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Assessment of Groundwater Quality of Dammam Aquifer on Corrosion of Well Casing and Other Equipments in Al-ahsa Oasis

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ABSTRACT
Al-Ahsa Oasis in one of the oldest and largest irrigated agriculture in Saudi Arabia. The main source of irrigation water is the groundwater extracted from different aquifers (Neogene, Al-Khobar and Dammam). The main objective of this study was to determine the impact of water quality of Dammam aquifer on well casing and other related equipments used for pumping water. The groundwater salinity ranged between 1.81-7.36 dS m^{-1} at various locations in the Oasis. The high salinity of groundwater may reduce the problems of corrosion by forming protected layers from some salts such as calcium carbonate ($CaCO_3$). The DO values ranged from 3.9-5.6 mg L^{-1} in the groundwater in Al-Ahsa Oasis. The SI values ranged from -0.1 to -0.5 in the northern sector, -0.4 to 0.3 in the central sector and -0.4 to 0.5 in the eastern sector. The SI values indicated non-existence of corrosion problems to well casing under the present conditions. The research findings suggest that well equipments (casings, pumps, water supply networks) should be manufactured free of corrosion problems to avoid huge income losses to the farming community. It is also suggested that well drilling should be carried in those areas where rock formation is solid and the solubility of geological material of aquifer is very low. Lastly, it is suggested that application of excess fertilizers, insecticides and pesticides should be minimized to avoid deterioration of groundwater water quality thus resulting in improving the corrosion process of well equipments.

Key words: Water salinity, pH, strohecker index, well casing, dissolved oxygen, irrigation network

INTRODUCTION
Al-Ahsa Oasis is one of the most important agricultural areas in the Kingdom of Saudi Arabia. The total area of the Oasis is around 20,000 hectares. Out of this only 8000 hectares is covered with irrigated agriculture (Fig. 1). Most of the wells in the area are in Neogene aquifer drilled at different depths and the groundwater total salinity varies depending on the total depth of each well. Presently, irrigated agriculture in the Oasis depends not only on groundwater sources but is also supplemented from other sources i.e., reuse of drainage water. High salinity of groundwater proved useful in reducing the problems of corrosion to well equipment which is of very limited scope in Al-Ahsa oasis in Saudi Arabia. The total water needs for agriculture are met up to 67% by groundwater while the remaining need is met by reuse of treated and untreated drainage water. Al-Ahsa Oasis contains many groundwater wells from the same aquifer untreated drainage water. Al-Ahsa Oasis contains many groundwater wells from the same aquifer but located at different depths which might differ in chemical and physical attributes depending on agricultural activity in the Oasis. The Dammam formation varies in depth ranging from 120-300 m covering mostly

