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Assessment of Well Water Quality in Obudu, Cross River, Nigeria: A Multi-Parameter and Regression-Based Water Quality Index Analysis.

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ABSTRACT

Access to clean and safe drinking water is essential for human health and well-being. This study evaluates the water quality of well water in Obudu Local Government Area, Cross River State, Nigeria, by correlating the Water Quality Index (WQI) with various physical, chemical, and bacteriological parameters. 65 well water samples were analysed using the Oregon WQI model, incorporating parameters such as temperature, electrical conductivity, pH, turbidity, total dissolved solids (TDS), heavy metals, and microbial contaminants. Results showed that temperature ranged from 26.1–27.9°C, pH from 7.01–7.98, and electrical conductivity from 138.1–217.2 µS/cm, all within acceptable World Health Organization (WHO) limits. However, concentrations of lead (0.01–0.08 mg/L), Iron (1.90-5.32) and total hardness (120.5-202.3) exceeded the WHO standard of 0.01 mg/L, 0.3 mg/l and less than 150 respectively. Results of total Coliforms and faecal Coliforms were too numerous to count (TNTC) in several wells, indicating contamination. WQI values ranged from 67.5 to 99.54, with some wells classified as poor to fair water quality (60–84 WQI), requiring treatment before consumption. Using multiple linear regression analysis (MLRA) water quality via WQI could be predicted by some physical, chemical and bacteriological parameters from Models 1-4. Model1 with adjusted R^2 value of 0.873 provided the best correlation. Water treatment interventions and sustainable management strategies are required to ensure safe drinking water for the local population.

Keywords: Well water, water quality index, multiple linear regression analysis, Obudu Local Government Area, correlation.

1.0 INTRODUCTION

Water, food and air are three basic needs for the survival of human beings. The water cycle also known as the hydrologic cycle describes the continuous movement of water on, above and below the surfaces of the earth (*Abbott et al., 2019).* Water is perhaps the most precious asset on earth. This is why it is important that water should be safe and portable. Water is obtained from different sources, which may not be safe and available throughout the year (*Grandjean, 2004).*Access to safe and clean drinking water is a fundamental human right, essential for human health and well-being (WHO, 2024). However, the quality of groundwater, a vital source of drinking water, is often compromised due to natural and anthropogenic factors (Kumar *et al*., 2017).World Health Organization (2006) recommends that high quality water should be free from pathogenic organisms and constituents that may be aesthetically objectionable. It should be clear, colourless and no objectionable taste and odour. In addition, it need not contain any concentration of chemicals that may be physiologically

harmful and economically damaging. The Water Quality Index (WQI) is a widely used tool to assess the overall quality of water, incorporating various physical, chemical, and biological parameters (Abbasi and Abbasi, 2017).

Obudu Local Government Area in Cross River State, Nigeria, is one region that relies heavily on well water for domestic and agricultural purposes. However, the water quality in this region has not been extensively studied, posing a risk to the health and livelihood of the inhabitants (Nwankwo and Ushie, 2017).

This study aims to correlate the Water Quality Index with water parameters of well water in Obudu Local Government Area, Cross River State. By analysing the relationships between WQI and various water parameters, this research seeks to evaluate the overall water quality in the study area, identify the most critical parameters affecting water quality, and provide recommendations for improving water quality and management practices.

2.0 MATERIALS AND METHOD

2.1 Materials

Water samples were obtained from sixty-five wells in Obudu Local Government Area (LGA) of Cross River State. The study areas are shown in Figure 1. There are ten (10) wards in Obudu LGA, namely, Alege/Ubang, Angiaba / Begiaka, Begiading, Ipong, Obudu Urban I, Obudu Urban II, Ukpe, Utugwang Central, Utugwang North, Utugwang South.In 5 wards, 7 samples were collected from 7 wells, giving a total of 35 samples. These wards are namely Obudu Urban I, Obudu Urban II, Begiading, Utugwang Central and Utugwang North. In the remainder five (5) wards, 6 samples were collected from 6 wells, giving a total of 30 samples.

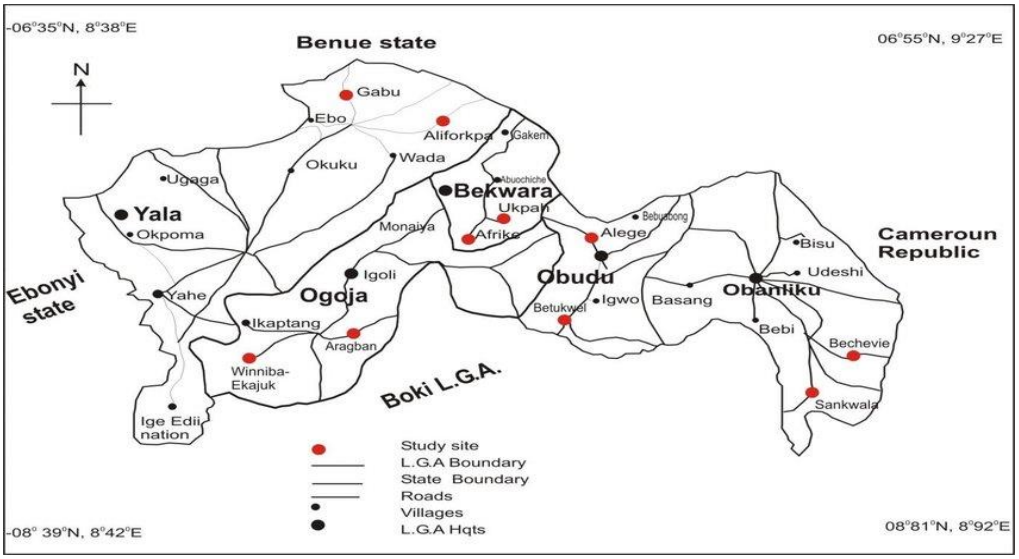

Figure 1: Map of Cross River State showing Obudu local Government area (Edu and Akwaji, 2017)

