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Spatial Pattern of Groundwater Quality and its Impact on Pipes and Wells Equipment Corrosion in Al-Hassa Oasis Kingdom of Saudi Arabia

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ABSTRACT
The aim of this study is to find a comparison between the different agricultural areas of Al-Hassa Oasis as spatial pattern of changes on groundwater quality in Al-Hassa Oasis to identify the most vulnerable areas of corrosion to pipes and well equipments. The study was carried from March 2009 to December 2010. A total of sixty water well samples were collected from Neogene aquifer in the study area segregated into three segments all over the Oasis (Northern Sector, Central Sector and Eastern Sector). The GPS technology was used to determine the locations of water samples in the whole Oasis. Water samples were analyzed to determine some of the elements to calculate the Langelier Saturation Index (LSI) for corrosion. The pH of groundwater was the most important criteria in the three sectors (Northern, Middle and Eastern) of the Neogene aquifer in Al-Hassa Oasis. The variation in pH indicated a potential corrosion in some sites as compared to other locations. The pH values ranged between 6.5-7.47. The dissolved oxygen ranged between 3.7 to 5.6 mg L^{-1} and showed a medium effect on pipes and equipment corrosion in the three sectors of the study area. The Langelier Saturation Index (LSI) ranged between -0.95 and 0.13 in Al-Hassa Oasis. The calculated mean LSI values in the three sectors indicated that wells water in all the sectors have the ability to compose a protective layer against corrosion. The order of LSI with respect to corrosion varied from maximum (1.131), medium (1.068) and minimum (0.593) for the Middle, Eastern and Northern sectors, respectively. In conclusion, it was observed that slightly increasing groundwater salinity is considered as an additional advantage as it helps greatly to reduce corrosion problem in wells.

Key words: Al-Hassa Oasis, groundwater salinity, pH, corrosion, Langelier Saturation Index (LSI), well casing and equipment

INTRODUCTION
Al-Hassa Oasis is one of the largest agricultural Oases in the kingdom of Saudi Arabia (Fig. 1) covering an area of about 20,000 ha. The irrigated agricultural area constitutes about 8,000 ha. It lies within the tropical area to the North of the equator between 25'20 and 25'40 North latitude and 49'30 and 49'50 East longitude. Its altitude ranges between 130 to 160 m above the sea level (Albarrak, 1993). The Al-Hassa province contains many water wells that vary in their natural and chemical characteristics. The agricultural activity in the Oasis depends primarily on

