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ASSESSMENT OF SEWAGE CONTAMINATION RISK IN BOREHOLES IN OWERRI URBAN AREA IMO STATE, NIGERIA

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ABSTRACT:

Indiscriminate siting of boreholes is on the increase in most cities in Nigeria Owerri Urban is not an exception. The essence of this study is to assess the risk of sewage contamination in Boreholes in Owerri. 10 boreholes were randomly selected from different locations within the study area. Samples were collected and analyzed under physical, chemical, and bacteriological parameters. Analytical Hierarchy Process (AHP) was applied to select six (6) sewage indicator parameters, $\mathrm{pH, NH_3, NO_3^-, Pb, E.\ coli\ and\ TCC}$, then weighted rates of: 0.28, 0.24, 0.24, 0.03, 0.10, and 0.10, were respectively. These weighted rates show the level of specific contribution of the parameters to sewage contamination and were applied to generate the groundwater contamination index (GWCI) for the ten (10) locations. The results of the GWCI showed that W_{10} with a horizontal separation (distance) of 27 m from the soak-away (septic system) gave a Contamination Index (CI) of 2.15972 which represent the best quality when compared with the other nine locations. The risk percentage is 53.7% which can be considered as medium risk. Other locations W_1, W_2, W_3, W4, W_5, W_6, W_7, W_8, and W_9 have GWCI of 1003.135, 203.5999, 203.6943, 106.1377, 102.5303, 402.1481, 103.2407,103.3082, and 402.7103, respectively with W_1 having a horizontal separation of 6 m from the septic system as the worst GWCI. The study revealed that there are possibilities of sewage contamination and as such the WHO standard for sitting Septic systems and boreholes which is 30 m should be adhered to strictly. Also, for urban settlements like Owerri, Central water treatment and distribution should be made functional to meet the population demands so as to reduce mindless drilling by individuals as there is huge competition for space.

KEYWORDS: Sewage, Contamination, Percentage Risk (PR), Percentage Quality Compliance (PQC), Groundwater Contamination index (GWCI).

INTRODUCTION

Many people in developing countries, such as Nigeria, rely upon untreated groundwater supplies for their drinking water. Groundwater is thus an important natural resource that should provide potable water for the present and future generations as well. However, its contamination is a problem that requires assessment and monitoring in order to reduce it to the barest minimum. One of the major sources of contamination or pollution is sewage from septic tanks and soak-away pits. In most urban cities in Nigeria including Owerri, groundwater is almost widely exploited by the increasing human population (Obi & Emeribe, 2018; Nestor *et al*., 2019). It is thus observed that owing to the failure of the public water supply system, many individuals as well as industries have turned to groundwater source, since it appeared to be the easiest available source of potable water. However, this notion is not true as groundwater is threatened by different forms of pollutions which include contaminants from septic tanks / soak-away pits. The problem is heightened by the massive rural-urban migration which has led to the overcrowding of urban cities which in turn has led to overbuilding of spaces in urban areas without consideration of safety standards especially as it affects the siting of septic tanks and boreholes.

Sewage Indicator Parameters in Groundwater

Domestic septic-tank effluent typically contains elevated concentrations of chloride, sulphate, nitrite plus nitrate, ammonia, organic nitrogen, total nitrogen, total phosphate, fecal coliform and fecal streptococci bacteria, and total organic carbon (TOC) (Canter and Knox, 1985). Nitrate is the most stable form of nitrogen in environments where abundant oxygen is available. Generally, nitrate does not degrade in shallow groundwater and dilution is the principal mechanism for reducing concentrations. Nitrate contamination problems may not become obvious immediately. However, the potential long-term impact of nitrate contamination should be borne in mind when planning sanitation programmes as remedial action is difficult and blending with low nitrate waters may be the only viable option. As nitrate may be derived from other sources, it is important to evaluate both the relative contribution of different sources and the total nitrate load. Nitrate concentration is relatively cheap and simple to determine and does not require an indicator (Chidavaenzi et`al., 2000) Ammonium ions in the effluents may be oxidized to nitrate which can be transported in the subsoil beneath the septic tank absorption field and subsequently to groundwater. Both fecal coliform and fecal streptococci bacteria are present in the gastrointestinal tract of humans and other warm-blooded animals. The presence of these bacteria in natural water indicates degradation by human or animal waste and may be related to septic tank waste (Hanchar, 1991). According to McQuillian (2004), “Chloride (Cl^-) is a useful indicator parameter for septic-system impacts as it is a non-reactive solute that occurs in all sewage, “Cl^- is a naturally occurring constituent of surface and groundwater and also found in waste water in elevated quantity as result of human dietary and culinary sources”.

