APPRAISAL OF THE WATER QUALITY OF THE BLUE AND THE WHITE NILES FOR IRRIGATION USE

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SUMMARY

Water quality of the Blue and the White Niles for irrigation use during the year 1971 was appraised according to the United States Salinity Laboratory Classification System based upon EC and SAR. According to this system the water quality class for both Niles were found to vary from C_1–S_1 when the Niles were high to C_2–S_1 when the Niles were low.

Since the Niles contain considerable bicarbonate concentrations, they were classified according to the criteria suggested by Wilcox, *et al* (1954) which is based upon the residual sodium carbonate (RSC) concept introduced by Eaton (1950). The Blue Nile was found to contain a safe level of bicarbonate during the whole year. The White Nile contained an unsafe level in June, a marginal level in May, and a safe level during the rest of the year.

Eaton's RSC concept was compared with a modified Langelier's (1936) saturation index as indicators of indirect sodicity hazards. It was concluded that the saturation index is better than RSC for appraising HCO_3—bearing waters.

The prevalence of sodic soils in the Gezira plain was associated with the presence of positive saturation index.

INTRODUCTION

Irrigation waters are electrolyte solutions that are characterized by their concentrations, relative proportions of Na^+ on the one hand and (CO_3 + HCO_3) on the other hand to (Ca + Mg), and by the concentration of phytotoxic substances, i.e. Boron if present. The criteria used for appraising their quality include the following four water indices:

(*a*) Electrical Conductivity, EC which is indicative of the salinity hazard. Prolonged use of water of high salinity level leads to salinization of soils by repeated evapotranspiration if proper leaching of salt is not catered for.

(*b*) Sodium Adsorption Ratio, SAR defined as equal to $Na/\left(\frac{Ca + Mg}{2}\right)^{\frac{1}{2}}$ (where cation concentrations are expressed in me/l). Prolonged use of high SAR water augments the Exchangeable Sodium Percentage, ESP of the soil. The staff of the United States Salinity Laboratory, USSL (1954) established a linear relationship between SAR of the irrigation water and ultimate equilibrium ESP of the soil.

(*c*) Residual Sodium Carbonate. RSC defined by Eaton (1950) as equal to $(CO_3 + HCO_3)$—$(Ca - Mg)$ (expressed inme/l). He suggested that irrigation waters containing $CO_3 + HCO_3$ in excess of $Ca - Mg$ may cause the precipitation of $CaCO_3$. This precipitation reduces the potential salinity hazard but augments the sodium hazard by increasing indirectly the SAR of the water and consequently the ESP of the soil.

(*d*) The concentration of phytotoxic substances.

The RSC index has been questioned by several authors (e.g. Babcock, 1959; Kelley, 1962). The following modified Langelier's (1936) " Saturation Index ", SI was thus suggested by Pratt (1960), and Bower (1961) to indicate the tendency for calcium in the irrigation water to precipitate as $CaCO_3$.

$$SI = pH_s - pH_c \quad .. \quad .. \quad .. \quad .. \quad .. \quad (1)$$

where the pH of the soil. pH_s was substituted for the actual pH of the water given by Langelier. pH_c is the theoretical pH that the water would have if it were in equilibrium with $CaCO_3$. Positive values of the index indicate precipitation of $CaCO_3$ and negative values indicate dissolution of $CaCO_3$ from water. Langelier's equation for calculating pH_c from water analyses data is given below:

$$pH_c = (pK_2 - pK_s) + pCa + pAlk \quad .. \quad .. \quad (2)$$

where pK_2 and pK_s are the negative logarithms of the second dissociation constant for H_2CO_3 and the solubility constant of $CaCO_3$ respectively, both corrected for ionic strength. pCa and pAlk are the negative logarithms of the total concentration of Ca and of the equivalent concentration of titrable base $(CO_3 + HCO_3)$ respectively.

