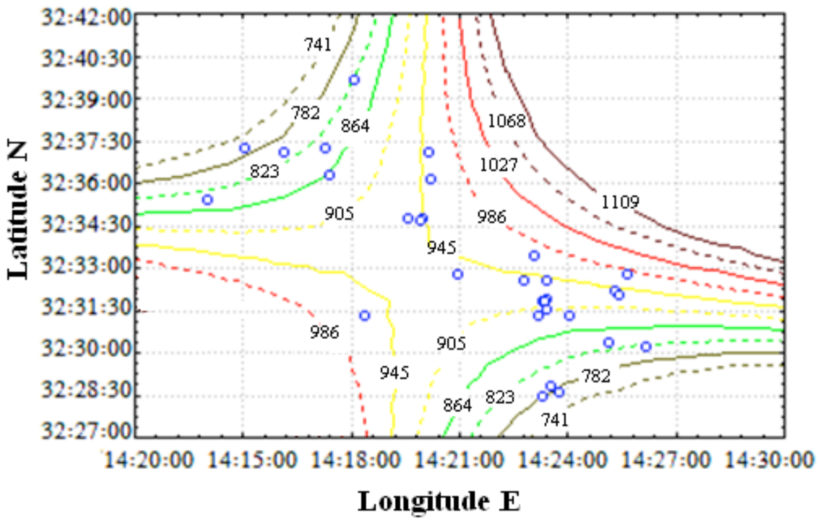

Fig (4): Variation of sulphate content (ppm) along the study area

Bicarbonate Content Distribution:
The studied water wells show low contents of bicarbonate and lack carbonate ion. Bicarbonate concentration ranges between 498 ppm at the southern part of the study area and 405 ppm at the northwestern part (Table 1 & Fig. 5). The higher value of bicarbonate content at the southern part of the study area may be attributed to local calcareous water bearing sediments. However, the distribution pattern shows a gradual decrease in bicarbonate content toward the northwest (Fig. 5).

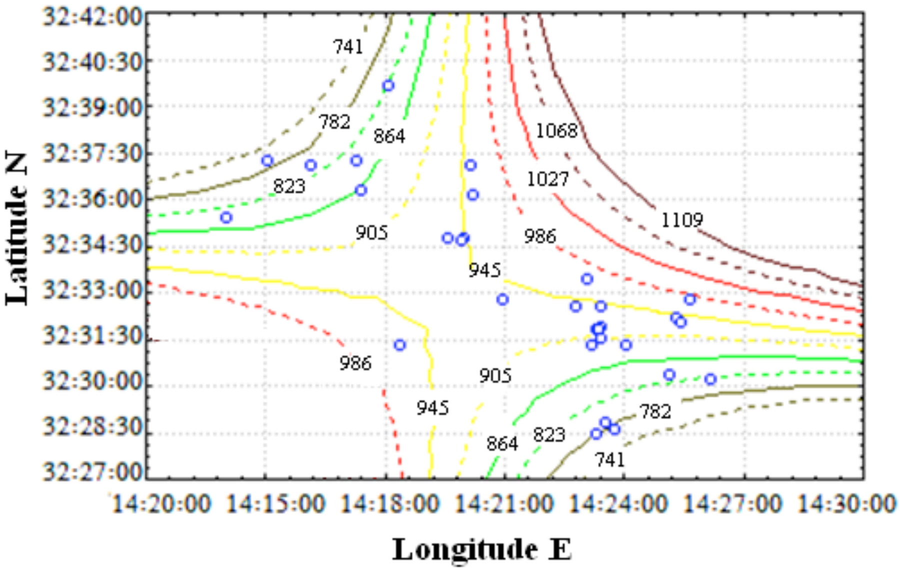

Fig (5): Variation of bicarbonate content (ppm) along the study area

Nitrate Content Distribution:
The nitrate content is, generally, low in the water of the study area (Table 1). Fig. 6 shows the variation in nitrate concentration. Generally, nitrate shows an opposite profile to that of bicarbonate (Figs.5 & 6). The nitrate content gradually increases toward the sea and the northwest. Nitrate concentration varies between 44.58 ppm near the Mediterranean Sea and 12.13 ppm at the southeastern part of the study area. The change in nitrate concentration is insignificant since 1973 (Table 1).