2.2 Methods

The following tests were carried out on the 65 water samples collected from the ten different wards in Obudu LGA. These are physical, chemical and microbiological tests.

2.2.1 Physical Parameters

Physical parameters include temperature, odour, taste, colour, dissolved solids, suspended solids, turbidity and electrical conductivity. These parameters are important as they affect other properties of water contamination. Temperature was determined using digital thermometer (ISO, 2018). Odour and taste were assessed using Olfactometry and taste panels in agreement with BS EN ISO 15680 (2018). Colour was determined using spectrophotometer (ISO, 2009). Dissolved Solids was and Electrical conductivity were determined using conductivity meter in accordance with ISO (2010). Suspended Solids and turbidity were estimated using turbidity meter or nephelometer (ISO, 2011).

2.2.2 Chemical Parameters

Chemical parameters include total hardness (TH), pH level, Calcium hardness, magnesium hardness, Chloride, Nitrate, Fluoride, Sulphate, Phosphate, Acidity, Alkalinity, Iron and manganese, Metal analysis, Dissolved oxygen, (DO), Biochemical Oxygen Demand(BOD).Using titration method, TH, Calcium Hardness, Magnesium Hardness, Chloride, Acidity, Alkalinity, were determined in accordance with BS ISO 9964-1 (2016).DO was determined using DO meter in accordance with BS ISO 9964-1(2016).BOD was determined using Winkler Method in agreement with ISO 5815-1 (2019).

2.2.3 Microbiological Parameters

Microbiological parameters include total Coliforms (TCC) and faecal Coliforms (FCC). TCC and FCC were obtained using membrane filtration (MF) Method in agreement with EN ISO 17994 (2014).

2.2.4 Water Quality Index Model Analysis

In this study, Oregon Water Quality Index (OWQI) model was used for the determination of water quality index (WQI)score as shown in equation 1 (Brown, 2019)**.**With Oregon model, each parameter is assigned a weight (wi) and a sub-index value (si) based on its importance and water quality standards. The OWQI uses six water quality parameters (DO, pH,BOD, temperature, total phosphorus (TP) and Faecal Coliform (FC).

WQI varies from 0 to 100, with 100 indicating excellent water quality.

$$\text{OWQI} = (\sum(Wi * Si)) / (\sum wi) \quad (1)$$

Where:

wi= the weight assigned to each water quality parameter (ranges from 0.05 to 0.25)

si = the sub-index value for each water quality parameter (ranges from 0 to 100).

The wi and si per water quality parameter was determined as follows:

Dissolved Oxygen (DO): wi: 0.25

si: Calculated based on the percentage of saturation (0-100%)

DO: si = (DO saturation %) * (0.01)

pH: wi: 0.15

si: Calculated based on the deviation from the ideal pH range (6.5-8.5)

pH: si = (1 - ((pH – 7) / 3)) * 100

Biochemical Oxygen Demand (BOD):

wi: 0.15

si: Calculated based on the concentration of BOD (mg/L)

BOD: si = (1 - (BOD / 30)) * 100

Temperature: wi: 0.10

si: Calculated based on the deviation from the ideal temperature range (10-20°C)

Temperature: si = (1 – [(Temperature – 15) / 10)] * 100

Total Phosphorus (TP): wi: 0.10

si: Calculated based on the concentration of TP (mg/L)

TP: si = (1 - (TP / 0.05)) * 100

Faecal Coliform (FC): wi: 0.05

si: Calculated based on the concentration of FC (colonies/100 mL)

FC: si = (1 - (FC / 200)) * 100

Table 1: Oregun Water Quality Index Classification(after Brown, 2019).

Water Quality Index	Rating
90 – 100	Excellent
85 – 89	Good
80 – 84	Fair
60 – 79	Poor
10 – 59	Very Poor

3.0 RESULT AND DISCUSSION

3.1 Results of Water Quality Parameters

Table 2 and 3 present the physicochemical and microbiological water quality parameters respectively. of water quality parameters from 65 wells in Obudu L.G.A of Cross River State. From the results, it was observed that some physical properties fall within the recommended values by WHO/NSDWQ (2007) standards. The temperature values range from26.1 – 27.9^{o}C. This temperature falls within the recommended WHO (2024) standard for safe water, which stipulates the range from24 °C to 30 °C. It is important to measure temperature, the state of water quality and identify any potential hotspots that could pose a risk (Riedel, 2019).The electrical conductivity ranges from

138.1-217.2 µs/cm, turbidity ranges from 0.33 – 3.09NTUand TDS ranges from 90.55- 197.1mg/l. These values are within the acceptable limit by WHO (2024) which recommends the conductivity, turbidity and TDS permissible maximum values to be1000 µs/cm, 5 NTUand 500 mg/l respectively. However, TSS and TH range from 0.00-0.99 mg/l and from 120.5-202.3 respectively. Some of these values are higher than the recommended maximum WHO standard values of 0.00 mg/l and <150 respectively (WHO, 2024).

