



## Seasonal Variation of Groundwater Quality Indices in Irrigation Watershed of Hadejia, North Western Nigeria

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### ABSTRACT

This study investigated seasonal variation of groundwater quality indices in irrigation watershed of Hadejia located along Hadejia River Basin of Jigawa State. Six transects, oriented perpendicular to the river channel were established within 1 km<sup>2</sup> in each site. Three tube wells were sampled and positioned along each transect at regular intervals, making a total of 18 wells. Six irrigation water quality indices (EC, SAR, MH, PI, %Na and KR) were computed and results were presented using ORIGIN software. Results showed that with the exception of EC and RSC which put the water under doubtful to unsuitable classes, all other indices put the water in the excellent to good classes for irrigation. However, the results also show that the suitability of the water is lower in the dry season than in the rainy season. This is because the dry season was found to have more concentration of these parameters than in the rainy season, suggesting the impact of evaporation which causes these parameters to precipitate in the groundwater during the dry season. Groundwater samples in the area are suitable only for tolerant and semi-tolerant crops in all the seasons of the year. Thus, highly sensitive crops to salinity such as onion and carrot may be affected by the present salinity condition of the water. Monitoring the suitability of groundwater quality indices is recommended in order to detect changes that require modifications in the management options for proper planning.

**Keywords:** Irrigation Watershed, Groundwater Quality, Indices, Season

### INTRODUCTION

Globally, irrigation accounts for more than 70% of total water withdrawals and for more than 90% of total water consumption (Adikhari *et al.*, 2013). As such, demand for freshwater, particularly for irrigation has led to drastic depletion and deterioration of groundwater in several parts of arid and semi-arid regions in recent decades (Sethy *et al.*, 2016). The development of agriculture has been identified as a key factor in the socio-economic growth of developing countries such as Nigeria, where agriculture is one of the major source of sustenance for a significant number of the population, principally the rural poor (FAO, 2017). More than 90% of the rural populations in the country have been predominantly engaged in rain-fed agriculture (Ajon *et al.*, 2014). However, due to climate change, rain-fed agriculture is becoming unreliable as a result of erratic rainfall and variable surface water flow especially in semi-arid regions of the country such as Jigawa (Tukur *et al.*, 2017). In Jigawa state, rain-fed agriculture has been suffering from varying lengths and intensities of rainfall, thus necessitating irrigation in order to satisfy the moisture requirements of crops needed to meet the demands for food and fibre (Mays, 2009, UNESCO, 2014). For this reason, exploitation of shallow groundwater in floodplain has increased greatly because it is reliable and readily available at the point of need at relatively cheaper cost. Exploitation of groundwater therefore remains the only option to supplement the ever-increasing demand for irrigation water. However, risk of the degradation of floodplain aquifer may be developed as

the competition for the utilization of its resources increases, particularly as researches have revealed that irrigation activities in floodplain increased by 125% between 1976 and 1995 (Iliya *et al.*, 2011).

Although a number of studies on groundwater quality with respect to irrigation purposes have revealed that groundwater quality is an important consideration in any hydrogeochemical evaluation of groundwater used for irrigation (Richards, 1954; Buckman and Brady, 1960; Sharma and Chippa, 2016; Ayers and Westcot, 1985; Western Fertilizer Handbook, 1995; Hanson *et al.*, 1999; Bauder and Brock, 2001; United States Development Agency Natural Resources Conservation Service, 2002; Tyagi *et al.*, 2009; Obiefuna and Sheriff, 2011; SHI Jians *et al.*, 2013; Narany *et al.*, 2014 and 2015; Mehra *et al.*, 2016; Sethy *et al.*, 2016; Narany *et al.*, 2016), irrigation water quality concerns have often been neglected in Nigerian's irrigation projects principally the quality of shallow groundwater in floodplain of dry regions like Jigawa (Tukur *et al.*, 2018). An overview of groundwater quality studies in Nigeria covering a period of 14 years (2002-2016) revealed that 61% of the studies centered on the evaluation of groundwater pollution (vulnerability) leaving 39% of the total reviewed papers aimed at assessing the suitability of groundwater for irrigation (19%) and drinking (20%) purposes (Tukur *et al.*, 2017). Despite, the recommendations made by Macdonal and Diyam Consulting Company in 1986 for a close monitoring of the suitability of groundwater in the floodplain of the region because of the high tendency of salinity hazard they

observed, it is worth to mention that the region has not yet considered the recommendation with a view to ascertain the suitability of the groundwater, principally the salinity, infiltration and toxicity hazards. This is evidenced by the absence of a comprehensive study on the issue by either individual researchers or corporate bodies (state, national and international) in the area.

