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Spatial Analysis of Groundwater Sources in the Duport Road (Shara and Cow Field) and Soul Clinic Diamond Creek communities, Paynesville City, Republic of Liberia

McClain James
Ph.D. Candidate, Department of Environmental Health, School of Public Health, Indiana University Bloomington

ABSTRACT

Groundwater is of significant water source use for drinking in sub-Sharan nations. About 90% of the family in the study area rely extensively on groundwater for drinking. The study area is selected communities in the Paynesville City, Greater Monrovia. The selected communities are the Duport Road Shara and Cow Field, and the Soul Clinic Diamond Creek communities. Ordinary Kriging and the Global Moran's Index methods were used to map the spatial distribution and dependence of water parameters present in the water infrastructure. The water infrastructure for this research defined as hand pump/borehole and opened and covered shallow wells. Results from the study showed 93% of the groundwater water infrastructures contaminated with total coliform bacteria. The distribution of the physical and chemical parameters in the groundwater reduced towards the north of the study area, the Soul Clinic Diamond Creek community. From the ordinary Kriging method, the nitrated distributed concentration and temperate has moderate to high spatial dependence, while peroxide, total dissolved solids, total alkalinity, and pH have weak spatial dependence. The Global Moran's Index results show that nitrate distribution and the temperature was statistically significant. Finally, the nitrate concentration is a public health and environmental issues. Finally, the water infrastructure in the community is a serious public health problem and need immediate attention. Most of the water infrastructure not suitable for drinking.

Keywords : Duport Road, Greater Monrovia, Paynesville, Ordinary Kriging, Global Moran's Index, groundwater, total coliform, microbial, chemicals, physical

I. INTRODUCTION

Groundwater and aquifers are complex and changeable ecosystems of grave importance for geochemical cycles [1]. Shallow wells are the primary source of collecting groundwater in many rural and peri-urban communities. Shallow wells are vulnerable to fecal contamination, which is often due to leaching pit latrines [2], sewage and surface runoff. Areas where the prevalence of open defecation is high, groundwater may be exposed to fecal contamination. The decrease in groundwater quality attributed to an increased contribution of non-point pollution sources (NPS), with strongly dependent on land use[3].

Human activities associated with water consumption or unsustainable groundwater depletion is a widespread practice across the globe [4], especially in developing nations. Groundwater quality compares to surface water is of good quality and better protected against contamination[5]. Groundwater in the study areas experiences seasonal variation in the volume of the water source. During the rainy season from mid-May to mid-October, groundwater level increased and in swamp area exceed the water table level. Improvement of water sources associated with the reduction global burden disease. In developing nations, about 80% of sickness is related to drinking polluted water[6].

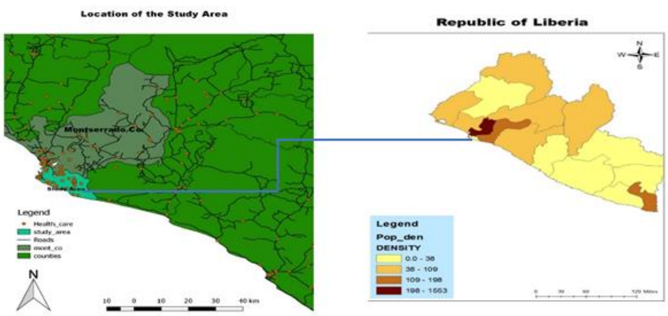

Figure 1: Left: Location of the Study Area in Montserrado County. Right: Map of the Republic of Liberia with the Montserrado County

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Groundwater is a fundamental source of drinking water in Sub-Saharan Africa [7]. However, the eco-environmental problem caused by the exploitation and utilization such as rising groundwater level associated with groundwater quality problem[8]. From Environmental Health perspective, human activities and developmental purposes increased population exposed to groundwater contaminant. Surface water and or groundwater pollution is related to increased population, economic growth, and industrialization [9].