Bower *et al* (1965) working with twenty-three synthetic waters obtained the following empirical relationship between pH_c and the amount of bicarbonate, HCO_3 that precipitated from water upon saturation with $CaCO_3$ in a closed system.

$$\log \Delta HCO_3 = 8.93 - 1.24\,(pH_c) \quad (r = .94) \quad .. \quad (3)$$

Under arid and semi-arid conditions the appraisal of water quality for irrigation use is of prime significance. In Sudan the soils in the Gezira plain which have been irrigated for decades with the Blue Nile waters are vertisols that are sodic and calcareous (Finck, 1961). Previous studies by the staff of the Research Division, Ministry of Agriculture (Beam, 1908; Jewitt, 1955) led to the conclusion that the Blue Nile is of excellent water quality. This perhaps explains the lack of attention given to this subject matter later on. The purpose of this study is threefold: to compute water quality indices for the Blue and the White Niles in order to classify them according to recognized classification systems, to compare between two indices used for appraising the influence of bicarbonate in water, namely RSC and pH_c, and to discuss the influence of the Blue Nile quality on the formation of sodic calcareous Gezira Vertisols.

PROCEDURES

The water samples were collected from the two Niles at Khartoum at the beginning of each month during the year 1971. The monthly water analyses were carried out by the staff of the Chemical Laboratories, Ministry of Health. Their monthly routine water analyses sheet did not include data for Na and $CO_3 + HCO_3$. The determination of these ions were rendered available at the author's request. The methods used for water analyses were basically similar to those recommended by the United States Salinity Laboratory.

SAR and RSC were calculated from their equations given herebefore in the introduction. pH_c was calculated according to equation (2) $p(Ca + Mg)$ was substituted for pCa in the equation since the chemical behavior of Mg in soils is similar to that of Ca. pK_2 . pK_s was calculated according to the following defined Debye-Huckel equation corrected for ionic strength, u (Bower *et al*, 1965):

$$pK_2 - pK_s = (2.0269 + .5092 \left(\frac{4u^{\frac{1}{2}}}{1+2u^{\frac{1}{2}}} + \frac{u^{\frac{1}{2}}}{1+1.45u^{\frac{1}{2}}} \right) \quad .. \quad (4)$$

The number 2.0269 is the difference between pK_2 and pK_s using $K_2 = 4.7 \times 10^{-11}$ and $K_s = 5.0 \times 10^{-9}$. The ionic strength of water was calculated from the total cation concentration, C by the following regression equation obtained by Bower *et al* for 200 natural waters.

$$1000u = 1.3477\ C + 0.5355\ (r = .99) \quad .. \quad .. \quad .. \quad (5)$$

The reliability of this equation was tested by using the following relationship:

$$u = \tfrac{1}{2} \sum_i Z_i^2 C_i \quad .. \quad .. \quad .. \quad .. \quad .. \quad .. \quad (6)$$

where Z_i and C_i are the valence and concentration (me/l) of the ion respectively.

ΔHCO_3 was calculated according to equation (3).

Average EC values for low and high Niles were calculated for the six years, 1961, 63, 65, 67, 69 and 1971. The Niles were considered to be high during four months: July, August, September and October, and low during the rest of the year.

Table 1.—Water analyses data for the Blue Nile (BN) and the White Nile (WN) during the year 1971

Month		Ca + Mg	Na (me/l)	Total cation* concentration	$CO_3 - HCO_3$
January	BN	1.66	0.22	1.88	2.22
	WN	1.57	1.30	3.20	2.34
February	BN	1.82	0.30	2.20	1.86
	WN	1.57	1.17	3.12	2.61
March	BN	2.32	0.44	3.14	1.93
	WN	1.82	1.52	3.73	2.93
April	BN	3.32	0.33	3.96	3.00
	WN	2.48	1.63	4.24	2.10
May	BN	2.57	0.54	3.75	3.55
	WN	2.23	1.74	4.23	3.75
June	BN	3.23	0.54	3.90	3.00
	WN	1.57	1.09	3.04	4.10
July	BN	4.71	1.30	6.53	1.80
	WN	2.32	0.65	3.61	2.36
August	BN	1.65	1.30	3.46	1.96
	WN	1.14	0.87	2.27	2.16
September	BN	1.41	0.22	2.14	1.60
	WN	1.32	1.09	2.79	2.05
October	BN	1.41	0.44	1.97	1.46
	WN	1.16	1.09	2.63	2.26
November	BN	2.07	0.44	2.63	1.41
	WN	1.56	0.87	2.69	2.02
December	BN	1.82	0.44	2.38	1.86
	WN	1.57	1.74	3.57	2.20

