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SUITABILITY INVESTIGATION OF SURFACE WATER QUALITY FOR AGRICULTURAL IRRIGATION IN EKOSODIN COMMUNITY OF OVIA-NORTH EAST LGA, BENIN CITY, NIGERIA

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Abstract

Crop sustainability and production depend on the attributes of the irrigating water. Ensuring that appropriate attributes and amounts of available water are used for irrigation is necessary to maximise crop yields. Consequently, the Ikpoba River, which flows through the Ekosodin community in the Ovia-North East LGA of Benin City, was assessed for suitability for irrigation in this investigation. A physicochemical analysis was conducted on samples of water obtained from three distinct places along the river, namely A-upstream, B-midstream, and C-downstream. With some results of the physicochemical test, irrigating water quality indicators, including the sodium adsorption ratio (SAR), permeability index (PI), potential salinity (PS), magnesium adsorption ratio (MAR), kelly ratio (KR), percentage sodium (%Na), as well as the irrigating water quality index (IWQI), were all assessed for those samples of water. Regarding all physicochemical analysis findings, every sample of surface water met the FAO permitted thresholds regarding irrigation water, except for a few heavy metals such as Mn^{2+}, Cu^{2+}, Cr^{2+}, and Cd^{2+} that were slightly over the allowable values. These heavy metals are less of a concern in water used for irrigation since they are essential plant micronutrients and are unlikely to directly harm plants. SAR, %Na, PI, PS, and KR, the irrigating water quality indicators, indicated that every river water sample tested was okay for irrigating but not for IWQI, which restricted irrigation water use to high-tolerance crops. For all water samples, the indices are A = 0.04, B = 0.05, and then C = 0.06; A = 21.31%, B = 22.01%, and then C = 21.84%; A = 3148.15%, B = 2384.29%, with C = 1928.58%; A = 2.60 meq/L, B = 1.04 meq/L, as well as C = 1.11 meq/L; A = 0.19, B = 0.20, while C = 0.20 for the SAR, %Na, PI, PS, and KR indices, respectively. As such, surface water within the research region is appropriate for irrigation.

1.0 INTRODUCTION

The process of artificially providing water to plants when rainfall is insufficient to support crop production is known as irrigation [1, 2]. When rainfall is erratic and infrequent, it is essential for plant growth [3]. Crop diversification and growth depend heavily on agricultural irrigation; this practice advances global food security and sustainability [3]. Water sources and quality must be evaluated prior to designing an irrigation project [1]. Potential irrigation sources of water include surface water and groundwater [4]. Nonetheless, owing to their availability, rivers are preferable [5].

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The Nigerian economy is heavily dependent on the agricultural sector. By the initial quarter of 2022, it was more than thirty percent of the GDP [6]. It is imperative to emphasise irrigated farming so as to address issues of inadequate food supply within the nation, given its significant contribution and the abnormalities in rainfall patterns caused by climate change [7]. Because surface water is readily available and abundant, it may be used to ensure sustainable agriculture. Surface water is extracted from rivers that are formed by rainfall and used for irrigation [8]. However, as a result of increased anthropogenic activity spurred on by urbanisation, industrialisation, and population growth, the quality of the majority of rivers has declined [8]. Surface water resources are contaminated by human activities via the intrusion of contaminated water, storm runoff, and other sources that discharge organic and inorganic pollutants, including pathogens, into the water [9, 10, 11, 12]. These contaminants impair the aquatic ecosystem and its elements, including fisheries, and can lead to cancer and genetic mutations [12]. The water is therefore unsuitable for aquatic life, irrigation, or human consumption [12]. These contaminants also accompany irrigating water and persist in the soil following evaporation as well as crop absorption, impacting the soil's and the crops' quality [13].

One of the main environmental risks connected to irrigation is salinity. It can have an impact on surface water quality, crop yield, and soil structure. Its watershed naturally replenishes surface water [5]. But worldwide, there has been a rise in the salinity of water in many watersheds, particularly in nations like Nigeria, where salty rocks have been subjected to weathering and erosion over time. A Quaternary sedimentary rock deposit from the Pliocene-Pleistocene age occurs beneath the Benin Region, which covers the majority of Nigeria [14]. The Benin Formation is the name attributed to this formation. Some Cretaceous sedimentary rocks of the Upper Senonian group are also found close to Benin City [15]; these rocks, together with those from the Quaternary period, include saline deposits that have the potential to erode into Benin City waterways [15]. Due to these salty deposits and the Ovia-North East LGA of Benin City's rapid growth [16], the majority of the region's rivers, including the Ikpoba River flowing through the Ekosodin community, are susceptible to contamination. Therefore, it is imperative that these rivers be managed appropriately. Monitoring water quality can improve surface water's potential to serve irrigation [3].

Past research [17, 18, 19] indicates that river water needs to be in compliance with irrigation water quality components and water quality indices established by different environmental, health, and agricultural organizations. According to studies [18], river water with high quality indices can become a possible supply to irrigation with respect to agricultural productivity and soil quality improvement. Nigeria, however, does not properly assess or manage its river water for the sake of crop production, environmental safety, and soil quality. The Ikpoba River flows through various communities, including the Ekosodin community in Benin City, providing water for various uses, including domestic, industrial, and agricultural purposes. However, the rapid population growth and urbanisation in Benin City (including the Ovia-North East LGA of Benin City) have led to increased pollution and pressure on water resources [16]. This has raised concerns about the quality of water available for irrigation and its potential impact on crop yield and soil health. In any case, there are no irrigation practices in the Ekosodin community, which may probably be due to a lack of information on the quality of the water sources in the community for irrigation. Therefore, the goal of this study is to ascertain how suitable the Ikpoba River, which flows through the Ekosodin village in Benin City, is for irrigation using appropriate indicators. The objectives of the study are to assess the physico-chemical properties of the river water and its suitability for agricultural irrigation using established water quality indices and guidelines to determine if the water meets the standards required for safe and effective irrigation. By achieving these objectives, the study aims to contribute to the sustainable management of water resources in the Ekosodin Community and support the agricultural sector in Ovia-North East LGA. The findings will be valuable for policymakers, farmers, and environmental managers in making informed decisions to protect and utilise the Ikpoba River effectively.

The limitation of this study is that it focusses on the Ikpoba River within the Ekosodin Community. This localised approach may not reflect the overall water quality of the entire river system for irrigation, which could vary significantly in different sections.