Although, the few exiting studies on groundwater quality for floodplain irrigation in northwestern Nigeria have recorded some achievements (Graham *et al.*, 2006; Enokela and Salifu, 2012; Ajon *et al.*, 2014; Ojo *et al.*, 2014; Akinyemi and Souley, 2014, Bakhari, 2014), they have a number of practical limitations. First, majority of these studies were limited to irrigation period only (mostly dry season), without considering the fact that groundwater, particularly those in shallow aquifer often demonstrates pronounced seasonal variations in chemical quality. Secondly, irrigation water quality were simultaneously assessed using traditional methods based on single individual parameters such as sodium, chloride, nitrate, electrical conductivity etc., without considering other influential indices, which include not only the aforementioned parameters which are not sufficient to provide an accurate representation and holistic picture of water quality, but also irrigation water quality indices such

as Sodium Absorption Ratio (SAR) , Kelly’s Ratio (KR), Permeability Index (PI), Percent Sodium (%Na), and Magnesium Hazard (MH).

To overcome these limitations, this study used groundwater quality indices based on two classes of irrigation water quality hazards (salinity and infiltration/permeability hazard) to evaluate the suitability of groundwater quality for irrigation in the floodplain of Hadejia, Jigawa state, northwestern Nigeria.

**MATERIALS AND METHODS**

**The Study Area**

Hadejia is located in the northwestern part of Nigeria. It lies from 12° 13' to 13° 60'N latitude and 9° 22' to 11° 00' E longitude (Graba *et al.*, 2016). The study area falls within the sedimentary basin located along the Hadejia river basin. As described by Olofin (2014), rainfall in the study location is characterized by irregularities in time and space and does not exceed 600 mm/year. The rainiest months are June, July, August and September, other months being the dry season. The average temperature for each month of the year is about 27.1 °C. The warmest period of the year is from April to July, when the maximum temperature recorded is 36.7 °C. The lowest temperature is normally recorded during the coolest period between December and January.