Semi-Qualitative Risk Assessment

This assessment tool is used to describe the relative risk scale. For example, risk can be classified into categories such as "low", "medium", "high" or "very high". Number of levels of risk can vary from 3 to 10 or more. In a semi-quantitative approach, different scales are used to characterize the likelihood of adverse events and their consequences. Analyzed probabilities and their consequences do not require accurate mathematical data. The objective is to develop a hierarchy of risks against a quantification, which reflects the order that should be reviewed and no real relationship between them (Vose, 2002)

This method requires risk estimation with numerical values and interpretation of results from qualitative considerations. It is presented as a matrix that takes into account the likelihood of producing threats and their impact. Risk level is categorized as High, Medium and Low. Probability to produce threats are assessed on a scale from 0.1 to 1 (0.1 - low 0.5 - Average, 1.0 - high), and the impact on a scale from 10 to 100 (10 - low, 50 - 100 medium - high) as shown in Table 1 (Radu, 2009).

Table 1: Risk-Level Matrix.

Threat Likelihood	**Impact**		
	Low (10)	**Medium (50)**	**High (100)**
High (1.0)	Low (1.0 x 10 = 10)	Medium (1.0 x 50 = 50)	High (1.0 x 100 = 100)
Medium (0.5)	Low (0.5 x 10 = 5)	Medium (0.5 x 50 = 25)	Medium (0.5 x 50 = 50)
Low (0.1)	Low (0.1 x 10 = 1)	Low (0.1 x 50 = 5)	Low x 100 = 10)

(Source: Radu, 2009).

Analytical Hierarchical Process (AHP)

Analytical Hierarchical Process (AHP) developed by Saaty (1980) is an approach to decision making that involves structuring multiple choice criteria onto a hierarchy, assessing the relative importance of these criteria, comparing alternatives for each criterion and determining an overall ranking of the alternatives. The foundation of the Analytic Hierarchy Process (AHP) is a set of axioms that carefully delimits the scope of the problem environment (Saaty, 1986). It is based on the well-defined mathematical structure of consistent matrices and their associated right eigenvector's ability to generate true or approximate weights, (Saaty, 1994).

MATERIALS AND METHODS

Study Area

The study area which is Owerri Urban is the capital of Imo State. It is located in the South-Eastern geopolitical zone of Nigeria. The area lies between latitudes 5º25'N and 5º33'N and longitudes 6º59'E and 7º06'E (Emeribeole, 2015). It covers an area of about $740\ km^2$, and is predominantly low-lying with a good road network. It is drained by two rivers, namely: Otamiri and Nworie. The hydrogeology of the area is characterised by aquifers with reasonable thickness and is extensive (Ikechukwu, 2014). The porous and permeable sands and inter-fingering sandy clay and gravels of the Benin Formation form a multi-aquifer system in which aquifer units are separated by semi-permeable sandy clay aquitards.