Metals like zinc ranges from 0.11-0.23 mg/l, calcium ranges from 22.1-101 mg/l, magnesium ranges from 22.4-79.1 mg/l, potassium ranges from 2.01-3.15 mg/l, and manganese ranges from 0.1-0.9. These values fall within the WHO recommended maximum permissible limit of 3 mg/l, 200 mg/l, 100 mg/l, 12 mg/l and 100 mg/l respectively.

Additionally, Nitrate concentrations range from 1.11-6.25 which is within the WHO specified maximum value of 50 mg/l. However, the content of free chlorine (FCl_2) is from 0 – 2 mg/l. Some of these values are higher than the recommended maximum value of 0.5 mg/l (WHO, 2024).

Results from Table 2 show that metals like Iron ranges from 1.90-5.32and lead ranges from 0.01-0.08. These values are above the *Nigerian Standard for Drinking Water Quality* (NSDWQ) and WHO Standards, which specifies maximum values of 0.3 mg/l and0.01 mg/l respectively. High content of lead in water has negative health effects such as, hearing loss, anaemia, hypertension, kidney impairment, brain damage, immune system dysfunction, and toxicity to the reproductive organs (Zhang *et al*., 2014). This shows that some well water in Obudu LGA with high lead concentration are unfit for consumption. The water need treatment before being suitable for consumption. Arsenic and Mercury were not detected (n/d)and below detection limit (bdl) respectively.

Further analysis on the microbiological water quality parameters showed that the Total Coliforms (TCC) and Faecal Coliforms (FCC) were too numerous to count (TNTC). This indicates again that the well waters were contamination.

The results of WQI ranges from 67.5-99.54.This shows that some of the well water in Obudu LGA are of poor and fair quality, since it falls in the WQI ranges of 60-79 and 80-84respectively (Table 1). Such well water is unfit for consumption and need treatment prior to consumption. Some well water in the LGA with WQI values below 90 shows a departure from excellent natural water quality (Brown, 2019). Also, the BOD_5 spans from 2.83-6.22 mg/L (average of 4.53 mg/L), while DO is from 9.13-12.84 mg/L (average 10.99 mg/L).

Table 2:PhysicochemicalWater Quality Parameters

Par	Tem	PH	Taste Odour	Col	Cond	Turb	Fe	TDS	TSS	Zn	Pb	Arsenic	Hg	Ca	Mg	TH	K	Mn	N	BOD_5	DO	$F.Cl_2$	Par
Units	oC				µs/cm	NTU	mg/l															ppm	%
Well 1	26.1	7.39	grassy	<5	163.4	0.48	3.12	106.21	0	0.16	0.05	n/d	bdl	88	37.9	153.1	2.31	0.15	0.5	3.48	12.65	0	81.66
Well 2	28.3	7.66			139.3	0.55	3.78	90.55	0	0.22	0.08			101	78.3	201.3	2.11	0.19	7	3.29	12.12	0.5	77.44
Well 3	26.3	7.98	earthy/musty		217.3	3.1	5.32	141.25	0.098	0.19	0.1			69	53.5	180.5	3.15	0.1	3.3	3.87	12.72	2	69.4
Well 4	26.3	7.71	grassy		145.9	2.03	3.06	94.84	0.064	0.2	0.06			66	49.6	133.6	2.96	0.08	3.6	4.02	11.41	1	69.45
Well 5	26.4	7.01	earthy/musty		194.2	2.94	3.98	126.23	0.038	0.18	0.08			75	59.2	142.2	3.02	0.1	1.8	4.2	11.33	0	67.5
Well 6	26.1	7.68	grassy		216.2	0.58	3.81	140.53	0	0.21	0.07			95.8	76.1	199.5	2.05	0.14	6.25	5.32	11.69	0.5	68.6
Well 7	26.2	7.28			162.4	0.59	3.21	106.11	0.089	0.15	0.06			87	48.6	163.9	2.04	0.16	0.6	4.75	11.65	2	76.4
Well 8	26.1	7.88			138.1	0.57	3.68	124.23	0	0.21	0.07			69.2	52.6	202.3	3.2	0.13	5	5.31	9.55	2	73.66
Well 9	27.3	7.67			163.4	3.02	4.95	94.73	0.096	0.23	0.08			68.1	59.1	170.5	2.86	0.11	3.2	3.72	10.24	0.5	72.43
Well 10	26.1	7.91			194.2	2.88	3.06	90.55	0.037	0.19	0.06			64	39.8	132.6	2.01	0.1	1.95	4.64	12.68	1	82.54
Well 11	26.6	7.84	earthy/musty		186.4	2.35	3.43	104.5	0.065	0.17	0.01			54	47.4	120.5	2.03	0.5	1.22	3.73	13.11	0.1	77.32
Well 12	26.8	7.79			176.2	2.21	4.23	164.4	0.082	0.18	0.02			61.2	48.3	125.3	2.04	0.12	1.23	4.45	12.22	0.2	75.4
Well 13	26.7	7.84	grassy		168.4	0.85	4.35	108.6	0.023	0.19	0.03			52.5	51.4	134.2	2.03	0.13	1.24	4.44	11.57	0.3	78.5
Well 14	26.8	7.77			183.5	2.74	4.23	97.5	0.093	0.12	0.04			34.2	34.3	167.4	2.09	0.14	1.25	3.06	12.25.	0.4	77.65
Well 15	26.8	7.9			198.2	3.02	4.12	97.8	0.021	0.11	0.06			42.4	32.5	165.2	2.07	0.15	1.27	5.65	9.85	2	83.44
Well 16	27.2	7.84	earthy/musty		169.3	2.65	4.6	105.3	0.023	0.13	0.01			68.2	27.4	131.4	2.03	0.16	1.29	4.34	10.26	1	86.55
Well 17	27.1	7.45	grassy		164.9	1.85	4.6	107.4	0.034	0.14	0.04			67.1	43.3	142.4	2.05	0.3	3.5	6.02	9.26	0.1	79.32
Well 18	27.4	7.45			192.7	0.96	3.4	122.5	0.048	0.15	0.05			66.2	49.2	123.5	2.02	0.4	3.5	5.12	11.54	0.2	79.23
Well 19	27.2	7.63			186.3	0.87	3.6	123.4	0.099	0.16	0.01			22.1	31.3	155.3	2.07	0.5	4.24	4.31	10.73	0.3	84.66
Well 20	26.6	7.78	earthy/musty		185.4	1.67	3.54	109.9	0.012	0.17	0.02			25.8	34.1	164.1	2.09	0.6	1.9	3.25	11.45	0.4	89.3
Well 21	26.3	7.83			165.3	2.87	4.91	108.8	0.017	0.19	0.03			38.9	38.6	187.2	2.04	0.7	1.2	2.83	12.21	0.5	87.66
Well 22	26.6	7.45	grassy		186.3	0.56	3.11	124.3	0.076	0.21	0.04			65.2	49.2	176.2	2.06	0.8	1.33	3.42	12.1	0.1	84.44

