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SPATIO-TEMPORAL GROUNDWATER LEVEL FLUCTUATIONS AND QUALITY AT KANO RIVER IRRIGATION PROJECT

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ABSTRACT

Continuous monitoring of soil and soil water conditions is important in controlling the salt build-up in irrigated fields and should be adopted as strategies to maintain and improve the salinity status in irrigation schemes. The problem of salinity and sodicity in the Kano River Irrigation Project (KRIP) is so intense that crop production is inhibited by the effect of salt. A study was conducted to investigate the sources of salinity and sodicity in the irrigation scheme. One hundred and twenty-six piezometric wells were installed to cover the entire 22,000 ha in the scheme to monitor groundwater for twenty-four months. Groundwater samples were taken during the dry and rainy seasons for water quality and salt content analyses. Data obtained were plotted to indicate the behaviours of the groundwater fluctuation. Results show water table fluctuations annually and were influenced by the rainfall during the rainy season. However, strong relationship exists between the rainy season and the irrigated areas concerning groundwater level fluctuations because groundwater level rises close to the surface during the rainy season, especially in areas where intensive irrigation happens. Though the water level rose to about 1 m to the ground surface, no part of the scheme had water risen to the surface. When groundwater level rose to 1m below the surface, there was a tendency for the water to reach the porous zone by piezometric force. This resulted to salt influx within the root zone and rose to the surface. Groundwater quality indicated a significant amount of Exchangeable Sodium Percentage (ESP) of 60% in some areas and this explains why the scheme had more sodic soils. Less than 25% of the soils in the scheme were saline, and fewer than 10% of the area had severe salinity cases. Therefore, sodicity is the most common salt problem, covering up to 75% of the salt-affected soils in the areas.

KEYWORDS: Soil Salinity Monitoring, Kano River Irrigation Project (KRIP), Groundwater Fluctuations, Exchangeable Sodium Percentage and Sodic Soils.

1.0 INTRODUCTION

Salt is a chemical substance that can dissolve in soil water (Suarez and Taber, 2007). It is usually mobile in the soil and potentially most damaging to crops. Salts are a huge concern in semi-arid and arid soils. They accumulate from irrigation water, but they concentrate due to evapotranspiration (ET). Salts are not a concern where precipitation significantly exceeds evapotranspiration, but is prominent in the dryland areas.

The process by which soluble salts accumulate in soils where drainage through the soil is poor and where water ponds and evaporates is called salinization. Under soil salinization, shallow water tables allow salty groundwater to move upward and deposit salts due to evaporation. Salinization can also occur when irrigation water containing high levels of soluble salts is applied to the land over a prolonged period (Sarwar and Adnan, 2015). Soil salinization resulting from shallow saline groundwater is a major global environmental issue causing land degradation, especially in semi-arid regions. The adverse impact of shallow saline groundwater on soil salinization varies in space and time due to the variation in groundwater levels and salt concentration. Understanding the Spatio-temporal variations of the groundwater behaviour and quality is therefore vital development for effective sodicity and salinity management strategy.

Saline soils are soils with a high enough concentration of soluble salts to impair crop growth. Sodic soils have a high level of exchangeable sodium (Na^+), and low levels of soluble salts and have a negative effect on crop growth and yield. Water salinity is classified according to the concentration of salt. Groundwater salinity concentrations can be measured on-farm using a salinity meter, expressed as electrical conductivity (EC). Groundwater can be a valuable source of irrigation supply. It can boost farm productivity by supplementing surface water supplies. However, where the groundwater quality is not suitable for crop growth, management may be required, depending on the water quality level (Udoh, 2016). Poor groundwater quality due to salt conditions can be brought into the root zone due to the piezometric effect (Panwar and Adnan, 2015).