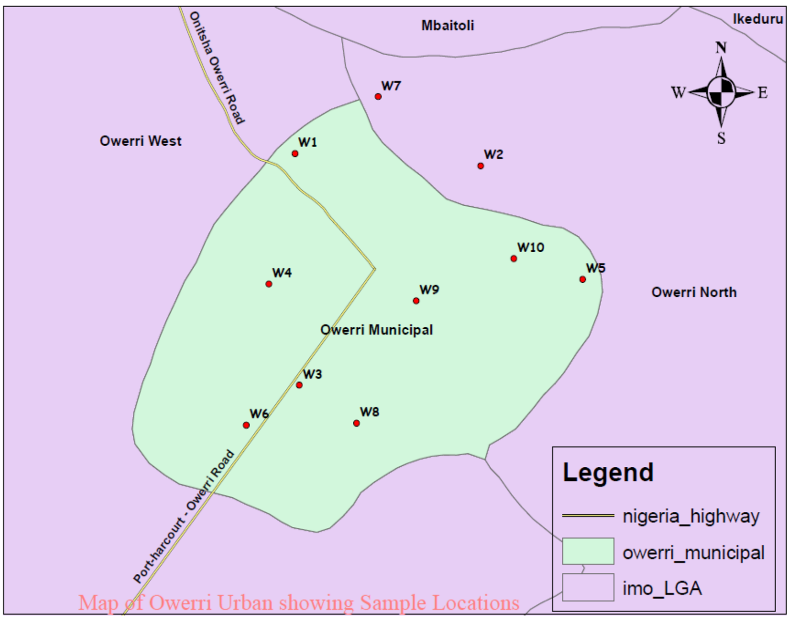

Figure 1: Map of the Study Area showing sample locations

Data Collection and Sampling

Water samples were collected randomly from 10 different borehole locations within the study area. The samples were collected in sterilized bottles with stoppers. Sufficient quantity of each sample was collected in order to perform all the tests required for the indicator parameters. To obtain representative samples from the wells, the taps from which the water samples were collected were flushed for at least 3-5 minutes. The collected samples were labelled W_1, W_2, W_3, W_4, W_5, W_6, W_7, W_8, W_9, and W_{10}. As changes of water quality may occur during transit and when stored, the samples were put in a cooled box while collection continued. The required time between sampling and analysis, which is four hours for nitrates and two hours for faecal coliforms was adhered to. Twenty (20) parameters were analysed and the parameters were analysed according to the procedures described by APHA standard (2005).

Generation of Sub-Contamination Index (SCI) and Groundwater Contamination Index (GWCI)

1. The value of each of the weights vector is used to obtain the sub-contamination index (SCI) using the formula:

$$\mathrm{SCI} = \mathrm{W_{ij}}\frac{\mathrm{C_o}}{\mathrm{C_s}} \qquad (1)$$

where: C_o = Observed Concentration, C_s= Allowable Standard Concentration, W_{ij} = the weights vectors obtained for each parameter considered.

2. The GWCI for each location is thus given as

$$\mathrm{GWCI} = \sum_{i=1}^{n} \mathrm{SQI} \quad = \sum_{i=1}^{n} \mathrm{W_{ij}}\frac{\mathrm{C_o}}{\mathrm{C_s}} \qquad (2)$$

where GWCI is Groundwater Contamination index

However, for the purpose of this work, the water contamination index was calculated using the method adopted by Zahra et al. (2015). According to them, the GWCI is computed using Equation (3):

$$\mathrm{GWCI} = \sum_{i=1}^{n} \mathrm{W_i}\frac{\mathrm{C_i}}{\mathrm{C_{S_i}}} \qquad (3)$$

Where

$\mathrm{W_i}$ = weighted rate, $\mathrm{C_i}$ = values obtained in the laboratory, $\mathrm{C_{S_i}}$ = Standard values.

Risk of contamination in terms of GWCI and Percentage Quality Compliance (PQC)

The risk percentage exposure of every location was calculated bearing in mind that the groundwater with the lowest contamination index (CI) i.e., CI = 1, will have 100% compliance to Standard and thus, 0% risk of contamination.

To calculate the Percentage Quality Compliance, we apply Equation 4

$$\%\ \text{Quality Compliance} = \frac{Standard}{observed} \times 100 \qquad (4)$$

While Equation 5 was applied in the calculation of risk percentage

$$\%\ Risk\ of\ contamination = 1 - quality\ compliance \times 100 \qquad (5)$$

where the standard Quality Compliance (QC) is taken to be 1.