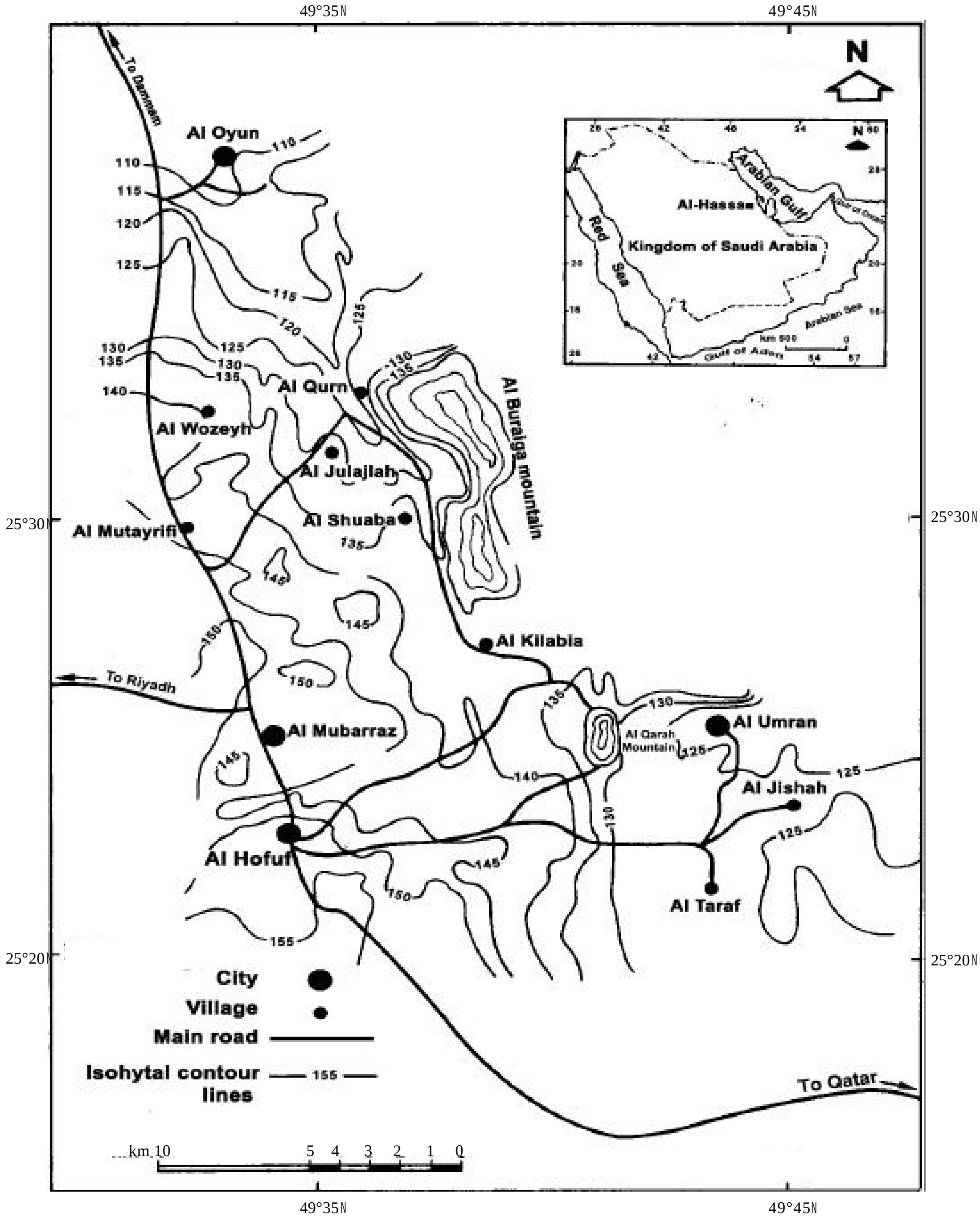

Fig. 1: Location map of Al-Ahsa Oasis

three layers of underground water aquifer i.e., Neogene, Al-Khoar and Um-Radhumah. The chemical composition of groundwater depends on the types of geological rocks of the aquifer and the interaction of water with soluble rocks and minerals in the aquifer.

Recent agricultural and industrial expansion in the Oasis has caused appreciable change in the groundwater quality resulting from use of high salinity drainage water for irrigation, intensive use

Fig. 2: Corrosion of well casing due to high salt concentration of groundwater

of inorganic fertilizers for increased agricultural production, application of insecticides and pesticides for insect-pest management of different crops (Hussain, 1982). Furthermore, leaching losses of biological and chemical pollutants due to over irrigation caused appreciable change in groundwater quality which posed a serious concern among the water users and emphasized to study the changes in groundwater quality. It has been observed by the investigator during study that groundwater containing different chemical compounds caused severe corrosion of well casing and other equipments as shown in Fig. 2.

Some study showed that high salt concentration of groundwater and adjoining soils caused high corrosion of well casings and its related equipments (Moore, 1987). Also, the presence of micro-organisms and bacteria in irrigation water lead to the problems of corrosion of the equipments and the irrigation network used for lifting water from groundwater wells and irrigation to fields (Iverson, 1981).

Most research conducted in South Africa and allied fields on the corrosion of water equipment is approximately 40% for the surface water which is mainly soft acidic water and responsible for corrosion (Lu *et al*., 2002). They further stated that water with low level of acidity increases the rate of corrosion due to the presence of hydrogen ion or entering the water. On the other hand, they found that water with high level of acidity reduces the rate of corrosion and protects the equipment due to the formation of protective layer (Lin *et al*., 2005; Lyon, 2009). As such, the degree of acidity is one of the most important factors in the corrosion process of well casings and allied equipments.

A study of water wells in the south-west region of Uganda showed corrosion problems with waters with acidity less than or equal to 6.5, but in some wells it was recorded with water acidity up to 4.5 or less (Pinter, 2005). The degree of acidity (pH) and alkalinity (calcium, carbon dioxide, chloride, sulphate and oxygen) are the most important factors determining the chemical corrosion. Corrosion occurs in well equipments due to a change in nature and chemical characteristics of soil and water which accounts for different parameters such as the ambient temperature, amount of sediment and the flow rate of water. While the chemical characteristics represent the degree of salinity, degree of acidity, cations (sodium, potassium, magnesium and calcium) and anions (chloride, sulphate, hydrocarbon, carbonates) in groundwater (Shams El Din, 2009). However, some of the chemicals are essential for human beings for health reasons especially for the patients such as dissolved gases (carbon dioxide, hydrogen oxide, hydrogen sulfide in addition to water born diseases and microbes (Beaumont, 1977).