*Key: Par=Parameter, Tem= Temperature, PH=Potential of hydrogen,Cond=Conductivity, Turb=Turbidity,TDS=Total dissolved solids. TSS= Total suspended solids, Hg=*Mercury,*Ca=Calcium, Mg=Magnesium, TH= Total Hardness, K=Potassium, Mn=Manganese, N=Nitrate,* , BOD_5*=Five-day biochemical oxygen demand,* DO= dissolved oxygen,*FCl.= Free Chlorine,WQI= Water Quality Index, nd=Not detected,, bdl=Below detection limit,tntc=Too numerous to count,* Fe=Iron, Zn = Zinc, Pb = lead, As = Arsenic

Table 2 Physicochemical water quality parameters (continued)

Par	Tem	PH	Taste/ Odour	Col	Cond	Turb	Fe	TDS	TSS	Zn	Pb	As	Hg	Ca	Mg	TH	K	Mn	N	BOD_5	DO	F.Cl2	WQI
Units	oC				µs/cm	NTU	mg/l															ppm	%
Well 23	26.6	7.4	grassy	<5	184.5	1.88	4.33	126.3	0.051	0.22	0.05	n/d	bdl	59.1	55.4	166.3	2.22	0.9	1.44	4.53	11.57	0.2	84.54
Well 24	26.7	7.02			184.4	2.89	3.8	132.2	0.011	0.15	0.06			43.1	44.6	169.3	2.04	0.11	1.45	4.65	10.42	0.3	79.56
Well 25	27.1	7.3			194.3	0.77	4.67	123.4	0.033	0.12	0.07			44.2	39.1	163.4	2.08	0.12	1.46	3.45	12.82	0.4	80.43
Well 26	26.4	7.56			194.3	1.69	3.65	123.4	0.029	0.17	0.08			56.2	38.4	144.3	2.05	0.13	1.12	4.57	10.22	0.1	82.54
Well 27	26.8	7.64			198.3	2.44	4.87	125.3	0.075	0.18	0.01			49.1	37.3	127.4	2.04	0.14	1.14	5.67	10.56	0.2	86.54
Well 28	26.9	7.43			196.2	0.33	3.65	143.3	0.026	0.19	0.02			39.2	36.3	133.5	2.01	0.15	1.19	3.88	12.29	0.3	92.1
Well 29	26.8	7.43			185.3	1.77	4.67	138.2	0.056	0.14	0.03			61.2	35.4	129.3	2.09	0.1	1.8	5.42	9.13	0.4	83.5
Well 30	26.8	7.43			164.7	2.4	3.55	123.4	0.022	0.13	0.04			62.2	34.1	141.4	2.04	0.2	1.7	5.42	10.53	0.1	82.54
Well 31	26.9	7.45			164.8	1.72	4.71	143.2	0.035	0.12	0.05			63.1	33.2	139.3	2.05	0.3	1.11	3.41	11.76	0.2	81.23
Well 32	27.1	7.34	earthy/musty		182.4	2.55	3.34	172.3	0.027	0.17	0.06			64.2	32.5	172.4	2.03	0.4	1.15	4.34	12.23	0.3	87.57
Well 33	26.6	7.43			195.3	3.05	4.22	165.3	0.088	0.15	0.07			66.1	31.6	164.3	2.02	0.5	1.19	3.84	12.45	0.4	84.3
Well 34	26.9	7.32	grassy		184.3	2.84	3.44	96.7	0.074	0.13	0.08			68.2	41.2	154.2	2.06	0.6	1.2	6.32	10.17	0.1	76.32
Well 35	26.8	7.73			184.3	1.67	4.67	132.3	0.043	0.19	0.02			51.1	42.4	155.2	2.03	0.7	1.3	4.23	12.73	0.2	85.8
Well 36	27.1	7.73	earthy/musty		184.4	0.99	3.31	122.9	0.057	0.11	0.01			52.2	43.1	149.2	2.05	0.8	1.11	4.55	12.12	0.3	79.65
Well 37	27.2	7.8	grassy		164.5	2.45	4.7	124.5	0.091	0.12	0.04			53.1	44.7	136.2	2.07	0.9	1.12	3.48	11.62	0.4	76.85
Well 38	27.3	7.34	earthy/musty		185.3	3.04	3.51	165.2	0.021	0.14	0.05			54.2	48.1	147.3	2.06	0.11	1.13	6.21	9.35	0.1	76.55
Well 39	26.8	7.04			185.4	1.22	3.4	147.9	0.044	0.21	0.08			55.1	45.2	154.1	2.04	0.12	1.14	4.22	10.57	0.2	83.43
Well 40	26.7	7.43			189.5	2.55	4.8	197.1	0.072	0.18	0.02			56.2	43.8	152.2	2.03	0.13	1.15	5.43	9.66	0.3	78.65
Well 41	26.8	7.35	grassy		197.5	0.4	4.8	148.4	0.098	0.14	0.07			57.1	31.2	155.3	2.07	0.14	1.16	3.44	10.53	0.4	84.23
Well 42	26.8	7.45			186.3	2.77	3.7	179.5	0.041	0.12	0.05			58.1	33.4	151.5	2.08	0.15	1.17	4.57	10.22	0.1	79.77
Well 43	27.2	7.34			165.4	1.44	3.5	97.6	0.079	0.18	0.03			59.2	28.3	132.1	2.09	0.2	1.18	3.44	12.84	0.2	88.54
Well 44	27.1	7.34			198.3	3.05	3.6	106.6	0.054	0.19	0.06			41.2	22.4	133.2	2.04	0.9	1.19	3.62	9.87	0.3	99.54