*Ca + Mg + Na + K.

Table 1 gives the water analyses data for the two Niles that was used in the calculation of SAR, RSC, and ΔHCO_3.

Salinity hazard

The monthly variation of the electrical conductivity, EC of the waters of the White and the Blue Niles is presented in Figure 1. It is evident that the White Nile was more saline than the Blue Nile for the whole year with the exception of July and August when their salinity level was more or less the same. The results indicated seasonal variations in the salinity level for both Niles.

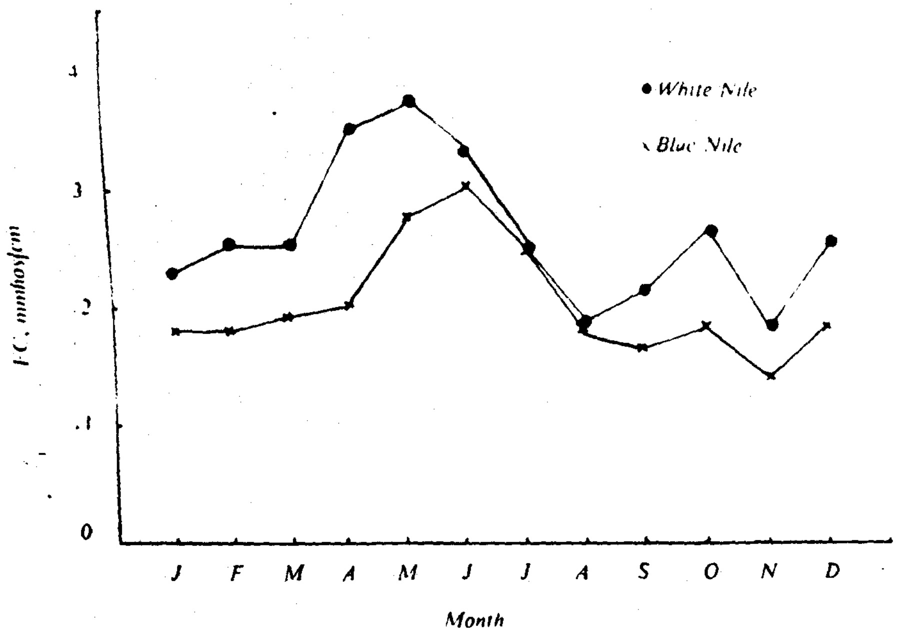

Figure 1—The Electrical Conductivity, EC of the Blue and the White Niles during the year 1971. Months are in consecutive order.

Direct sodicity hazard

The monthly variation in the SAR of the two Niles is shown in Figure 2. It can be seen that for ten months the SAR of the White Nile water was higher than that of the Blue Nile. In July the SAR of the Blue Nile approached that of the White Nile. Whilst in August the Blue Nile water rendered a SAR value higher than that of the White Nile. In December the White Nile water gave the highest SAR value which was 1.96 $(me/l)^{\frac{1}{2}}$. This was four fold that of the Blue Nile. The latter gave the highest SAR value equal to 1.44 $(me/l)^{\frac{1}{2}}$ in August.

