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Original Article

Groundwater quality for irrigation of deep aquifer in southwestern zone of Bangladesh

Mirza A.T.M. Tanvir Rahman[1]*, Syed Hafizur Rahman[1] and Ratan Kumar Majumder[2]

[1] *Department of Environmental Sciences, Jahangirnagar University, Savar, Dhaka-1342, Bangladesh*

[2] *Institute of Nuclear Science and Technology, AERE, Savar, GPO Box 3787, Dhaka-1000, Bangladesh*

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Abstract

In coastal regions of Bangladesh, sources of irrigation are rain, surface and groundwater. Due to rainfall anomaly and saline contamination, it is important to identify deep groundwater that is eligible for irrigation. The main goal of the study was to identify deep groundwater which is suitable for irrigation. Satkhira Sadar Upazila, at the southwestern coastal zone of Bangladesh, was the study area, which was divided into North, Center and South zones. Twenty samples of groundwater were analyzed for salinity (0.65-4.79 ppt), sodium absorption ratio (1.14-11.62), soluble sodium percentage (32.95-82.21), electrical conductivity (614-2082.11 µS/cm), magnesium adsorption ratio (21.96-26.97), Kelly's ratio (0.48-4.62), total hardness (150.76-313.33 mg/l), permeability index (68.02-94.16) and residual sodium bi-carbonate (79.68-230.72 mg/l). Chemical constituents and values were compared with national and international standards. Northern deep groundwater has the highest salinity and chemical concentrations. Salinity and other chemical concentrations show a decreasing trend towards the south. Low chemical concentrations in the southern region indicate the best quality groundwater for irrigation.

Keywords: irrigation water quality, salinity, SAR, deep tubewell, Satkhira

1. Introduction

Irrigation water quality directly affects soils and crops, and their management. It is possible to produce high quality crops only by using high-quality irrigation water when other inputs are kept optimal. Characteristics of irrigation water can vary with the source of the water. Regional differences in water characteristics will result from variation of geology and climate and climatic parameters' are the most important factors related to irrigation (Shirazi *et al.*, 2011a). Moreover, there may also be great differences in the quality of water available on a local level depending on whether the source is from surface water bodies (e.g., rivers and ponds) or from aquifers with varying geology, and whether the water has been chemically treated. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot, 1985; Rowe *et al.*, 1995).

In the coastal area of Bangladesh, there are mainly three sources of irrigation water – surface water, rainwater and groundwater. Owing to the effect of climate change, rainfall anomaly causes uncertainty of rainwater as a source of irrigation water. Moreover, monsoon rains are available for only four months (May to August). Surface water in the coastal region is subjected to seawater intrusion due to continuous influence of high and low tides and the salinity is increasing daily due to effects of climate change. During the monsoon, salinity of surface water decreases but in other

* Corresponding author.
Email address: tanvir497@gmail.com

seasons salinity remains high depending on the geology of the area. This makes surface water unsuitable to use as irrigation water throughout the year, especially in the dry season (November to April).

Groundwater is the main source of irrigation (Shirazi *et al.*, 2010), which is around 30 to 40 percent of net cultivable area of Bangladesh (Huq and Naidu, 2002). The contribution of groundwater in relation to total irrigated area increased significantly from 41% in 1983 (Ali *et al*., 2003) to 86% in 2002 (BADC, 2002; Hasan *et al.*, 2007). The total area under irrigation in Bangladesh is 5,049,785 ha and 78.9% of this area is covered by groundwater sources including 3,197,184 ha with 1,304,973 shallow tubewells and 785,680 ha with 31,302 deep tubewells (DPHE and JICA, 2010) but heavy pumping of groundwater may create another agro-ecological problem (Shirazi *et al.*, 2010). In the coastal region of Bangladesh, many shallow aquifers have high salinity due to seawater intrusion. Again, most shallow aquifers including coastal region 60 districts out of 64 are contaminated with arsenic (As) (BGS and DPHE, 2001) and are used for irrigation. It has been found that annual As input with irrigation water is about 4.4 kg/ha in paddy field (Dittmar *et al.*, 2010) and in rice grains As is found above 1.7 µg/g (Meharg and Rahman, 2003). Earlier study has confirmed that 95% of nail, 96% of hair, and 94% of urine samples contain As above the normal level in the people of As contaminated areas (Anawar *et al.*, 2002). Nearly 60-70 million people are at a potential health risk of As exposure and several thousand have already been affected by chronic arsenicosis (Bhattacharya *et al.*, 2007). Therefore, water supply wells should penetrate deeper to find water of acceptable quality where the aquifer is free from As contamination.