RESULTS AND DISCUSSION

Table 2: Results of the physical, chemical and biological analysis of raw water samples.

Physical Analysis										
Parameters	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9	W_{10}
Physical appearance	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
TSS (mg/l)	132.50	9.00	26.50	4.00	90.00	12.00	48.00	16.50	6.00	96.00
Turbidity (NTU)	0.00	2.79	0.00	1.98	2.76	0.36	2.59	1.4	1.70	0.00
pH	4.6	3.00	5.20	6.40	3.6	4.60	3.90	6.60	4.70	5.20
Temperature ($°C$)	26.70	27.60	27.70	27.00	26.20	27.20	26.00	26.40	25.80	28.50
Conductivity ($\mu s/cm$)	30.00	130.00	10.00	220.00	30.00	70.00	20.00	10.00	170.00	50.00
TDS (mg/l)	19.50	60.00	6.50	110.00	10	30.00	10.00	6.50	90.00	20.00
Chemical/Heavy Metals Analysis (all units are in mg/l)										
Iron (Fe)	ND	ND	0.136	ND	ND	0.145	0.011	0.047	0.108	ND
Total Chloride (Cl-)	209.94	123.96	96.97	147.95	111.97	139.96	201.93	156.95	188.94	114.97
Phosphate (PO_4^{3-}	0.286	0.261	0.622	0.249	0.392	0.361	0.373	0.274	0.342	0.261
Phosphorus (P)	0.095	0.087	0.207	0.083	0.130	0.120	0.124	0.091	0.114	0.087
Nitrate (NO_3)	6.6	10.40	8.60	9.80	6.4	3.60	7.20	11.60	5.20	9.00
Ammonia-Nitrogen (NH_3-N)	0.075	0.023	0.061	0.068	0.098	0.094	0.087	0.038	0.085	0.053
Lead (Pb)	0.87	0.95	1.0	1.26	0.64	0.51	0.87	0.97	0.75	0.58

	0	6	85	2	8	3	4	6	7	3
Ammonia (NH_3)	0.05 9	0.01 8	0.0 48	0.05 3	0.07 7	0.07 4	0.68 0	0.03 0	0.06 8	0.04 2
Biological/Bacteriological Analysis										
$BOD_5 = DO_1 - DO_5$ (mg/l)	0.7	2	0.3	0.4	0.2	1.20 0	1.10 0	2.8	0.2	0.9
$DO_1(mg/l)$	6.5	6.4	6.5	7.5	7.7	8.20 0	7.10 0	7.6	7.4	6.3
$DO_5(mg/l)$	5.8	4.4	6.2	7.1	7.5	7.00 0	6.00 0	4.8	7.2	5.4
$COD = 1.6 \times BOD_5(mg/l)$	1.12	3.2	0.4 8	0.64	0.32	1.92	1.76	4.48	0.32	1.44
Total Coliform Count $(Cfu/100ml)$	8	6	3	2	3	18	0	3	1	0
$Total\ E.coli\ (Cfu/100ml)$	10	2	2	1	0	4	1	1	4	0

$Cfu/100ml$ – Colony forming unit, ND – Not detected, µS/cm- micro Siemens per centimetre, mg/l - milligram per litre,

NTU – Nephlometry Turbidity Unit.

Result of Groundwater Contamination Index (GWCI)

Based on the obtained normalized weight from AHP, the GWCI was computed using Equation (3). This index was then used to show the participation level of each parameter tested in the samples collected from various locations in the study area. The parameters having the highest weight were selected as they have more contribution to the contamination of the groundwater. Table 3 show the normalized weight which is the weighted rate of the selected parameters obtained from AHP and the allowable limit of the various indicator parameters required for computing the GWCI value.

Table 3: Normalized weight and allowable limits for indicator parameters.