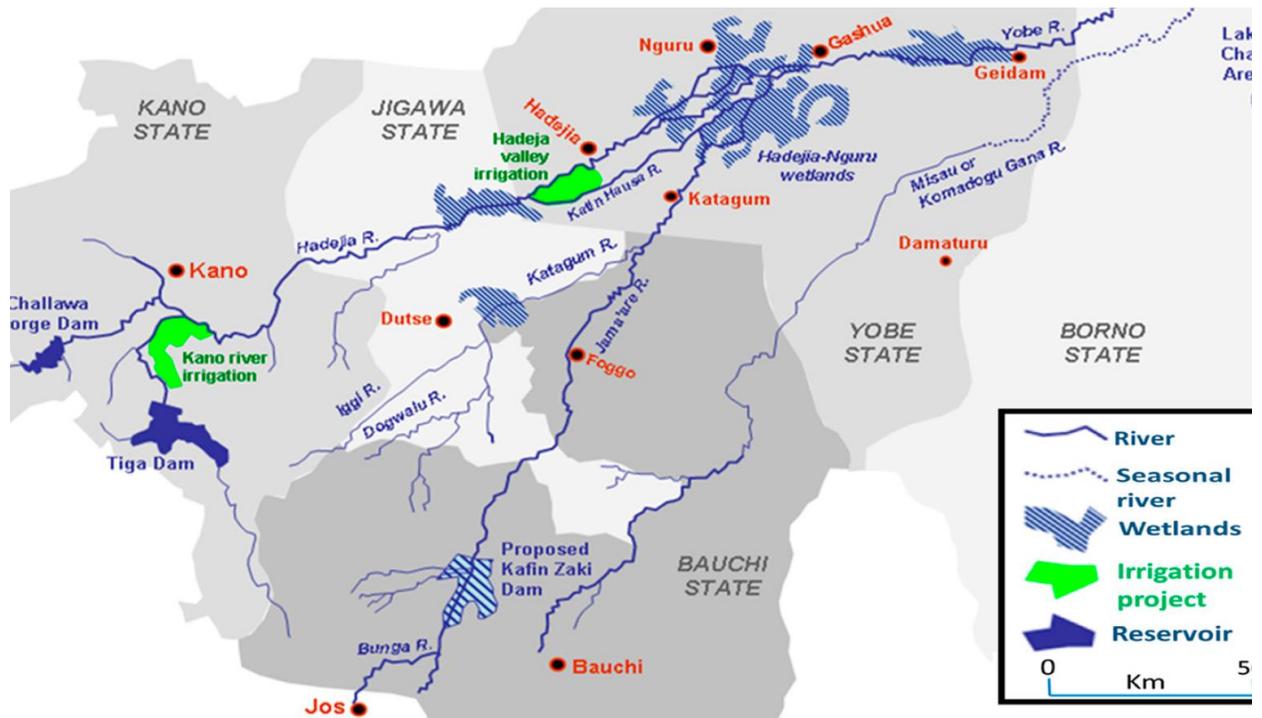


Figure 1: River Basins of Northwestern Nigeria Showing Hadejia Irrigation Project Area.

Six transects were established within one km<sup>2</sup> of each selected point along the basin and were oriented perpendicular to the river channel. Three tube wells were sampled and positioned along each transect at regular intervals making a total of 18 wells. The sampling standard methods prescribed by American Public Health Association (APHA, 2005) were followed carefully for the groundwater samples collection and laboratory analysis to determine the concentration of water quality parameters. In order to

evaluate the suitability of groundwater for irrigation, this study used the indices for evaluating groundwater quality recommended by Food and Agricultural Organization (1998). The indices are: Electrical Conductivity (EC), Percentage Sodium (%Na), Sodium Adsorption Ratio (SAR), Magnesium Hazard (MH), Permeability Index (PI) and Kelly's Ratios (KR) and were computed using the equations below where the ions concentrations were expressed in meq/l.

$$\text{Percent Sodium } \%Na = \left( \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \right) \times 100 \dots\dots\dots (1)$$

$$\text{Sodium Adsorption Ratio } SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \dots\dots\dots (2)$$

$$\text{Magnesium Hazard } MH = \left( \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \right) \times 100 \dots\dots\dots (3)$$

$$\text{Permeability Index } PI = \left( \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \right) \times 100 \dots\dots\dots (4)$$

$$\text{Kelly's Ratio } KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \dots\dots\dots (5)$$

**Salinity Hazard**

Salinity hazard can be measured by electrical conductivity (EC) values. In general, high electrical conductivity reduces the amount of water available to the crop. In order to assess the salinity hazard, electrical conductivity was separated into five classes based on Richards (1959). Usually, water with EC values greater than 3000 μS/cm is considered to be an unsuitable quality for irrigation purposes.

**Electrical Conductivity (EC)**

Electrical conductivity (EC) is a good measure of salinity hazard to crops, as it reflects the TDS in groundwater. High EC indicates that less water is available to plants. Based on EC values obtained in this study presented in Table 1, none of the groundwater samples from all the 18 wells fall within

the excellent class of suitability in both the dry and rainy season. This indicates more accumulation of salt in the soil. During dry season of the study period, more samples of groundwater falls within good (22%) and moderate (78%) class of suitability for irrigation than in rainy season. This indicates high contamination of groundwater during rainy season which increases salt concentration in the water due to transportation of salt from different sources, principally non-point sources. Generally, groundwater samples falls within good and moderate class of suitability for irrigation during dry season. However, significant number of samples (83%) falls within poor class of suitability in rain season which is not suitable for irrigation of crop with low level of salinity tolerance.

**Table 1:** Electrical Conductivity

EC (μS cm <sup>-1</sup> )	Water Class	% of Samples in Dry Season	% of Samples in Rainy Season
Range			
< 250	Excellent	0	0
250-750	Good	22	0
750-2000	Moderate	78	17
2000-3000	Poor	0	83
> 3000	Very Poor	0	0

### Relative Salinity Tolerance of Selected Agricultural Crops

Richards (1954) classified some selected crops based on their level of tolerance to salinity. Table 2 shows the distribution of crops under four classes of salinity tolerance level. From the table, only cotton and date palm have high tolerance of salinity condition. Similarly, only sorghum and wheat crops have moderate tolerance of salinity. These crops are mostly field crops with the high resistance to salinity condition of water. High sensitive crops on the other hand include only onion, carrot and citrus which are all vegetable crops. Furthermore, moderately sensitive crops accounts for the highest number which are mostly

vegetables crops and a few of field crops. This table is presented to guide in evaluating the suitability of floodplain irrigation water with respect to salinity concentration and the major crops produced in the study locations. Based on the salinity level and types of crops produced in the floodplain of the study location, it is clear that the water fall within good to moderate for the irrigation which will not affect most of the field crops cultivated. However, vegetable crops cultivated may be affected by the salinity problem as they are the majority of crops produced in the area. Therefore, management of salinity problem or choosing alternatives related to high tolerance crops could be the best option.

