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Evaluation of Groundwater Quality for Irrigation in Central Saudi Arabia

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ABSTRACT. Appraisal of groundwater used for irrigation in El-Gassim region of Central Saudi Arabia was made by chemically analysing 217 representative water samples.

Based on previous water criteria guidelines and a modification by us, the data obtained were intensively processed and transformed. Accordingly, water quality and suitability maps were developed under the conditions of this study with special focus on wheat production.

The water quality parameters investigated revealed the following: 1) water salinity ranged from 210-8200 ppm with an average of 2375 ppm (*i.e.* between 16.6 and 83 t ha^{-1} of salt deposited in soil per season for wheat and alfalfa cultivation); 2) extensive water extraction caused a significant increment in $SO_4^{=}$ / Cl^- ratio; 3) accumulation of reactive constituents such as H_2S, FeS and $SO_4^{=}$ caused corrosion and damaged the pivot pipeline and 4) irrigation water contributed to soluble potassium which amounted to 475 and 2500 kg K_2SO_4 ha^{-1} $season^{-1}$ for wheat and alfalfa crops, respectively.

Lack of good quality water for irrigation is an obstacle confronting development in many countries of the arid and semi-arid regions. In 1979, the Kingdom of Saudi Arabia adopted a proper plan to develop the agricultural land in Nejd district especially in El-Gassim region, Central Saudi Arabia. Accordingly, questions have arisen about irrigation water supply to satisfy the water requirements of different field crops.

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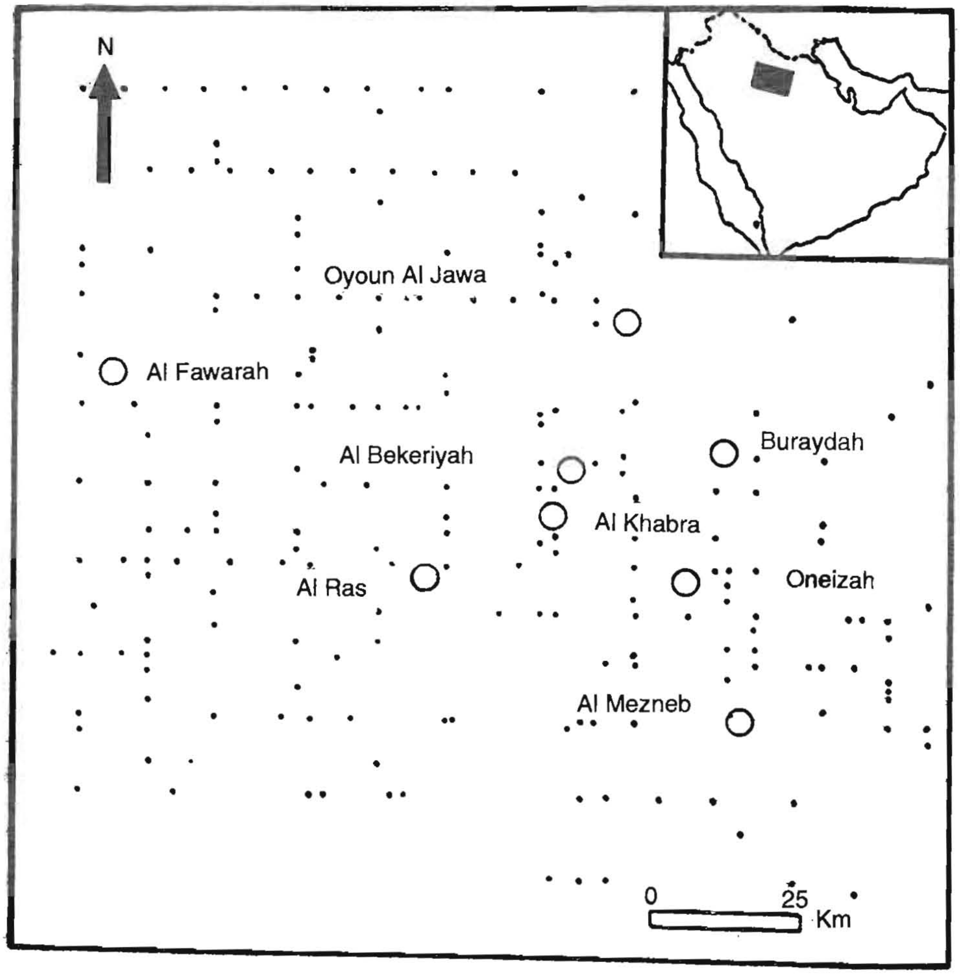
The main aquifer which could supply irrigation water in El-Gassim region is Saq sandstone. In this area it has been noticed that the underground water table ranges approximately from 400 to 1000 meters, with some exceptions to the North and North-East of Buraydah City where the groundwater table is encountered at an average depth of only 150 meters (Abul-Haggag 1979). Some of the Wadi Al-Rumma's water (a local name for this watercourse) should have also reached deeper horizons to constitute an additional source of underground water.