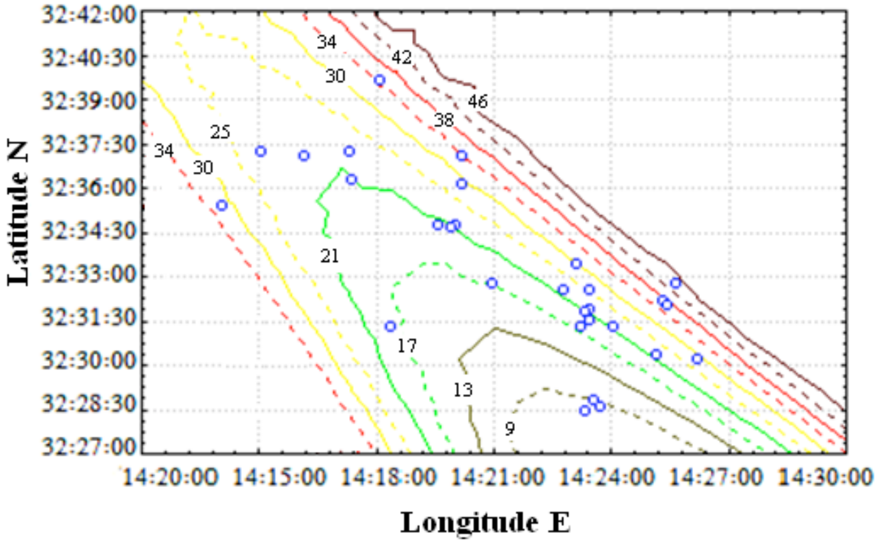

Fig (6): Variation of nitrate content (ppm) along the study area

Sodium Content Distribution:
Sodium concentration ranges between 923.25 ppm near the Mediterranean Sea and 606.33 ppm at the northwest and southeast of the study area (Table 1 & Fig.7). Distribution of sodium content shows a gradual decrease landward (Fig. 7). The present Sodium content is higher than that reported by the Ministry of agriculture, in 1973 (322-602 ppm) and 1978 (371-682 ppm). The similarity of sodium and chloride profiles suggests their concurrent presence, which is a decisive indication of NaCl presence.

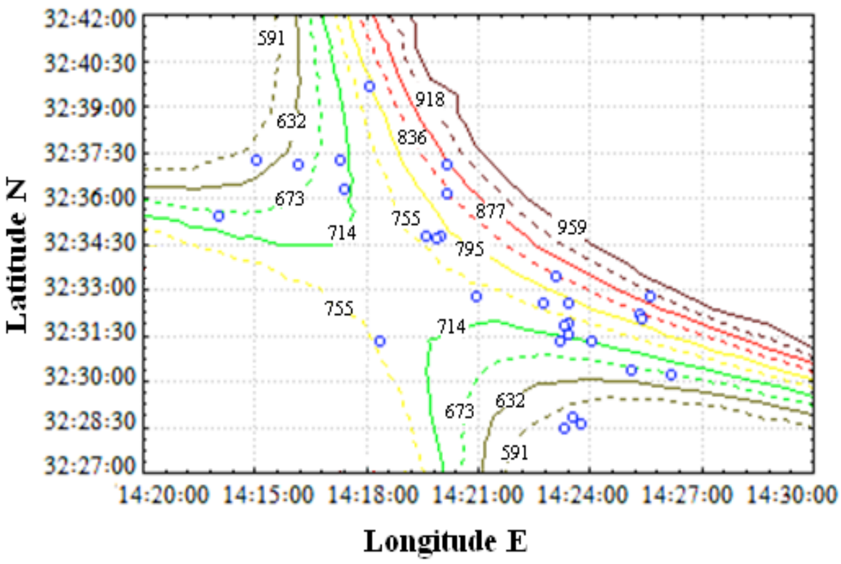

Fig (7): Variation of sodium content (ppm) along the study area

Potassium Content Distribution:

Potassium content is generally lower than that of sodium. The potassium content ranges between 27.30 ppm near the Mediterranean Sea and 9.71 ppm at the southeastern part of the study area (Table 1 & Fig. 8). Generally, potassium content distribution is rather similar to that of sodium content (Figs 7 and 8).