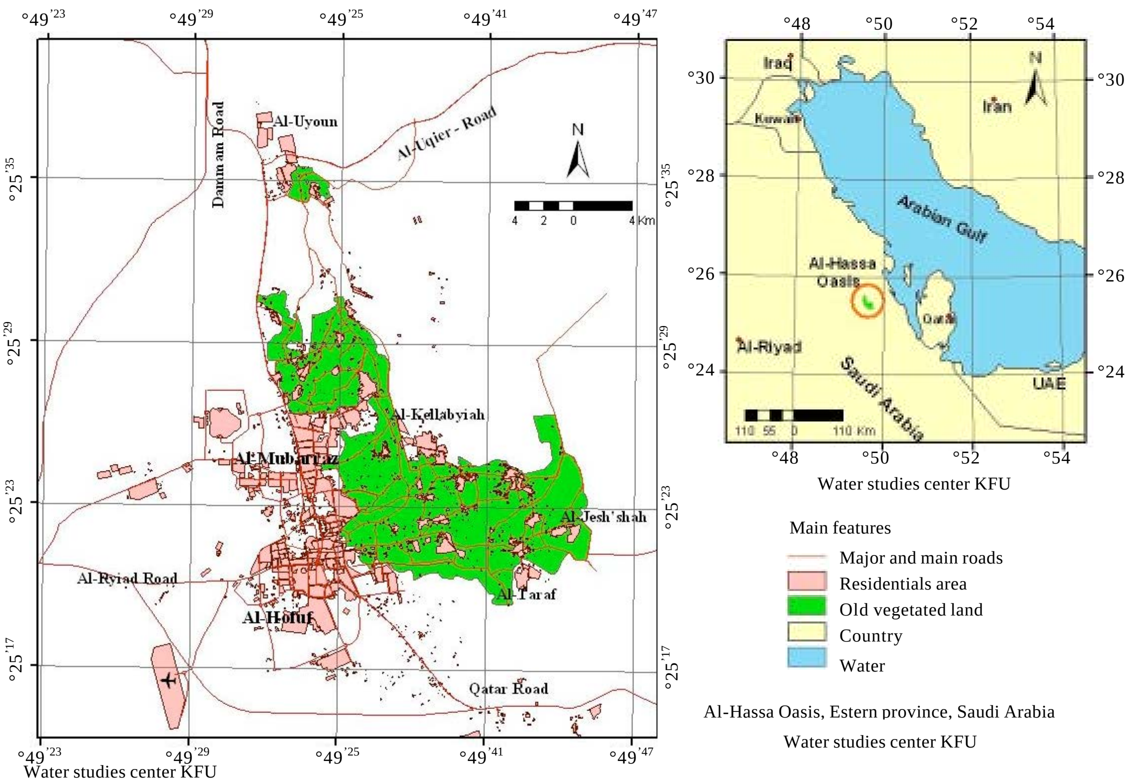

Fig. 1: Location map of Al-Hassa province and the percentage of the agricultural land to residential space areas

the irrigation water provided from many resources. However, groundwater is the most important resource which provides around 67% of the total water used for irrigation. While, the treated wastewater and the agricultural drainage water covers the remaining water needs.

The groundwater resources in the Al-Hassa Oasis are located in three aquifer layers. These rank from the lowest to the highest depths i.e., the Neogene layer (30-120 m), Al-Dammam layer (120-300 m) and Um Arradomah layer (300-500 m). The lithology and hydrology of the aquifers in the Oasis differs considerably both in quantity and quality. Also, the chemical characteristics of well waters vary from one aquifer to another depending on the composition of water reservoir and its reaction with dissolvable rocks and minerals. The groundwater characteristics are further affected by the amount of rainwater. The Al-Hassa Oasis suffers from extreme shortage of groundwater due to huge agricultural expansion during the last two decades coupled with the misuse of water through the irrigation of agricultural crops in addition to the dry climate conditions of Al-Hassa. Besides, rainwater is the only recharge source of the surface layer (The Neogene). However, the agricultural authorities in Al-Hassa region formulated laws that prevent drilling wells and lifting water from this layer in order to protect the other layers from depletion.

The expansion of agricultural and industrial activities in Al-Hassa Oasis led to a considerable change in the quality of groundwater. Thus, this change is ascribed to many reasons such as

Fig. 2: Impact of corrosion on pipes used for pumping water

disposal of wastewater from the residential and industrial activities. Moreover, the excessive use of agricultural fertilizers and pesticides affected the quality of these sources. This led to the creation of a proper environment for the contaminants and harmful materials to leach into groundwater. This and in addition to the biological and chemical reactions, made a change in the nature of water thus contaminating with some chemical compounds entering into the groundwater resources which in turn lead to the corrosion of pipes and wells equipment as well as creating human, animal and plant health hazards.

The corrosion of wells pipes and equipment is a serious problem that reduces the lifespan of the irrigation wells. Because, due to the recent changes in the water quality, farmer's complaints increased at the level of the Oasis about the corrosion of wells equipment used for water lifting and its distribution (Fig. 2). This led to reduce the efficiency of well equipments which requires not only maintenance but also substitution at a high cost resulting in an economical loss to farming community.