As development of water resources brings more land into irrigated agriculture, problems of soil salinity increase. Nowadays, groundwater taken, either from shallow or in deep aquifers, is widely utilized for crop production in El-Gassim region. Land-owners drill wells and may pump excessive amounts of water, even if the ground water basin is in condition of overdraft or is highly saline. The risk that pumping will agravate saline water intrusion is often ignored. Accordingly, salinity build up occurs concomitantly with a lowering of the level of groundwater may be expected. Because of the extensive use of groundwater for crop production in El-Gassim region, the quality of this water may have changed as a result of recycling. Therefore, the main target of the present work was to establish water quality standards and irrigation water suitability maps for common field crops with special reference to wheat production. In addition an assessment of irrigation pipeline corrosion was made along with the contribution of irrigation water to potassium requirement of crops, and soil salinity build up.

Materials and Methods

Two hundred and seventeen irrigation water samples, representing the irrigation wells in El-Gassim region, were randomly collected after a discharge period of one hour from 1986 through 1993 (Map 1). The samples were collected just before wheat sowing in October - November in each of the investigated years. The sites were chosen on the basis of their importance as potential wheat and other crops growing areas. Soluble cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) in addition to soluble Fe and B and anions ("$CO_3^{=}$ + HCO''_3 Cl^{-} and $SO_4^{=}$) were determined according to Page *et al.* (1982). The samples were analysed for pH, EC (electric conductivity), adj SAR (adjusted sodium adsorption ratio), and RSC (residual sodium carbonate) according to Richards (1954). The accumulating rust-like material resulting from the interaction between constituents of irrigation water and center-pivot pipeline (corrosion) was collected and analysed for organic matter content by the Walkley-Black method (Jackson 1958), total Fe, Mn and SO_4, (Black 1965 and Chapman and Pratt 1961) and X-rayed using a Philips PW 1140/90 X-ray diffractometer.



Map (1) : Location of water samples. ■ Study area (El-Gassim Region).

Results and Discussion

Quality potential of water for irrigation:

Table 1 shows the statistics of the results of chemical analysis of irrigation water samples. Key characteristics limiting the quality of irrigation water are presented and discussed below.

Table 1. Descriptive statistics of irrigation water (groundwater) in El-Gassim region

Sampling intervals (Years)	No. of samples	Ion species (meq L^{-1})											
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-} + HCO_3	SO_3^{2-}	Cl^{-}	EC dSm^{-1}	adj. SAR	RSC meq L^{-1}	SO_4^{*} / Cl^{-} Ratio	pH
		1 - Means											
1986-1991	99	11.3	8.0	21.6	**	2.9	12.9	25.2	3.6	9.4	−16.4	0.5	7.3
1991-1992	71	12.1	11.4	17.3	1.0	2.6	11.9	29.8	4.2	7.4	−21.0	0.4	7.3
1992-1993	47	10.5	9.5	17.3	0.6	2.7	17.4	17.6	3.3	7.8	−17.3	1.0	7.4
1986-1993	217	11.3	9.6	18.7	0.8	2.7	14.0	24.2	3.7	8.2	−18.2	0.6	7.3
		2 - Minimum											
1986-1991	99	1.6	0.5	0.9	**	0.4	0.5	1.4	0.5	1.7	−1.7	0.4	6.2
1991-1992	71	0.5	0.8	0.2	0.2	0.8	0.5	2.2	0.9	1.2	−0.5	0.01	6.7
1992-1993	47	2.5	0.7	1.2	0.1	0.9	2.4	2.5	0.3	2.3	−2.3	0.40	5.4
1986-1993	217	0.5	0.5	0.2	0.1	0.4	0.5	1.4	0.3	1.2	−2.3	0.01	5.4
		3 - Maximum											
1986-1991	99	42.3	37.0	79.6	**	16.0	49.5	100.0	12.2	15.8	−63.3	0.5	9.0
1991-1992	71	48.8	55.0	53.0	3.1	4.9	56.3	77.1	12.8	10.0	−98.9	5.4	8.2
1992-1993	47	30.2	23.0	48.0	3.6	4.6	42.8	52.5	8.9	12.0	−48.6	2.9	7.9
1986-1993	217	48.8	55.0	79.6	3.6	16.0	56.3	100.0	12.8	15.8	−98.9	5.4	9.0