Indicator Parameter	**Weighted rate obtained from AHP**	**Normalized weighted rate**	**Allowable Limit, C_{S_i}**
pH	0.25	0.28	6.5
NO_3^-	0.22	0.24	40
NH_3	0.22	0.24	1.5
Pb	0.03	0.03	0.01
E. coli	0.09	0.10	0.001
TCC	0.09	0.10	10
Total	0.90	1.00	

Note: Column 3 was obtained by normalizing the weighted rate in column 2. Thus, the normalized weighted rate will be used in the computation of GWCI.

Discussion of Result of AHP and GWQI

The result obtained from the AHP technique showed that the indicator parameters with the highest weighted rate have more roles to play in sewage contamination of the groundwater. However, six indicator parameters which include: pH, NO_3^-, NH_3, Pb, TCC, and E.Coli were selected and their various weight were further normalized, the weight obtained ranged from 0.03 to 0.28. These rates were applied to Equation 2 to obtain the values in table 4 which showed the range of the sub-contamination indices generated with respect to the indicator parameters in the study area and column 8 showing the sum of the SCI which gives the value of the GWCI of each sample location ranging from 2.15972 to 1003.135. W_{10} which has an index value of 2.15972 represents a very good quality while W_1, W_2, W_3, W4, W_5, W_6, W_7, W_8, and W_9 with quality index of 1003.135, 203.5999, 203.6943, 106.1377, 102.5303, 402.1481, 103.2407, 103.3082, and 402.7103, respectively have poor quality respectively with W_1 as the highest contamination index and in turn, represents the worst water quality. The result is shown on Figure 1.

Table 4: Computed GWCI values for the indicator parameters.

Sample	pH	NO_3^-	NH_3	Pb	TCC	E.Coli	GWCI
W_1	0.395652	0.0396	0.00944	2.61	1000	0.08	1003.135
W_2	0.606667	0.0624	0.00288	2.868	200	0.06	203.5999
W_3	0.35	0.0516	0.00768	3.255	200	0.03	203.6943
W_4	0.284375	0.0588	0.00848	3.786	100	2	106.1377
W_5	0.505556	0.0384	0.01232	1.944	100	0.03	102.5303
W_6	0.395652	0.0216	0.01184	1.539	400	0.18	402.1481
W_7	0.466667	0.0432	0.1088	2.622	100	0	103.2407
W_8	0.275758	0.0696	0.0048	2.928	100	0.03	103.3082
W_9	0.387234	0.0312	0.01088	2.271	400	0.01	402.7103
W_{10}	0.35	0.054	0.00672	1.749	0	0	2.15972
Maximum	0.606667	0.0696	0.1088	3.786	1000	2	1003.135
Minimum	0.275758	0.0216	0.00288	1.539	0	0	2.15972
Mean	0.401756	0.04704	0.018384	2.5572	260	0.242	263.2664
Standard deviation	0.096059	0.014125	0.030273	0.662253	276.4055	0.58818	276.2506