Groundwater containing carbon oxide vary significantly for its effect on the corrosion processes in the water carrying networks. This is especially true for its effect on water wells and network pipelines with some degree of corrosion that occurs due to the presence of groundwater with limited amount of oxygen (Nielsen, 1996). It has been also noticed that some groundwaters contain calcium carbonate ($CaCO_3$) due to eruption of volcanic rocks, carbonic acid (H_2CO_3), dissolved carbon dioxide (CO_2) and baking lime (CaO). Normally, it works by deposition on the inner walls of wells casings and protect well corrosion. However, if the water contains high level of acid (carbonic acid), then there is a serious problem of corrosion on the un-insolated iron pipes especially due to lack of oxygen or the so-called increase in the concentration of active carbon dioxide (Zhang and Huang, 2006; Escalante, 1981).

According to FAO (1980), the temperature and the level of acidity affect the chemical balance of water thus giving an indication of the presence of erosion. The relationship between the water acidity and the rate of corrosion in well equipments was established by Ahmed (2007) and Kelly and Kemp (1974) (Table 1). Kim *et al*. (2010) observed that corrosion rate is high and minimum at subcritical temperature and at supercritical temperature, respectively. Also, the increasing concentration of Cr improved the corrosion resistance. Subramanian *et al*. (2013) reported significant reduction in the corrosion and corrosion release of carbon steel as a result of water chemistry modified with Magnesium ion.

The problems of corrosion can be forecasted by field observations and test of oxygen level in water at site. Also, the presence of some iron oxide stains of reddish colour on well infrastructure indicates that the well water contains iron (Fe) with less oxygen level from all aquifers and the equipments for pumping water and its distribution (Kaesche, 1966). According to the Manual of Water Pumps (KSB, 1968) and FAO (1980), the water containing iron (Fe), Zinc (Zn) and Copper (Cu) alloy might cause corrosion of well casings and equipments if these are present as stated below:

- Presence of pH less than 7.0
- Presence of dissolved oxygen more than 2 mg L^{-1}
- Presence of dissolved Hydrogen Sulfide (HS) up to 1 mg L^{-1} will cause severe corrosion of iron (Fe) and copper (Cu) metals
- Presence of free carbon oxide (CO_2) between 2-50 mg L^{-1}
- Presence of chloride (Cl) ion less than 500 mg L^{-1}
- Maximum limit of Total Dissolved Solids (TDS) for corrosion is 1000 mg L^{-1}, therefore manufacturing of metals resistant to corrosion is necessary (Ahmed, 2007)

There are many indicators to identify the problems of corrosion. One of these is the Strohecker Index (SI). It is a useful to determine accurately the degree of hardness of water. The SI calculates

Table 1: Relationship between pH of water and level of corrosion of well equipments

pH of water	Corrosion level
More than 7.5	No corrosion
7.5-5.0	Medium corrosion
Less than 5	High corrosion

Table 2: Values of SI for its effect of well corrosion

Value of SI	Level of effect on corrosion
Less than zero (0)	No corrosion
1	Weak corrosion
2	Medium to strong
3	Strong to very strong
4	Very severe

the materials leading to corrosion through the water analytical data (Barringer *et al.*, 1993). If the value of SI is more than zero (0), then there is possibility of corrosion of well casings. But if the value of SI is more than 2, then severe corrosion of metal of well casings starts in the system (McIntyre and Mercer, 2009).

Based on the IS values, the assessment of well corrosion problem according to Barringer *et al.* (1993) is presented in Table 2.

The main objective of this study was to assess groundwater quality of Dammam Formation and its corrosion impact on well casing and related equipments applying Strohecker Index (SI) of corrosion in Al-Ahsa Oasis.

MATERIALS AND METHODS

A total of 60 groundwater samples were collected from wells located the northern, central and eastern sectors in Dammam Aquifer formation from different depths in Al-Ahsa Oasis during 2011-2012 season. The sampling location is shown in Fig. 3. The samples were collected in sterile polyethylene bottles, airtight, stored in an ice chest and transferred to analytical laboratory for analysis. Measurements such as temperature, pH and Electrical Conductivity (EC) were taken in the field at the time of sample collection according to methods described in USDA (1954).

The SI and the contour maps were used to determine the impact of water quality on well equipment corrosion in Al-Ahsa in order to make appropriate recommendations for the solution of corrosion problem in the study area for the safety of well and allied equipments as well as for the benefit of farming community.

The Strohecker Index (SI) is a useful tool to calculate the degree of corrosion from irrigation water quality. The value of SI was calculated according to the procedure of McIntyre and Mercer (2009) as follows:

$$SI = pHs\text{-}pH$$

where, pHs can be calculated as:

$$pHs\ \text{-}11.39\text{-}2\ \log\ (CO_{2\ re}t)$$

where, pH is the degree of acidity of actual water sample. pHS is the value of carbonate acidity of water sample.