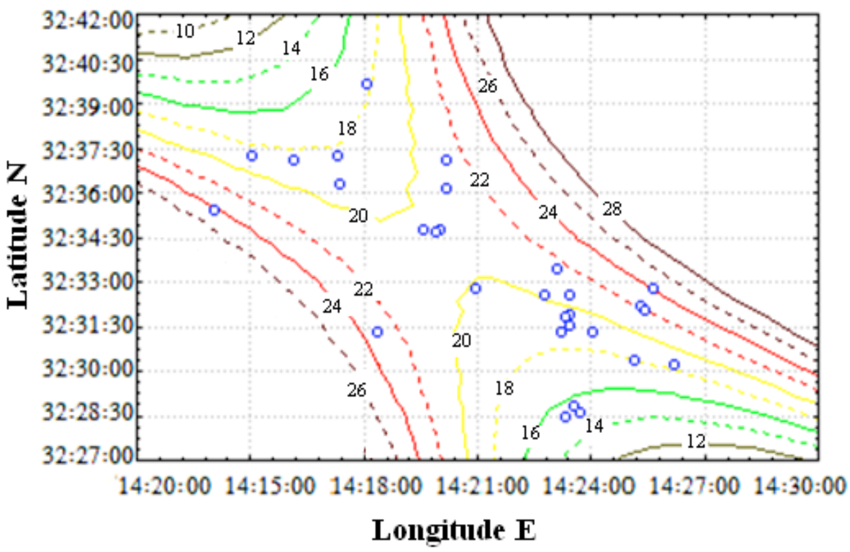

Fig (8): Variation of potasium content (ppm) along the study area

Magnesium Content Distribution:

Magnesium content varies between 256 ppm near the Mediterranean Sea and 124.8 ppm at the northwestern and southeastern parts of the study area (Table 1 & Fig. 9). The relatively high magnesium content at the southeastern part of the study area (Fig.9) may be attributed to local surface and subsurface environments related to the lithology of water – bearing rocks. Moreover, surface evaporites intercalated with the water – bearing sediments are a possible source for magnesium.

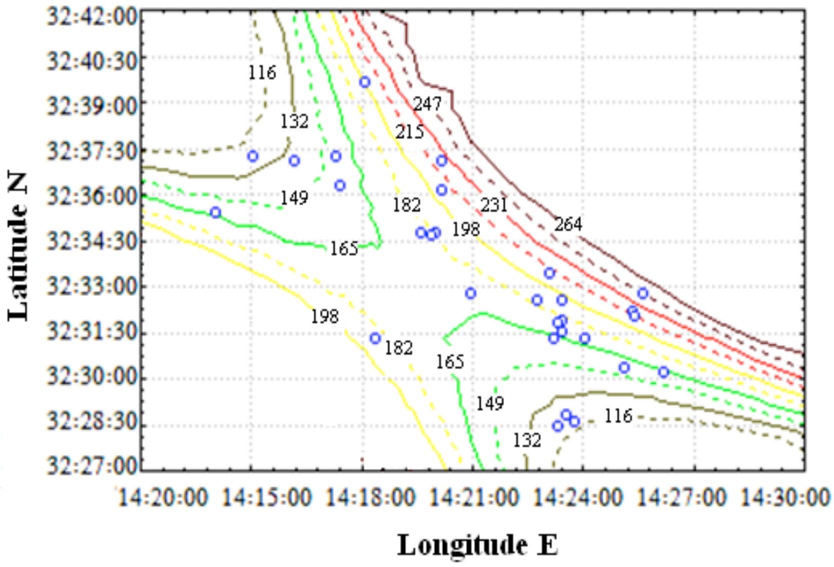

Fig (9): Variation of magnesium content (ppm) along the study area

Calcium Content Distribution:

Calcium content varies between 269.33 ppm and 153.3 ppm (Table 1). The distribution pattern of calcium content shows gradual decrease in calcium content toward the Mediterranean Sea (Fig.10). This may give an indication about its source mainly from the land. The high values of calcium may be related to the lithology of water – bearing sediments and surface calcareous materials which is dominant along the study area.