Recent research indicated that nature and the chemical characteristics of groundwater appreciably vary from one site to another. Also, the corrosion of well casing material (iron) by groundwater ranges between simple and severe level even if the metal is resistant to corrosion (Gopi *et al.*, 2009; Lyon, 2009). The most important chemical factors that cause corrosion is acidity (pH), calcium, high levels of carbon dioxide, chloride, sulfate and oxygen.

A study on wells suffering from corrosion reported a pH value up to 6.5 but in some cases this value was 4.5 or less (Pinter, 2005). While, De Souza *et al.* (2002) defined the acidic water and its impact on the corrosion of pipes and wells equipment. Furthermore, corrosion of wells equipment occurs when the natural and chemical characteristics of the medium (soil and water), in which these equipment found, witnesses a change. The natural characteristics include temperature, the amount of sediment and water flow rate. While, the chemical characteristics include salinity (Shams El Din, 2009), pH, cations (sodium, potassium, magnesium and calcium) and anions (chloride, sulphates, carbons, bicarbonates), dissolved gases (carbon dioxide, dissolved oxygen and hydrogen sulfide), in addition to hard water and microorganisms (Beaumont, 1977).

Table 1: Relationship between pH values and the corrosion possibility

pH values	State
>7.5	No corrosion
= 5-7.5	Stability
<7	Corrosion

Despite the difficulty of preparing data about the continuity of corrosion, it is necessary to predict the characteristics of the aqueous medium which makes the metals susceptible to corrosion. Also, there is a wide variation in these characteristics such as, pH, temperature, electrical conductivity and the dissolved gases (oxygen, carbon dioxide and hydrogen sulfide) (Baek *et al*., 2001; Zhang and Huang, 2006). Although, chemical corrosion is a complex process but still is not defined properly (Sweet, 1978). Gu *et al*. (1999) explained that chemical characteristics of groundwater greatly affect the corrosion rates of pipes and water equipment made of iron. The water containing bicarbonate and sulfate ions is conducive to iron corrosion. Groundwater varies considerably in hardness and the amount of carbon dioxide. These two factors control the corrosion of the exposed compounds, especially wells equipment and pipelines. Often some degrees of corrosion occur in the main underground formations, where the available water contains limited amounts of oxygen (Nielsen, 1996). These waters usually form protective layers of carbohydrate and hydroxide on the internal surface of these pipes. In case the water contains excessive proportion of carbonic acid, the non-galvanized iron will be potentially vulnerable to corrosion in the absence of oxygen which is called the emission of active carbon dioxide (Escalante, 1981).

Other components of groundwater such as hydrogen sulfide, chloride and sulphate ions are source of corrosion to water carrying equipments (Gannon, 1978). Temperature and pH of waters indicates the possibility of the presence of corrosion (FAO., 1980). Kim *et al*. (2010) reported that high temperature will results in higher corrosion particularly in waters containing high concentration of carbon dioxide with low pH (Johnson, 1975). Although the temperature affects the solubility of many metals but indirectly affects the water distribution system (Martinius *et al*., 2005; El-Egamy *et al*., 1994) thus making it an important factor in the corrosion process due to its positive effect on the growth of microorganisms.

A pH value of 7 or less with a high level of carbon dioxide indicates severe corrosion against iron based pipes and wells equipment. While, high pH values (more than 8) indicate to low water hardness with the tendency to form a crust (Mogg, 1972) (Table 1). According to the water pumps manual of FAO (1980) and KSB (1986), water is considered corrosive to iron, pig iron, zinc and copper alloys if contained:

- pH value less than 7
- Free dissolved oxygen more than 2 mg L^{-1}
- Free hydrogen sulfide, reaching to 1 mg L^{-1} of hydrogen sulfide indicates to severe corrosion of iron and copper
- Free dissolved carbon dioxide of $50<CO_2<2$ mg L^{-1}
- Chloride ions less than 500 mg L^{-1}
- Total dissolved solids more than 1000 mg L^{-1}, where electrical corrosion is expected to take place. Thus, manufacturing corrosion-resistance refinery is necessary (Ahmed, 2007)