2.0 MATERIALS AND METHODS

2.1 Study Area

Ovia North-East Local Government Area (LGA) of Edo State has the Ekosodin village, which is situated east of Isihor (Figure 1). The LGA spans 2,301 square kilometres and is headquartered in Okada town [20]. It is found in the middle province belonging to Edo

State, between the longitude lines 5° 45' 1" E and 6° 15' 1" E and the latitude lines 5° 15' 1" N and 6° 45' 1" N. Ovia North East is located in Benin City, which happens to be in the tropical rainforest area of Nigeria [16]. The region experiences average monthly temperatures of 25 to 28 degrees Celsius and 1500 to 2500 mm of rain on average every year [21]. Sedimentary formations underlie the Benin Region, which is a portion of the South Sedimentary Basin [14]. The area primarily consists of thick clay/shale interbeds with a strong capacity to retain groundwater and huge, porous, coarse sand. This kind of sand makes up more than 90% of the Benin formation [22]. Reddish earth made up of literalised or ferruginized clay sand is what defines Benin City's geology [14]. There are over 7,000 people living in the Ekosodin community [23], and the Ikpoba River flows through it.

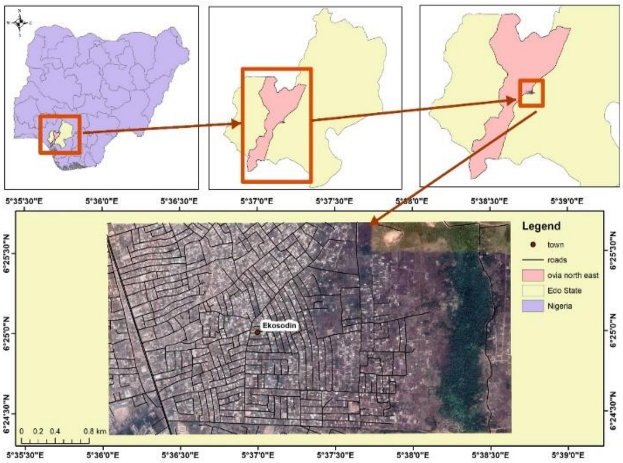

Figure 1: Map Showing Ekosodin in Ovia-North East LGA, Benin City, Edo State [21], [24]- modified by the Authors, 2024

2.2 Water Sampling and Analysis

Three points by the river were sampled for some water within November and December 2023: upstream (A), midstream (B), and downstream (C). This was done because Fipps [25] recommended that potential irrigation periods be taken into consideration. The sampling locations (A, B, and C) were created as described by Sani [12]. Figure 2 displays each sampling point. These samples were taken in 75-cL sterile plastic bottles. To assure accuracy through replication, a minimum of three randomly selected samples were taken from each location. The samples were collected in the late mornings, specifically between 9:00 a.m. and 11:00 a.m., during a period when temperatures tend to be stable. After being labelled and sealed, the plastic cans were taken to the Martlet Environmental Research Laboratory in Benin City so that they could be examined. A total of twenty-two physiochemical parameters (22) were examined in the samples: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}), Bicarbonate (HCO_3^{-}), Sulphate (SO_4^{2-}), Nitrate (NO_3^{-}), Chloride (Cl^{-}), Iron (Fe^{2+}), Manganese (Mn^{2+}), Chromium (Cr^{2+}), Lead (Pb^{2+}), Cadmium (Cd^{2+}), Zinc (Zn^{2+}), Copper (Cu^{2+}), Nickel (Ni^{2+}), Boron (B^{3+}), and a biological characteristic (Coliforms-Col). Every laboratory test was carried out following the guidelines outlined by [27], as well as those suggested by [16] and [26]. The methods utilised to examine the parameters related to river water quality are shown in Table 1. All water-related test findings were statistically analysed using Microsoft Excel 2010.

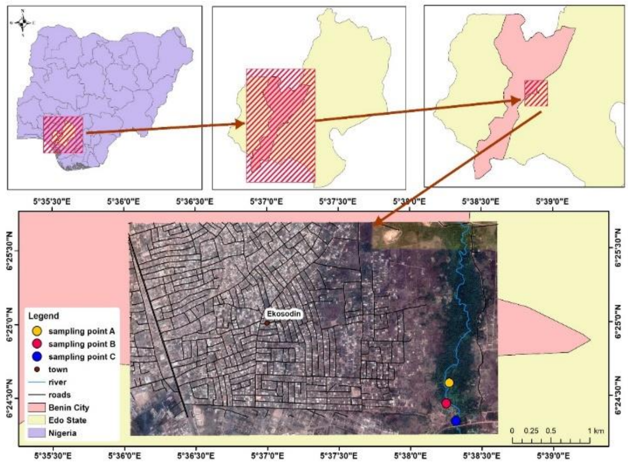

Figure 2: A map of Ekosodin that displays the river with the locations of sampling

Table 1: Techniques for Analyzing Water Quality Characteristics

Parameters	Techniques of Analysis
pH	Flame Photometry
Electrical Conductivity	Flame Photometry
Total Dissolved Solids	Flame Photometry
Total Hardness	Titrimetry
Calcium	Titrimetry
Magnesium	Titrimetry
Sodium	Flame Photometry
Potassium	Flame Photometry
Bicarbonate	Titrimetry
Sulfate	Flame Atomic Absorption Spectroscopy
Nitrate	Flame Atomic Absorption Spectroscopy
Chloride	Titrimetry
Iron	Flame Atomic Absorption Spectroscopy
Manganese	Flame Atomic Absorption Spectroscopy
Chromium	Flame Atomic Absorption Spectroscopy
Lead	Flame Atomic Absorption Spectroscopy
Cadmium	Flame Atomic Absorption Spectroscopy
Zinc	Flame Atomic Absorption Spectroscopy
Copper	Flame Atomic Absorption Spectroscopy
Nickel	Flame Atomic Absorption Spectroscopy
Boron	Flame Atomic Absorption Spectroscopy
Coliforms	Fibre- based Filtration Media

2.3 Irrigation Water Quality Indices

The experimental findings were then subjected to a variety of irrigation water quality indicators, as recommended by [1], so as to ascertain if the river waters were appropriate for agricultural irrigation. These metrics are: Magnesium Adsorption Rate (MAR), Kelly's Ratio (KR), Permeability Index (PI), Potential Salinity (PS), Sodium Adsorption Rate (SAR), Percentage of Sodium (%Na), plus Irrigation Water Quality Index (IWQI). Additionally, a comparison was done between the FAO's [28] suggested thresholds regarding irrigation water quality and the heavy metal levels. The conversion values listed in Table 2 were used to convert each value of some parameter to milliequivalent per litre (meq/L) so as to calculate the water quality indices [1]. Subsequently, using each irrigating water quality indicator, all water samples were categorised using Table 3's classification system and computed using the following equations [3].