* Calculated from the determined SO_4^{2-} and Cl^{-}

** Not determined.

Salinity:

Salinity of irrigation water (EC_w) expressed in dSm^{-1} covers the range of 0.33 to 12.81 with an average of 3.71; *i.e.* 210-8200 ppm with an average of 2375 ppm. Normally, change in groundwater salinity is expected as a result of extensive water extraction. The data obtained were therefore, analysed to monitor the changes in the salinity status. It was found that during the first period (1986/91) the salinity of underground water did not apparently change. Thereafter, an increase in salinity concentration (1991/92) was followed by a decrease (1992/93) when compared with that of the first period (1986/91). It is worth mentioning that soils of the region are receiving seasonally an average of 16.6 and 88 t/ha as deposited salts for irrigated wheat and alfalfa crops, respectively. These amounts of salts were calculated according to the water requirements of the two crops as reported by the FAO (1988) on the basis of an average salinity concentration of 2375 ppm in irrigation water.

1- Ion species:

The data presented in Table 1 for the cationic species in the various periods studied revealed the dominance of Na^+ over the other cations. Generally, $Na^+ > Ca^{++} > Mg^{++} > K^+$. Potassium concentration (0.78 meq/L) is of paramount importance in planning K-fertilization programmes. On the other hand, Cl^- dominated the anionic species throughout the studied periods. Generally, $Cl^- > SO_4^= > (CO_3^= + HCO_3)$. As expected the behaviour of the individual ionic species concentrations is, generally, similar to that of EC_w throughout the irrigation intervals studied. However, the mean for $SO_4^=$ was greatest in 1992/93, when EC was lowest. This effect was examined by calculating the $SO_4^= /Cl^-$ ratio along the study intervals (Table 1). It is clear that there is a significant rise in the ratio during the period (1992-1993). This could be due to: 1) the extensive utilization of groundwater for crop production that may have changed water quality; 2) the relative mobility of Cl^- compared with that of $SO_4^=$; 3) the lower solubility of most of the $SO_4^=$ bearing minerals compared with that of Cl^-. Accordingly, one may expect the dominance of the Cl^- ion during the first pumping period when the rate of water extraction was relatively much less compared with that during the last interval.

These changes in salinity status and in ionic ratios are later utilized in judging the effect of sprinkler irrigation on the performance of a field crop such as wheat.

Soluble boron and iron in representative water samples ranged from 0.3-1.38 ppm and 0-88 ppm, respectively.

Sodicity:

Examining the data for the two sodicity parameters, *i.e.* Adj. SAR and RSC as presented in Table 1, it can be observed that the former covers the range of 1.2 - 15.8 with an average of 8.2, whereas, the latter ranges between –0.5 to –98.9 with an average of –18.2 meq L^{-1}. As the majority of soils of El-Gassim region are categorized as sands to loamy sands with palygorskitic, kaolinitic and chloritic type clays having low cation exchange capacities (Mashhady *et al.* 1980, and Al-Rumain 1993) the sodicity build up is not expected as a result of using these waters to irrigate such soils (FAO 1976). In a few exceptional instances, waters were classified as sodium hazardous. Furthermore, a mode of desodicity is obvious during the last two periods.

2- Water quality criteria:

Compared to the recommendations of the United States Salinity Laboratory (USSL) guidelines (Richards 1954), and the guidelines introduced by the FAO (1976) and Ayers (1977) the present study introduced some modifications depending on the prevailing environmental conditions in the region. These conditions are the aridity of the region, crop types and patterns and the chemical composition of irrigation water which dictates this system of classification. According, water quality classes were developed as given in Tables 2 and 3. Several workers (Clark *et al.* 1963, Ayers 1975 and Troeh *et al.* 1980) have suggested certain guidelines for the interpretation of water quality for irrigation and the consequent salinity hazards.