Key: Par=Parameter, Tem= Temperature, PH=Potential of hydrogen, Cond=Conductivity, Turb=Turbidity, TDS=Total dissolved solids. TSS= Total suspended solids, Hg=Mercury, *Ca=Calcium, Mg=Magnesium, TH= Total Hardness, K=Potassium, Mn=Manganese, N=Nitrate,* , BOD_5*=Five-day biochemical oxygen demand*, DO= dissolved oxygen, *FCl.= Free Chlorine, WQI= Water Quality Index, nd=Not detected,, bdl=Below detection limit, tntc=Too numerous to count,* Fe=Iron, Zn = Zinc, Pb = lead, As = Arsenic

Table 2 Physicochemical Water Quality Parameters (Continued)

Par	Tem	PH	Taste Odour	Colour	Cond	Turb	Fe	TDS	TSS	Zn	Pb	As	Hg	Ca	Mg	TH	K	Mn	N	BOD_5	DO	$F.Cl_2$	WQI
Units	oC				µs/cm	NTU	mg/l															ppm	%
Well 45	27.4	7.85	grassy	<5	168.4	2.81	4.8	98.8	0.027	0.16	0.02	n/d	bdl	42.1	43.2	144.2	2.03	0.3	1.21	4.27	11.25	0.4	83.32
Well 46	27.2	7.34			164.8	1.39	4.9	132.9	0.056	0.13	0.04			43.2	37.5	156.3	2.04	0.7	1.22	4.62	11.45	0.1	83.4
Well 47	26.6	7.85			184.3	2.58	4.8	142.4	0.047	0.21	0.08			44.1	39.4	167.5	2.07	0.1	1.2	3.22	12.1	0.2	84.3
Well 48	26.7	7.37			185.3	3.09	4.3	124.3	0.028	0.22	0.03			45.2	51.2	139.1	2.05	0.4	1.6	3.45	12.52	0.3	82.4
Well 49	26.8	7.84			195.3	1.22	4.8	143.3	0.034	0.16	0.01			37.1	52.1	138.4	2.04	0.3	1.18	4.27	11.25	0.4	77.4
Well 50	26.8	7.43	earthy/musty		194.3	0.99	4.6	122.4	0.032	0.18	0.02			34.2	39.3	137.3	2.09	0.5	1.5	4.62	11.45	0.1	87.65
Well 51	27.2	7.35	grassy		168.3	2.29	4.3	142.7	0.055	0.11	0.03			65.2	38.4	136.2	2.01	0.6	1.7	3.22	12.1	0.2	88.6
Well 52	26.3	7.43			175.3	1.24	4.2	96.8	0.069	0.15	0.04			49.1	35.4	135.5	2.02	0.7	1.11	3.45	12.52	0.3	84.23
Well 53	26.9	7.34			175.3	2.61	4.6	109.3	0.099	0.18	0.05			63.2	38.1	134.6	2.03	0.8	1.13	4.32	10.63	0.4	88.65
Well 54	27.2	7.85			179.9	3.01	3.8	102. 9	0.052	0.12	0.06			55.1	32.7	133.4	2.04	0.9	1.15	5.23	11.21	0.1	87.43
Well 55	27.1	7.65	earthy/musty		186.4	0.92	3.5	112.76	0.045	0.14	0.01			59.2	39.3	132.1	2.05	0.11	1.17	6.22	9.45	0.2	89.43
Well 56	26.8	7.34	grassy		197.3	1.36	2.55	158.25	0.095	0.16	0.08			68.2	41.2	131.3	2.06	0.13	1.16	4.24	11.27	0.3	79.65
Well 57	26.8	7.34			185.4	2.48	2.8	157.9	0.068	0.17	0.02			51.2	42.1	141.2	2.09	0.12	1.3	3.33	11.48	0.1	79.44
Well 58	26.6	7.34			176.5	3.05	1.9	132.7	0.043	0.12	0.03			49.1	44.3	142.3	2.08	0.4	1.11	4.25	10.23	0.4	76.43
Well 59	26.8	7.26	earthy/musty		185.4	0.46	2.6	190.8	0.012	0.15	0.01			59.1	47.1	143.1	2.07	0.5	1.14	5.42	11.34	0.2	82.32
Well 60	26.8	7.85			184.4	1.94	3.6	106.3	0.033	0.17	0.07			61.2	48.1	144.2	2.06	0.6	1.17	4.31	10.41	0.3	82.22
Well 61	26.9	7.54	grassy		175.6	2.48	2.8	1069	0.017	0.18	0.04			62.1	43.2	145.2	2.05	0.7	1.19	3.11	12.43	0.4	87.65