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad (1)$$

$$\%Na = \frac{Na^+ + K^+}{(Ca^{2+} + Mg^{2+} + Na^{2+} + K^+)} \times 100 \qquad (2)$$

$$PI = \frac{Na^+ + \sqrt{HCO_{3-}}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \qquad (3)$$

$$PS = Cl^- + \sqrt{SO_4^{2-}} \qquad (4)$$

$$MAR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \qquad (5)$$

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \qquad (6)$$

$$IWQI = \frac{\sum_{i=1}^{n} W_{cv} \times Q_{rv}}{\sum_{i=1}^{n} W_{cv}} \qquad (7)$$

Where;

$$Q_{rv} = \frac{C_v}{RS_v} \times 100 \qquad (8)$$

$$W_{cv} = \frac{1}{RS_v} \qquad (9)$$

Where;

Q_{rv} = Values for Quality Ratings;

C_v = Concentration values observed;

RS_v = Each Water Quality Variables' Recommended Standard Values;

W_{cv} = Parameters' Relative Weighting.

Table 2: Conversion Table of mg/L to meg/L

Ions (mg/L)	To Convert to meg/L, multiply by
HCO_3^-	0.0164
Ca^{2+}	0.0499
Mg^{2+}	0.0823
SO_4^{2-}	0.0208
Cl^-	0.0282
Na^+	0.0435

Source [29]

Table 3: System of Classification of Irrigation Water Quality Indicators

System of Classification	Range	Categories
SAR	<10	Excellent
	10-18	Good
	> 8-26	Fair
	>26	Poor
	>200-300	Hard
	>300	Very Hard
%Na	Up to 20	Excellent
	>20-40	Good
	>40-60	Permissible
	>60-80	Doubtful
	>80	Unsuitable
PI (%)	>75	Excellent
	25-75	Good
	<75	Unsuitable
PS (meq/L)	<5	Excellent to Good
	5-10	Good to Injurious
	>10	Injurious to Unsatisfactory
MAR (%)	<50	Acceptable
	>50	Non-Acceptable
KR	<1	Suitable
	>1	Unsuitable
IWQI (%)	85-100	Excellent
	70-85	Good
	55-70	Poor
	40-55	Very Poor
	0-40	Unsuitable for Irrigation Use

Source [3] and [30]

3.0 RESULTS AND DISCUSSIONS

Tables 4 and 5 give the findings from the assessments of both the physicochemical analysis and the irrigating water quality indices. All results regarding the evaluations of the irrigating water quality indicators and the physicochemical analysis are depicted in Tables 4 and 5.

Table 5 displays all computed river waters' quality indices, and Table 4 provides a statistical overview of the river water samples's physicochemical parameters and how they compare to the recommended levels [28].

With the exception of a few heavy elements like Mn^{2+}, Cu^{2+}, Cr^{2+}, Cd^{2+}, Table 4 demonstrates that all values tested at the three locations (upstream, midstream, and downstream of the river) were within and below the FAO acceptable limit for irrigation. Additionally, it was noted that, with the exception of heavy metals where the opposite was true, parameter levels were higher downstream compared to upstream. This could possibly be explained by human activities occurring in the river area, as proposed by Adiyiah et al. [31]. The Mn^{2+} levels in each water sample differed starting from 0.2840–0.8810 mg/L with a 0.6326 mg/L mean at location A; 0.2550 to 0.7300 mg/L with a 0.5034 mg/L mean at spot B; as well as 0.1870–0.7010 mg/L with a 0.4238 mg/L mean at spot C. Cu^{2+} levels differed starting from 0.1100–0.6540 mg/L with a 0.3822 mg/L mean at Location A, 0.0890–0.5520 mg/L with a 0.3142 mg/L mean at Location B, and 0.0710–0.4980 mg/L with a 0.2598 mg/L mean at Location C. Cr^{2+} levels at site A differed starting from 0.0560–0.4210 mg/L with a 0.1676 mg/L mean; at spot B, they differed starting from 0.0420–0.3330 mg/L with a 0.1306 mg/L mean; while at spot C, they differed starting from 0.0400–0.320 mg/L with a 0.1130 mg/L mean.

Table 4: Statistical Overview of the River Water Samples's Physicochemical Parameters and How they Compared to the Recommended Levels