**Table 2:** Relative Salinity Tolerance of Selected Agricultural Crops (After Richards, 1954)

High Tolerant	Moderately Tolerant	Moderately Sensitive	High Sensitive
Cotton	Sorghum	Cabbage	Onion
Date palm	Wheat	Lettuce	Carrot
		Pepper	Citrus
		Potato	
		Tomato	
		Raddish	
		Turnip	
		Grape corn	
		Maize	

### Permeability/Infiltration Hazard

The infiltration and permeability hazard occurs when high sodium ions decrease the rate at which irrigation water enters the soil's lower layers (Simsek and Gunduz, 2007). Therefore, crops cannot extract sufficient water from the soil which reduces agriculture production. In this study, five irrigation water quality indices for evaluating permeability/infiltration hazards namely; SAR, %Na, PI, MH and KR were used to evaluate the suitability of groundwater for irrigation. This is to provide a broad picture of the suitability of water for irrigation in the study area.

### Sodium Adsorption Ratio (SAR)

Richard (1954) suggested a classification of groundwater suitability for irrigation based on SAR. The relative concentration of sodium, magnesium, and calcium in water is known as the sodium adsorption ratio (SAR), is used to measure the sodium hazard in irrigation water. A more specific presentation for the suitability of water for irrigation is made by plotting the data on the United State Salinity Laboratory (USSL, 1954) diagram, in which EC is taken as salinity hazard and SAR as permeability hazard (Richard, 1954). The analytical data plotted on USSL diagram (figure 2) illustrates that 22% of groundwater samples in all the seasons belonged to C2-S1, suggesting a medium salinity and low sodium hazard groundwater category that could be used with moderate amount of

leaching and with little danger for the development of harmful levels of exchangeable sodium. Plants with moderate salt tolerance such as millet, maize tomato, cabbage, potatoes, onion, mangoes, bananas, pear, apples and citrus fruits (Sharma and Chippa, 2016) could be grown in C2-S1 groundwater in most cases without special salinity practices for salinity control (Richard, 1954). The remaining 88% of the groundwater samples fall in the C3-S1, indicating high salinity/low sodium groundwater category.

### Sodium Percent (%Na)

The concentration of sodium in irrigation water is also known as the sodium percent or soluble sodium percent (%Na). Wilcox (1955) used %Na and specific conductance to evaluate groundwater suitability for irrigation using the Wilcox diagram. Figure 3 presents the result of %Na in the groundwater samples of the study area. From the figure, 94 and 89% of groundwater samples fall within good to permissible class for irrigation during dry and rainy season, respectively. Only 6% (dry season) and 11% (rainy season) of the samples fall within excellent to good and permissible to doubtful for irrigation, respectively. No samples of groundwater fall within either, doubtful to unsuitable or unsuitable class. Therefore groundwater samples in the area can not cause soil aggregates to disperse, hence suitable for irrigation.