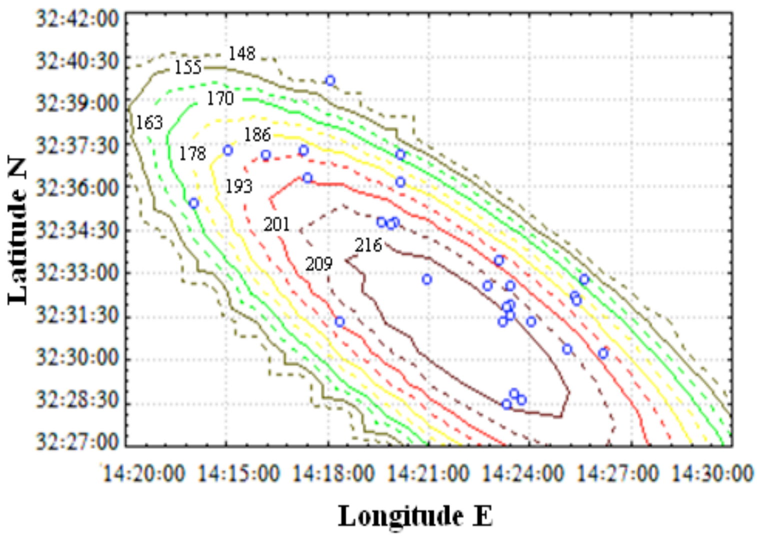

Fig (10): Variation of calcium content (ppm) along the study area

Temperature versus TDS:

The studied ground water samples have temperatures range between 26.9 ^{o}C at the northwestern part of the study area and 20 ^{o}C near the Mediterranean Sea (Table1& Fig.11). Temperature and TDS distributions show consistent patterns, lower temperature and higher TDS near the shoreline and higher temperature and lower TDS landward. The gradual decrease in temperature values toward the Mediterranean Sea may indicate the effect of the relatively cooler seawater intrusion along the coastal area.

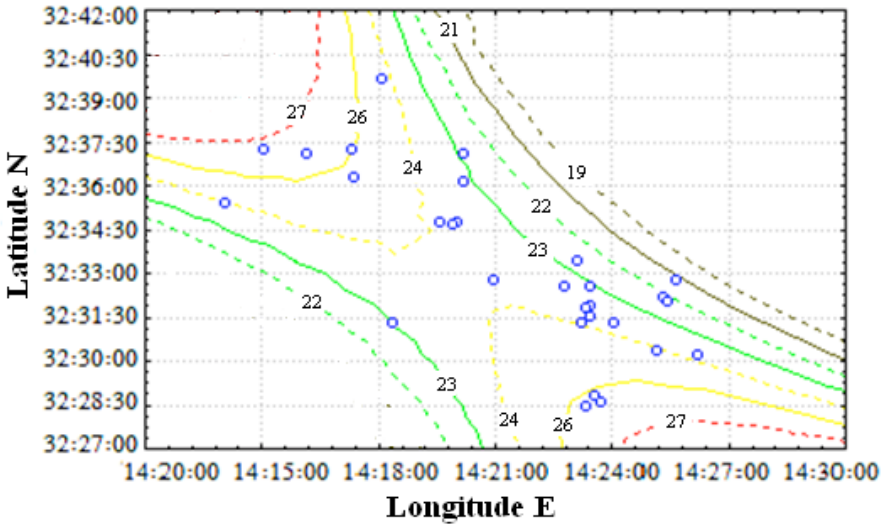

Fig (11): Variation of temperature degrees (°C) along the study area

pH Value Distribution:

The pH values of the collected samples range between 6.67 (slightly acidic) and 7.51 (slightly alkaline) (Table 1). The distribution of pH values across the study area (Fig.12) indicates that, the ground water is dominantly slightly alkaline and becomes slightly acidic near the shoreline. This may give indication that, the TDS is not the single factor affecting the pH value of the studied ground water and may be attributed to the recharging of the ground water by rainfall, which is relatively high in the study area.