Well 62	28.9	7.43	earthy/musty		185.4	3.06	3.6	164.2	0.013	0.19	0.03			43.2	41.5	146.1	2.04	0.8	1.15	4.91	10.36	0.2	92.4
Well 63	26.8	7.34	grassy		185.6	1.44	3.8	122.5	0.026	0.21	0.06			47.1	55.3	147.4	2.03	0.9	1.6	3.52	12.48	5	86.43
Well 64	26.9	7.34	earthy/musty		187.5	2.57	3.5	116.5	0.083	0.22	0.08			43.2	52.1	148.3	2.02	0.12	1.12	5.22	9.86	0.1	83.5
Well 65	27.2	7.42	grassy		186.6	3.07	3.6	129.8	0.073	0.11	0.04			45.1	49.2	149.1	2.08	0.15	1.11	4.47	10.14	0.2	73.34

Key:

Par=Parameter; Temp= Temperature; PH=Potential of hydrogen; Cond =Conductivity; Turb=Turbidity; TDS=Total dissolved solids. TSS= Total suspended solids; Hg=Mercury; *Ca=Calcium; Mg=Magnesium; TH= Total Hardness; K=Potassium; Mn=Manganese; N=Nitrate;*;BOD_5*=Five-day biochemical oxygen demand*; DO= dissolved oxygen; *FCl.= Free Chlorine; WQI= Water Quality Index;nd=Not detected;;bdl=Below detection limit; tntc=Too numerous to count;* Fe=Iron; Zn = Zinc; Pb = lead; As = Arsenic

3.2 Multiple Linear Regressions between WQI and Water Parameters

Multiple linear regressions(MLR) between WQI and water parameterswas carried out in SPSS. WQI as dependent variable and water parameters as independent variables. The independent variables were varied interchangeably and the results are presented in Table 3.

Table 3: Multiple Linear Regression between WQI and water Parameters

Model No	Water Parameters	Model Summary			ANOVA	
		R	R^2	AdjustedR^2	F	Sig
1	Temp ,pH, Cond, Turb, Iron, TDS, TSS, Zinc, Lead, Ca, Mg, TH, K, Mn, N, F.Cl_2	0.947	0.897	0.873	26.267	0.000
2	Temp ,Turb, TSS, Zinc, Mg, K, Mn, F.Cl2	0.942	0.887	0.871	55.147	0.00
3	Temp, TSS, Zinc, Mg, K, N, Ca,Mn,	0.935	0.874	0.856	48.375	0.00
4	Temp, Turb, TSS, Zinc, Mg, K, Mn,F.Cl2, Cond	0.944	0.891	0.874	50.200	0.00
5	PH, TDS, Lead, TH	0.381	0.145	0.088	2.549	0.048
6	Temp, Turb, TSS, Zinc, Cond	0.364	0.133	0.059	1.806	0.126
7	K, Mg, Ca, F.Cl2, TSS, Zinc	0.874	0.764	0.739	31.227	0.000
8	Cond, PH, K, N, CA, MN	0.692	0.479	0.0425	0.883	0.000

Note: Temp = Temperature, pH=Potential of hydrogen, Cond =Conductivity, Turb =Turbidity, TDS = Total dissolved solid, TSS = Total suspended solid, Ca=Calcium, Mg=Magnesium, TH=Total Hardness, K=Potassium, Mn=Manganese, N=Nitrate, TCC=Total Coliforms FCC=Faecal Coliforms, F.Cl_2=Free Chlorine. WQI=Water Quality Index.

Eight models were analyzed; four models 1-4 have values of adjustedR^2greater than 0.8, while four models 5-8 have values of adjusted R^2 less than 0.8. The results for models 1-4 with the values of adjusted$R^2 > 0.8$ show that these models are fit for correlation, while models 5-8 with adjusted R^2 less than 0.8 demonstrate that they are unfit for correlation.