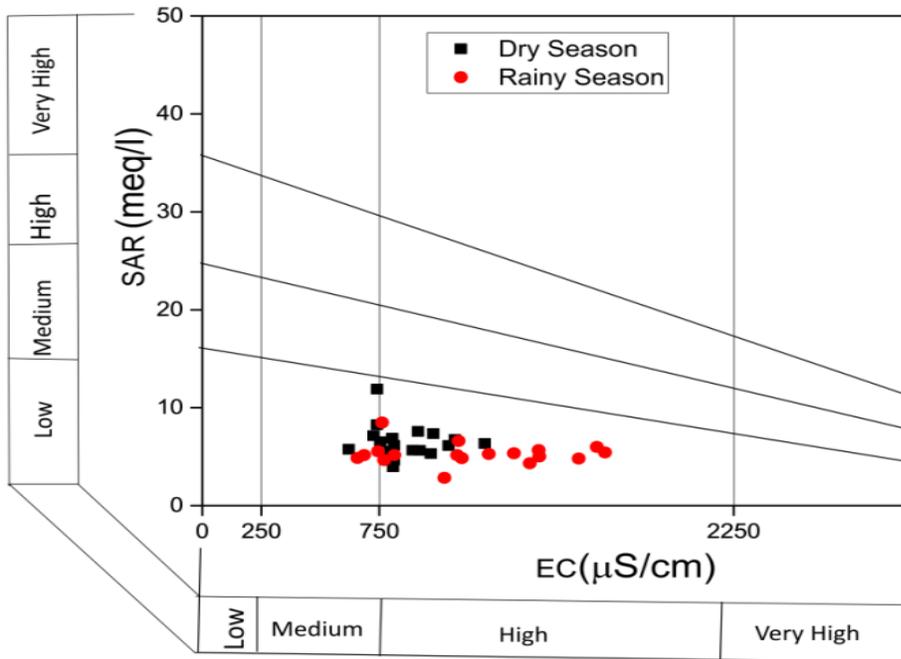


Figure 2: Suitability of groundwater for irrigation in USSL diagram

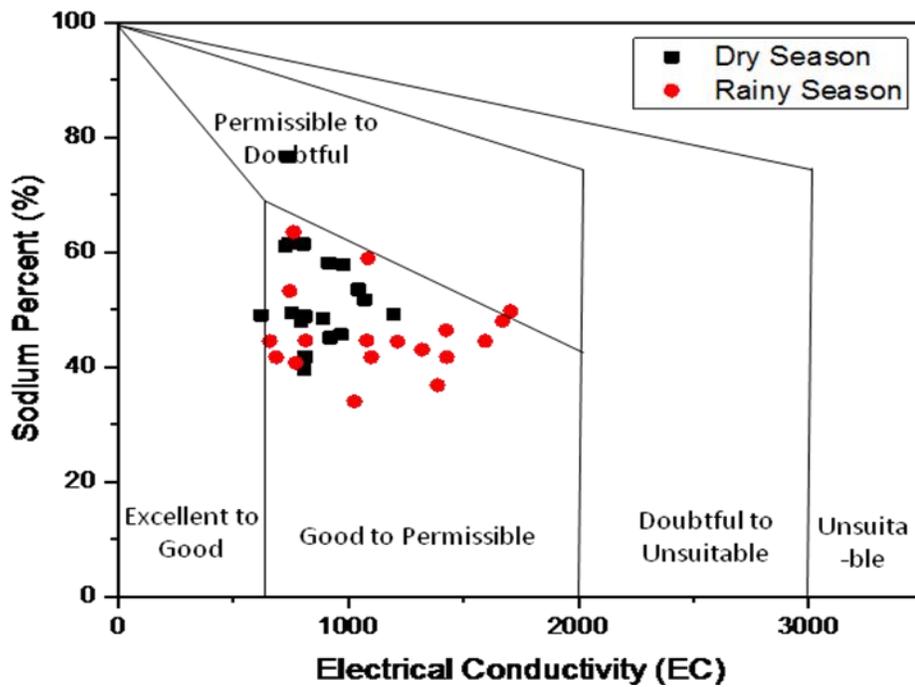


Figure 3: Suitability of groundwater for irrigation in Wilcox diagram

**Kelly's Ratio**

Sodium measured against calcium and magnesium was developed by Kelly (1940) and Paliwal (1967) to evaluate the infiltration/permeability hazard of irrigation water. The Kelly's ratio of unity or less than is indicative of suitable water for irrigation whereas above one is suggestive of

unsuitability for irrigation purpose due to alkali hazard. From the result presented in Table 3, More than 80% in dry season and 90% in rainy season of groundwater samples falls within suitable class in the study area. Therefore according to Kelly's ratio, the water is suitable for irrigation.