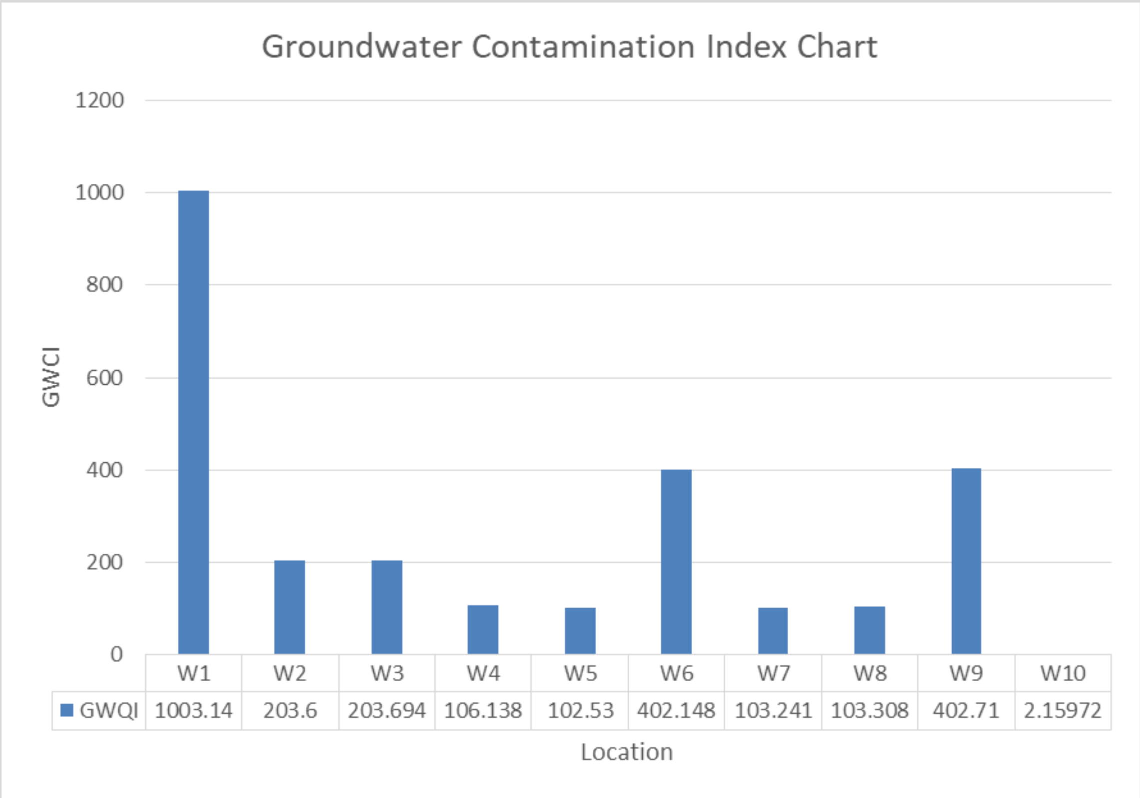

Figure 1: Groundwater contamination index chart.

Risk Percentage and Quality Compliance Computation

From Table 4., we can calculate the risk percentage exposure of every location bearing in mind that the groundwater with the best Quality index (QI) is the one with QI = 1, and thus has 100% compliance to Standard and 0% risk of contamination.

To calculate the Percentage compliance, we apply Equations (4) and (5), where the standard QI is 1.

For location 1, W_1, the percentage compliance is given as:

$$\frac{1}{1003.135} \times 100 = 0.1\ \%$$

The percentage risk of contamination is given as:

$$1 - 0.001 \times 100 = 99.9\ \%$$

Table 5 is the summary of the percentage compliance and percentage risk of contamination for the sampled locations in the study area.

Table 5: Quality Percentage compliance of GWQI and Risk Percentage

Location	GWCI	Quality Percentage Compliance	Compliance value	Risk value	Risk Percentage
W_1	1003.135	0.1	0.001	0.999	99.9
W_2	203.5999	0.5	0.005	0.995	99.5
W_3	203.6943	0.5	0.005	0.995	99.5
W_4	106.1377	0.9	0.009	0.991	99.1
W_5	102.5303	1.0	0.01	0.99	99
W_6	402.1481	0.2	0.002	0.998	99.8
W_7	103.2407	1.0	0.01	0.99	99
W_8	103.3082	1.0	0.01	0.99	99
W_9	402.7103	0.2	0.002	0.998	99.8
W_{10}	2.15972	46.3	0.463	0.537	53.7

Discussion of Percentage Compliance and Risk percentage result

The result shown in Table 5 revealed that the percentage compliance of W_1 – W_9 were very low also their risk percentage were very high with W_1, W_6, and W_9 risk percentage of almost 100 %. Here only W_{10}, which has the longest horizontal separation from septic system, has a moderate compliance and moderate risk. These are shown in Figures 2 and 3.