Salt-affected soils generally occur in arid and semi-arid climates where precipitation is not adequate to leach salts, causing them to remain in the soil profile (Rengasamy, 2006). Salts will build up over time if water cannot leach it out of the soil profile. Soil salinity/sodicity is one of the most damaging environmental problems worldwide occurring in arid and semi-arid regions where leaching of the profile is highly restricted (Allbed and Sinha, 2014). Salt-affected soils represent a major challenge to agriculture and the environment, they are widely distributed throughout the world (Mastrocicco and Colombani, 2021). A considerable area of land globally is becoming unproductive every year because of soil salinity and sodicity problems (Asmamaw et al., 2018). Excess soluble salts in the root zone reduce plant growth through either osmotic stress or specific ion toxicities. These salt-affected soils develop from a wide range of factors including soil type, field slope and drainage, irrigation system type and management, fertilizer and manuring practices, and other soil and water management practices. Even though closely related and had many characteristics in common, soil salinity and sodicity are two different problems, which should be dealt with differently and require slightly different management practices (Udoh et al., 2016).

Due to increased demand for food by the increasing world population, irrigated agriculture presently accounts for about one-third of the world's production of food and fiber, and it is anticipated that the demand will triple by nearly 50 percent by the year 2040 (Udoh et al., 2016). This will likely create some difficulties because extensive areas of irrigated land have been and are increasingly becoming degraded by salinization and waterlogging resulting from over-irrigation and other forms of poor agricultural management. Therefore, this study is aimed at assessing the groundwater quality in terms of salt build-up and fluctuations within the Kano River Irrigation scheme, given that salinity control and monitoring would not be complete without understanding the groundwater fluctuation.

2.0 METHODOLOGY

A study was conducted at Kano River Irrigation Project, located between latitudes 11°32`N and 11°51`N and longitudes 8°20`E and 8°40`E within the Sudan savannah zone of Northern Nigeria. Average annual rainfall in the area ranges from 635 to 889 mm, about 60% of which falls in July and August and varies considerably from year to year (Maina, et al, 2012) within the area.

2.1 Monitoring Groundwater Fluctuations

Boreholes were drilled for monitoring water table fluctuations and assessment of groundwater quality to detect its influence on the lingering salinity problem in KRIS. Local wash bore system which involved the use of portable hand drilling equipment was used to drill the wells. Each well was driven to a depth of 6.0 m. Standpipes stabilized with cement at the base were installed and an end plug was used to cover it to prevent rainwater and other foreign materials from entering the well. The wells were labelled for identification and the coordinates, as well as the sectors, were also recorded for easy identification and sample collection. A total of one hundred and twenty-six piezometric wells were installed across the entire 22000 ha of KRIS to monitor groundwater fluctuation**.** Monitoring of the groundwater fluctuation from piezometric wells was done monthly for two consecutive years. Data on the water table fluctuation were collected and recorded at the end of every month. The water table depth was measured using an infrared meter from the ground surface.

Fig. 1: Piezometer well for monitoring groundwater fluctuation.

2.2 Water Sample Collection and Analysis

Irrigation water samples were collected from the upper, mid, and lower stages of the downstream such that water reaching all the sectors were sampled. At each sampling point, three samples were taken from canals supplying different sectors. Forty samples of water were taken with 75 cl plastic bottles and properly labelled. The bottles used were properly washed and rinsed 3 times with distilled water and then with the sample water and stored immediately in a plastic cooler. The samples were conveyed to the Centre for Dry Land Agriculture at the Bayero University, Kano for laboratory analyses. The samples were analysed for chemical parameters such as organic carbon, EC, pH, Ca, Mg, K, Na, CO_3 and HCO_3. These analyses were carried out for all the samples collected in four batches in each year for both dry and wet seasons. From the results obtained sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) were calculated as follows:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \ldots\ldots 1.$$

$$ESP = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \ldots\ldots 2$$

Where SAR represent the sodium adsorption ratio and ESP the exchangeable sodium percentage.