Several research papers (Zaman and Mojid, 1995; Mridha *et al.*, 1996; Talukder *et al.*, 1999; Zaman *et al.*, 2001, Khan *et al.*, 2002; Sarkar and Hassan, 2006; Raihan and Alam, 2008; Islam and Shamsad, 2009; Sultana *et al.*, 2009) have documented groundwater quality of various locations of Bangladesh. The deep aquifer of coastal region of Bangladesh has been contaminated by salinization due to the previously entrapped seawater (Rahman *et al.*, 2010). However, because of diversified geologic settings of Bangladesh, location-specific spatial distribution must be known to judge the groundwater quality for its suitability for irrigation usage. Moreover, for crop-intensified agricultural activities in the coastal area, farmers cannot rely on rainwater or surface water for irrigation purposes. Since not all locations groundwater are contaminated with saline water, it is important to identify potential aquifers which can supply enough water throughout of the year for irrigation. With this thinking, a study has been made with the specific goal to identify deep groundwater that has the potential to meet irrigation water quality. Therefore, an attempt has been made to investigate the deep aquifer quality for irrigation in the study area.

2. Materials and Methodology

2.1 Area of study

The study area was Satkhira Sadar Upazila of Satkhira district, Bangladesh, with an area of 400.82 km^2 (Figure 1). Total cultivable land comprise 25,728.45 ha and cultivable land under irrigation occupies 20,388 ha (Banglapedia, 2010). Average temperature of Satkhira varies from 21.43 to 31.44° C and total normal rainfall is 1,742.9 mm with 98 normal rainy days in a year (BMD, 2011). The Bay of Bengal is situated about 80 km south of the study area. For convenience in analysis, the study area had been divided into three zones named '*north*' including nine samples, '*center* ' including seven and '*south*' including four samples.

2.2 Sampling and chemical analysis

From different locations of the study area, 20 deep groundwater samples were collected in August, 2009. The sampling location is shown in Figure 1. Each well was pumped until steady state chemical conditions (pH, electrical conductivity and temperature) were obtained. The depth of the wells varied from 150 to 305 m. Samples were collected in 500 ml polyethylene bottles. The bottles were rinsed with distilled water before collecting the sample water. From each location, two sets of samples were collected. One was non-acidified and other was acidified with 0.01 molar hydrochloric acid. The bottles were transported to the laboratory in an opaque bag. The geographical location of each well was determined with a handheld global positioning system (GPS) (Explorist 200, Megellan).

Temperature and pH were measured by EcoScan Ion 6, electrical conductivity (EC) by Hanna HI 8633, and salinity

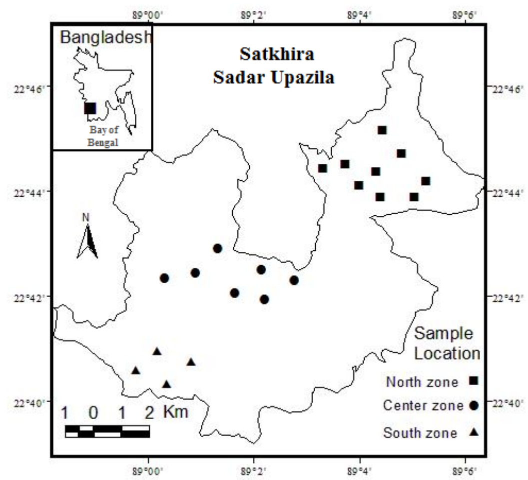

Figure 1. The location map of the groundwater sampling (map modified from Banglapedia, 2010)

by EcoScan Salt 6 portable meters. Total dissolved solids (TDS) and total hardness (TH) were calculated by using Aquachem software (version 3.7.42). The bicarbonate (HCO_3^-) had been measured by injection point titration (IPT) method (US Geological Survey, 2006). Sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chlorine (Cl^-), sulfate (SO_4^{2-}) and nitrate (NO_3^-) were measured by Metrohm 761 Compact Ion Chromatography using standard methods (APHA, 1998).

2.3 Irrigation water quality

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and miscellaneous (Ayers and Westcot, 1985). To assess water quality for irrigation, there are four most popular criteria: TDS or EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na^+, Cl^- and/or B^- and residual sodium carbonate (RSC) (Michael, 1992 and Raghunath, 1987). For current irrigation water quality assessment, the following parameters were considered.