Parameters	Upstream				Midstream				Downstream				Guideline
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	FAO, 2015
pH	6.1000	7.7000	6.6800	0.6099	6.3000	7.4000	6.6400	0.4506	6.1000	7.3000	6.6000	0.4416	6.50–8.50
EC (µS/cm)	10.0000	28.0000	22.8000	7.2938	26.0000	36.0000	29.2000	3.8987	28.0000	40.0000	33.8000	6.0166	3,000
TDS (mg/L)	5.0000	14.0000	11.4000	3.6469	13.0000	18.0000	14.6000	1.9494	14.0000	20.0000	17.0000	3.0000	2,000
TH (mg/L)	0.6700	1.4000	1.1500	0.3431	0.1940	1.9400	1.2808	0.6719	1.5300	2.5300	2.1280	0.4884	712
Ca^{2+} (mg/l)	0.1200	0.2800	0.2200	0.0693	0.2500	0.3500	0.2960	0.0456	0.3000	0.4700	0.3920	0.0705	400
Mg^{2+} (mg/L)	0.0900	0.1900	0.1460	0.0434	0.1400	0.2700	0.2160	0.0550	0.1900	0.3500	0.2800	0.0781	60
Na^{+} (mg/L)	0.0600	0.1400	0.1000	0.0308	0.1000	0.1800	0.1460	0.0321	0.1500	0.3000	0.2000	0.0596	900
K^{+} (mg/L)	0.0400	0.0900	0.0720	0.0249	0.0800	0.1300	0.1080	0.0179	0.0130	0.2100	0.1246	0.0742	0–2
HCO_3^- (mg/L)	35.5000	55.7000	44.5800	7.2151	40.6000	61.5000	52.0000	7.6082	52.1000	61.5000	58.6400	3.9055	600
SO_4^{2-} (mg/L)	0.0330	0.0550	0.0406	0.0088	0.0400	0.0580	0.0488	0.0081	0.0490	0.0620	0.0562	0.0048	1,000
NO_3- (mg/L)	0.0110	0.0180	0.0160	0.0031	0.0170	0.0250	0.0210	0.0031	0.0220	0.0310	0.0274	0.0039	0–10
Cl^- (mg/)	22.4000	331.0000	91.9800	133.7366	30.1000	40.2000	36.6800	4.1668	35.5000	44.4000	39.3600	3.8501	1,100
Fe^{2+} (mg/L)	0.8800	1.8540	1.3518	0.3765	0.7410	1.3330	1.0466	0.2126	0.6630	1.0480	0.9022	0.1524	5.00
Mn^{2+} (mg/L)	0.2840	0.8810	0.6326	0.2479	0.2550	0.7300	0.5034	0.1733	0.1870	0.7010	0.4238	0.1827	0.20
Cr^{2+} (mg/L)	0.0560	0.4210	0.1676	0.1449	0.0420	0.3330	0.1306	0.1155	0.0400	0.3020	0.1130	0.1070	0.10
Pb^{2+} (mg/L)	0.0320	0.0720	0.0506	0.0154	0.0280	0.0610	0.0412	0.0130	0.0220	0.0530	0.0326	0.0119	2.00
Cd^{2+} (mg/L)	0.0180	0.0480	0.0330	0.0119	0.0150	0.0400	0.0260	0.0104	0.0010	0.0400	0.0182	0.0144	0.01
Zn^{2+} (mg/L)	0.5680	1.0250	0.8982	0.1924	0.3890	0.8970	0.7576	0.2122	0.3580	0.7730	0.5944	0.1613	0-2.0
Cu^{2+} (mg/L)	0.1100	0.6540	0.3822	0.2208	0.0890	0.5520	0.3142	0.1846	0.0710	0.4980	0.2598	0.1625	0.10
Ni^{2+} (mg/L)	0.0190	0.1300	0.0454	0.0475	0.0090	0.1100	0.0344	0.0424	0.0070	0.0150	0.0112	0.0030	5.00
B^{3+} (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0–2
Col. (Pt.Co)	0.5000	3.3000	1.8000	1.1225	0.7000	3.7000	2.5000	1.3360	0.8000	5.1000	3.0000	1.7393	<200

ND = Not Detected

Moreover, Cd^{2+} values differed at spots A, B, and C. They were 0.0180–0.0480 mg/L with a 0.0330 mg/L mean, 0.0150–0.0400 mg/L with a 0.0260 mg/L mean, as well as 0.0010–0.0400 mg/L with a 0.0182 mg/L mean. Elevated levels of these heavy metals (Mn^{2+}, Cu^{2+}, Cr^{2+} and Cd^{2+}) detected in the samples of river water at locations A, B, and C, respectively, are likely attributed to human-induced actions (like the careless application of some heavy metal-containing herbicides and manure) in the nearby agricultural land [32, 33, 34]. Research has also shown that Benin City's rivers have high concentrations of these heavy metals [35, 36]. Although these heavy metals in irrigation water are of less concern because they are vital plant micronutrients and are not directly toxic to plants, excessively high levels of them can disrupt plant metabolism and inhibit plant morphology and physiology [37, 38, 39, 40]. Among the parameters analysed, the concentrations of EC, HCO_3-, and specific ions (such as Na^{2+}, Cl^-, and B^{3+}) are vital in irrigation water assessment [41].

The pH of the water at the A, B, and C locations ranged from 6.1000 to 7.7000 with a mean of 6.6800; 6.3000 to 7.4000 had a mean of 6.6400; and 6.1000 to 7.3000 had a mean of 6.6000. These results suggest that the water is acidic [40]. These figures are between the acceptable ranges (6.5–8.5) set by the FAO [30] for irrigation water. Since numerous plants could handle a broad range of pH and the pH of water is usually buffered by the soil, the pH of water and soil cannot directly impair plant growth [42, 41]. On the other hand, persistent use of water at pH values higher than recommended limits may result in deficiencies in certain micronutrients and other problems with soil fertility [33, 1]. The overall salinity or total solids in each water sample are indicated by the EC. All water samples collected at A, B, and C sites had EC values starting from 10.0000–28.0000 µS/cm with a 22.8000 µS/cm mean, 26.0000–36.0000 µS/cm with a 29.2000 µS/cm mean, and 28.0000–40.0000 µS/cm with a 33.8000 µS/cm mean. These findings indicate low salinity in irrigation water because they are all below the FAO [28] recommended limit of 3000 µS/cm. Furthermore, as the EC values were significantly lower than 250 µS/cm, they are also in the excellent water category [3]. Water's electrical conductivity influences plant development. Soil salinity levels that are excessive could lead to a "physiological" drought [41, 1]. The high osmotic potential of plant roots inhibits them from receiving water from the soil, which is why this occurs. Thus, wilting occurs when the plant shoot loses water through transpiration and cannot replenish it [41, 1]. The HCO_3- figures are as follows: 35.5000–55.7000 mg/L with a 44.5800 mg/L mean; 40.6000–61.5000 mg/L with a 52.0000 mg/L mean; and 52.1000–61.5000 mg/L with a 58.6400 mg/L mean at A, B, and C locations. Despite their high levels, these HCO_3- concentrations are within the permitted irrigation water threshold of 600 mg/L [28]. Since the majority of rocks tend to be hydrophilic and their level in water is according to the pH of all water, weathering increases the HCO_3-content of all water. Magnesium carbonate ($MgCO_3$) tends to precipitate when irrigation water with high HCO_3-concentrations becomes concentrated due to evapotranspiration. As a result, the plant's ability to absorb and metabolise minerals would be harmed by the increased sodium ions in the soil [42].