The results obtained from SI were compared with the results obtained by GPS graphs to identify the problems of severe corrosion of water wells in Al-Ahsa oasis to suggest appropriate recommendations to avoid the problem of corrosion and damage to well and related equipments used for water conveyance.

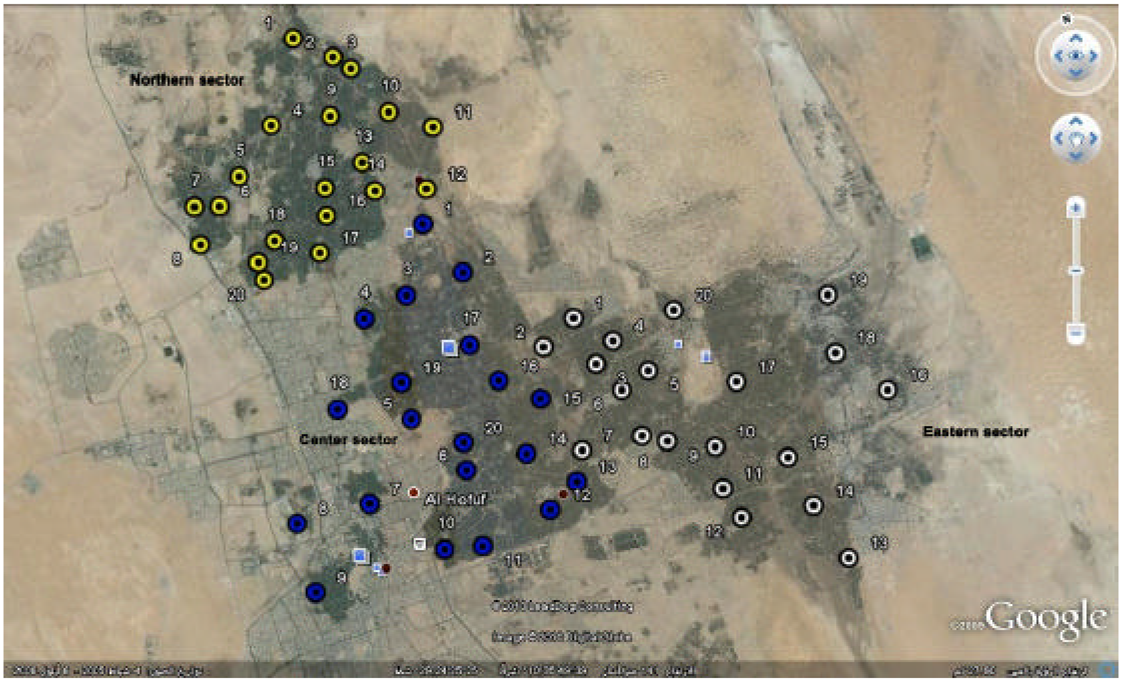

Fig. 3: Location map of water sampling in Al-Ahsa Oasis

Data analysis: The experimental data were analyzed by ANOVA and Regression analysis according to SAS (1984) and Snedecor and Cochran (1973).

RESULTS AND DISCUSSION

Generally, the mean values of water salinity (EC, dS m^{-1}) ranged between 1.81-7.36 in different wells at different locations in the Oasis (Table 3). The difference in water salinity could be attributed to the difference in well depth and the characteristics of aquifer geology containing soluble minerals in the rock formation.

However, the EC of sample No. 17 was the highest (7.36) in the central sector of Oasis, whereas, it was lowest (EC = 1.81 dS m^{-1}) for sample No. 20 in the eastern sector. It is also mentioned that sample No. 17 is located in the urban sector and has shallow depth, While the other samples are located in the Far East of Oasis in Dammam formation. Also, this explains the variability in water salinity which could be attributed to the rocky mountains of the oasis and the topography which is low compared to the agricultural activity in the regions located out of the study area.

The comparison of three sectors indicated that the trend of increasing water salinity in ascending order was higher in central followed by the eastern and northern sector which came to 4.68, 4.32 and 3.55 dS m^{-1}, respectively. This could be due to varying geological components in addition to the presence of direct correlation between adjacent urban areas and the old farms where agricultural operations are being carried out for a long periods and raise the level of salinity as well as the pollutants in groundwater.