According to Richards (1954), sodium adsorption ratio (SAR) is expressed as:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

Todd (1980) defined soluble sodium percentage (SSP) as:

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

Gupta and Gupta (1987) expressed residual sodium bicarbonate (RSBC) as:

$$RSBC = HCO_3^- - Ca^{2+}$$

Doneen (1962) defined permeability index (PI) as:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$$

Magnesium adsorption ratio (MAR) (Raghunath, 1987) was calculated as:

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Kelley's ratio (KR) (Kelley, 1963) described as:

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

All ionic concentrations are in milli equivalent per liter (meq/l).

3. Results and Discussion

3.1 General physico-chemical characteristics

If the anion-cation balance is less than 5%, the chemical analysis is assumed to be good. If the balance is much greater than 5% then the analysis is poor (inaccurate), other constituents are present that were not used to calculate the balance, the water is very acidic and the H^+ ions were not included in calculation, or organic ions are present in significant quantities (Hounslow, 1995). The anion-cation balances of all sample water in the current research work ranged from -24.59% to 3.39% which is less than 5% that indicates the accuracy of the experimental chemical analyses, absence of any other major chemical constituents, absence of high H^+ ion concentration and absence of significant amount of organic ions.

Geologic structure of the study area is such that extractable water in the *south* zone is found at the lowest depth of all. Average depths of the *north*, *center* and *south* zones sampled water were about 225 m, 249 m and 192 m, respectively. Temperature of all zones varied from 27.3 to 30.02°C. pH was slightly alkaline all over the study area ranging from 7.09 to 7.87. EC, TDS, Na^+, and Cl^- showed a wide range of variation. In parts per thousand (ppt) scale, the lowest salinity of 0 ppt was found at the *south* and the highest of 6.4 ppt found at the *north*. Average values of all parameters are shown in Table 1. Ca^{2+} and Mg^{2+} were present in high concentration in the *center* zone. Except for these two parameters, the spatial distribution for all other physico-chemical parameters showed a continuous decreasing trend from *north* to *south*. For example, Figure 2 shows spatial distribution of Na^+ and Cl^- in the study area where low concentration is found in the *south* zone.

3.2 Groundwater quality for irrigation purpose

According to DoE (1997), BWPCB (1976), WHO (2004) and UCCC (1974), temperature, pH and EC of all water samples are within acceptable limit of irrigation water quality (Table 1). TDS is important to be considered in the calculation of irrigation water quality, because many of the toxic solid materials may be imbedded in the water, which may cause harm to the plants (Matthess, 1982). In the absence of non-ionic dissolved constituents, TDS and EC are indicative of saline water (Michael, 1992). In terms of 'Degree of restrictions on use', TDS values <450, 450-2000 and >2000 mg/l represent the irrigation water as 'none', 'slight to moderate' and 'severe', respectively (UCCC, 1974). According to this standard, the *south* is classified as 'none,' and both *north* and *center* zones as 'slight to moderate'. Moreover, the *north* zone water samples also exceeded TDS standard of DoE (1997) and WHO (2004). In the case of salinity, the limit for agriculture irrigation water is 2 ppt (Engineering ToolBox, 2005) which is only found in the *south* zone.

EC and Na^+ play a vital role in suitability of water for irrigation (Rao, 2005). Soil containing a large proportion of Na^+ with HCO_3^- or Cl^-/SO_4^{2+} are turned alkaline or saline soil, respectively (Todd, 1980). Higher salt content in irrigation water causes an increase in soil solution osmotic pressure. Since plant roots extract water through osmosis, the water uptake of plants decreases. The osmotic pressure is propor-