All data obtained were subjected to statistical analysis using descriptive statistics. GIS software was used to map the area based on the data obtained. The area was grouped into classes based on the equal interval method of classification with the GIS software. The frequency distribution of each variable predicted was used for the distribution of each class in terms of area in hectares and percentage covered with the groundwater within the study area**.** The classes were presented in the legend of the maps indicating the total area covered under each of the classes, giving the range with upper limit and the lower limit.

3.0 RESULTS AND DISCUSSION

3.1 Groundwater Fluctuation

The Spatio-temporal groundwater fluctuation monitored and recorded for two years indicated that the ground levels had a definite trend pattern. The fluctuation varied over the years in the same pattern. Water table began to increase from May and rose gradually to its peak in September where it declined in April of the following year. This trend was repeated for the second year and expected to repeat the same pattern into the subsequent years. The rising and falling of the water table pattern followed the seasons, which indicated that the rainy season contributed to the rising water table level, since the pattern increased in the groundwater level during raining season and decreased during the dry season. The result indicates that the water level increases as rainfall intensifies during the rainy season. Rainfall in this area reaches its peak in August which influences the water table to rise to its peak in September (Fig. 3.1).

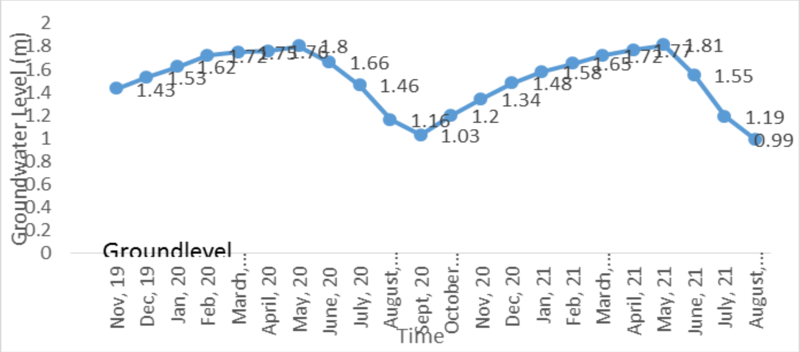
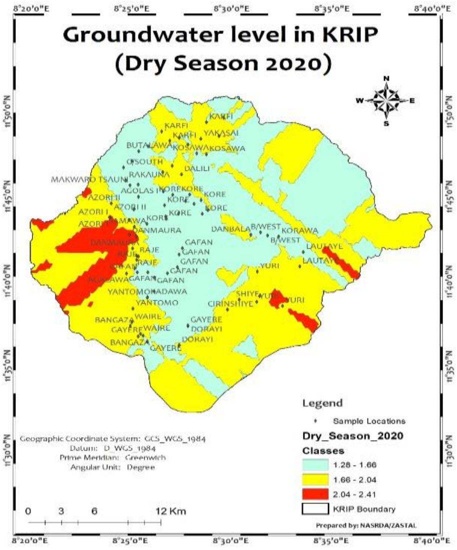


Fig. 3.1 Groundwater level fluctuation.

3.2 Water Level Mapping and their Influence on Root Zone

The rising water table plotted in the form of Map by the Kriging method to display the spatial distribution across the entire area is presented in Figure 3.2 and 3.3 for the dry seasons of the year 2020 and 2021, respectively. The water table was high in areas where irrigation activities were taking place, whereas areas especially the western part of the scheme showed low water table as well as the extreme eastern part of the scheme.

The pattern of the groundwater table in the rainy season is presented in Fig. 3.4 and 3.5. Unlike the dry season, the wet season had generally high groundwater levels in almost the entire scheme. However, like the dry season, the western part of the scheme still had a low water table. This was because there were few irrigation activities taking place in the western part of the scheme during the period of the study. The fact remains that the water table was high within the area where irrigation activities were taking place.