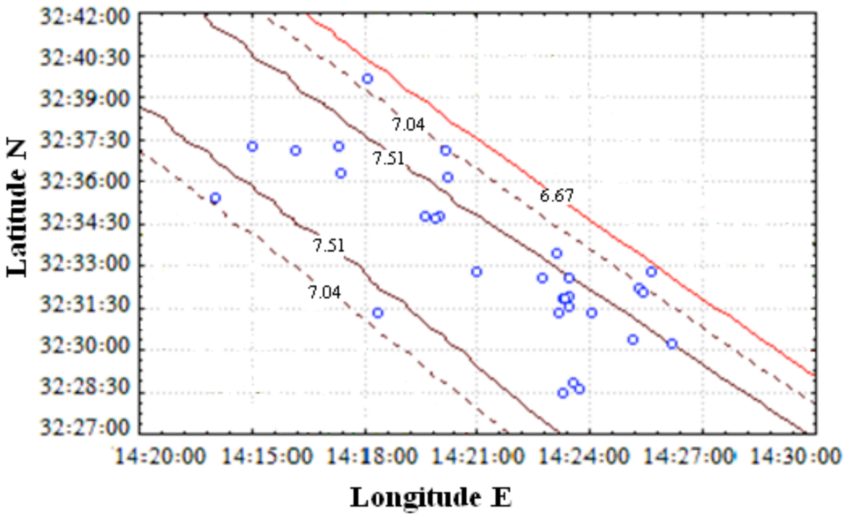

Fig (12): Variation of pH values along the study area

Electrical Conductivity Distribution:

E.C values are listed in table 1 and their distribution across the study area is shown in Fig. 13. The ground water show high E.C values ranging between 6.60 mmohs/cm, near the Mediterranean Sea, and 4.51 mmohs/cm northwest and southeast the study area. Comparing the distribution of E.C Values to those of cations and anions, it is clear that, E.C Values increase with the increase of salt content. In addition, the variation of TDS is very similar to that of chloride, sulphate, sodium, potassium and magnesium. This indicates that, their enrichment is associated with TDS rise and therefore, shows higher E.C Values.

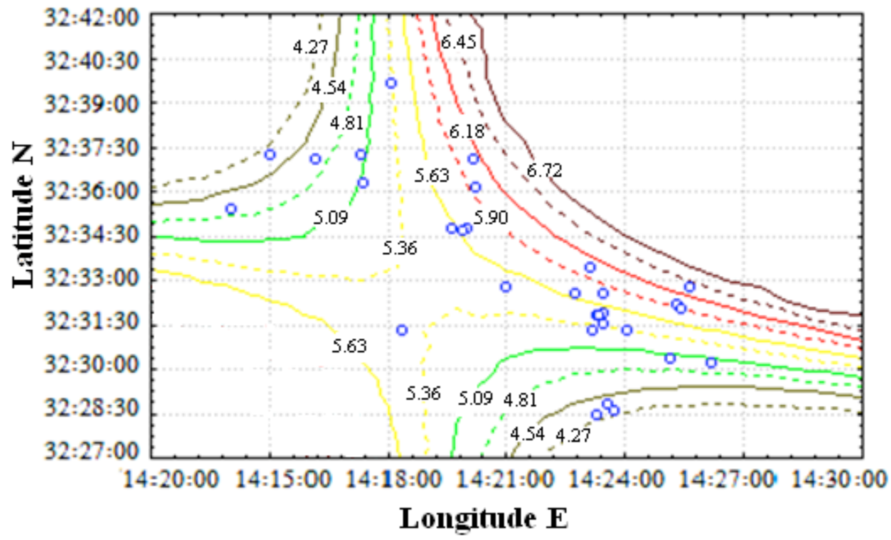

Fig (13): Variation of E. C. Values (mmohs/cm) along the study area

Water type:

The variation in compositions of chemicals present in the studied ground water are represented in the trilinear diagram of Piper (1944). The diagram (Fig.14) indicates that, Na is the dominant cation in the cation triangle; chloride is the dominant anion in the anion triangle and is the dominant salt.

The alkali elements (Na^+ + K^+) exceed the alkali earths (Ca^{++} + Mg^{++}) and the analyzed ground water samples fall in the right side of the upper triangle of the diamond shape. This indicates that, the ground water posses secondary TDS character (where SO_4^{--} + Cl^- exceed CO_3^{--} + HCO_3^-) which may be linked mainly to seawater intrusion along the studied coastal area.

