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Water quality index of rainwater harvested in Owerri, Imo state, Nigeria

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Abstract
Background: Harvested rainwater is one of the natural sources of water that serves as an alternative source of water supply. Due to increasing urbanization, industrialization and other developmental activities, this source of water is being polluted. The present study aimed at determining the Water Quality Index (WQI) of harvested rainwater in Owerri, Imo state, Nigeria, a growing urban city.
Methods: This was achieved by collecting samples from four different (4) locations in Owerri, Imo state and subjecting the samples to standard physicochemical analysis and calculation of water quality index.
Results: The WQI obtained varied across the locations. From 15.34 (poor quality) in Douglas to 188.80 in Orji to 141.20 in Imo Housing Estate and to 104.25 in Eziobodo (all excellent quality).
Conclusions: The harvested rainwater of the locations sampled needs some degree of treatment before use for public health purposes including those with excellent status.

Keywords: water quality; harvested rainwater; urbanization; environmental microbiology; waterborne diseases

Introduction

Globally, water scarcity is a rapidly growing concern [1, 2]. Furthermore, inaccessibility and poor quality of available sources of water has resulted in various waterborne diseases such as diarrhoea, typhoid and cholera [3, 4, 5]. Water is a clear coloured and odourless substance. It is one of nature's most abundant and useful compound making up part of the essential elements for the existence of living things - human beings, animals and plants [6, 7, 8]. In developing countries such as in Nigeria, where there is scarcity of water [9, 5], rainwater harvesting is serving as an alternative and additional source of water supply especially for rural dwellers [6]. To prevent waterborne diseases and promote health, there is need for water quality monitoring and assessment and Water Quality Index (WQI), a useful tool for quick estimation of quality of any water resource [10, 11]. Water quality index (WQI) was first formulated by Horton (1965) [12, 13]; since then various diverse approaches to WQI's calculation can be found in the literature [11, 14, 13]. WQI is an index used for the detection and evaluation of water pollution and may be defined as a composite impact of different water quality parameters on the overall quality of water [12]. Water quality index provide information on a rating scale from zero to hundred. The higher values of WQI indicates better quality of water and lower value shows poor water quality [13]. WQI numerically summarizes the information from multiple water quality parameters into a single value. Much of the research has been done on the water quality indices for the quality assessment of different water resources [15, 16, 17] [15, 18, 19].

However, there is paucity of data on the water quality index of harvested rainwater. Hence, the present study aimed at determining the Water Quality Index of rainwater harvested In Owerri the capital of Imo state in Nigeria.

Methodology

Study Area

Owerri is the capital of Imo state. It lies within the 5°29′06″N 7°02′06″E and 5.485°N 7.035°E Coordinates. Owerri consists of three Local Government Areas including Owerri Municipal, Owerri North and Owerri West. It has approximately 100 square kilometers (40 sq mi) in area and estimated population of about 400,000 as of 2006 National population census of Nigeria. Owerri is bordered by the Otamiri River to the east and the Nworie River to the south. Its mean annual temperature ranges from 25 - 30°C and mean annual rainfall range of 2500 – 3500mm.

Sample Collection and Analysis

Rainwater samples were collected from four [4] different locations Douglas road in Owerri municipal; Imo housing estate in New Owerri; Orji in Owerri - north and Eziobodo in Owerri-west in Imo state. Samples were collected aseptically in sterile plastic containers, sealed properly, labelled and transported to the lab for standard physiochemical analysis.

Physiochemical parameters such as pH, electrical conductivity, temperature, TDS, DO, Nitrate, COD, BOD, Alkalinity, Phosphate, hardness, sulphate, calcium and heavy metals were analysed using Atomic Absorption Spectrophotometer, Digital meters in addition to titration methods. Result of the analysis were compared with WHO standards for drinking water and The Nigerian Standard for Drinking Water Quality where applicable.

Water quality index (WQI) of each location calculated using the Horton's formula.

Water Quality Index Calculation

The Water Quality Index (WQI) was calculated using the Weighted Arithmetic Index method. The quality rating scale for each parameter was calculated by using this expression

$$WQI = \sum QnWn / \sum Wn \quad (1)$$

Where,
Qn = Quality rating of nth water quality parameter.
Wn = Unit weight of nth water quality parameter.

Quality rating (Qn)

The quality rating (qn) is calculated using the expression given in Equation (2).

$$Qn = [(Vn – Vid) / (Sn – Vid)] \times 100 \quad (2)$$

Where,
Vn = Estimated value of nth water quality parameter at a given sample location.
Vid = Ideal value for nth parameter in pure water. Vid for pH = 7 and 0 for all other parameters.
Sn = Standard permissible value of nth water quality parameter.