Table 3: Mean water salinity (electrical Conductivity, EC dS m^{-1}) of Dammam aquifer in three sectors

Sample No.	Aquifer	EC (dS m^{-1})
North sector		
2	D	3.06
4	D	3.51
6	D	3.92
8	D	3.33
10	D	3.82
12	D	3.69
14	D	3.24
16	D	3.71
18	D	3.25
20	D	3.44
Central sector		
2	D	3.77
4	D	5.24
6	D	6.74
8	D	5.49
10	D	4.49
12	D	3.88
14	D	3.74
16	D	6.21
18	D	6.71
20	D	2.72
Eastern sector		
2	D	3.92
4	D	4.71
6	D	3.94
8	D	3.12
10	D	3.24
12	D	3.11
14	D	4.14
16	D	7.35
18	D	6.96
20	D	1.81

The pH values of three sectors (northern, central and eastern) ranged between 6.3-7.4 which shows the acidity and alkalinity status of water of Dammam formation in Al-Ahsa oasis (Fig. 4). A comparison of acidity in the three sectors showed a low possibility of corrosion in the northern sector where the level of acidity (in terms of pH) is of the order of 6.9, 7.0 and 7.1.

The main reason for the insignificant results among different sectors might be due to the rock composition in water aquifer, because all the results are similar in the whole Oasis. The study results agree with those of Ahmed (2007) and Kelly and Kemp (1974) who stated that water having pH value from 5.0-7.5 causes medium level of corrosion of well casing and allied equipments.

Mean Dissolved Oxygen (DO) values ranged between 3.9-5.6 mg L^{-1} in the eastern sector being the highest level, whereas, the lowest level of DO was recorded in the northern sector ranging from 3.8-4.6 mg L^{-1}. The level of DO measured was 4.5, 4.0 and 4.3 mg L^{-1} in the eastern, northern and central sectors, respectively. The relationship between dissolved oxygen and the level of acidity showed high variability of dissolved oxygen with having an inverse relationship between these

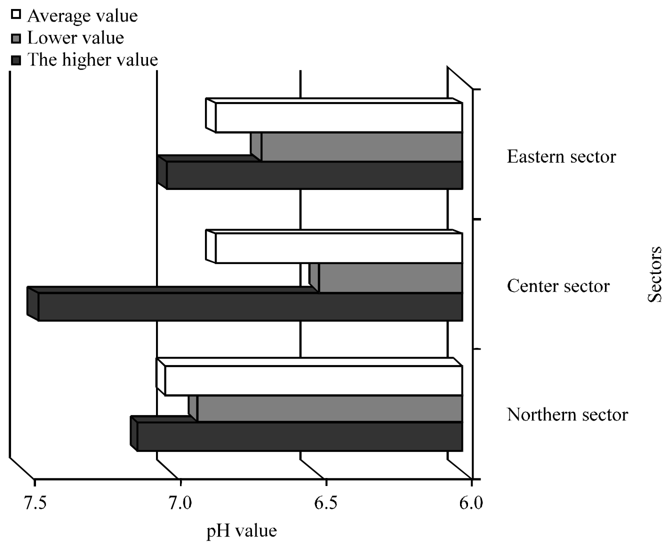

Fig. 4: pH values of water in different sectors in Al-Ahsa Oasis

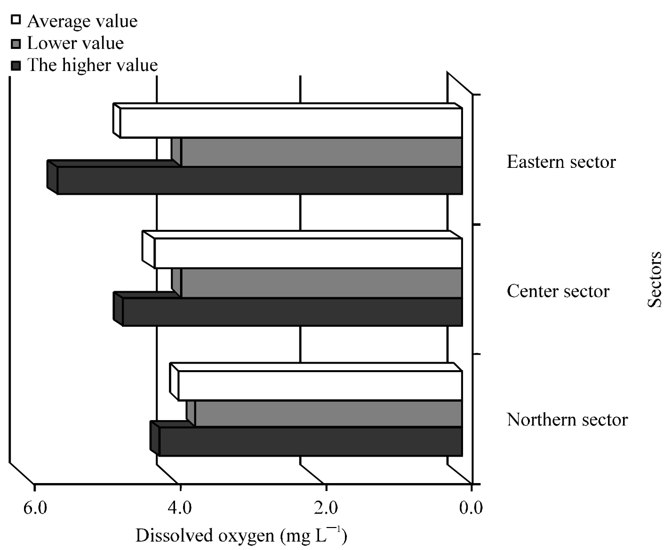

Fig. 5: Concentration of dissolved oxygen in waters of different sectors Al-Ahsa Oasis

parameters. Because, the northern sector has the highest level of acidification with low value of oxygen followed by central and eastern sectors in descending order. The availability of excess Dissolved Oxygen (DO) gives an indication of the presence of some microorganisms causing corrosion of water supply network and well equipments (Fig. 5). Similar findings were reported by Atasoy and Yesilnacar (2010) who determined the level of scale formation tendency/corrosivity of water considering pHs, Langelier index and Ryznar index of groundwater samples. The research findings showed that precipitation, excessive irrigation and change in groundwater level caused seasonal variation in corrosive characteristics of well casing and the related equipments. They found that the rate of corrosion rate increases with increasing temperature of well water. The ideal pH of water to avoid corrosion ranged between 6.5-8.0. The study results were also supported by Zhang and Huang (2006) that dissolved oxygen of water caused iron corrosion coating on iron grains in a zero-valent iron system.