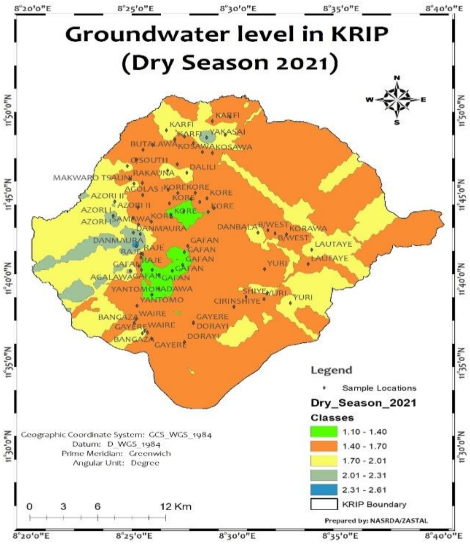
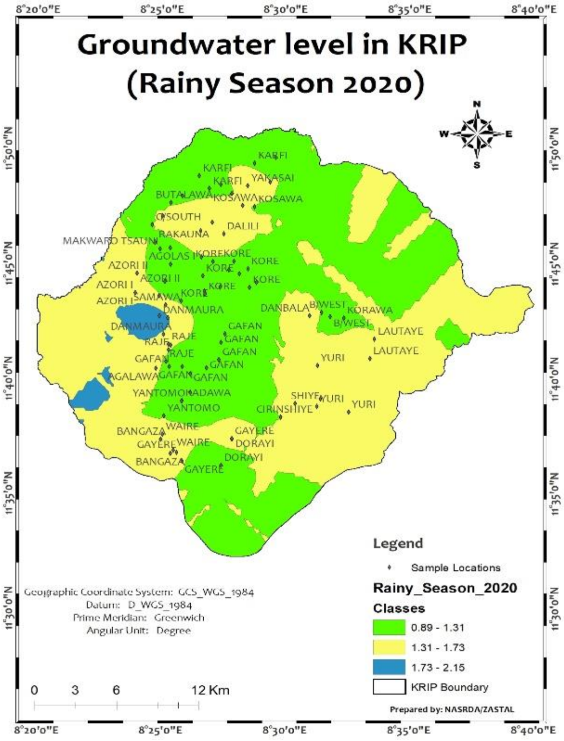


Fig. 3.2: Groundwater levels in dry season-2020 Fig. 3.3 Groundwater level in dry season- 2021.

The interaction between the irrigation activities and the rainy season brought the water table of the areas under irrigation as close as 1 m to the surface. When the water table had reached 1 m below the surface, there was an inflow of moisture due to capillary rise into the root zone which resulted to salt built up within the root zone. The surface of the soils in the area cannot be categorically stated that dissolved salt in the groundwater contributed to the salt accumulation. This and many related questions may be answered only when other experiment(s) is/are carried out to determine the rate of salt inflow into the root zone. It was not also clear as to what extent water moved by capillary rise.



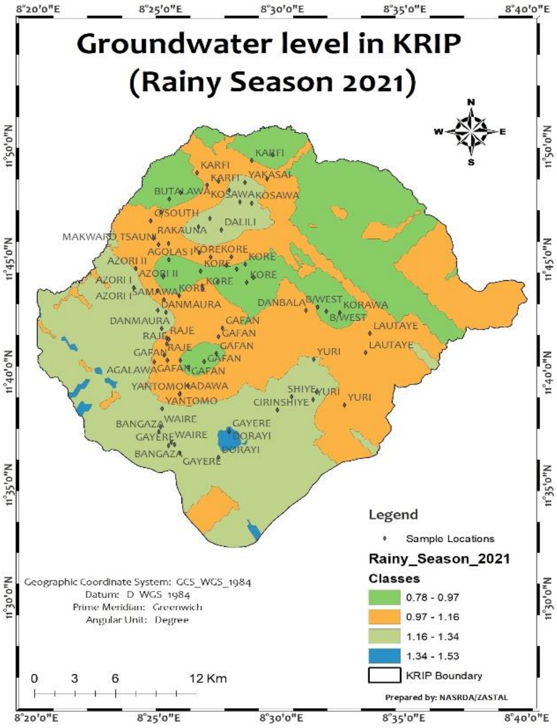


Fig. 3.4 Groundwater levels in rainy season-2020 Fig. 3.5 Groundwater levels in dry season-2021.