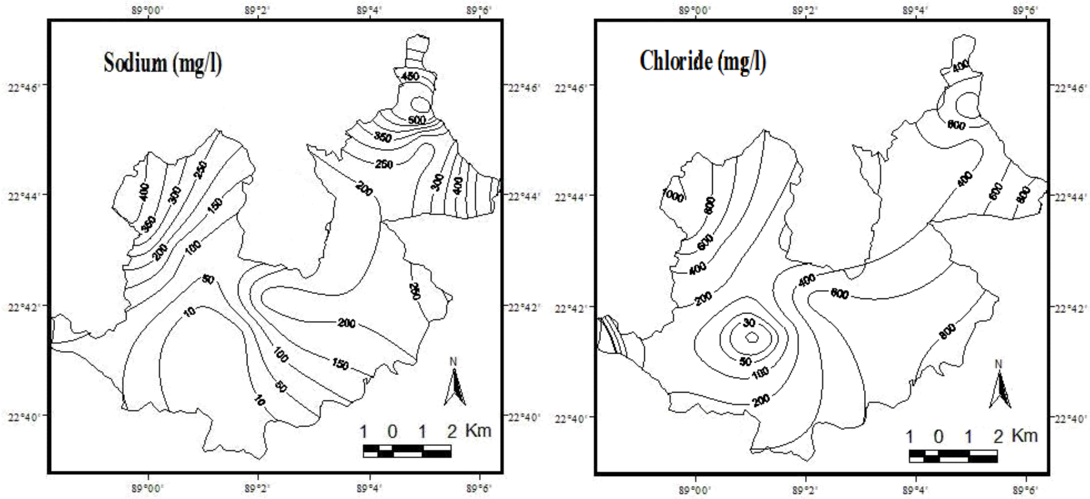

Figure 2. Spatial distribution of sodium and chloride in the study area

Table 1. Average values of the parameters of three different zones of the study area compared with different standards

Parameters	Sources				Zone of Study Area		
	DoE (1997)	BWPCB (1976)	WHO (2004)	UCCC (1974)	North	Center	South
Depth (m)					225.19	248.63	191.26
Temp. (°C)	20-30				27.84	29.07	28.1
pH	6.5-8.5	6.5-89.2	6.5-8.5	6.5-8.4	7.75	7.47	7.51
EC (µS/cm)	2250			700-3000	2082.11	1594.29	614
TDS (mg/l)	1000	1500	1000	450-2000	1098.38	905.39	250.9
Salinity (ppt)					4.79	3.13	0.65
Na^+(mg/l)	200		200	68-204	344.63	172.51	32.49
K^+(mg/l)	12				18.52	11.58	5.09
Ca^{2+}(mg/l)	75				47.98	90.24	48.14
Mg^{2+}(mg/l)	30-35		50		11.40	21.45	7.46
Cl^-(mg/l)	150-600	600	250	133	544.83	436.52	5.47
SO_4^{2-}(mg/l)	400	400	250		15.94	10.09	5.47
NO_3^-(mg/l)	10	45	50	5	14.80	12.81	4.56
HCO_3^-(mg/l)				91	278.69	169.92	197.21

tional to the salt content or salinity hazard. The salts, besides affecting the growth of plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. In addition, high Na^+ content can cause displacement of exchangeable Ca^{2+} and Mg^{2+} from the clay mineral of the soil (Matthess, 1982). According to Ayers and Westcot (1985), the *south* zone water is excellent for irrigation and other zones' water are good (Table 3). Again, the total concentrations of soluble salts in irrigation water can be classified into low (C1), medium (C2), high (C3) and very high (C4) salinity zones based on EC. These zones (C1 to C4) have values of EC of <250 µS/cm, 250 to 750 µS/cm, 750 to 2,250 µS/cm and >2,250 µS/cm, respectively (Rao, 2005). According to this classification, all samples from the *north* and *center* zones have been classified as high saline water. Only the *south* zone possesses medium saline water.

An important chemical parameter for judging the degree of suitability of water for irrigation is sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR). SAR measures the potential dangers posed by excessive sodium in irrigation water (Alagbe, 2006). The sodium hazard or SAR is expressed in terms of classification of irrigation water as low (S1: <10), medium (S2: 10 to 18), high (S3: 18 to 26) and very high (S4: > 26). A high SAR value implies a hazard of sodium (alkali) replacing Ca^{2+} and Mg^{2+} in the soil through a cation exchange process that damages soil

Table 2. Irrigation water indicative parameters of study area

Parameters	Mean		
	North Zone	Center Zone	South Zone
EC (µS/cm)	2082.11	1594.29	614
SAR	11.62	4.22	1.14
TDS (mg/l)	1098.38	905.39	250.9
SSP	82.21	52.63	32.95
RSBC (mg/l)	230.72	79.68	149.07
PI	94.16	68.02	77.93
TH (mg/l)	166.60	313.33	150.76
MAR	26.97	24.24	21.96
KR	4.62	1.28	0.48
Mg:Ca	0.44	0.40	0.29
Na:Ca	6.63	1.72	0.64

Table 3. Limits of some important parameter indices for rating groundwater quality and its suitability in irrigation use