Certain specific chemical components found in irrigation water, such as Na^{2+}, Cl^{-}, and B, have the potential to directly affect crops and cause harm to plants. The Na^{2+} levels varied for the A, B, and C sites, respectively, starting from 0.0600–0.1400 mg/L with a 0.1000 mg/L mean; 0.1000–0.1800 mg/L with a 0.1460 mg/L mean; and also 0.1500–0.3000 mg/L with a 0.2000 mg/L mean. It is evident that none of the water samples had sodium contents that were more than the 900 mg/l permissible range for irrigation [28]. High Na^{2+}concentrations in irrigation water impact soil physical characteristics and could spur the degradation of soil structure because sodium-soil exchange results in both soil dispersion and permeability loss [43, 41]. Crop poisoning is mostly caused by chlorides found in irrigation water. The soluble anion chloride, also known as Cl^{-}, is present in any water and easily seeps into drainage water. The range of values of Cl^{-} levels detected in water samples from spots A, B, and C, correspondingly, was 22.4000–331.0000 mg/L with a 91.9800 mg/L mean; 30.1000–40.2000 mg/L with a 36.6800 mg/L mean; and 35.5000–44.4000 mg/L with a 39.3600 mg/L mean. All chloride concentrations recorded inside every water sample taken from sites A, B, and C were within the allowable threshold of 1,100 mg/L regarding irrigation water [28]. Chlorides are required for plant development; too much can stunt plant development, be extremely poisonous to certain plant species, and cause necrosis in plants, be extremely poisonous to certain plant species, and cause necrosis in plants. This is typically followed by premature leaf loss or removal [41, 33]. While it is necessary in small amounts, all plants need boron (B^{3+}) for normal growth. It was noted that in all three locations' water samples (A, B, and C), B^{3+} was not found. Following FAO [28], B^{3+} values in all water are in the range of 0 to 2 mg/L, which complies with all permissible ranges for irrigation water. Plant damage (or toxicity) could result from high boron concentrations in irrigation water [41]. Plant diseases and a decrease in agricultural productivity are linked to toxic B^{3+} levels [44].

Table 5: Estimated River Water Quality Indices (Irrigation Parameters)

Indices	Location		
	A (Upstream)	**B (Midstream)**	**C (Downstream)**
SAR	0.04	0.05	0.06
%Na	21.31	22.01	21.84
PI (%)	3148.15	2384.29	1928.58
PS (meq/L)	2.59	1.04	1.11
MAR (%)	52.40	54.60	53.99
KR	0.19	0.20	0.20
IWQI (%)	40.58	45.64	50.73

According to Srinivasamoorthy et al. [45] and Zaman et al. [41], the SAR effectively predicts the likelihood of salt solutions producing a notable quantity of exchangeable salt in soil, making it a valuable indicator for indicating a sodium danger in irrigation water. For all samples of water from all three locations—A (0.04), B (0.05), and C (0.06)—low SAR values were found in Table 5. The river's waters are regarded as excellent to supply irrigation (Table 3) since these values are less than 10. This points out that there is no danger of sodicity due to the water's low salt concentration. But when water drainage and leaching are regulated, extended use of low-sodium irrigation water can lead soils to become sodic, which lowers permeability [41].

Considering the detrimental effects of sodium in water, irrigation water quality may also be categorised using percentage sodium (% Na) [46, 47]. Increased salinity in irrigation water makes the soil sodic, which lowers the permeability of the soil [48, 47]. Locations A, B, and C have % Na values of 21.31%, 22.01%, and 21.84%, respectively. These values, which fall between 20 and 40 percent, reveal that the river's waters are appropriate for irrigation as they satisfy the excellent water type standards (see Table 3).

Permeability index (PI) is another kind of indicator that is used to determine whether surface waters are acceptable for agricultural irrigation. It's influenced by levels of Na^{2+}, Ca^{2+}, Mg^{2+}, and HCO_3- [3]. The samples of water had high PI values: 3148.15% at spot A, 2384.29% at spot B, and 1928.58% at location C. These elevated results may be associated with the elevated HCO_3- levels observed in water samples that are primarily carried on by calcareous and calcite rock deposits that seep into the river. Low-PI water won't alter the surrounding soil's structure since it doesn't alter its porosity [49]. Because the PI values at all three locations (A, B, and C) are greater than 75%, which describes the water samples obtained as excellent, the surface water standard is suitable for irrigation (see Table 3).

Potential salinity (PS) is the term that is used to describe the amount of soluble salts inside irrigation water [1]. For location A, the PS value is 2.59 meq/l; for location B, it is 1.04 meq/l; and for location C, it is

1.11 meq/l. Since these values are less than 5 meq/L (as indicated in Table 3), the water samples from all three locations fell within the category of excellent to good water types, meaning the river water could be utilised for irrigation. The water quality indices (SAR, %Na, PS) fall within the same range as those reported by Talabi et al. [50] in their research on River Owan in Edo State.

Magnesium ions in water influence crop production; thus, there is a need to check for magnesium hazards in water for agricultural irrigation. The magnesium hazard (MH) that is used for this study to express the amount of magnesium adsorption rate (MAR). The water samples from spots A, B, and C had calculated MH values of 52.40%, 54.60%, and 53.99%, respectively. These values are slightly above 50%, which is the recommended value for the waters to be accepted for irrigation; however, they are more in the range of 50%, which will not impact crop yield, hence the water is safe for irrigation [46]. Because magnetite enhances the formation of chlorophyll, which promotes the photosynthesis necessary for plant growth, it may have a favourable effect on the moderate values of MH found [46]. But too much magnesium can raise the pH of the soil, especially when paired with calcium ions. This can lead to phosphorus insufficiency and lower crop yields [1]. Research has recorded MAR>50% for river water in Edo State [50].

Another method for determining if the quality of water is appropriate for agricultural irrigation is Kelly's ratio (KR). It shows how much salt is present and how that could affect the irrigation quality. Table 5 shows that the KR values of every water sample at spots A, B, and C, respectively, are 0.19, 0.20, and 0.20. All of the water samples from all three locations (A, B, and C) fit into the acceptable water category based on these values, which are less than 1, suggesting that there isn't a noticeable excess of sodium in the surface water. The irrigation water quality index (IWQI) is one way of analysing the overall influence of several attributes expressed as a single numerical number [3, 51]. In this study, the IWQI was estimated using pH, EC, Na, Cl, HCO_3-, Mg, Ca, and SAR, which are eight water quality variables as proposed by Gidey [51] and Tiri et al. [3]. The IWQI values for water samples from spots A, B, and C are 40.58%, 45.64%, as well as 50.73%, respectively. These findings indicate that all water samples are very poor for agricultural irrigation, and so all water is only ideal for high-tolerance crops [3]. The degradation in the surface waters as reflected by IWQI may be due to excessive anthropogenic activities in the study area [52, 47].