The values of SI indicate the effect of water quality on level of corrosion on the well equipments and water supply network. If the value of SI is higher than 2, the water has the capacity to cause very sever corrosion as shown in Table 1. However, if the SI values ranged between-0.41 to 0.51which were recorded in sample No. 5 in the eastern sector being the highest value, while the lowest value of SI was recorded in sample No. 20 located in the central sector (-0.4). Overall, low values of SI were recorded in the eastern sector as compared to the other two sectors and proved to be less vulnerable to corrosion, but the most vulnerable sector to corrosion is the northern sector with central sector being moderate between the other two sectors.

The range of SI values in the northern sector gave a possibility of low corrosion and the absence of corrosion in sample No 5 having the highest value of SI (-0.1) in sample Nos. 5, 6, 7, 13, 14 and 19. Whereas sample No 15 showed the low value of SI (-0.5). Also the prediction of SI index for expected corrosion depends on some of the elements such as chlorine and dissolved carbon dioxide in groundwater. Since the quality of groundwater is good in this sector according to the total salt concentration of cations and anions which is considered as good protection against the corrosion. The SI values for the north sector are presented in Fig. 6.

The results of SI index in central sector showed the level of corrosion between the lowest and its absence. However, highest value of SI was in sample No. 6 (0.3) and the lowest in sample No. 20 (-0.4). As mentioned previously, some of the anions such as chloride (Cl) provided such water quality that has the ability to limit the actions of corrosion on well equipments. The values of SI obtained in the middle sector are presented in Fig. 7.

In the case of eastern Sector, the SI values ranged between low corrosion to without corrosion. The highest value of SI was in sample No. 5 (0.5) and the lowest value was in sample No. 1 (-0.4). A comparison between the three sectors indicated that the SI value in the eastern sector showed less protection against corrosion to well equipments. The SI values in the eastern sector are presented in Fig. 8.

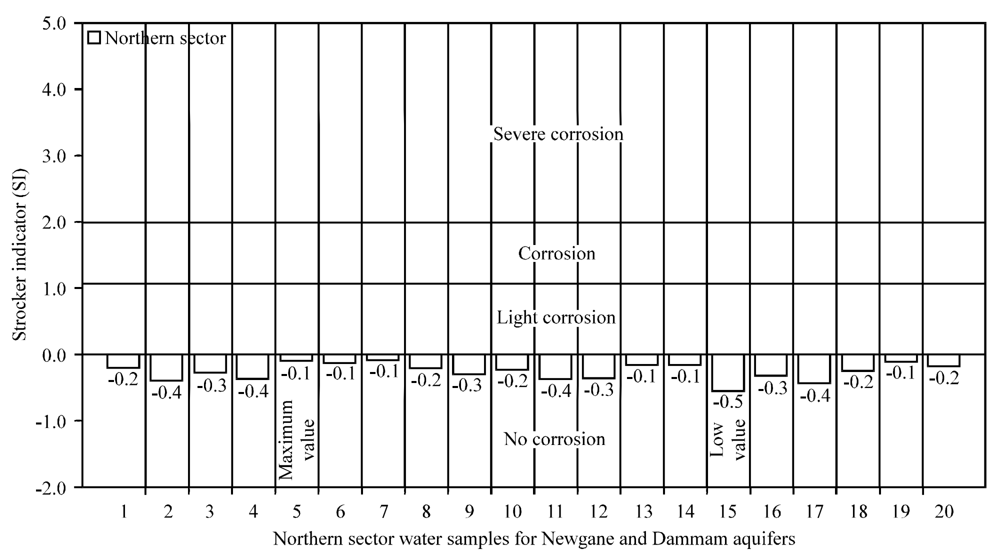

Fig. 6: Strohecker index values of water samples in Northern sector of Al-Ahsa Oasis