Table 2. Thresholds of irrigation water characteristics (El-Gassim Region, Saudi Arabia) "Defined use ; irrigation of crops in general"

Class designation	Water characteristics					
	EC_w (dSm^{-1})	pHw*	Adj SAR	$SO_4^=$	$CO_3^=$ + HCO_3^-	Cl^-
				meq L^{-1}	meq L^{-1}	meq L^{-1}
1	< 0.75	6 - 7	< 1.7	< 2.8	< 0.5	< 4.9
2_a	0.75 - 2.25	7 - 7.5	1.7 - 5.0	2.8 - 8.5	0.5 - 1.6	4.9 - 14.7
2_b	2.25 - 4.0	7.5 - 8.5	5.0 - 8.7	8.5 - 15.1	1.6 - 2.9	14.7 - 26.1
3	4.0 - 6.0	8.0 - 8.5	8.7 - 13.3	15.1 - 22.7	2.9 - 4.4	26.1 - 39.1
4	> 6.0	> 8.5	> 13.3	> 22.7	> 4.4	> 39.1

$$\text{Value of class (i) of characteristic (X)} = \frac{\text{EC limit of class (i)}}{\text{Mean value of EC}} \times \text{Mean value of (X).}$$

*pH range (max - min) was divided to establish pH classes.

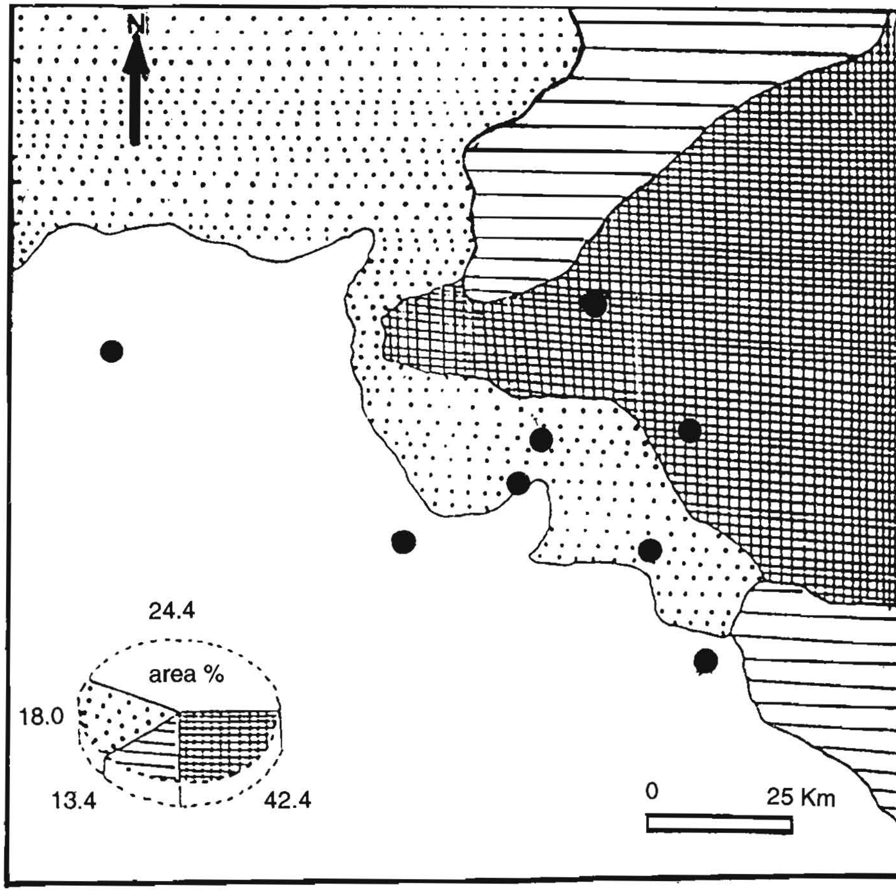
Table 3. Percent distribution of the different water classes

Characteristic	Classes			
	1	2 (2a + 2b)	3	4
EC_w	1.8	60.4	13.4	24.4
pH	25.8	70.1	3.2	0.9
Adj SAR	5.1	65.9	11.0	18.0
$SO_4^=$	11.5	59.0	7.8	21.7
$(CO_3^= + HCO_3^-)$	0.5	64.0	26.7	8.8
Cl^-	12.0	52.5	11.5	24.0
All characteristics	0.5	61.7	13.4	24.4

3- Water quality and suitability maps:

It was appropriate to transform the data obtained into a mapped form Map 2 takes into account the salinity classes of irrigation water (refer to Tables 2 and 3) to satisfy the water quality requirement of normal field crops. The best quality waters are concentrated in the Southwest, West and Northwest of the region (~ 65% of the surveyed wells), and the relatively inferior quality water is mainly located in the East and Northeast of the region (~ 25%).