4.0 CONCLUSION

The Ikpoba River flows through the Ekosodin community in Ovia-North East LGA of Benin City. The river's irrigation potentials have been assessed by first analysing the physicochemical parameters of water samples from three different locations (A-upstream, B-midstream, and C-downstream). Employing some of the physicochemical parameters, SAR; %Na; PI; PS; MAR; KR; and IWQI have been assessed. With regard to the outcome of the physicochemical study, all samples of river water fell within and below FAO acceptable levels for irrigating water, but for Mn^{2+}, Cu^{2+}, Cr^{2+}, and Cd^{2+}, whose concentrations were slightly above permissible ranges. There is less worry about these heavy metals in irrigation water as they are essential plant micronutrients and are unlikely to directly damage plants. SAR, %Na, PI, PS, and KR, which are irrigating water quality indicators, indicated that every river water sample tested was okay for irrigation but not for IWQI, which restricted irrigation water use to high-tolerance crops.

REFERENCES

[1] Fadipe, O. O., Abiola, U., Adebanjo, A. U., Thanni, M. O., Olawuyi, O. A. "Assessment of Groundwater Quality for Irrigation Purposes in Ilesha West Local Government, Osun State, Nigeria". *Water Cycle*, vol. 3, 2022, pp. 160–170. DOI: https://doi.org/10.1016/j.watcyc.2022.10.001

[2] Denomme, D. "What is Irrigation". Available online from https://study.com/academy/lesson/definition-types-of-irrigation.html, Accessed on September 21, 2023.

[3] Tiri, A., Belkhiri, L., Asma, M. and Mouni, L. "Suitability and Assessment of Surface Water for Irrigation Purpose". *Water Chemisrty Chapter 1*, Murat Eyvaz and Ebubekir Yüksel Edition, IntechOpen, London, UK, 2020, pp 1-18. DOI: 10.5772/intechopen.86651

[4] CDC "Types of Agricultural Water Use", *Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Disease (NCEZID), Division of Foodborne, Waterborne, and Environmental Diseases (DFWED)*, 2016. Available online from: https://www.cdc.gov/healthywater/others/agricultural/types.html Accessed on September 21, 2023.

[5] FAO. The State of the World's Land and Water Resources for Food and Agriculture (SOLAW) – Managing Systems at Risk. Rome: *Food and Agriculture Organization of the United Nations and London*: Earthscan, 2011. http://openknow

ledge.fao.org/handle/20.500.14283/cb9910en Accessed on December 27, 2023.
[6] Nigerian Finder. "Importance of Irrigation in Nigeria". Available online from: https://nigerianfinder.com/importance-of-irrigation-in-nigeria/, Accessed on September 21th, 2023.
[7] Oladepo, K. T., Jimoh, A. A. and Jeje, J. O. "Assessment of Groundwater for Irrigation Purpose in Ife –North Local Government Area, Southwestern Nigeria". *Civil and Environmental Research*, vol. 9, no. 8, 2017, pp. 55–64. https://www.iiste.org/Journals/index.php/CER/article/view/38551/0 Accessed on August 24, 2023.
[8] Kumar, M., and Kumar, R. "Assessment of Physic chemical Properties of Groundwater in Granite Mining Areas in Goramachia, Ilansi, UP, India". *International Research Journal of Environmental Sciences*, vol. 2, no. 1, 2013, pp. 19-24. https://www.isca.in/IJENS/Archive/v2/i1/4.ISCA-IRJEvS-2012-091.pdf Accessed on September 01, 2023.
[9] Odiyo, J. O., Chimuka, L., Mamali, M. A., and Fatoki, O. S. "Trophic Status of Vondo and Albasini Dams; Impacts on Aquatic Ecosystems and Drinking Water", *International Journal of Environmental Science and Technology*, vol. 9, 2012, pp. 203–211. DOI: 10.1007/s13762-012-0034-x
[10] Edokpayi, J. N., Odiyo, J. O., and Durowoju, O. S. "Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa". *In Water Quality*, Chapter: 18; Hlanganani, T., Ed.; IntechOpen: London, UK, 2017, pp. 401–416. DOI: https://doi.org/10.5772/66561
[11] Qureshi, A. S. *Water Management for Sustainable Agriculture*, Oweis, T. (ed.), Burleigh Dodds Science Publishing, Cambridge, UK, 2018. DOI: https://doi.org/10.1201/9781351114608
[12] Sani, A., Musa, M. U., Adamu, U. K., Sanda, A. R, Adam, I. A. and Almu, H. "River Water Quality Assessment and Suitability for Irrigation in Northern Sudan Savanna, Ecological Zone of Nigeria", *International Journal of Environment and Pollution Research*, vol. 8, no. 3, 2020, pp. 30-40. https://eajournals.org/wp-content/uploads/River-Water-Quality-Assessment-and-Suitability-for-Irrigation-in-Northern-Sudan-Savanna-Ecological-Zone-of-Nigeria.pdf Accessed on August 19, 2023.
[13] Almuktar, S. A. A. A. N., Abed, S. N., and Scholz, M. "Wetlands for Wastewater Treatment and Subsequent Recycling of Treated Effluent: A Review", *Environmental Science and Pollution Research*, vol. 25, 2018, pp 23595-23623. DOI: https://doi.org/10.1007/s11356-018-2629-3
[14] Ikhile, C. I. "Geomorphology and Hydrology of the Benin Region, Edo State, Nigeria". *International Journal of Geosciences*, vol. 7, 2016, pp.144-157. DOI: 10.4236/ijg.2016.72012
[15] Eiríksson, J., Símonarson, L. A., and Knudsen, K. L. "An Age Model for the Miocene to Pleistocene Tjörnes Sequence, North Iceland", *Pacific-Atlantic Mollusc Migration*, 2021, pp. 213–236. DOI: https://doi.org/10.1007/978-3-030-59663-7_6
[16] Rawlings, A., and Ikediashi, A. I. "Impact of Urbanizing Ovia-North East on the Quality of Groundwater using Water Quality Index", *Nigerian Journal of Environmental Sciences and Technology (NIJEST)*, vol. 4, no. 1, 2020, pp. 87 – 96. DOI: https://doi.org/10.36263/nijest.2020.01.0180
[17] Bauder, T. A., Waskom, R. M., Sutherland, P. and Davis, J. D. *Irrigation Water Quality Criteria Crop Series|Irrigation Module*, Fact Sheet No. 0.506. Colorado State University, Extension, USA, 2011. https://extension.colostate.edu/docs/pubs/crops/00506.pdf Accessed on November 03, 2023.
[18] Tsado, P. A., Lawal, B. A., Eze, P. C., Afolabi, S. G., Saidu, O. I., and Igwe, C. A. "Assessment of the Suitability of Water Quality for Irrigation in Minna, Niger State", *International Journal of Research in Agriculture and Forestry*, vol. 1, no. 2, 2014, pp. 13–17. https://staff.futminna.edu.ng/SLM/content/journal/PF2051/8.pdf Accessed on July 28, 2023.
[19] Al-Isawi, R., Scholz, M., and Alfaraj., F. "Assessment of Diesel-Contaminated Domestic Wastewater Treated by Constructed Wetlands for Irrigation of Chilies Grown in Green House", *Environmental Science and Pollution Research*, vol. 23, no. 24, 2016, 25003-25023. DOI: https://doi.org/10.1007/s11356-016-7706-x
[20] Akinbo, F. O., and Okaka, C. E. "Hyperendemicity of onchocerciasis in Ovia North-East Local Government Area, Edo State, Nigeria", *East African Journal of Public Health*, vol. 7, no. 1, 2010, pp. 84-86. DOI: 10.4314/eajph.v7i1.64702
[21] Rawlings, A., and Seghosime, S. "Evaluation of Water Supply, Sanitation and Hygiene Facilities in Ekosodin Community of Ovia