Unit weight (Wn)

The unit weight (Wn) is calculated using the expression given in Equation (3).

$$Wn = K / Sn \quad (3)$$

Where,
Sn = Standard permissible value of nth water quality parameter.
K = Constant of proportionality and it is calculated by using the expression given in Equation (4).

$$k = [1 / (\sum 1/ Sn = 1, 2...n)] \quad (4)$$

Table 1: WQI and corresponding water quality status

Status	WQI	Possible use(s)
Excellent	95-100	Drinking, Irrigation and Industrial
Good	80-94	Domestic, Irrigation and Industrial
Fair	65-79	Irrigation and Industrial
Marginal	45-64	Irrigation
Poor	0-44	Proper treatment required before use

Source: Global Drinking Water Quality Index Development and Sensitivity Analysis Report (20)

Results

The results of the physiochemical analysis of the water samples collected and analysed for Douglas road in Owerri municipal; Imo housing estate in New Owerri; Orji in Owerri - north and Eziobodo in Owerri – west in Imo state is shown in tables 2, while the calculated water quality index (WQI).

For each of the locations sampled is shown in tables 3 (Douglas road, Owerri Municipal); 4 (Imo Housing Estate, New Owerri); 5 (Orji, Owerri – North) and 6 (Eziobodo, Owerri West); with a summary of water quality index (WQI) in table 7.

Table 2: Results of the physiochemical analysis of harvested rainwater in different locations in Owerri, Imo state, Nigeria.

Parameter, Unit	WHO Standard	Douglas Road	Imo Housing Estate	Orji	Eziobodo
pH	6.5 – 8.5	6.6	7.6	6.2	6.3
Conductivity, µs/cm	100	13	5	27	103
Dissolved Oxygen, mg/l	5	0.9	2.6	0.6	4.8
Total Solids, mg/l	250	194	80	88	142
Total Dissolved Solids mg/l	250	9.55	1.72	18.65	68.05
BOD	5	0.3	0.8	0.1	2.4
Calcium, mg/l	300	0.39	0	0.22	0.3
Hardness	150	0.27	0	0.84	0.05
Magnesium, mg/l	0.2	0	0	0	0.23
Alkalinity	100	102	84	16	58
Nitrate NO3-, mg/l	50	81.1	43	18	27.1
Sulphate, mg/l	250	506.6	571.22	544.5	316.9
Total chlorine, mg/l	5	0.22	0	0.23	0.25
Manganese, mg/l	0.2	0	0.3	0.4	0.2
Turbidity	5	20.93	18.23	32.52	23.98

In the present study, the measured parameters when compared with WHO and Nigerian Standard for Drinking Water Quality met 60% of the requirements (Table 2 above). pH is an important operational water quality parameter [21] is normal within the locations sampled in the present study. Nitrate known to cause various adverse health diseases such as asphyxia in children, enlargement of thyroid gland and certain cancers [22, 23] [24] had the highest concentration in the harvested rainwater from Douglas road. This could be as result of the heavy urbanisation in the area [6] and a mixture of nitrate containing fertilizers with atmospheric nitrate [25]. A study done in Greece and Mexico on the health implications of high manganese consumption found that it cause neurological disorders [26, 28].

In the present study Imo Housing Estate and Orji recorded the highest manganese content, however the present study has no data on the effect of this in the population living in these locations Turbidity was high in all locations sampled within this study this indicates presence of sand, clay and particle matter [6, 29]. This could be as result of the particles on the roofing sheet and the quality of air in these locations. Rainwater is relatively free from contaminations, except those picked up by the rain from the atmosphere [21].

Table 3: calculation of WQI in Dou glas road, Owerri municipal.

Parameter, Unit	WHO Standard (Sn)	Vn	Qn	Wn	Wn Qn
Ph	6.5 - 8.5	6.6	-26.6667	0.019661	-0.5243
Conductivity, µs/Cm	100	13	13	0.001671	0.021726
Dissolved Oxygen, Mg/L	5	0.9	18	0.033424	0.60164
Total Solids, Mg/L	250	194	77.6	0.000668	0.051875
Total Dissolved Solids Mg/L	250	9.55	3.82	0.000668	0.002554
BOD	5	0.3	6	0.033424	0.200547
Calcium, Mg/L	300	0.39	0.13	0.000557	7.24E-05
Hardness	150	0.27	0.18	0.001114	0.000201
Magnesium, Mg/L	250	0	0	0.000668	0
Alkalinity	100	102	102	0.001671	0.170465
Nitrate NO_3^-, Mg/L	50	81.1	162.2	0.003342	0.542144
Sulphate, Mg/L	250	506.6	202.64	0.000668	0.135463
Total Chlorine, Mg/L	5	0.22	4.4	0.033424	0.147067
Manganese Mg/L	0.2	0	0	0.835611	0
Turbidity	5	20.93	418.6	0.033424	13.99147
				∑ Wn = 1	15.34091
Water Quality Index (WQI) = ∑ QnWn / ∑ Wn = 15.34					