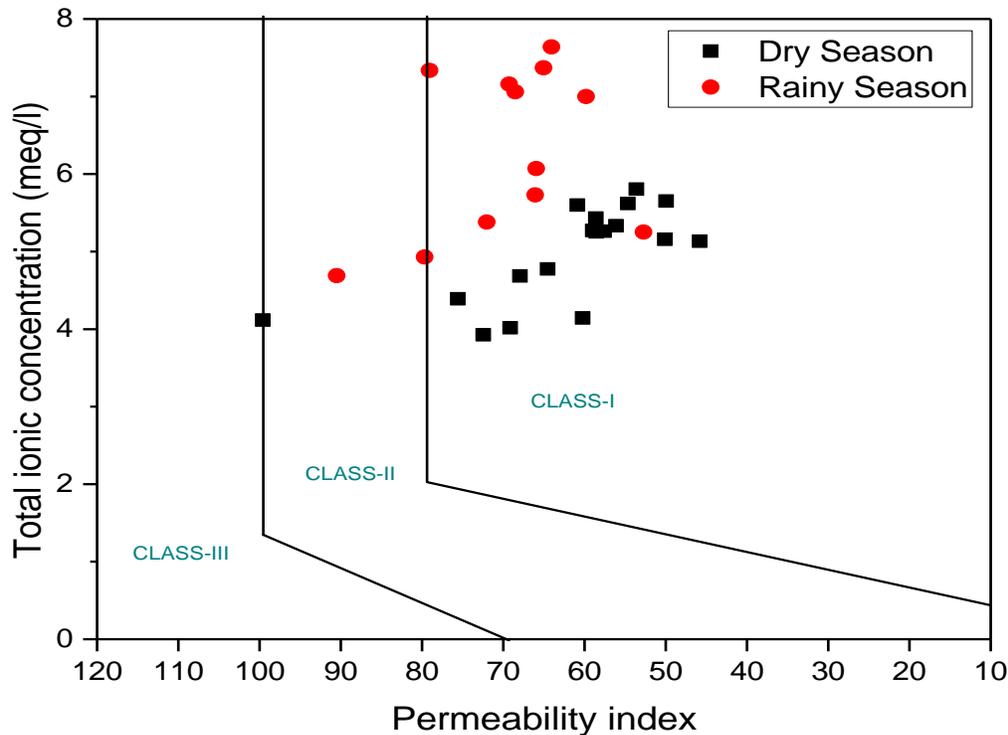
**Table 3:** Kelly's Ratio

	KR (meq/l)	% of Samples in Dry Season	% of Samples in Rainy Season
<b>Range</b>	<b>Water Class</b>		
< 1	Suitable	89	94
> 1	Unsuitable	11	6

**Permeability Index**

Another significant water quality factor that influences the soil permeability is the permeability index (PI). Doneem (1964) classified irrigation water in three PI classes. Class-I and Class-II water types are suitable for irrigation with 75% or more of maximum permeability, while class-III types of water with 25% of maximum permeability are

unsuitable for irrigation. Based on the Doneem's classification (figure 4), 94 and 100% of the groundwater samples, respectively in dry and rainy season fall in class-I and II, implying that the majority of the groundwater samples is suitable for irrigation. Only 6% of the groundwater sample in dry season belongs to class-III, the unsuitable category for irrigation.



**Figure 4:** Suitability of groundwater for irrigation in Doneem diagram

### Magnesium Hazard

Permeability or infiltration hazard is a function of not only sodium and calcium, but also magnesium concentration. For that, Doneen (1964) proposed a magnesium hazard (MH) for assessing the suitability of water quality for irrigation. The yield of barley, wheat, maize and sugar beets are significantly reduced when the Mg/Ca ratio in the soil water is >50%. Results presented in Table 4 revealed that more than 70% and 90% of the groundwater samples in

the dry and rainy season respectively have MH below 50%, indicating the suitability of water for irrigation. The remaining 22% of the groundwater samples in dry season and 6% in rainy season shows a MH above 50%. If MH exceeds the value of 50%, the water associated with such a value is considered to be harmful and hence is unsuitable or irrigation. Groundwater samples in the study area have more samples belonging to suitable category than unsuitable class in both the seasons.

**Table 4:** Magnesium Hazard (MH)

MH (meq/l)		% of Samples in Dry Season	% of Samples in Rainy Season
Range	Water Class		
< 50%	Suitable	78	94
> 50%	Unsuitable	22	6

### CONCLUSION

An evaluation of groundwater quality indices for floodplain irrigation along in Hadejia northwestern Nigeria was undertaken. Based on salinity hazard, majority of the groundwater samples fall within moderate to poor suitability class especially during rainy season. Permeability hazard has no problem as majority of the indices (%Na, KR, PI and MH) show good to permissible water for irrigation. Only SAR show high salinity and low sodium water for irrigation. Seasonally, groundwater suitability declines in the rainy season than in the rainy season based on salinity hazards (EC) investigated. The fact that, the study area is among the dry (semi-arid) regions in Nigeria which is characterized with prolonged dry season with high demand on groundwater for irrigation due to inadequate surface water availability, routine monitoring of groundwater quality, principally the salinity condition should be considered as recommended by the Macdonal and Diyam Consulting company over three decades now.

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