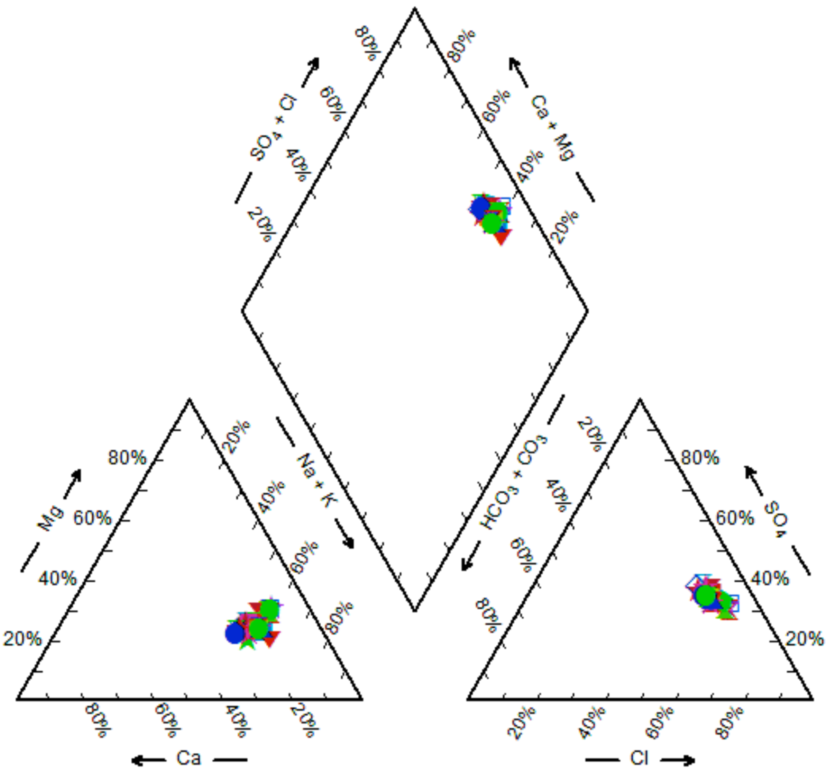

Fig (14): Piper diagram of ground water studied samples

Evaluation of Ground Water for Domestic and Irrigation Purposes:

Uses for human drinking:

The studied water wells show high TDS (3124 ppm to 4276 ppm). According to Jaster et al. (1978) and Beede (2005), the water of studied coastal wells is unsuitable for human drinking.

Livestock Watering

Both the US and Canada have developed "Guides to the Use of Saline Waters for Livestock Watering." The Canadian Task Force on Water Quality (1987) published both a Summary Guidelines for Livestock Drinking Water Quality and a Guide to Use of Saline Water for Livestock Watering. The poultry livestock drinking water guidelines for TDS, Sulfate and Calcium are 3000, 1000 and 1000 mg/l respectively. The ground water along the study coastal area is suitable for consumption by livestock except poultry (Table 1).

Irrigation Water Uses

Peterson (1999) pointed out that TDS levels below 700 mg/l are considered safe; TDS between 700 mg/l and 1,750 mg/l are considered possibly safe, while values above these levels are considered hazardous to any crop. Peterson (1999) also listed the tolerance of selected crops to TDS in irrigation water, for example, corn as slightly tolerant (TDS < 800 mg/l) and soybean as very tolerant (TDS < 3500 mg/l). However, as long as the TDS value is less than 2,800 mg/l, no reduction in crop yield for moderately sensitive crops including corns and soybeans (Peterson, 1999). Generally, forage crops are the most resistant to TDS, followed by field crops, vegetable crops, and fruit crops, which are generally the most sensitive.

The calculated sodium adsorption ratio (SAR) for the studied water wells are ranging between 5.35 and 7.16. However, lower SAR values can be attributed to higher content of calcium and magnesium. According to Tanjj (1990) and Mills (2001), the ground water across the study area are excellent for irrigation purposes where SAR<10 (Table 1), but due to their high TDS, (>3000 ppm) they are unsuitable for irrigation purposes. Therefore, only the more tolerant crops can be grown with such water, and only when the water is used copiously and the subsoil drainage is good. However, people use the ground water for washing purposes.

CONCLUSIONS

The distribution patterns of total dissolved solids, chloride, sulphate, sodium potassium, magnesium and electrical conductivity show gradual decrease in their values landward and reflect the Mediterranean Sea water intrusion. Wadi Libda and Wadi Kaam play an important role in reducing seawater intrusion around their basins.

The Mediterranean Sea water intrusion is relatively high in the middle area between the basins of Wadi Libda and Wadi Kaam. The ground water across the study area is unsuitable for human drinking and suitable for consumption by livestock except poultry.

Due to seawater intrusion, the studied water wells are unsuitable for irrigation purposes and only more salt-tolerant crops can be grown with the studied ground water. Across the study area people use the ground water for washing purposes.

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