The WQI of harvested rainwater in Douglas road in Owerri Municipal is 15.34 (Table 3 above). From table 1 this qualifies as poor quality water and requires adequate treatment before use. Douglas Road is an industrial area in Owerri Municipal. This is consistent with the study by Chiagoziem and her colleagues [6] which observed that urbanisation in this area played a role in the quality of harvested rainwater.

Table 4: Calculation of WQI in IMO Housing Estate, New Owerri.

Parameter, Unit	WHO Standard (Sn)	Vn	Qn	Wn	Wn Qn
Ph	6.5 - 8.5	7.6	40	0.019661	0.786457
Conductivity, µs/Cm	100	5	5	0.001671	0.008356
Dissolved Oxygen, Mg/L	5	2.6	52	0.033424	1.73807
Total Solids, Mg/L	250	80	32	0.000668	0.021392
Total Dissolved Solids Mg/L	250	1.72	0.688	0.000668	0.00046
BOD	5	0.8	16	0.033424	0.534791
Calcium, Mg/L	300	0	0	0.000557	0
Hardness	150	0	0	0.001114	0
Magnesium, Mg/L	250	0	0	0.000668	0
Alkalinity	100	84	84	0.001671	0.140383
Nitrate NO_3^-, Mg/L	50	43	86	0.003342	0.28745
Sulphate, Mg/L	250	571.22	228.488	0.000668	0.152742
Total Chlorine, Mg/L	5	0	0	0.033424	0
Manganese Mg/L	0.2	0.3	150	0.835611	125.3416
Turbidity	5	18.23	364.6	0.033424	12.18655
				∑ Wn = 1	141.1983
Water Quality Index = ∑ QnWn / ∑ Wn = 141.20					

The WQI of the samples collected in Imo Housing Estate in New Owerri was 141.20 (Table 4 above) and this value exceeded 100 for an excellent water (Table 1), hence the water needs no further treatment before use and can be used for domestic uses [13, 29].

Table 5: Calculation of Wqi in Orji, owerri North.

Parameter, Unit	WHO Standard (Sn)	Vn	Qn	Wn	Wn Qn
Ph	6.5 - 8.5	6.2	-53.3333	0.019661	-1.04861
Conductivity, µs/Cm	100	27	27	0.001671	0.045123
Dissolved Oxygen, Mg/L	5	0.6	12	0.033424	0.401093
Total Solids, Mg/L	250	88	35.2	0.000668	0.023531
Total Dissolved Solids Mg/L	250	18.65	7.46	0.000668	0.004987
BOD	5	0.1	2	0.033424	0.066849
Calcium, Mg/L	300	0.22	0.073333	0.000557	4.09E-05
Hardness	150	0.84	0.56	0.001114	0.000624
Magnesium, Mg/L	250	0	0	0.000668	0
Alkalinity	100	16	16	0.001671	0.02674
Nitrate No_3^-, Mg/L	50	18	36	0.003342	0.120328
Sulphate, Mg/L	250	544.5	217.8	0.000668	0.145597
Total Chlorine, Mg/L	5	0.23	4.6	0.033424	0.153752
Manganese Mg/L	0.2	0.4	200	0.835611	167.1222
Turbidity	5	32.52	650.4	0.033424	21.73925
				∑ Wn = 1	188.8015
Water Quality Index = ∑ QnWn / ∑ Wn = 188.80					

The WQI of the samples collected in Orji in Owerri North was 188.80 (Table 5 above) and this value exceeded 100 for an excellent water (Table 1). However, further treatment at the point of ingestion may be applied to ensure better quality of the water and reduce associated health risks. Similar to Imo Housing Estate, Orji is predominantly residential than industrial and could explain the WQI calculated in the area.