3.3 Groundwater Quality Mapping in KRIS

The results for the water quality assessments are presented in Tables 1 to 6. The data in the tables were used for plotting the EC and ESP values on maps in Figure 3.6 and 3.7, while prediction measurement errors were shown on Figure 3.8 a, b and c and Figure 3.9 a, b and c. Using the Geostatistical Analyst tool of GIS (ordinary kriging), different variable measurement values were interpolated to predict maps of spatial variability and the probability of their distribution in the study area.

In Figure 3.6 the salinity distribution in the irrigation project showed mild salinity level, with very few places having a severe concentration of salinity. The groundwater EC value higher than 4 dS/m, above the threshold for most plant growth, was observed in the northern part of the scheme, and the soil making the soil to be saline. The extent of coverage was not significant, since few areas were involved. However, where the EC value was observed to be below 4 dS/m and ESP of 15% and above, the soil was considered to be sodic (Fig. 3.7). The ESP distribution in the area showed that more than 80% of the salt problem in irrigation scheme was due to sodicity. Sodicity tended to be the major problem affecting Kano River Irrigation Scheme, which was also evident from the kriged map. The sodicity was severe at the western part of the scheme, with ESP values above 60%. Most of the active irrigation areas have moderate severity to sodicity which indicated that the area under cultivation, especially by irrigation practices increases the effect of salt. This salinity and sodicity of the groundwater might have contributed to the salt build-up within the scheme.

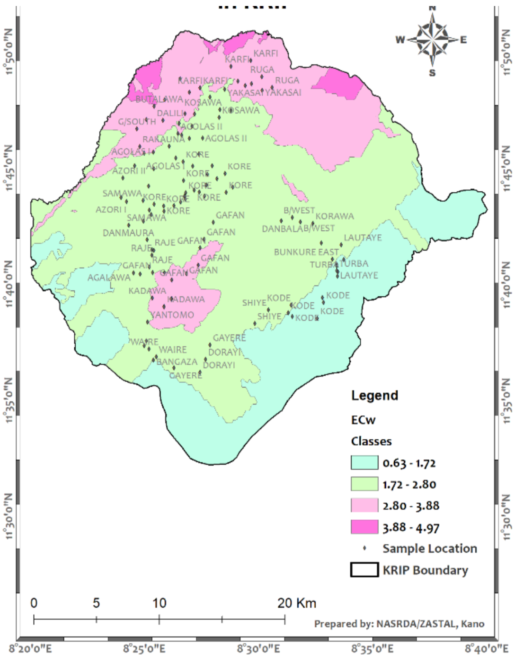


Fig. 3.6: Groundwater EC distributions.

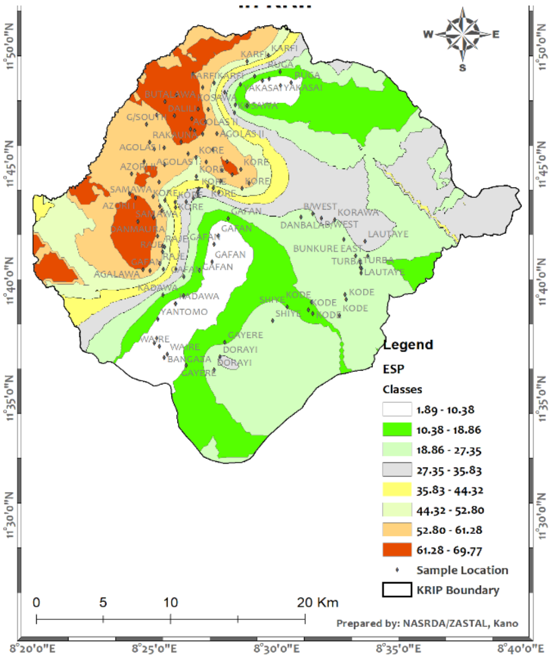


Fig. 3.7: Groundwater ESP distributions.