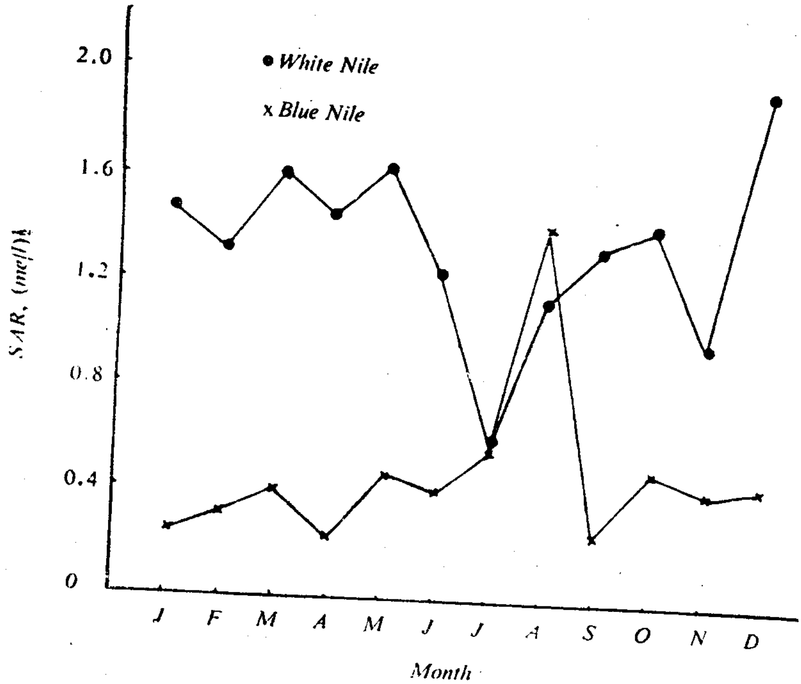

Figure 2.—The Sodium Adsorption Ratio, SAR of the Blue and the White Niles during the year 1971. Months are in consecutive order.

Indirect sodicity hazard

(i) RSC index. Figure 3 shows the monthly variations of both RSC and pHc for both Niles. Waters containing Ca+Mg in excess of CO_3+HCO_3 were considered to have zero RSC indicating absence of the indirect hazard. For positive RSC values the White Nile gave a higher RSC value than the Blue Nile for the whole year except in November when the latter rendered a slightly higher RSC value than the former. In four months, March, April, June and July the Blue Nile water did not give a positive RSC. The highest RSC value equal to 0.98 me/1 was obtained in May. For the White Nile, only in April was the water free of the indirect sodicity hazard. In May the residual sodium carbonate was such that 1.2 RSC 2.5. In June RSC was greater than 2.5. For the rest of the year the RSC was less than 1.2.

The results indicate seasonal variations of RSC for both Niles

(ii) pHc index. Except in March and April pHc values for the two Niles were slightly different. In January, May. June, July, August and December pHc values for the White Nile were slightly greater than those for the Blue Nile. In February, September, October, and November the reverse occured. In March and April the pHc values for the White Nile were seven or four per cent respectively higher than those of the Blue

Nile. The pHc for both Niles were higher for seven months from August to February than in the remaining five months. The average pHc for the seven months was 8.0 for both Niles. Whereas the average pHc for the other five months were 7.5 and 7.7 for the Blue and the White Niles respectively. It is evident that RSC showed more seasonal variations than pHc.