There are many indexes to identify the problem of corrosion and very useful to determine the degree of water hardness accurately. The substances that cause corrosion are calculated by

Table 2: Relationship between Langelier index values and the possibility of corrosion (Langelier, 1936)

LSI	State
-0.5-2.0	Severe corrosion
0-0.5	Corrosion
0.0	Stability with probability of corrosion
0.5-0.0	Low corrosion
2.0-0.5	No corrosion

analyzing water data and the most common used one is Langelier Saturation Index (LSI). The Langelier saturation index indicates lack of stability regarding calcium carbonate storage (Langelier, 1936; NALCO Chemical Company, 2009; Marangou and Savvides, 2001) and amended by CACC (1965) as given in Table 2.

Several methods have been proposed for the prevention of corrosion through insulations and water treatment or even changing the nature of the medium in which it occurs and selecting corrosion-resistant materials (FAO.,1980). The use of materials highly resistant to corrosion and changing surrounding environmental medium is the best available method to prevent corrosion. As far as water wells in Saudi Arabia is concerned, we found that the only way and the most effective equipment for wells is to select materials highly resistant to water hardness and other water qualities (Nielsen, 1996). Whereas, Barringer *et al.* (1993) calculated the corrosion indicators using the water quality data for 370 wells and evaluated using Langelier index which was positive. They also stated that groundwater unsaturated with calcium carbonate formed a protective layer of corrosion with a medium probability of corrosion.

Previously, many investigators determined the characteristics of groundwater in the Kingdom of Saudi Arabia (Tayeb, 1983; Hussain, 1982; Abdel-Aal *et al.*, 1997; Al-Naeem, 2008) especially for irrigation in Qassem Middle region of Kingdom of Saudi Arabia. They found that the degree of salinity ranges from 210-8200 mg L^{-1}, the expansion in the extraction of water from the region may cause a significant increase in the percentage of sulfate ions (SO_4) and chloride ions, the components resulting from the adverse interactions of hydrogen sulfide (H_2S), sulfate ions of iron ($FeSO_4.7H_2O$) and sulfur ions ($FeSO_4$) caused corrosion and wasting of water coaxial pipes.

Therefore, the aim of this study is to study the characteristics of groundwater in the Oasis of Al-Hassa for Neogene aquifer and study the effect of corrosion on pipes and equipment used to pump and distribute the water through Langelier Saturation Index (LSI) of corrosion and to identify areas (North, Middle East) in the Oasis that are most vulnerable to corrosion.

MATERIALS AND METHODS

The water sampling sites were randomly selected in the Oasis using GPS technology as shown in Fig. 3.

A total of 60 water samples were collected from the Neogene aquifer from different depths and three sectors distributed over the Oasis (Northern, Middle and Eastern sector). Twenty water samples were collected for each sector as shown in Table 2. The water samples were collected in plastic and polyethylene bottles under low temperature to reduce the bacterial activity that may affect the characteristics of the water in the samples. Water samples were subjected to laboratory analysis after filtering of some samples to get rid of plankton. Data field include the coordinates of the well, height above sea level, temperature, pH and the concentration of dissolved salts.

Well water samples were chemically analyzed in order to calculate the corrosion index as follows: Cations concentration as meq L^{-1} (Ca, Mg, Na, K) and the concentration of anions as meq L^{-1} (SO_4, NO_3, HCO_3, CO_3, Cl) and identifying all the elements (Fe, Mn, Cu, NO_3) according