Wheat is a strategic food security crop in Saudi Arabia and exhibits moderate salt tolerance. It was, therefore, decided to develop a water quality suitability map for wheat production in the region. The data obtained were classified into different classes, according to the quality criteria given in Tables 4 and 5. Then the suitability map was obtained using all the criteria investigated to produce the classes shown in Map 3. It is easy to notice the similarity between Map 2 and Map 3. About 75% of water wells in the region have good water quality for wheat production. However, more than 25% reduction in crop yield in the area located mainly in the Eastern part of El-Gassim region is expected (Troeh *et al.* 1980 and Schwab *et al.* 1981), this constitutes ~ 25% of the investigated wells.



Map (2) : Salinity Classes of Irrigation Water (El-Gassim Region)

Class No.	2		3	4
	2a	2b		
Symbol				
EC (dS m^{-1})	0.75 – 2.25	2.25 – 4.00	4.00 – 6.00	6.00 –13.00

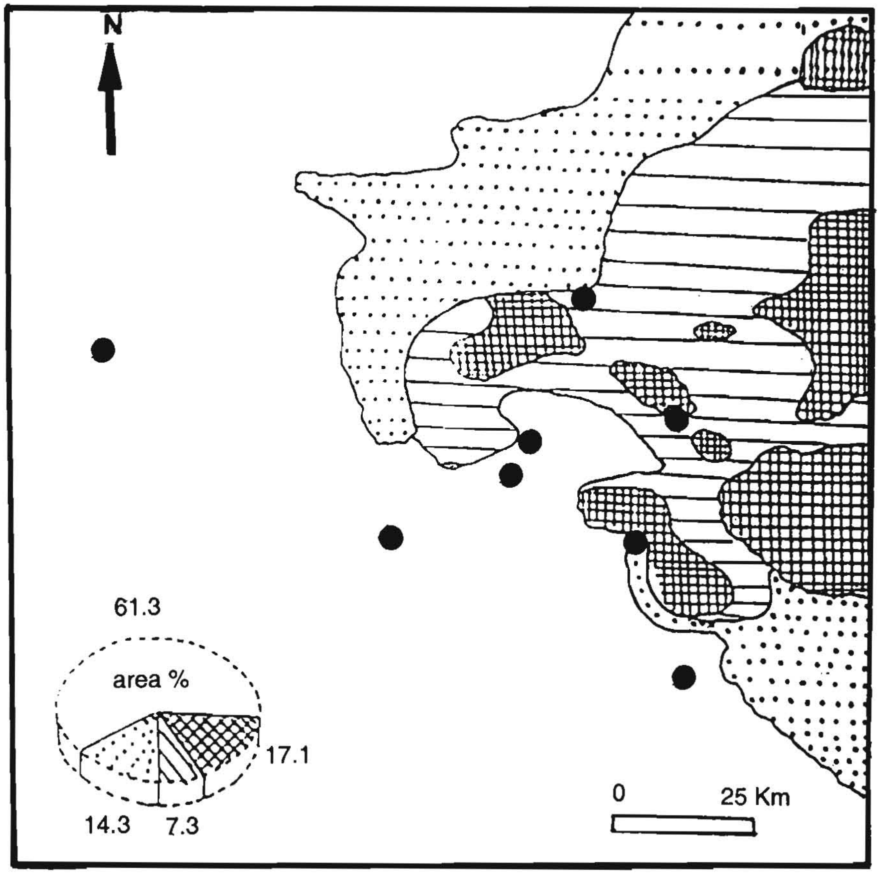
Class 1 has so small area (1.8 %) that it was eliminated during map simplifcation.

Table 4. Thresholds of irrigation water characteristics (El-Gassim Region, Saudi Arabia) "Defined use ; irrigation of winter wheat"

Class designation	Water characteristics					
	EC_w (dSm^{-1})	pHw	Adj SAR	$SO_4^=$	$CO_3^=$ + HCO_3^-	Cl^-
				meq L^{-1}		
1	< 4	6 - 7.5	< 8.8	15.1	2.9	< 26.
2_a	4 - 6.3	7.5 - 7.7	8.8 - 14	15.1 - 23.8	2.9 - 4.6	26 - 41
2_b	6.3 - 8.7	7.7 - 8.0	14.0 - 19.2	23.8 - 32.9	4.6 - 6.0	41 - 56.7
3	> 8.7	> 8.0	> 19.2	> 32.9	> 6.0	> 56.7