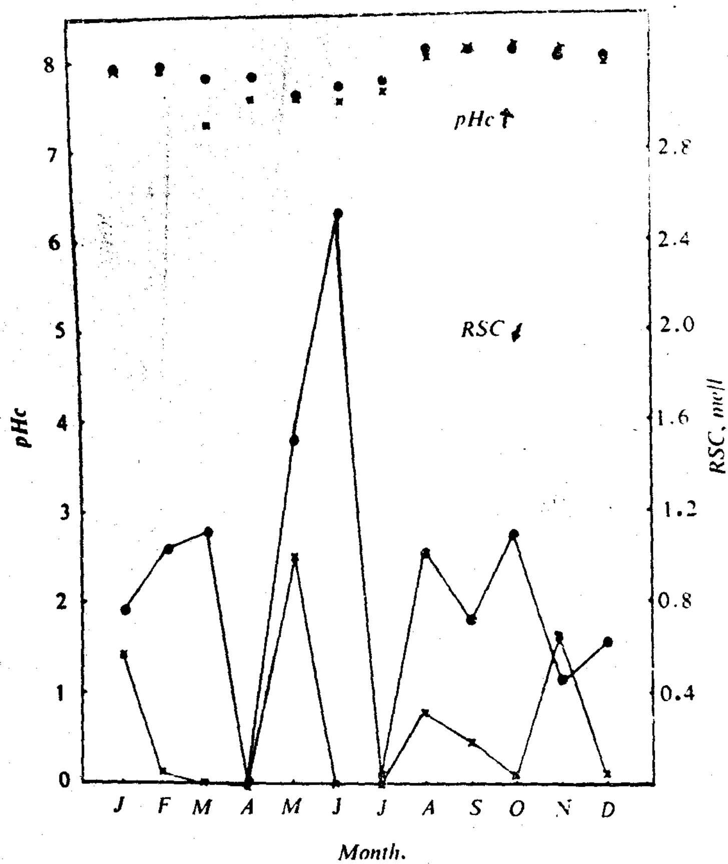

Figure 3.—pHc and RSC monthly variations for the Blue and the White Niles during the year 1971. Months are in consecutive order.

Figure 4 indicates the monthly variations in ΔHCO_3 for both Niles. Unlike pHc, ΔHCO_3 reflects the relative amounts of the bicarbonate in water that would precipitate. Seasonal variations similar to those obtained for pHc were found. However more seasonal variations were indicated by ΔHCO_3 than by pHc.

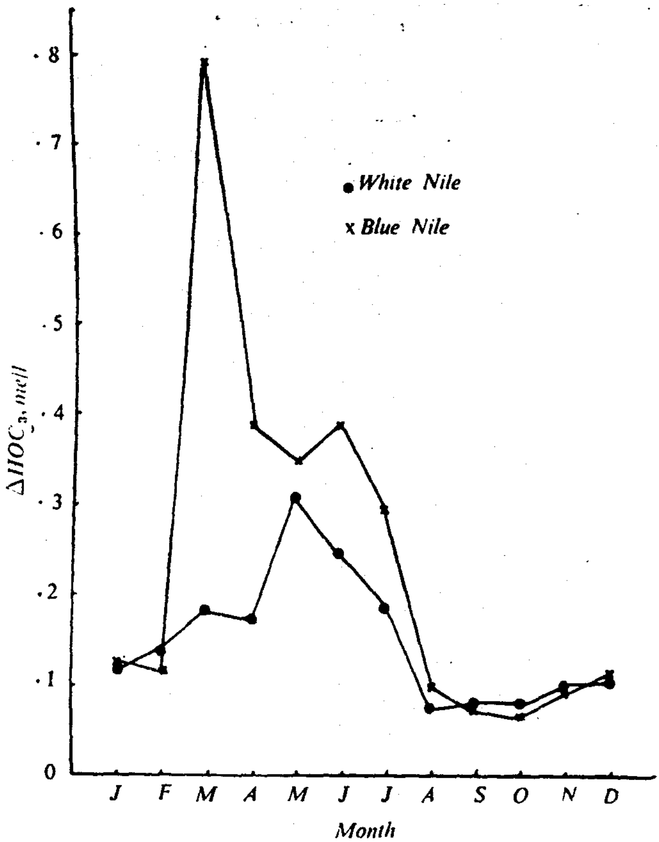

Figure 4.—ΔHCO_3 monthly variations for the Blue and the White Niles during the year 1971. Months are in consecutive order.