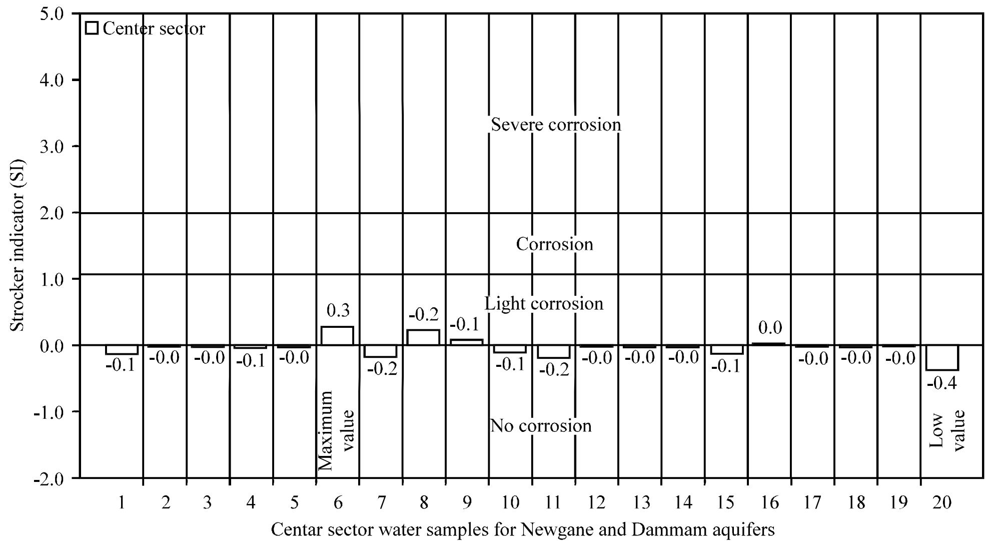

Fig. 7: Strohecker index values of water samples in central sector of Al-Ahsa Oasis

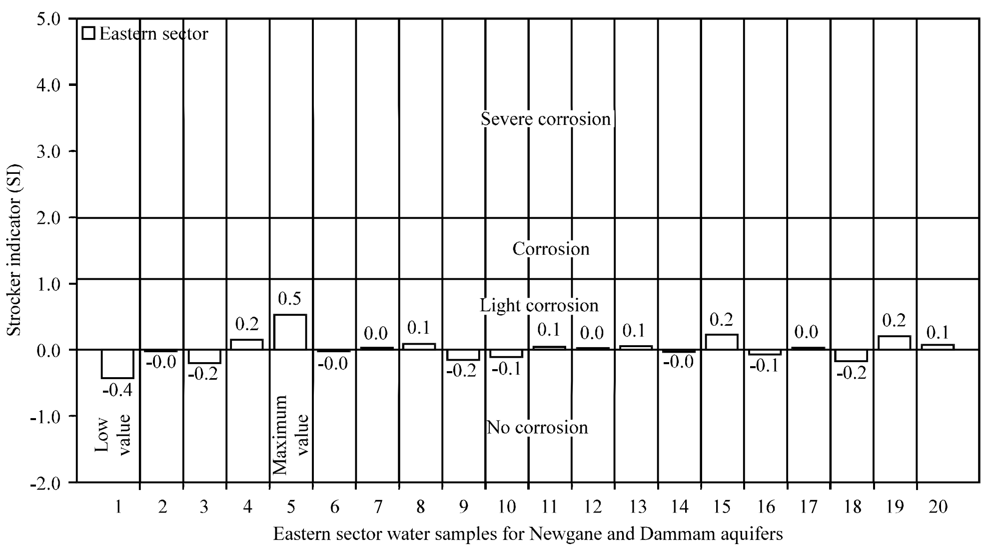

Fig. 8: Strohecker index values of water samples in Eastern sector of Al-Ahsa Oasis

Overall, the Strohecker Index (SI) values in all the three sectors are less than 1 which means that the groundwater in Al-Ahsa Oasis will not cause any corrosion problems to well casing and allied equipments. These results are in line with those of McIntyre and Mercer (2009) and Barringer *et al.* (1993) who concluded that waters having SI value less than 1 will not cause any corrosion problems to well casing and allied equipments used in irrigation network.

Overall corrosion problem: Data in Fig. 9 shows the special distribution of Strohecker Index (SI) for corrosion of well casing due to groundwater quality. It was found that the severity of well casing corrosion is concentrated mainly in the central and eastern sectors as the SI values are very low in the northern sector. This could be attributed to the installation of wells in the rock aquifer