Table 5. Suitability classes percent of the different water characteristics for wheat production

Characteristic	Classes		
	1	2 (2a + 2b)	3
EC_w	61.3	32.7	6.0
pH	77.9	17.9	14.2
Adj SAR	71.0	15.2	13.8
$SO_4^=$	70.5	18.0	11.5
($CO_3^=$ + HCO_3^-)	64.5	33.2	2.3
Cl^-	64.5	18.4	17.1
All characteristics	61.3	21.7	17.0



Map (3) : Suitability of Irrigation Water for Wheat production (El-Gassim Region).

Class No.	1	2 2a	 2b	3
Symbol				
EC (dS m^{-1})	< 4	4 – 6.3	6.3 - 8.7	> 8.7
Yield reduction %	0-0	< 25	25 - 50	> 50

4- Special considerations:

a - Corrosion of centre pivot pipes:

In spite of the suitability of EC_w of irrigation water for growing several field crops; *e.g.*, wheat, there exist some ion species that may cause harmful effects to the centre pivot pipes. Such effects normally develop during water flow in the system, thus encouraging the interaction between water constituents such as H_2S, FeS, and $SO_4^{=}$ and the materials of the pipes. This occurs under both aerobic and anaerobic conditions as follows:

1 - Aerobic conditions:

a - Case (1):

$FeS + 2H_2O \longrightarrow Fe(OH)_2 + 2H_2S$

Iron (II) sulphide from deep well water → Iron (II) Hydroxide

$H_2S + 2O_2 \longrightarrow 2H^+ + SO_4^{2-}$ (Sulphate ions)

$2H^+ + SO_4^{2-} + Fe(OH)_2 \longrightarrow FeSO_4 + 2H_2O$ (Iron (II) sulphate)

$2SO_4^{2-} + 4H^+ + 4FeSO_4^{2-} + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$ (Iron (III) Sulphate)

b - Case (2):

$4Fe(OH)_2 + 2H^+ + 3O_2 \longrightarrow 2Fe(OH)_3 + 2H_2O$

(Iron (II) Hydroxide) → (Iron (III) Hydroxide)

$2\,Fe(OH)_3 \longrightarrow Fe_2O_3, 3H_2O$ (Hydrated Fe Oxides)

Dehydrated Fe-Oxide: Fe_2O_3 (Hematite)

2 - Anaerobic conditions:

SO_4^{2-} + *Desulfovibrio desulfuricans* $\longrightarrow$ $H_2S + Fe$ $\longrightarrow$ FeS

(From irrigation equipment materials) → Fe

(Sulphate from (underground irrigation water) → (Hydrogen Sulphide) Iron, (II) sulphide)

Biochemical pathway

These biochemical reactions lead to pipe corrosion, scaling of rising mains, irregular distribution of irrigation water in the field and finally cause serious damage of the pivot piping system. To elucidate the pathways of these reactions the materials deposited in the pivot pipelines were analysed. The data obtained revealed that the precipitated material consisted mainly of organic matter, iron and manganese (Table 6). Moreover, X-ray analysis (Fig. 1) of the precipitated material confirmed the presence of Fe-forms with Fe_2O_3 (hematite) being the dominant form as shown in case (2) of the chemical reaction.

Table 6. Some chemical data for the materials deposited in the pivot pipelines

Constituent	%
Organic matter	2.46
Total Fe	2.02
Total Mn	0.005
Total $SO_4^{=}$	0.00