Whether the groundwater rises to the surface or not the fact that groundwater contained some level of dissolved salt. Also, groundwater raised to about 1 m to the surface had tendency of transmitting the salt to the root zone. However, the argument remains whether the dissolved salt was because of parent materials dissolving into the water and raised by capillarity, as a result of the fresh irrigation water added to the surface during irrigation that might have contributed to the groundwater salt concentration, or as claimed by some researchers that fertilizers and chemicals added to the soil also caused salts problem.

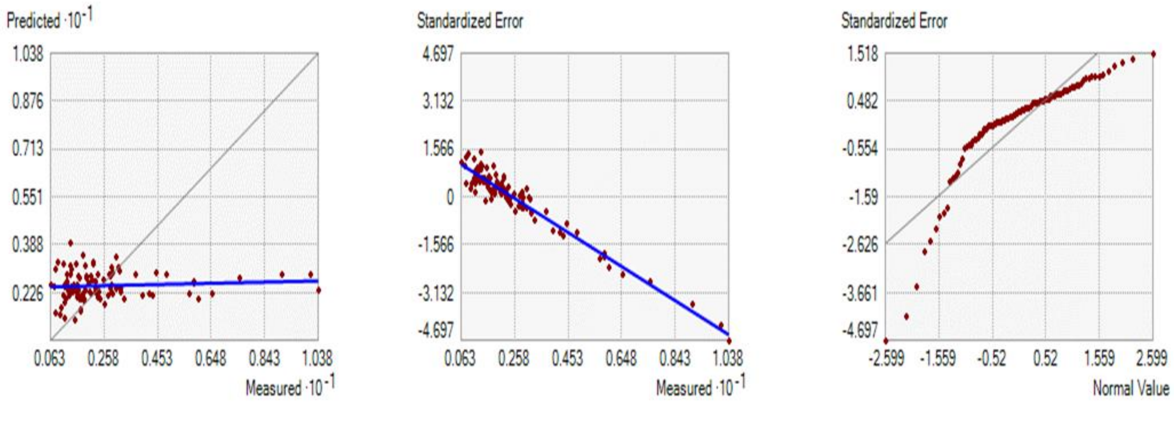
Table 3.1: Descriptive Statistics for Salinity (EC).

Prediction Errors	**Value**
Samples	107 of 107
Mean	0.036812704
Root-Mean-Square	1.815393098
Mean Standardized	0.023151319
Regression function	0.0204786517656348 * x + 2.43897163344936

Table 3.2: Descriptive Statistics for Salinity (ESP).