North-East LGA, Benin City, Edo State, Nigeria". *Nigerian Journal of Technology (NIJOTECH),* vol. 41, no. 4, 2022, pp. 632-643. DOI: http://dx.doi.org/10.4314/njt.v41i4.1

[22] Adegbite, J. T., Aigbogun, C. O., and Kuforijimi, O. "Physiochemical Analysis of the Quality of Groundwater in Egbeta, Ovia North East Local Government Area of Edo State, Nigeria". *Journal of Applied Geology and Geophysics*, vol. 6, no. 3, 2018, pp. 9 - 32. https://www.iosrjournals.org/iosr-jagg/papers/Vol.%206%20Issue%203/Version-3/E0603032932.pdf Accessed on August 21, 2023. Accessed on December 15, 2023.

[23] Ogeah, F. N., and Ajalaye, V. "Students' Off-campus Residence and Impact on Localities: The Case of the University of Benin and Ekosodin Village", *Global Journal of Social Sciences,* 10(1&2), 2011, pp. 37-43. https://www.ajol.info/index.php/gjss/article/view/79474/69765 Accessed on September 21, 2023.

[24] Google Earth. "Map" https://earth.google.com, Accessed December 15, 2021.

[25] Fipps, G. "Irrigation Water Quality Standard and Salinity Management Strategies", 2021. Available online from: https://irrigation.tamu.edu/files/2021/04/EB-1667.pdf Accessed on October 18, 2023.

[26] Rawlings, A., and Seghosime, S. "Effect of Open Dumping of Municipal Solid Waste on Groundwater Quality in Ekurede Itsekiri, Warri South LGA, Delta State, Nigeria", *Journal of Engineering Research*, 27(1), 2022, 11-25. https://jer.unilag.edu.ng/article/download/1590/1232/ Accessed on March 20, 2022.

[27] Lipps, W. C., Braun-Howland, E. B., Baxter, T. E., eds. "American Public Health, APHA, American Water Works Association, Water Environment Federation", *Standard Methods for the Examination of Water and Waste water*, 24th ed. Washington DC: APHA Press; 2023. https://secure.apha.org/testimis/ItemDetail?iProductCode=978-087553-2998&Category=BK&WebsiteKey=b04418ea-e87d-4d4c-92e8-72c97f1ae2c4 Accessed on October 25, 2023.

[28] FAO-AQUASTAT. *Global Information System on Water and Agriculture*, 2015. Available online from: http://www.fao.org/nr/water/aquastat/main/index.stm Accessed on November 11, 2023.

[29] Wallender, W. W. and Kenneth, K. "Conversion Tables". *Agricultural Salinity and Assessment Management*, Second Edition, American Society of Civil Engineers (ASCE), Reston, Virgina, USA, page 1073, 2011. DOI: https://ascelibrary.org/doi/pdf/10.1061/9780784411698.fm

[30] Anjaly, C. S., Sathian, K. K., Anu, V. and Jinu, A. "Assessment and Mapping of Water Quality of a Shallow Aquifer near an Industrial Belt using Hydro-chemical Parameters and Irrigation Water Quality Index", *Journal of Agricultural Engineering (India)*, 60(1), 2023, 60-73. DOI: https://doi.org/10.52151/jae2023601.1797

[31] Adiyiah, J., Aboagye-Larbi, H., and Acheampong, M. A. "Comparative Assessment of the Upstream and Downstream Water Qualities of River Tano in Ghana", *Journal of Environmental Science and Engineering,* vol. A 2, 2013, pp. 283-292. https://www.academia.edu/8847724/A_COMPARATIVE_ASSESSMENT_OF_THE_UPSTREAM_AND_DOWNSTREAM_WATER_QUALITY_OF_RIVER_TANO_IN_THE_BRONG_AHAFO_REGION_GHAH Accessed on July 20, 2023.

[32] Varol, M. and Sen, B. "Assessment of Nutrient and Heavy Metal Contamination in Surface Water and Sediments of the Upper Tigris River, Turkey", *Catena*, vol. 92, no. 1, 2012, pp. 1-10. DOI: 10.1016/j.catena.2011.11.011

[33] Ogunfowokan, A. O., Obisanya, J. F. and Ogunkoya, O. O. "Salinity and Sodium Hazards of Three Streams of Different Agricultural Land Use Systems in Ile-Ife, Nigeria", *Applied Water Science*, vol. 3, no. 1, 2013, pp. 19–28. DOI: https://doi.org/10.1007/s13201-012-0053-2

[34] Adesiyan, I. M., Bisi-Johnson, M., Aladesanmi, O. T., Okoh, A. I. and Ogunfowokan, A. O. "Concentration and Human Health Risk of Heavy Metals in River in Southwest Nigeria", *Journal of Health and Pollution,* vol. 8 (180907), no. 19, 2018. DOI: https://ehp.niehs.nih.gov/doi/pdf/10.5696/2156-9614-8.19.180907 Accessed on September 25, 2023.