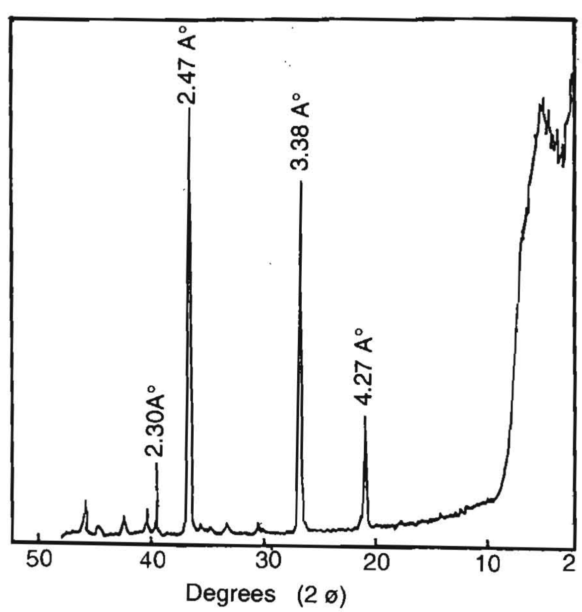
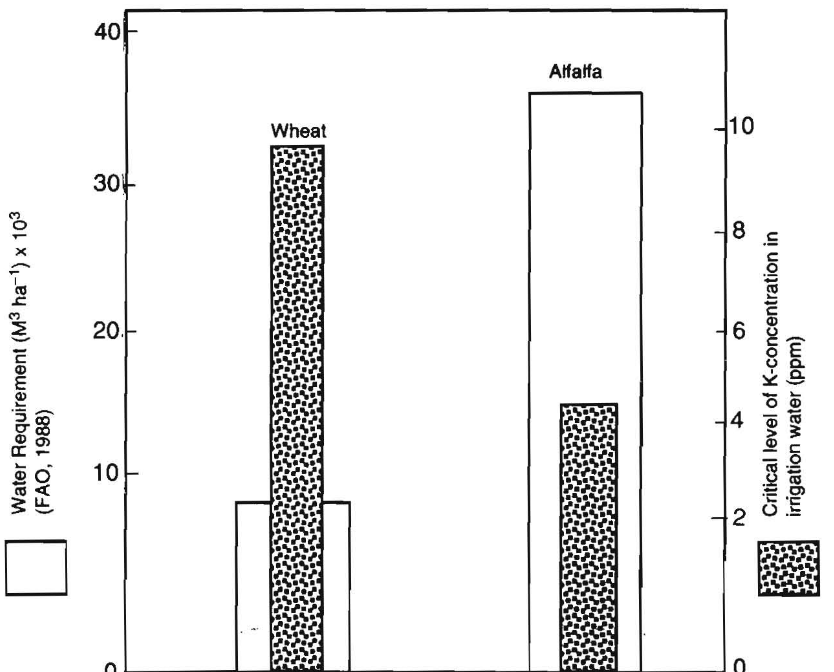


Fig. 1. X-ray diffractogram of the precipitated and rust-like material in the pivot-pipeline which confirms the presence of Fe– froms with the majority of Y–Fe_2O_3 (Hematite)*.

Contribution of irrigation water to K-fertilization:

The content of K in irrigation water in El-Gassim region contributes significantly to K-nutrition of the crops grown in the region (Rabie *et al.* 1993). Table 1 shows the data obtained for the K content in irrigation water. Therefore, when planning fertilization programmes the content of K in irrigation water must be taken into consideration (Fig. 2).



Fertilizer requirement as kg K_2SO_4 ha^{-1}	150	250	
K-added by irrigation Water as Kg K_2SO_4 ha^{-1} $season^{-1}$	475	2500	(FAO 1980)
K-concentration in irrigation water (ppm)	30		

Fig. 2. Contribution of irrigation water to K-fertilization (El-Gassim Region).

In conclusion it may be inferred that excessive utilization and extraction of groundwater may deplete the sources and change the quality as well. Therefore, addressing the water problems inherent to this part of the world is warranted, otherwise a looming water crisis will be eminent in the near future.

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References

Abul Haggag, Y. (1979) On the artesian water of Nejd, Saudi Arabia. Dept. Geog., Ain-Shams Univ., Egypt. Societe De Geographie D'Egypte, 57-65 pp.

Al-Rumain, F.M. (1993) *Nitrogen use efficiency of urea in calcareous soils.* M.SC. Thesis. Soil Sci. Dept., College of Agric., King Saud Univ., Riyadh, Saudi Arabia.

Ayers, R.S. (1975) Quality of water for irrigation. Proceedings of irrigation and drainage division. Speciality conference. American Society of Civil Engineering. Logan, Utah, U.S.A. 24-56pp.

Ayers, R.S. (1977) Quality of water for irrigation. *J. Irrig. and Drain Div., ASCE,* **103:** 135-154.

Black, C.A. (1965) Methods of soil analysis, Part 2, Am. Soc. Agron. Inc. Madison, Wisconsin, U.S.A.

Chapman, H.D. and **Pratt, P.F.** (1961) Methods of analysis for Soils, Plants and Waters. Univ. Calif., Div. Agric. Sci.

Clark, J.W., Viessman, W. Jr. and **Hammar, M.J.** (1963) *Water supply and pollution control.* **2nd ed.** International Textbook Company, New York, U.S.A. 235 p.