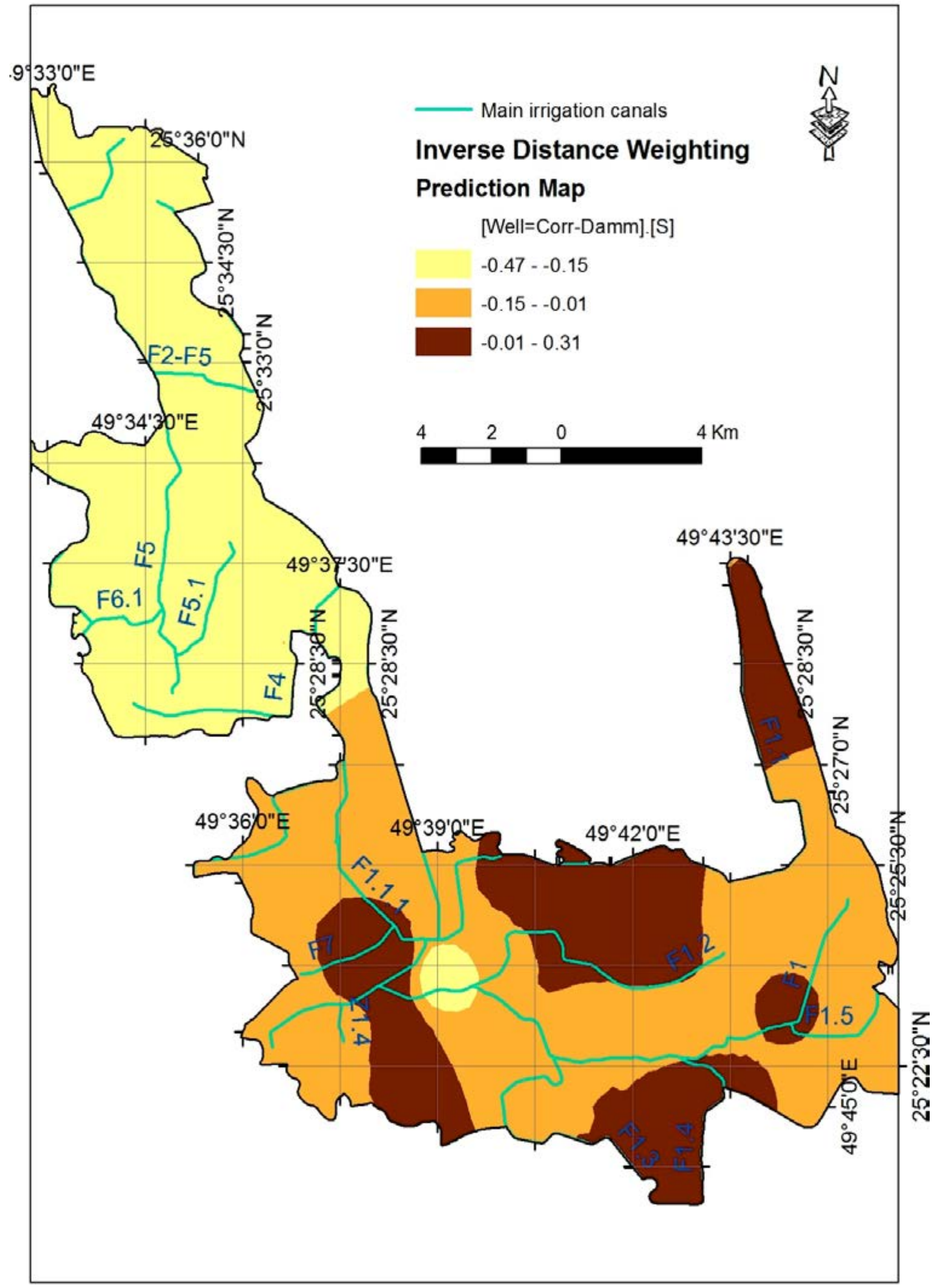

Fig. 9: Strohecker index values of water samples in Eastern sector of Al-Ahsa Oasis

of the Oasis and the topography of the area causing less agricultural activity in the direction of central sector. Also it is adjacent to urban areas with old date palm plantation where agricultural operations are being carried out over a long period of time thus increasing the groundwater salinity of shallow aquifer and a source of pollutants to groundwater.

CONCLUSIONS

The groundwater quality of Dammam formation in Al-Ahsa Oasis ranged between medium to poor based on the total salinity and the SI values. The water salinity ranged between 1.81-7.36 dS m^{-1} at various locations in the Oasis. The high salinity in water from wells is likely to reduce the problems of corrosion by forming protected layers from some salts such as calcium carbonate ($CaCO_3$). The DO values ranged from 3.9-5.6 mg L^{-1} in the groundwater in Al-Ahsa Oasis. The range of SI values was-0.1 to-0.5 in northern sector,-0.4 to 0.3 in central sector and-0.4 to 0.5 in eastern sector. The research findings suggest that well equipments (casings, pumps, water supply networks) should be manufactured free of corrosion problems to avoid huge income losses to the farming community. As an alternative, heavy duty PVC pipe should be used instead of iron or steel structures which are free of corrosion. It is also suggested that well drilling should be carried in those areas where rock formation is solid and the solubility of geological material of aquifer is very low. Lastly, it is suggested that application of excess fertilizers, insecticides and pesticides should be minimized to avoid deterioration of groundwater water quality thus resulting in improving the corrosion process of well equipments.

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