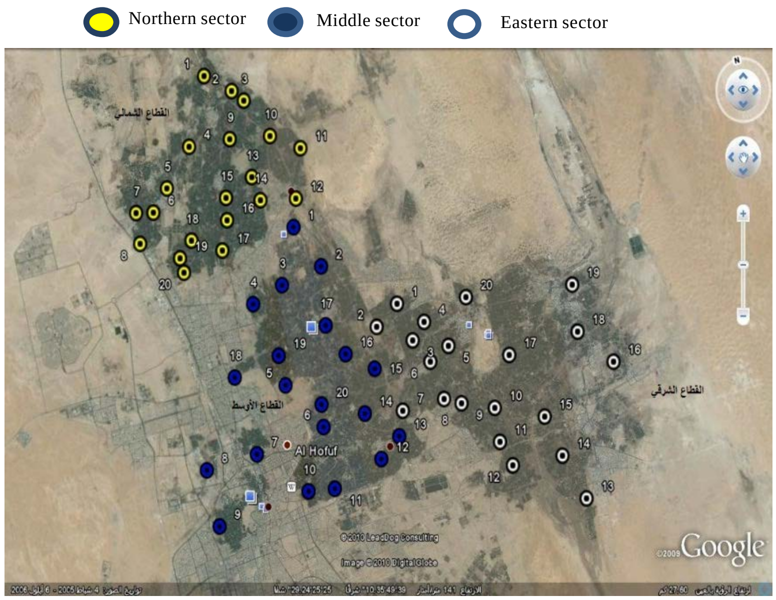

Fig. 3: Map shows sites of water samples and Neogene collected from wells

to the methods indicated for in Black (1965). The aforementioned above is analyzed according the mentioned methods in Richards (1954) except iron; also the dissolved oxygen was analyzed according to the method of Kelly and Kemp (1974). Langelier Saturation Index (LSI) values were calculated as in the following equation:

$$LSI = pH-pCa-pAlk-C$$

Where:

- pH = The actual value of water acidity
- pCa = Negative allegortim of the calcium concentration, it is obtained by a special equations
- pAlk = Negative allegortim of the bicarbonate concentration, it is obtained by a special equations
- C = Indicates the Total Dissolved Solids (TDS)

Special contour maps of the study area (Northern, Middle and Eastern) were made and the most vulnerable areas of corrosion were specified. The results obtained were compared with the recommended values, depending on the criteria for the US Salinity Laboratory Standards about the quality of irrigation water in the Oasis to track changes in the quality of these waters. Some software were such as smart draw program was used to show the results of chemical analysis and determine the quality of groundwater. Langelier Saturation Index (LSI) was used and some graphs were done in order to know the resulting damage on the wells equipment, therefore many recommendations to this problem were proposed in the study area.

RESULTS AND DISCUSSION

The pH values of groundwater ranged between 6.5-7.47 in three different sectors of Neogene aquifer of Al-Hassa Oasis. The pH indicated a possibility of corrosion to stability (Fig. 4a). The