Category	Groundwater quality indices*			Suitable for irrigation
	EC (µS/cm)	SAR	SSP	
I	<700	<10	<20	Excellent
II	700-3000	10-18	20-40	Good
III	>3000	18-26	40-80	Fair
IV	-	>26	>80	Poor

* According to Ayers and Westcot (1985), Todd (1980) and Wilcox (1955), respectively

structure, mainly permeability, and which ultimately affects the fertility status of the soil and reduces crop yield (Gupta, 2005). Seventy eight percent of samples from the *north* fall in the 'good' range and the rest of the samples from the *north* are in the range of 'excellent' (Table 3). All higher SAR values have been found at the *north* zone of the study area. *Center* and *south* zones possessed low SAR values. The *south* zone has the lowest SAR value. In a common trend, SAR value decreased toward the *south* (Figure 3).

The highest value of TH of 313.33 mg/l is found in the *center* and the lowest value of 150.76 mg/l in the *south* zone. According to the TH classification (Sawyer and McCarty 1967), the groundwater of *north* and *south* zones is hard (150–300 mg/l) and the *center* zone groundwater is very hard (>300 mg/l). Considering SSP, the *south* zone water is good, the *center* zone water is fair and the *north* zone water is poor for irrigation according to Wilcox (1955). Average RSBC of the study area varies from 79.68 to 230.72 mg/l and the average PI value varies from 68.02 to 94.16. Highest RSBC and PI are found in the *north* zone and lowest in the *center* zone. A positive RSBC value indicates that the contents of dissolved Ca^{2+} and Mg^{2+} ions is less that of CO_3^{2-} and HCO_3^- (Raihan and Alam, 2008). RSBC and PI are not satisfied in the study area. To be considered satisfactory, irrigation water should have RSBC value <5 mg/l (Gupta and Gupta, 1987) and according to Donen's chart PI <1 (Raghunath, 1987). However, in terms of MAR, irrigation water of all zones is

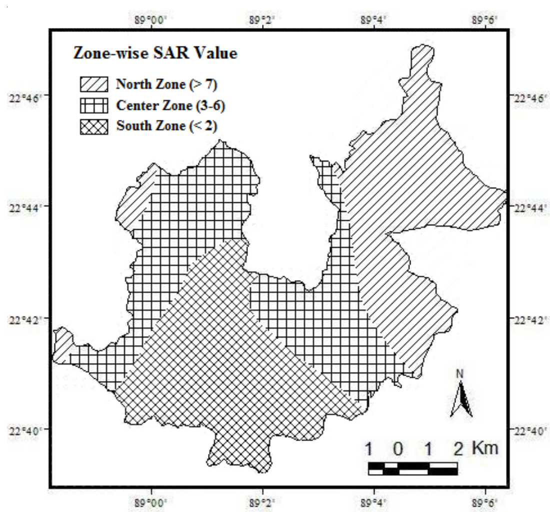

Figure 3. SAR value in *north*, *center* and *south* zones

acceptable. MAR causes a harmful effect when exceed a value of 50 (Gupta and Gupta, 1987). In present study area, average MAR ranged from 26.97 in the *north* to 21.96 in the *south*.

In the study area, average HCO_3^- value ranged from 2.78 meq/l in the *center* to 4.57 meq/l in the *north*. Irrigation water rich in HCO_3^- content tends to precipitate insoluble Ca^{2+} and Mg^{2+} in the soil which ultimately leaves higher proportion of Na^+ and increases the SAR value (Michael, 1992) as:

$$2HCO_3^- + Ca^{2+} = CaCO_3 + H_2O + CO_2 \uparrow$$

It has also been reported that, although ordinary HCO_3^- is not toxic, it can cause zinc deficiency in rice and this is severe when zinc exceeds 2 meq/l in water used for flooding growing paddy rice (Ayers and Westcot, 1985). However, Kelly (1963) suggested that KR for irrigation water should not exceed 1.0. Only groundwater of the *south* zone satisfies such a restriction; that means that a good balance of Na^+, Ca^{2+} and Mg^{2+} is present only in the *south* of the study area. This also indicates a good tilth condition of the soil of the *south* zone with no permeability problem.