From the MLR carried out between WQI as dependent variables and water parameters as independent variables. The best fit models were selected as model number 1, 2, 3, and 4. The selection were done base on the value of R^2 range from 0.8 to 1. The output results among the selected models using SPSS are described as follows:

Model number 1,WQIis the dependent variable and water parameters (Temp, pH, Cond, Turb,Fe, TDS, TSS, Zn, Pb, Ca, Mg, TH, K, Mn, N, FCl_2) are independent variables. Model 1 summary is contained in Table 4, while the coefficients are presented in Table 4.

Table 4: Coefficients of WQI and Water Parameter (Temp, pH, Cond, Turb, Fe, TDS, TSS, Zn, Pb, Ca, Mg, TH, K, Mn, N, FCl_2)

Model		Coefficients Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	6.032	26.090		.231	0.818
	Temp	3.489	0.732	0.266	4.763	0.000
	PH	-0.859	1.390	-0.034	-0.618	0.540
	Cond	0.031	0.021	0.077	1.446	0.155
	Turb	-0.799	0.355	-0.121	-2.252	0.029
	Fe	0.289	0.436	0.034	0.662	0.511
	TDS	0.001	0.002	0.011	0.232	0.818
	TSS	-41.433	10.588	-0.200	-3.913	0.000
	Zn	90.948	10.105	0.507	9.001	0.000
	Pb	-7.631	16.728	-0.030	-0.456	0.650
	Ca	0.025	0.026	0.062	0.972	0.336
	Mg	-0.488	0.041	-0.812	-11.825	0.000
	TH	0.002	0.020	0.007	0.117	0.907
	K	-5.592	1.385	-0.249	-4.037	0.000
	Mn	5.512	1.106	0.254	4.983	0.000
	N	-0.317	0.347	-0.065	-0.913	0.366
	FCl_2	0.682	0.419	0.083	1.629	0.110

a. Dependent Variable: WQI

Key: Temp = Temperature, pH=Potential of hydrogen, Cond = Conductivity, Turb =Turbidity, Fe = iron, TDS = Total dissolved solid, TSS = Total suspended solid, Ca=Calcium, Mg =Magnesium, TH=Total Hardness, K=Potassium, Mn =Manganese, N=Nitrate,FCl_2*=Free Chlorine. WQI=Water Quality Index.*

Therefore, Model 1 is presented in Equation 2 thus:

$$\text{WQI} = 6.032 + 3.489\text{Temp} - 0.859\text{pH} = 0.031\text{Cond} - 0.799\text{Turb} = 0.289\text{Fe} = 0.001\text{TDS} - 41.433\text{TSS} + 90.948\text{Zn} - 7.631\text{Pb} + 0.025\text{Ca} - 0.488\text{Mg} + 0.002\text{TH} - 5.592\text{K} + 5.512\text{Mn} + 0.317\text{N} + 0.682\text{FCl}_2 \quad (2)$$

Adjusted $R^2 = 0.873$

Similarly, model number 2,WQI represents the dependent variable and water parameters the independent variables (Temp, Turb, TSS, Zn, Mg, K, Mn and FCl_2). The summary of the model is contained in Table 4 and coefficients presented in 5.

Table 5: Coefficients of WQI and Water Parameter (Temp, Turb, TSS, Zn, Mg, K, Mn, FCl_2)

Model		Coefficients Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
2	(Constant)	19.954	17.783		1.122	.267
	Temp	3.090	0.642	0.236	4.813	0.000
	Turb	-0.716	0.310	-0.108	-2.307	0.025
	TSS	-38.011	9.636	-0.183	-3.945	0.000
	Zn	90.334	9.534	0.504	9.475	0.000
	Mg	-0.490	0.034	-0.815	-14.579	0.000
	K	-6.551	1.199	-0.292	-5.463	0.000
	Mn	5.334	1.046	0.246	5.102	0.000
	FCl_2	0.588	0.394	0.071	1.492	0.141

a. Dependent Variable: WQI

Note: Temp = Temperature, Turb =Turbidity, TSS = Total suspended solid,Zn=Zinc, K=Potassium, Mn=Manganese, FCl_2*= Free Chlorine. WQI=Water Quality Index.*

Therefore, Model 2 is shown in Equation 3:

$$\text{WQI} = 19.954 + 3.090\text{Temp} - 0.716\text{TURB} - 38.011\text{TSS} + 90.334\text{Zn} - 0.490\text{Mg} - 6.551\text{K} + 5.334\text{Mn} + 0.588\text{FCl}_2 \quad (3)$$

Adjusted $R^2 = 0.871$

Similarly, the model summary of Model 3 is contained in Table 4, while the coefficients are presented in Table 6.