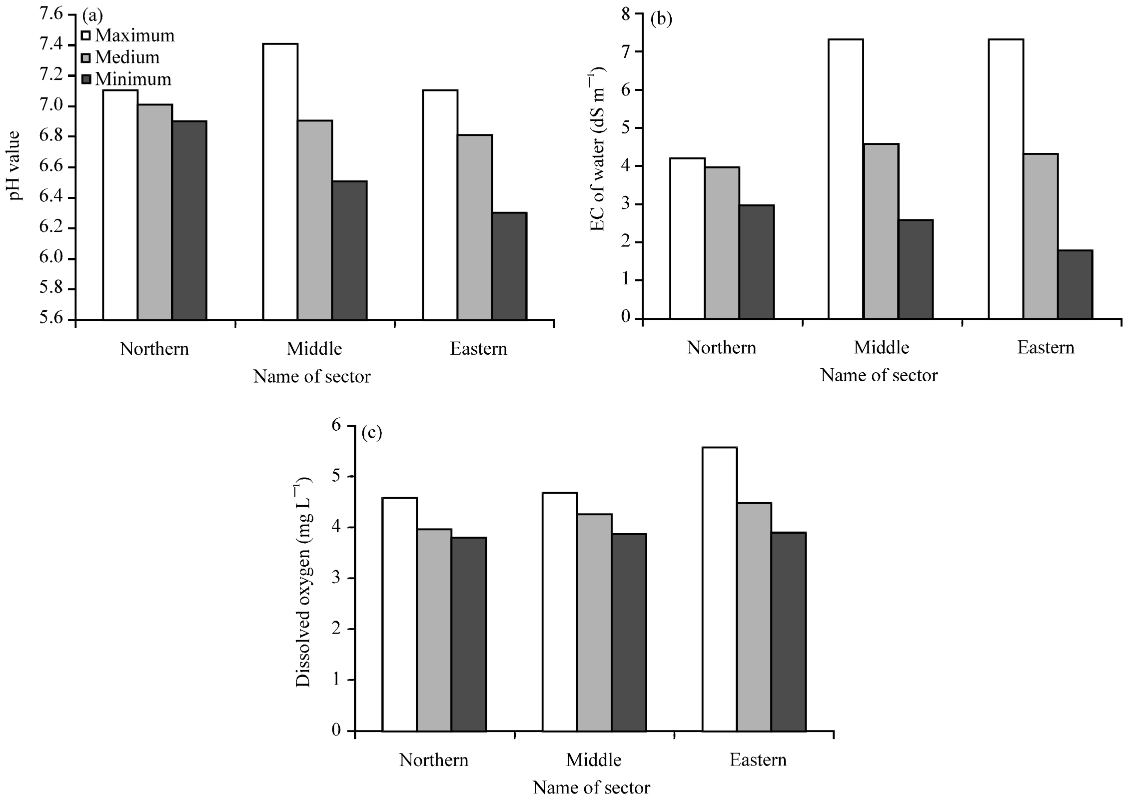

Fig. 4(a-c): Comparison of, (a) pH values of groundwater, (b) Water salinity and (c) Dissolved oxygen in three sector of Al-Hassa Oasis

maximum pH (7.47) was in sample No. 20 and minimum in sample No. 6 (6.5) of the middle sector. However, none of the samples in all sectors exceeded pH value of 7.5 which is the safe limit for corrosion. Based on pH values, the order of corrosion in different sectors came as Northern < Middle < Eastern with average pH value of 6.84, 6.91 and 7.01, respectively. The main reason for different results in all the sectors is the nature of aquifer layer which is highly identical all over the Oasis. The study results agree with those of De Souza *et al.* (2002) who stated that 40% of the surface water is considered soft acidic water as corrosive.

A comparative study of the groundwater salinity in the Neogene aquifer indicated that the mean water salinity was maximum in the middle sector (4.6 dS m^{-1}) followed by in that order in the Eastern (4.3 dS m^{-1}) and Northern sector (3.5 dS m^{-1}), respectively (Fig. 4b). This variation in water salinity may be attributed to the geological formation of the Neogene aquifer as well as to a positive correlation between urban areas and the old farms where agricultural operations are being carried out for a long time thus resulting higher water salinity in addition to pollutants. The water salinity (1.81) was minimum in sample No. 20 of the Neogene aquifer in the Eastern sector located in the Shallow layer of the urban areas that clarifies the variance in the degree of salinity. There is also possibility of increasing water salinity in the Oasis aquifer due to the topography of agricultural activity areas as compared to agricultural areas located outside in the Oasis. Similar results were reported by Corcoran *et al.* (1977) and Moore (1987) who observed that well structures and other equipments are damaged by the characteristics of surrounding medium such as water and soil.

The concentration of Dissolved Oxygen (DO) indicates a degree of water hardness against the iron based pipes and wells equipment. Also, there is a probability of presence of iron bacteria. A pH value of 6 or less indicates corrosion against iron while the highest pH value (more than 8) indicates low water hardness with a tendency to form a crust.