Table 6: Calculation of WQI in Eziobodo, Owerr-West

Parameter, Unit	WHO Standard (Sn)	Vn	Qn	Wn	Wn Qn
Ph	6.5 - 8.5	6.3	-46.6667	0.019661	-0.91753
Conductivity, µs/cm	100	103	103	0.001671	0.172136
Dissolved Oxygen, mg/l	5	4.8	96	0.033424	3.208745
Total Solids, mg/l	250	142	56.8	0.000668	0.03797
Total Dissolved Solids mg/l	250	68.05	27.22	0.000668	0.018196
BOD	5	2.4	48	0.033424	1.604373
Calcium, mg/l	300	0.3	0.1	0.000557	5.57E-05
Hardness	150	0.05	0.033333	0.001114	3.71E-05
Magnesium, mg/l	250	0.23	0.092	0.000668	6.15E-05
Alkalinity	100	58	58	0.001671	0.096931
Nitrate NO_3^-, mg/l	50	27.1	54.2	0.003342	0.18116
Sulphate, mg/l	250	318.9	127.56	0.000668	0.085272
Total chlorine, mg/l	5	0.25	5	0.033424	0.167122
manganese mg/l	0.2	0.2	100	0.835611	83.56108
Turbidity	5	23.98	479.6	0.033424	16.03036
				$\sum W_n = 1$	104.246
Water Quality Index = $\sum$ QnWn / $\sum$ Wn = 104.25					

The WQI in Eziobodo in Owerri West is 104. 25 (Table 6 above) and this value exceeds excellent water quality of 100 (Table 1). However, the magnesium content of the water in this area exceeds WHO standards and so, the water needs some level of treatment before portable use.

Table 7: Water Status of Harvested Rainwater in Owerri, Imo state, Nigeria.

Area	WHO Standard	WQI calculated	Status
Douglas Road	95-100	15.34	Poor
Imo Housing Estate	95-100	141.20	Excellent
Orji	95-100	188.80	Excellent
Eziobodo	95-100	104.25	Excellent

Table 7 is a summary of the result of the WQI calculated from all the locations sampled in the present study.

Discussion

This study is the first study that attempted to calculate the WQI of harvested rainwater. Previous studies looked at WQI of other sources of water supply (surface, ground water) [16, 33, 34] and rainwater with respect to catchment materials [35, 36]. The present study provided reference information on the water quality index of harvested rainwater at different locations in Owerri, Imo state, Nigeria.

In the last few decades, there has been an increase in the demand for water due to speedy growth of population and development [18]. In low and middle income countries, where scarcity of water is endemic, water harvesting is still one of the sources of water to improve the availability of water [30, 31]. One of such sources is rainwater [32].

Rainwater is relatively free from impurities except those picked up by rain from the atmosphere [32]. These atmospheric contaminants are as a result of human activities following urbanisation [6]. This is true for the high value of turbidity recorded in all four locations sampled in this study (Table 2).

Sulphide was also high across the locations sampled in the present study (Table 2). Rainwater is said to be slightly acidic [32], the harvested rainwater in the present study were normal pH values. Douglas rainwater (Table 2) was alkaline.

According to the results in the present study, the Water Quality Index (WQI) of the harvested rainwater in different locations in Owerri, Imo sate was calculated using fifteen [15] physiochemical parameters. The index ranged from 15.34 – 188.80 with Orji having the highest index rating (188.80) and Douglas road the least [15, 34]. Water Quality Index (WQI) is considered as one of the most effective methods of measuring water quality in a mathematical equation by rating water quality and determining the suitability of the water for drinking [37]. It ascribes a quality value to an aggregate set of measured parameters [38].

Our findings are consistent with previous studies on Water Quality of Pearl River Delta Economic Zone, China [39]; Preto River in Formosa, Goiás State [40] and Uruguay River in western Santa Catarina [41] both in Brazil on how urbanisation impacts water quality [6]. The high value of WQI has been found to be mainly from the higher values of sulphate, turbidity, nitrate, manganese and pH levels in the harvested rainwater.

A previous study on the impact of urbanisation on harvested rainwater showed that an increase in urbanisation in an area led to decrease in air quality and hence impacted on the quality of rainwater harvested [6]. Of all 4 locations sampled, Eziobodo in Owerri West, is rural while Imo Housing area in New Owerri and Orji in Owerri North is residential and Douglas in Owerri Municipal is an Industrial area. This could explain the varying WQI recorded in the locations.

Conclusion

Safe and readily available water is key for public health, whether it is used for drinking, domestic use, industrial purposes. Improved water supply and sanitation, can boost countries' economic growth as fewer people are sick and absent from work and school and can contribute greatly to poverty reduction.

Our data failed to detect the direct health implications of using this water resource in the locations sampled, further studies should investigate the health effects of using harvested rainwater in Owerri, Imo State, Nigeria.

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