Table 6: Coefficients of WQI and Water Parameter(Temp, TSS, Zn, Mg, K, Mg, N, and Ca)

Model		Coefficients			t	Sig.
		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta		
3	(Constant)	23.444	19.524		1.201	0.235
	Temp	2.857	0.688	0.218	4.155	0.000
	TSS	-41.908	10.166	-0.202	-4.122	0.000
	Zn	92.261	10.221	0.514	9.026	0.000
	MG	-0.472	0.041	-0.786	-11.412	0.000
	K	-6.531	1.294	-0.291	-5.047	0.000
	N	-0.193	0.310	-0.039	-0.622	0.537
	Ca	0.017	0.023	0.042	0.742	0.461
	Mn	5.560	1.104	0.256	5.038	0.000

a. Dependent Variable: WQI

Note: Temp = Temperature, TSS = Total suspended solid, Zn*= Zinc, Mg=Magnesium, K=Potassium, N=Nitrate, Ca=Calcium, Mn=Manganese, WQI=Water Quality Index.*

Thus, Model 3 is presented in Equation 4 as:

$$\text{WQI} = 23.444 + 2.857\text{Temp} - 41.908\text{TSS} + 92.261\text{Zn} - 0.472\text{Mg} - 6.531\text{K} - 0.193\text{N} + 0.017\text{Ca} + 5.560\text{Mn} \quad (4)$$

Adjusted $R^2 = 0.856$

In addition, for Model4, WQI is the dependent variable and water parameters the independent variables (Temp, Turb, TSS, Zn, Mg, K, MN, FCl_2 ,Cond). The model summary is contained in Table 2, while the coefficients are presented in Table 8.

Table 8: Coefficients of WQI and Water Parameter (Temp, Turb, TSS, Zn, Mg, K, MN, Cond and FCl_2)

coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
4	(Constant)	8.720	19.256		.453	.652
	Temp	3.295	0.652	0.251	5.057	0.000
	Turb	-0.786	0.311	-0.119	-2.525	0.014
	TSS	-40.320	9.677	-0.195	-4.167	0.000
	Zn	89.493	9.461	0.499	9.459	0.000
	Mg	-0.491	0.033	-0.817	-14.754	0.000
	K	-6.035	1.240	-0.269	-4.865	0.000
	Mn	5.462	1.039	0.252	5.255	0.000
	FCl_2	0.584	0.390	0.071	1.497	0.140
	Cond	0.028	0.019	0.069	1.444	0.155

a. Dependent Variable: WQI

Note: Temp = Temperature, Turb =Turbidity, TSS = Total suspended solid, Zn=Zinc, Mg=Magnesium, K=Potassium, Mn=Manganese, FCl_2=Free Chlorine, Cond=*Conductivity, WQI=Water Quality Index.*

Model 4 is presented in Equation 5:

$$\text{WQI} = 8.720 + 3.295\text{Temp} - 0.786\text{Turb} - 40.320\text{TSS} + 89.493\text{Zn} - 0.491\text{Mg} - 6.035\text{K} + 5.462\text{Mn} + 0.584\text{FCl}_2 + 0.028\text{Cond} \quad (5)$$

Adjusted $R^2 = 0.874$

4.0 CONCLUSIONS

The current study examined 65 samples of well water from 65 wells in Obudu Local Government Area, Cross Rivers State. Well water physical, chemical, biological parameters and water quality index were determined. A comparison was made between well water parameters and WHO/NSDWQ standards. The following conclusions can be drawn:

The results of physical water parameters such as temperature (26.1 – 27.9 ^{o}C),electrical conductivity (138.1-217.2 µs/cm),turbidity (0.33 – 3.09 NTU)and TDS (90.55- 197.1 mg/l) fall within the recommended permissible maximum values by WHO/ NSDWQ standards which should be 30 °C, 1000 µs/cm, 5 NTU and 500 mg/l respectively. However, the values of total suspended solids (0.00 to 0.099 mg/l) and total hardness (120.5-202.3) from Obudu well water are above the maximum values recommended by WHO standards for drinking water quality, which should be 0.0 mg/l and less than 150 respectively.

1) The concentration of metals like zinc (0.11-0.23 mg/l), calcium (22.1-101 mg/l), magnesium (22.4-79.1 mg/l), potassium (2.01-3.15 mg/l), manganese (0.1-0.9 mg/l) fall within the WHO recommended maximum permissible limit of 3 mg/l, 200 mg/l, 100 mg/l, 12 mg/l and 100 mg/l respectively. However, the concentration of metals like Iron ranges (1.90-5.32) and leads ranges (0.01-0.08), are above the NSDWQ and WHO Standards, which specifies maximum values of 0.3 mg/l and 0.01 mg/l respectively. The results of total Coliforms and faecal

Coliforms were too numerous to count (TNTC). This indicates again that the well waters were contamination. The values of WQI for well water in Obudu LGA range from 67.5-99.54. The calculated WQI values for some wells fell below the threshold of 90, indicating that the water quality is below excellent (Brown, 2019). Consequently, some well water sources in Obudu LGA are deemed unfit for human consumption.

2) Considering the excess concentration of total suspended solids, total hardness, Iron, lead, total Coliforms, faecal Coliforms and WQI of some well water in Obudu LGA. It is unfit for consumption and need treatment before being suitable for consumption.

3) From MLRA, WQI could be predicted from some water parameters based on adjusted R-squared values above 0.8. Models 1 to 4, represented in Equations 2, 3, 4 and 5 show a good prediction of WQI using water index parameters. Therefore, Models 1 to 4, (Equations 2-5) are recommended for the prediction of WQI in Obudu LGA of Cross River State. Further studies on investigation of well water parameters and subsequent correlation of WQI with water parameters need to be conducted at other LGA such as Obanliku LGA in Cross River State.

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