A comparison showed that mean Dissolved Oxygen (DO) ranged between 3.7-5.6 mg L^{-1} in different sectors of the Oasis (Fig. 4c). The DO value was highest in sample number 2 in the Eastern sector and lowest in samples No. 8 and 11 in the Northern sector. In general, the results of dissolved oxygen for all the sectors showed the average corrosion of pipelines and wells equipment for the three sectors where the Eastern sector scored the highest degree and then the Middle sector then the North, respectively (4.02, 4.31, 4.59 mg L^{-1}). Because there is a relationship between the dissolved oxygen and pH. The higher pH causes proportionate increase in the dissolved oxygen. Also, there is an inverse relationship as the DO was highest and lowest in the Northern sector followed by Middle and the Eastern sectors. Besides, the presence of dissolved oxygen indicates the presence of microorganisms which can cause corrosion of pipes and wells equipment. The study results are in line with those of Iverson (1981) who stated that due to the presence of dissolved oxygen, some microorganisms cause corrosion to water lifting equipments from underground wells. Similarly, high pH of waters tends to reduce corrosion by forming a protective layer around the water lifting equipments (Broo *et al*., 1998; Lu *et al*., 2010).

Comparison between sectors in the light of Langelier Saturation Index (LSI): Generally, the LSI values ranged between 0.13-0.95 in all the sectors in Al-Hassa Oasis. The LSI value was highest in sample No. 15 in the Northern sector and the lowest in sample No. 6 in the Middle sector. The Langelier Saturation Index (LSI) value from zero and above (positive) indicates a possibility of precipitation of calcium carbonate ($CaCO_3$) as a result of water saturation state of equilibrium. This process forms a protective layer on the pipes and well lifting equipment which in turn limits the corrosion processes. According to Langelier Saturation Index (LSI), the probability of corrosion occurrence is present in all the sectors ranging from least to the most in the Oasis. The order of possible corrosion is more in Northern sector (-0.0918) followed by the Middle (-0.42095) and Eastern sector (0.45335), respectively.

In Northern sector of the Oasis, the LSI values ranged between corrosion and slight corrosion where sample No. 15 showed the highest value (0.1) and sample No. 1 showed the lowest value (-0.2). The Langelier Saturation Index (LSI) refers to the quality of water in terms of salts saturation and their ability to prevent corrosion. It is well known from the previous studies on water quality in the Oasis that this kind of water can stop altogether or somehow can delay the corrosion process. The study findings agree with those of Barringer *et al.* (1993) who stated that many indexes including Langelier gave identical LSI values calculated from water analytical data to identify the corrosion problems in water lifting equipments. The data in Fig. 5 shows sites that are most vulnerable to corrosion in the Oasis among all sectors.

In the middle sector of the Oasis, the LSI values ranged between corrosion and extreme corrosion. The LSI value was highest (0) in sample No. 7 and the lowest (-0.9) in sample No. 6. However as compared to the Northern sector, it was found that water quality is poor in this aquifer layer, although the mean water salinity is less than the previous sector. The situation of water quality in this sector is due to its proximity to the population and urban areas which helped to deteriorate water quality due to seepage of pollutants in the Neogene aquifer.