Classification

The quality of the waters for irrigation use was appraised according to the United States Salinity Laboratory Classification System based upon EC and SAR. As regards the influence of the bicarbonate the waters were classified according to the criteria of Wilcox, *et al.* (1954). According to USSL classification system the Blue Nile's water for the whole year was of low salinity level, c_1 (EC <250 umho/cm) except in May and June when it was of medium salinity level, C_2 (250 <EC <750 umho/cm). In July the EC was equal to 250 umho/cm which is the lower limit of the medium salinity water. The White Nile water was of low salinity level during the year except in April, May and June when it became of medium salinity level. However in February, March, July, October and December the EC of the water was equal to 250 umho/cm. With regard to the direct sodicity hazard both the White and the Blue Niles' waters are low sodium waters, S_1.

According to Wilcox *et al* system the Blue Nile's water contained a safe level of bicarbonate (RSC < 1.2 me/l) throughout the year. The White Nile's water contained an unsafe level of bicarbonate in June (RSC > 2.5 me/l), a marginal level in May (1.2 < RSC < 2.5 me/l), and a safe level during the rest of the year.

Figure 5 indicates the annual variations in the salinity level of the two Niles.

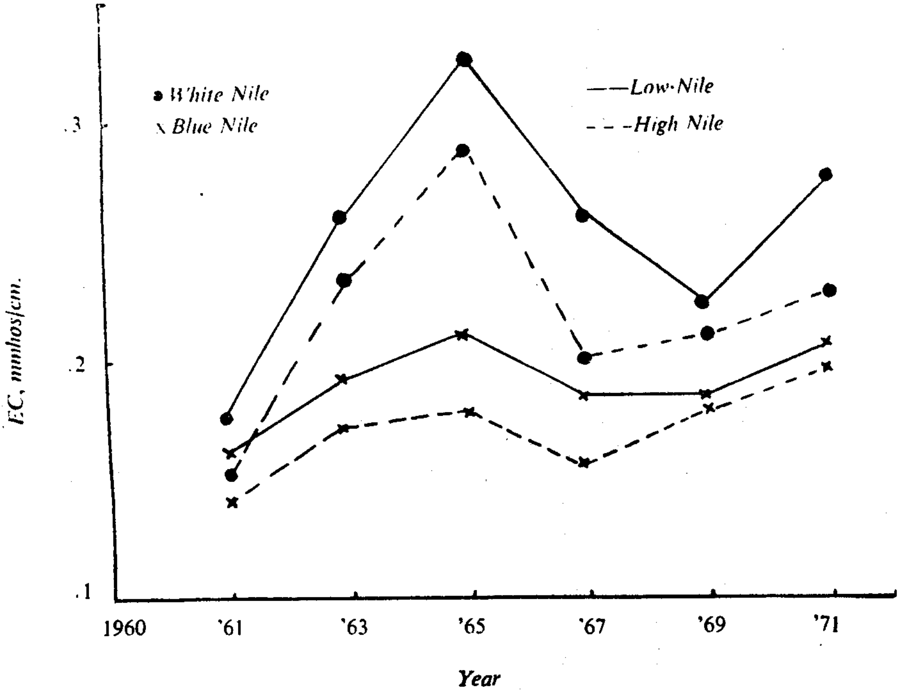

Figure 5.—The annual variations in the Electrical Conductivity, EC of the Blue and the White Niles for six years.

DISCUSSION AND CONCLUSIONS

According to the United States Salinity Laboratory Classification System the water quality class for both Niles varies from C_1–S_1 when the Niles are high to C_2–S_1 when the Niles are low. The White Nile is generally more saline than the Blue Nile. Although the waters are of low salinity level during most months of the year some leaching is required especially in the Gezira soil where the soil water conductivity is extremely low (Greene, 1928b; Zein El Abdein & Stremcki, 1970). This leaching is essential if the gradual development of soil salinity is to be evaded in the long future. Eaton (1950) reported that the Tigris' water though of medium salinity caused the salinization of millions of acres of once non-saline irrigated lands in Iraq. This was attributed to lack, at that time, of proper reclamation programs.