FAO (1976) Water quality for agriculture, irrigation and drainage, Paper No. 29, Rome.

FAO (1980) Soil and plant testing as a basis of fertilizer recommendations. Soil Bull. Paper No. 2812.

FAO (1988) Guide for crop irrigation requirements in the Kingdom of Saudi Arabia. Ministry of Agric. and Water, Dept. Agric. Dev. Riyadh, Saudi Arabia.

Jackson, M.L. (1958) *Soil Chemical Analysis.* Prentice Hall. Inc., England.

Mashhady, A.S., Reda, M. and **Makenzie, R.C.** (1980) Clay and silt mineralogy of some soils from Qassim, Saudi Arabia. *J. Soil. Sci.,* **31:** 101-115.

Page, M.L., Miller, R.H. and **Keeney, D.R.** (1982) *Methods of soil analysis,* Part II. **2nd ed.** Chemical and Microbiological properties. American Society of Agronomy, Inc., Soil Science Society of America Inc., Madison, Wisconsin, U.S.A.

Rabie, R.K., Abdel-Magid, H.M., Sabrah, R.E.A., Abdel-Aal Sh.I. and **Ghoneim, M.F.** (1993) Effect of K-fertilization on the production of wheat grown in sandy soils under sprinkler irrigation. *J. Agric. Sci.,* Mansoura Univ., Egypt, **18:** 1566-1574.

Richards, L.A. (Ed.) (1954) *Diagnosis and Improvement of Saline and Alkali Soils,* USDA Agric. Handbook No. 60, Washington, D.C.

Schwab, G.O., Frevert, R.K., Edminster, T.W. and **Barnes, K.K.** (1981) *Soil and Water Conservation Engineering.* **3rd ed.** Irrigation principals. PP. 416-431: Crop salt tolerance levels for different crops P. 424. John Wiley and Sons. New York, U.S.A.

Troeh, F.R., Hobbs, J.A. and **Donahue, R.L.** (1980) Irrigation and reclamation. *In: Soil and water conservation for productivity and environmental protection.* Prentice Hall, Inc., Englelwood Cliffs, New Jersey 07632, U.S.A. 527-570 pp.

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تقييم نوعية الماء الجوفي لأغراض الري في المنطقة الوسطى بالمملكة العربية السعودية

شفيق ابراهيم عبد العال و رجاء عليوه أحمد صبره و رأفت خلف الله ربيع و هجو محمد عبد الماجد

قسم التربة والمياه - كلية الزراعة والطب البيطري - فرع جامعة الملك سعود بالقصيم
بريدة - ص .ب (١٤٨٢) - المملكة العربية السعودية

تم تقييم نوعية الماء الجوفي في منطقة القصيم بالمنطقة الوسطى من المملكة العربية السعودية عن طريق إجراء التحليل الكيميائي لعدد ٢١٧ عينة ممثلة لماء الآبار المنتشرة في المنطقة ، وبتطبيق بعض المعايير المتوفرة من قبل وما قدمته هذه الدراسة من تعديلات على تلك المعايير أمكن عمل خرائط لنوعية ومدى صلاحية الماء لري المحاصيل بالمنطقة وبصفة خاصة محصول القمح .

وقد أوضحت قياسات نوعية الماء التي تم إختبارها الآتي :

١- تقع ملوحة ماء الري في المدى ٢١٠-٨٢٠٠ وبمتوسط ٢٣٧٥ جزء في المليون ولذا يصبح ما يستقبله الهكتار من الأملاح بالطن في الموسم هو ١٦,٦ و ٨٣ لكل من محصولي القمح والبرسيم الحجازي على التوالي .

٢- نظراً للإستخراج الزائد للماء في السنوات الأخيرة إزدادت نسبة $\frac{SO_4^{=}}{CL^{-}}$.

٣- أدى تراكم المكونات الذائبة سريعة التفاعل لكل من H_2S ، FeS ، SO_4^{2-} إلى إتلاف شبكة جهاز الري بالرش المحوري نتيجة للتآكل الذي تحدثه في المواسير .

٤- متوسط ما تجلبه مياه الري من البوتاسيوم الذائب هو ٤٧٥ و ٢٥٠٠ كجم في صورة سماد K_2SO_4 للهكتار في الموسم لمحصولي القمح والبرسيم الحجازي على التوالي . وعليه فيجب أخذ ذلك في الإعتبار عند وضع البرامج التسميدية البوتاسية .