[35] Imuiwa, M. E., Opute, P., and Ogbeibu, A. E. "Heavy Metal Concentrations in Bottom Sediments of Ikpoba River, Edo State, Nigeria", *Journal of Applied Sciences and Environmental Management,* vol. 18, no. 1, 2014, pp. 27-32. DOI: 10.4314/jasem.v18i1.4

[36] Izegaegbe, J. I., and Iyi-Aguebor, E. G. "Evaluation of the Levels of Heavy Metals in River Water and Selected Species of Fish from Ogba River in Benin City, Nigeria", *Journal of Applied Sciences and Environmental Management*, vol. 21, no. 6, 2017, pp. 1093-1096. DOI: 10.4314/jasem.v21i6.16

[37] Singh, H.P., Mahajan, P. and Kohli, R. K. "Chromium Toxicity and Tolerance in Plants". *Environmental Chemistry Letters*, vol. 11, 2013, pp. 229-254. DOI: https://doi.org/10.1007/s10311-013-0407-5

[38] Shabbir, Z., Sardar, A., Shabbir, A., Abass, G, Shamshad, S., Khalid, S., Natasha, Murtaza, G., Dumat, C., Shahid, M. "Copper Uptake, Essentiality, Toxicity, Detoxification and Risk Assessment in Soil-plant Environment", *Chemosphere*, vol. 259 (127436), 2020. DOI: 10.1016/J.CHEMOSPHERE.2020.127436

[39] Haider, F. U., Liqun, C., Coulter, J. A., Cheema, S. A., Wu, J., Zhang, R., Wenjun, M. and Farooq, M. "Cadmium Toxicity in Plants: Impacts and Remediation Strategies", *Ecotoxicology and Environmental Safety*, vol., 211 (111887), 2021. DOI: 10.1016/j.ecoenv.2020.111887

[40] Sela, G. "Manganese in Plants and Soil", 2023. Available online from: https://cropaia.com Accessed on January 27, 2023.

[41] Zaman, M., Shahid, S. A., and Heng, L. "Irrigation Water Quality", *ResearchGate*, 2018, pp 113-131 Available online from: https://www.researchgate.net/publication/329241298 Accessed on July 17, 2023.

[42] Arshad, M., and Shakoor, A. "Irrigation Water Quality". *ResearchGate*, 2017, pp 145-160. Available online from: https://www.researchgate.net/publication/320531819 Accessed on July 71, 2023.

[43] Holgate, L. C., Aitkenhead-Peterson, J. A. And Gentry, T. J. "Irrigation Water Chemistry: Impact on Microbial Community Composition and Biogeochemical Leaching Under Perennial Ryegrass (Lolium perenne [L])". *International Scholarly Research Network-ISRN Ecology Journal*, vol., 1, 2011, pp. 1-9. DOI: 10.5402/2011/797910

[44] Saleem, M., Khanif, Y. M., Ishak, F., Samsuri, A. W. and Hafeez, B. "Importance of Boron for Agriculture Productivity: A Review", *International Research Journal of Agricultural Science and Soil Science*, vol. 1, no. 18, 2011, pp. 293-300. https://www.interesjournals.org/articles/importance-of-boron-for-agriculture-productivity-a-review.pdf Accessed on January 21, 2024.

[45] Srinivasamoorthy, K., Gopinath, M., Chidambaram, S., Vasanthavigar, M., Sarma, V. S. "Hydrochemical Characterization and Quality Appraisal of Groundwater from Pungar sub basin, Tamilnadu, India", *Journal of King Saud University-Science*, vol. 26, 2014, pp. 37–52. DOI: 10.1016/j.jksus.2013.08.001

[46] Eruola, A. O., Makinde, A. A., Eruola, A. O. and Oladele, R. "Water Quality Assessment of Owiwi River for Potential Irrigation of Vegetables", *Nigerian Journal of Technology (NIJOTECH)*, vol. 39, no. 1, 2020, pp. 293-300. DOI: 10.4314/njt.v39i1.32

[47] Elsayed, S., Hussein, H., Moghanm, F. S., Khedher, K. M., Eid, E. M. and Gad, M. "Application of Irrigation Water Quality Indices and Multivariate Statistical Techniques for Surface Water Quality Assessments in the Northern Nile Delta Egypt", *Water*, vol. 12, no. 3300, 2020, pp. 1-26. DOI: https://doi.org/10.3390/w12123300

[48] Purushothman, P., Rao, M. S., Kumar, B., Rawat, Y. S., Krishan, G., Gupta, S., Marwah, S., Bhatia, A. K., Kaushik, Y. B., Angurala, M. P., Singh, G. P. "Drinking and Irrigation Water Quality in Jalandhar and Kapurthala Districts, Punjab, India: Using Hydrochemistry", *International Journal of Earth Sciences and Engineering*, vol. 5, 2012, pp. 1599–1608. https://www.academia.edu/28327777/Drinking_and_Irrigation_Water_Quality_in_Jalandhar_and_Kapurthala_Districts_Punjab_India_Using_Hydrochemsitry Accessed on September 21, 2023.

[49] Bouderbala, A. "Assessment of Groundwater Quality and its Suitability for Agricultural Uses in the Nador Plain, North of Algeria", *Exposure and Health*, vol. 7, no. 4, 2015, pp. 445–457. DOI: https://doi.org/10.1007/s12403-015-0160-z

[50] Talabi, A. O., Afolagboye, L. O., Aturamu, A. O. and Olofinlade, S. W. "Suitability Evaluation of River Owan Water for Irrigation", *Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)*, vol. 11, no. 4 Ver. I, 2017, pp. 74-80. DOI: 10.9790/2402-1104017480

[51] Gidey A. "Geospatial Distribution Modeling and Determining Suitability of Groundwater Quality for Irrigation Purpose Using Geospatial Methods and Water Quality Index (WQI) in Northern Ethiopia", *Applied Water Science*, vol. 8, no. 82, 2018, pp. 1-16. DOI: https://doi.org/10.1007/s13201-018-0722-x

[52] Khan, M.Y., Gani, K. M., Chakrapani, G. J. "Spatial and Temporal Variations of Physicochemical and Heavy Metal Pollution in Ramganga River—A tributary of River Ganges, India", *Environmental Earth Sciences*, vol. 76,

no. 231, 2017, pp. 129-135. DOI: https://doi.org/10.1007/s12665-017-6547-3