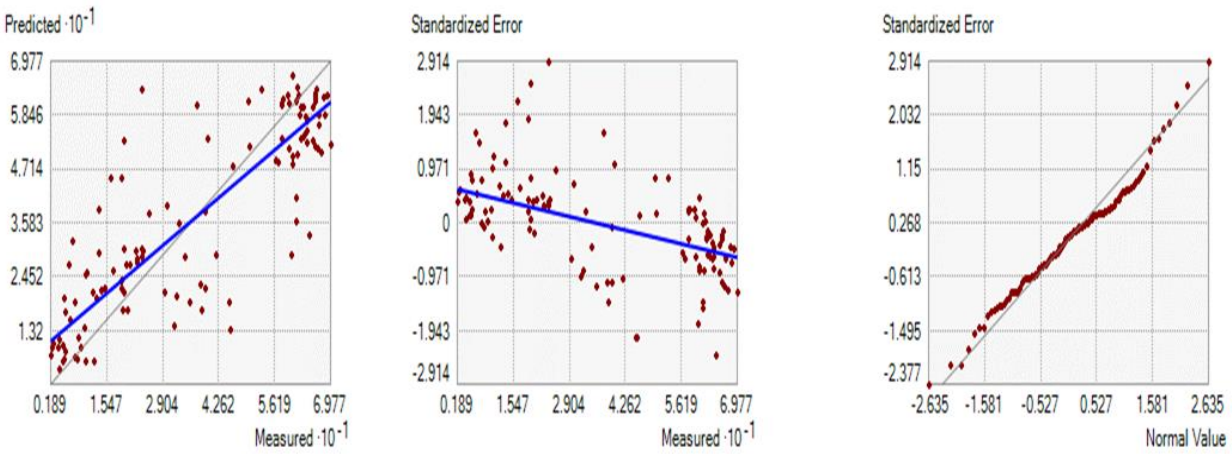
Prediction Errors	**Value**
Samples	119 of 119
Mean	-0.134796978
Root-Mean-Square	12.69797385
Mean Standardized	-0.00571532
Root-Mean-Square Standardized	0.89574714
Average Standard Error	14.4442463
Regression function	0.73980201207397 * x + 9.56825549486295

Tables 3.1 and 3.2 and Figures 3.8 and 3.9 present the descriptive statistics and prediction measurement errors; predicted error, standardized error, and the normal value as in the QQ-plot. These measurements indicated the data integrity, the prediction of the Kriging method qualifies to be used in this regard and the results are acceptable by these indices.



a- predicted error b- standadized error c- normal QQ-plot

Figure 3.8: prediction measurement errors for EC.



a- predicted error b- standadized error c- normal QQ-plot

Fig. 3.9: Prediction measurement errors for ESP.

3.4. Parameter Distribution and Classifications

A different number of classes were considered for each variable based on the equal interval method of classification with GIS software. The frequency distribution of each variable predicted (Table 3.3 and 3.4) showed the distribution of each class in terms of area in hectares and percentage covered with the groundwater within the study area**.** The classes were presented in the legend of the map indicating the total area covered under each of the classes, giving the range with upper limit and the lower limit.

Table 3.3: The area and percentage of each class obtained for Salinity (ECw).

Classes	Min. value	Max. value	Area (ha)	Area coverage (%)
C1	0.63	1.72	16994.59	23.80
C2	1.72	2.80	38680.61	54.16
C3	2.80	3.88	14271.51	19.98
C4	3.88	4.97	1467.64	2.06
Total	-	-	71414.34	100.00

Table 3.4: The area and percentage of each class obtained for Sodicity (ESP).

Classes	Min. value	Max. value	Area (ha)	Area coverage (%)
C1	1.89	10.38	5368.56	7.52
C2	10.38	18.86	11943.93	16.72
C3	18.86	27.35	21991.01	30.79
C4	27.35	35.83	10101.16	14.14
C5	35.83	44.32	3098.62	4.34
C6	44.32	52.80	4476.32	6.27
C7	52.80	61.28	9105.19	12.75
C8	61.28	69.77	5329.55	7.46
Total	-	-	71414.34	100.00

4.0 CONCLUSION

The water level was monitored for twenty-four months from the 126 piezometric wells spread across the entire Kano River Irrigation Project. The results indicated a pattern of the trend of the fluctuations that happened every year. Water table fluctuations were influenced by the rainfall received during the rainy season, however, there was a strong relationship between the rainy season and the irrigation concerning groundwater level fluctuations. Even though the water level raised about 1 m to the ground surface, no part of the scheme had received a water table to the surface. When groundwater level was raised to 1 m below the surface there is a tendency that water reaches the porous zone by piezometric force and that showed likely influx of salt within the root zone and even raised to the surface. The groundwater salt content was also measured, and it was found that there was a significant amount of ESP in the water which raised suspicious as to whether the scheme has more areas under sodic soils. it can be concluded that the groundwater salt content has been affecting plant growth in the scheme for the fact that it contains high ESP.

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