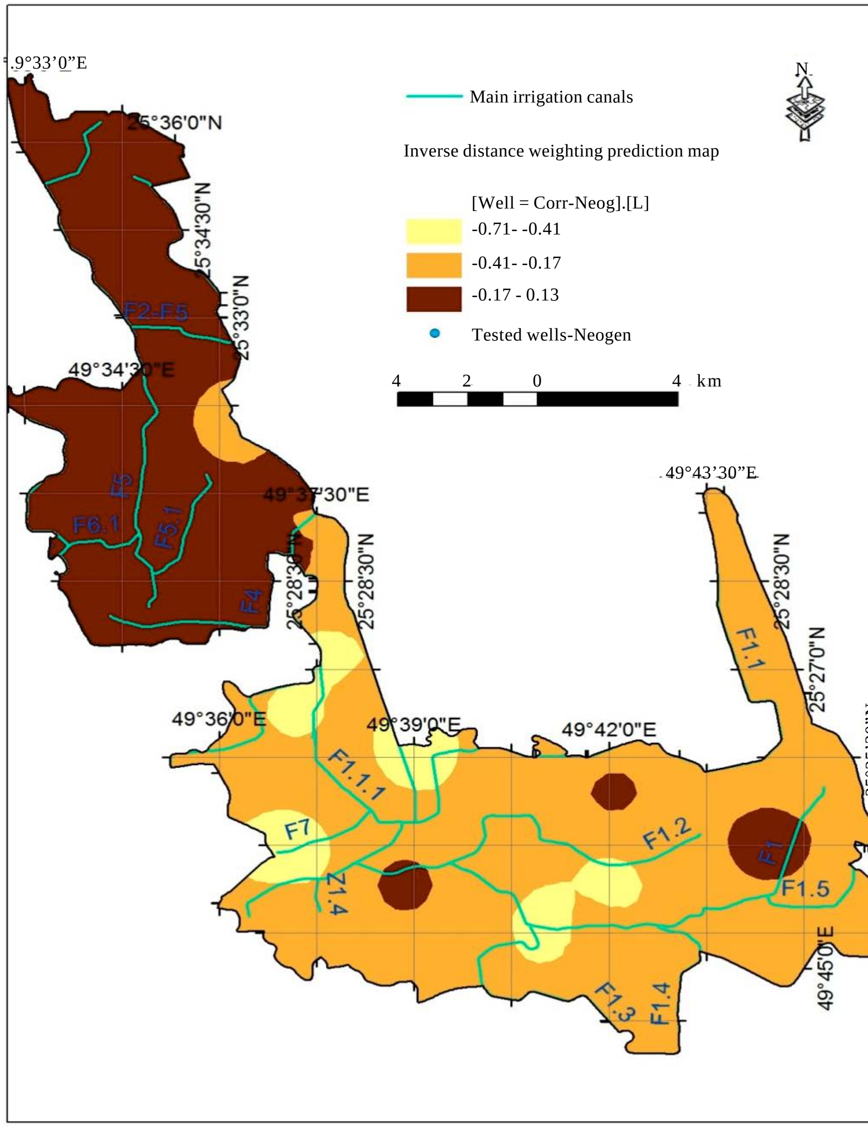

Fig. 5: Contour map showing the Langelier Saturation Index (LSI) values in the three sectors

In the Eastern sector, the LSI values ranged between corrosion and extreme corrosion. The highest LSI value (0.0) was in sample No. 3 and the lowest (-1.1) in sample No. 5. The water quality is poor, somehow, in this sector due to its proximity to the population and urban areas which caused deterioration in water quality. Above all, it is one of the oldest areas in the Oasis where agricultural operations are being carried out for the last many years thus leading to a decline in the water quality of the aquifer.

CONCLUSION

Generally, well waters in Al-Hassa Oasis are considered either medium or poor quality as in all over the Kingdom. The medium salinity is a good feature because it significantly helps to reduce the problems of corrosion by forming protective layers resulting from salts and compounds such as calcium carbonate. This action reduces the loss of the farmers resulting from the high cost of maintenance or replace of water pipes. Whereas the researchers, who have adopted the problem of corrosion, believe that the life span of these pipes and equipment is 12 years. Therefore, it can safely be concluded that the problem of corrosion in Al-Hassa is of limited scope. Based on the study results, the use of iron based pipes and well equipment is recommended since the corrosion has little effect on iron at least in the near term, due to the quality of saline water. In addition to that, using plastic pipes with high durability will help to fully get rid of corrosion problems. It also further suggested that certain procedures and by-laws should be enforced for drilling wells especially with the concrete tiles that have a profound impact in the qualities of groundwater as a result of mixing between the layers which lead to corrosion on pipes and equipment. Lastly, reducing water-polluting factors such as the use of pesticides and fertilizers in large quantities play a vital role in changing the qualities of water.

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