At the same level of salinity and SAR, adsorption of Na^+ by soils and clay minerals is greater at higher Mg:Ca ratios. This is because the bonding energy of Mg^{2+} is less than that of Ca^{2+}, allowing more Na^+ adsorption and it happens when the ratio exceed 4.0 (Michael, 1992). Ayers and Westcot (1985) also reported that soil containing high levels of exchangeable Mg^{2+} causes an infiltration problem. In the study area, the ratio of Mg^{2+} and Ca^{2+} for all zones was less than 1.0 (Table 2). Thus, it indicates a good proportion of Ca^{2+} and Mg^{2+}, which maintains a good structure and tilth condition with no permeability problem of the soil of all zones. However, considering Na:Ca ratio, the *south* zone's groundwater showed high suitability as irrigation water. The presence of excessive Na^+ in irrigation water promotes soil dispersion and structure breakdown when Na^+ to Ca^{2+} ratio exceeds 3:1. Such a high Na:Ca ratio (>3:1) results in severe water infiltration problems, mainly due to lack of sufficient Ca^{2+} to counter the dispersing effect of Na^+. Excessive Na^+ also creates problems in crop water uptake, poor seedling emergence, lack of aeration, plant and root diseases etc (Ayers and Westcot, 1985). Only Na:Ca value of the *south* zone of the study was below 1:1 (Table 2), which indicates that only the groundwater of the *south* zone is suitable for crop production and should not create any of the problems mentioned above.

The US Salinity Laboratory's diagram is used widely for rating irrigation water where SAR is plotted against EC (Richards, 1954). Here, SAR is an index of sodium hazard and EC is an index of salinity hazard. In Figure 4, all of the *north* zone's water had both high to very high SAR and EC. Five out of 7 samples of the *center* zone possessed low SAR value but high EC. Three out of 4 samples of the *south* had medium salinity and low SAR. This water was most suitable for irrigation according to US Salinity Laboratory's diagram. Shirazi *et al.* (2011b) also reported that half of the deep aquifer of the northern parts of Bangladesh is also safe for irrigation as well as for drinking purpose in respect of SAR, SSP, EC, PI, KR, MR, arsenic and physic-chemical properties of water.

Wilcox's diagram (Wilcox, 1948) is especially implemented to classify groundwater quality for irrigation. Figure 5 can provide the apparent situation to understand the suitability of water for irrigation. Only 30% of all samples were excellent, good or fair. The other 70% samples were poor, very poor or unsuitable for irrigation. Within this 30%, most of the *south* zone water falls within excellent to good regions. Water of the *north* zone of the study area is very poor in quality. In the *center* and *south* zones, groundwater is more suitable for irrigation and the *south* zone contains the best water for irrigation. Geographically these zones are shown in Figure 3.

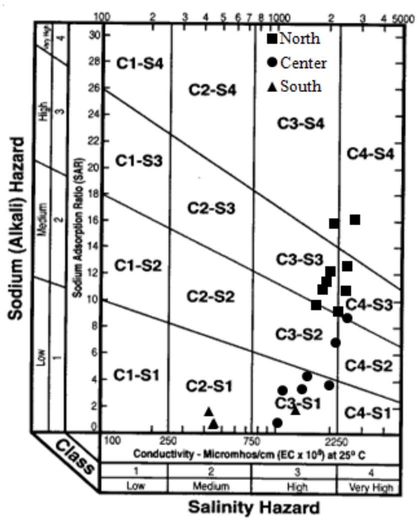

Figure 4. Sample water classification for irrigation according to US Salinity Laboratory's diagram (Richards, 1954)

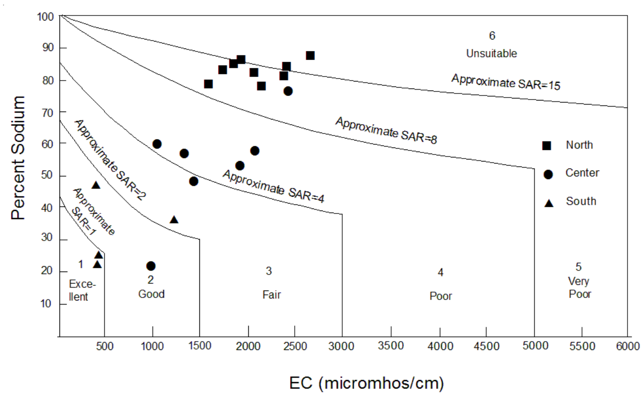

Figure 5. Wilcox's diagram for irrigation water classification (Wilcox, 1948)

4. Conclusion

Low chemical constituents in the *south* zone of the study area suggest that the southern region has the best water for irrigation. On the basis of EC, SAR, SSP, MAR, KR, Mg:Ca and Na:Ca, deep groundwater of the *south* zone has the best quality of all three zones.

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