The direct sodicity level constitutes no immediate danger since the greatest SAR values attained by the White and Blue Niles were 1.96 and 1.44 $(me/l)^{\frac{1}{2}}$ respectively. The maximum permissible SAR value of a water classified as C_2–S_1 is 6. However the initial SAR index is not enough for appraising the sodicity hazard of HCO_3-bearing waters. This necessitated the use of indirect sodicity indices namely RSC and pH_c.

While it is generally accepted that the use of HCO_3-bearing waters will augment the initial SAR of the water and the ultimate equilibrium ESP of the soil, there are differences in opinion regarding the reactions involved. Eaton (1950) and Bower *et al* (1965) among others argued that this increase in SAR is a consequence of $CaCO_3$ precipitation according to the following reaction:

$$Ca + 2HCO_3 \rightleftharpoons CaCO_3 + CO_2 + H_2O$$

Babcock *et al* (1959) attributed it to cation dilution effect and possible production of $(CaOH)^+$ and $(MgOH)^+$ species by the following reaction:

$$Ca + HCO_3 + H_2O \rightleftharpoons (CaOH)^+ + H_2CO_3$$

Again Eaton (1950) visualized the formation of Na_2CO_3 and hence he suggested the RSC concept. Whereas Kelley (1962) predicted the formation of $NaHCO_3$ due to the continued presence of CO_2 in the soil solution resulting from $CaCO_3$ precipitation, root respiration and microbiological processes. He concluded that the expression of Residual Na_2CO_3 is a misnomer.

According to Wilcox *et al* (1954) classification system based on RSC values, the Blue Nile contained a safe level of bicarbonate throughout the year. The White Nile contained a safe level of bicarbonate throughout the year except in June and May when it contained an unsafe and a marginal level respectively. No similar classification system based on saturation index has been suggested. Pratt *et al* (1960) found a significant linear correlation coefficient ($r = 0.91$) between the modified saturation index and the amount of HCO_3 precipitated. The amount precipitated depended upon several factors, i.e. amount of leaching, the removal of calcium in harvested crops, calcium added from fertilizers and amendments and type of crop.

This study indicates that the greatest pH_c equal to 8.2 was rendered by the Blue Nile water in October. The pH of most soils in the Gezira plain is greater than 8.2 (e.g. Greene, 1928a). This suggests that a positive saturation index can be obtained for the two Niles and most soils in the Gezira. It is interesting to note that ΔHCO_3 computed for all waters was positive. This ΔHCO_3 may prove a valuable water index suitable for appraising indirect sodicity hazard for HCO_3-bearing waters.

It is evident from Figure 3 that RSC index may lead to a totally different conclusion from pH_c index regarding the tendency of HCO_3-bearing waters to precipitate $CaCO_3$. It can be seen that waters with widely different RSC values rendered similar pH_c values. For example the White Nile water in June with an unsafe RSC level rendered a pH_c value similar to that of the Blue Nile water with a safe RSC level.

In view of the objections raised against RSC index and to the fact that it does not take the soil pH into account one is inclined to prefer the use of the modified saturation index especially for waters with no RSC values.

Eaton (1950) attributed the prevalence of black alkali soils in the Nile valley in Egypt to the presence of residual sodium carbonate in the Nile. This may be the cause of the prevalence of sodic vertisols in the Gezira plain, since the Blue Nile contained positive RSC values during most months of the year. It has been implied herebefore that the modified saturation index is a better parameter indicative of the formation of sodic soils.

Wilcox *et al* classification system based upon RSC index is indeed tentative in view of the variety of factors that influence the extent of carbonate precipitation from irrigation waters (Pratt *et al*, 1960; Bower & Wilcox, 1965). A safe RSC level in a given water used to irrigate a soil under a given set of conditions may be unsafe for another soil under different unfavourable set of conditions. Until carbonate precipitation approaches quantitativeness, the presence of RSC or better still a positive modified saturation index should be considered as a warning that the build up of soil sodicity should be checked through proper management practices.

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