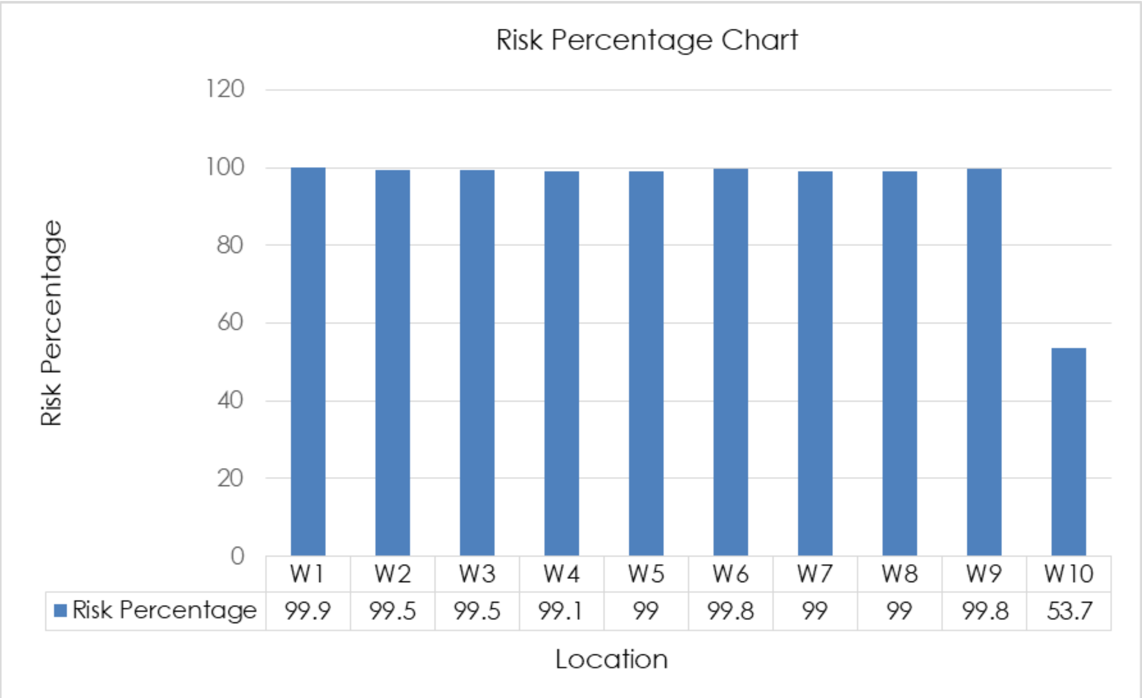

Figure 2: Risk percentage chart

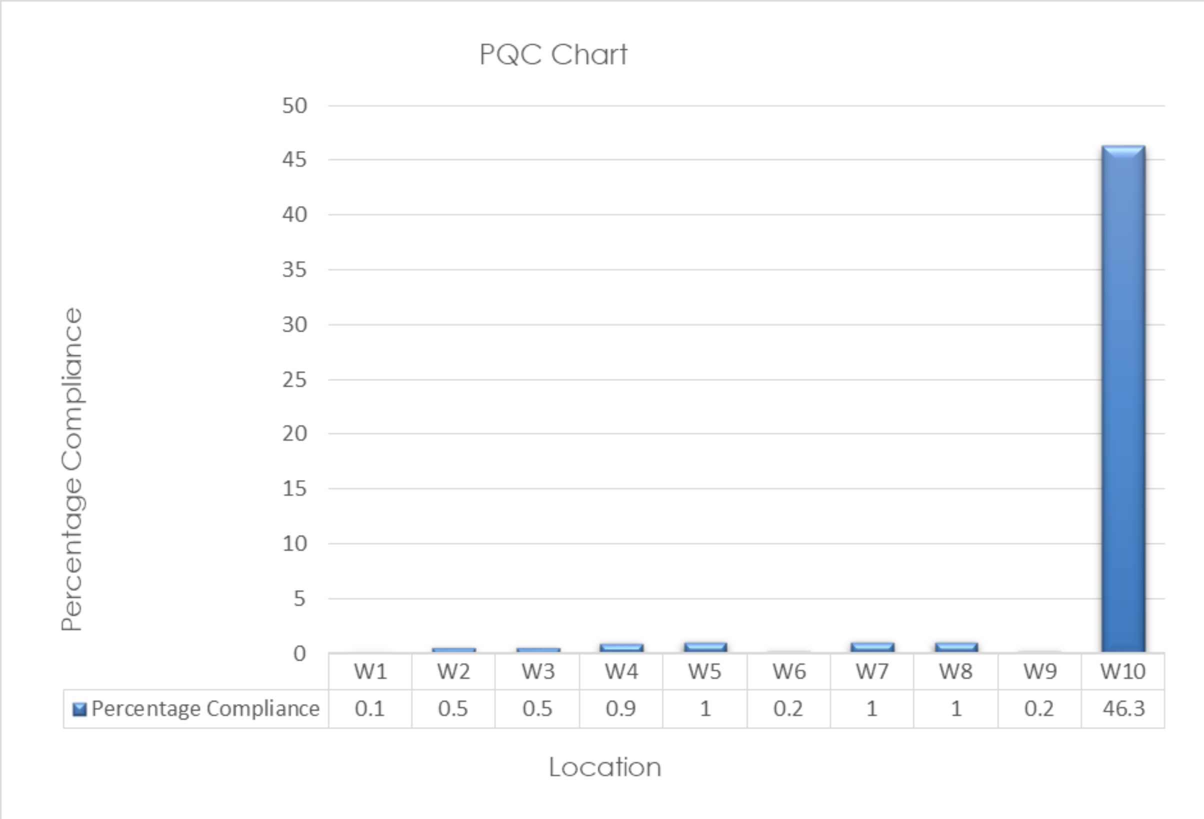

Figure 3: Percentage compliance chart.

CONCLUSION & RECOMMENDATIONS

The percentage compliance of the quality indices to standard of Wells (W_1 to W_9) were found to be very low except for Well (W_{10}) which has a percentage compliance of 46.3%, thus it is considered to be moderate. However, all the samples collected from the study area revealed that there is high risk of sewage contamination as they all surpass the risk percentage of 50 % as shown in Table 5 and compared with Table 1.

The water quality assessment of the samples collected randomly from different locations in the study area showed that there is possibility of sewage contamination of the various boreholes in the area which is most likely as a result of improper sitting of boreholes and the septic systems as well as other contaminant sources. This assertion resulted from the fact that out of the ten (10) borehole samples tested, only one which is W_{10}, passed the bacteriological analysis when compared with WHO and NSDWA quality standards. Also, all the samples tested had traces of lead (Pb) above the acceptable limit of 0.01, this finding is thus suspected to be part of the contributing factor to the increase in the cases of renal failure in our society today. Based on this, Lead (Pb) was considered as one of the indicator parameters.

The application of AHP made it easier for the selection of the sewage indicator parameters; the process yielded a weighted value or rate (w_i) for ten parameters considered and six parameters with the highest weighted rates were selected as the sewage indicator parameters. The six selected weighted rates which were normalized yielded values for sub-Contaminant indices (SCI) for each of the parameters defining the contribution of each parameter to the sewage contamination and were in turn summed up to give the GWCI of the area or the location under investigation.

Based on the findings of this research, the following recommendations are made:

1. Treatment compartments or chambers should be installed for all boreholes to take care of any contaminations and improve the quality.
2. In places where individual households cannot afford the cost of mini treatment plant each, they can come together to put resources together and set up one that will serve all the households together.
3. Indiscriminate drilling of boreholes should be discouraged by government authorities because, if individual households are allowed to own private boreholes, it will be difficult to keep safe distance from the septic system and contamination will be inevitable especially in places where the water table is low.
4. If recommendation 3 must hold, it is highly recommended that government authorities make provision for alternative source of potable water supply by setting up municipal water treatment plant and distribution systems.

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