Solid waste management and sewage disposal or open defecation are significant to the quality of groundwater in the study areas. In the study, the prevalence rate of open defecation is 28%, and water sources not adequately managed. Therefore, the objective of the survey is to spatially determine the path of the contaminant (chemical, physical, and microbial) in the water infrastructure.

II. METHODS AND MATERIAL

Groundwater contamination is a global challenge due to rapid industrialization and population growth [10]. The groundwater sample was collected between the month of May to August 2016 from the Soul Clinic and Duport Road communities in Paynesville City, Montserrado County, Republic of Liberia. The water sample was collected from protected and unprotected water sources from May 2016 to August 2016 to obtain the water parameter. The water sample parameter measured from the chemical, physical and biological contaminants in the water sample. The water sample collected from 43-water infrastructure. Parameters tested included; chemical (include nitrate, nitrite, peroxide, metals), physical (TDS, Total Hardness, Total Alkalinity) and the biological and related parameters include total coliform bacteria, pH, temperature.

Study Area. The study area located in Greater Monrovia, Republic of Liberia. The Republic of Liberia situated on the West Coast of Africa with a land cover of 43000 square miles. The climate is tropical. The study areas focused on selected communities in Paynesville City. In the selected communities-Duport Road and Soul Clinic, approximately 90% of families rely on groundwater for drinking and domestic work. Groundwater in the study collected from a constructed water infrastructure. The water infrastructures in the study areas are hand pump and opened and covered shallow wells.

Parameter. The chemical and physical parameters were analyzed directly on the field using HACH DR 900 handheld equipment. For the microbial analysis (total coliform bacteria) the LaMotte total coliform test kit was used. The theory of the test kit based on presence and absence of total coliform bacteria. The GPS coordinate was logged using the GARMIN ETREX 10 GPS.

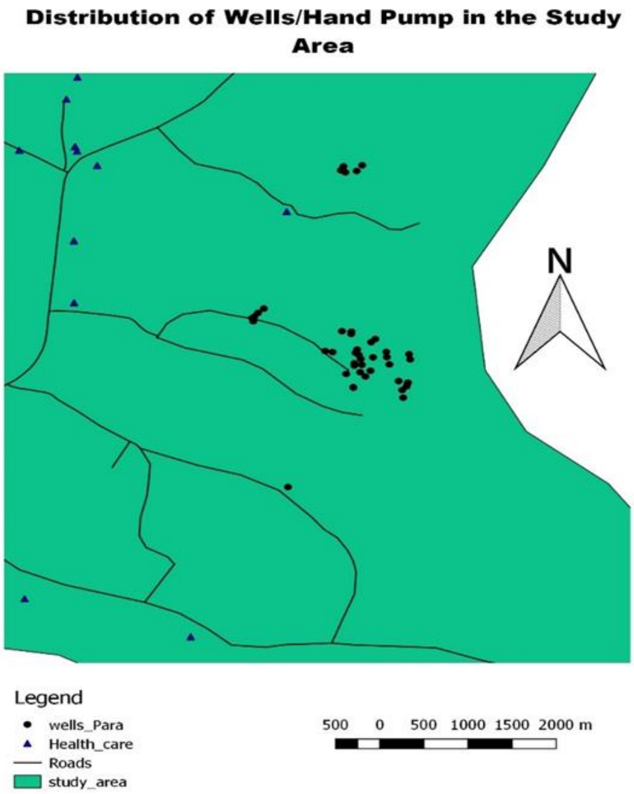

Figure 2: Distribution of Wells/Hand Pump in the Study Area

III. RESULTS AND DISCUSSION

The analysis process and prediction of the water parameters in the study area done using geostatistical (Ordinary Kriging) and spatial analysis (Global Moran' Index) tools. For the geostatistical analysis, normalization was fundamental for with high skewness or kurtosis using the log transformation (Table 1). The geostatistical and spatial analysis was done using ArcGIS version 10.4.

Descriptive

The descriptive results generated from the geostatistical-Ordinary Kriging tools. Table 1, depicts descriptive statistic summary of the groundwater parameters obtained from the water sample. Table 1 gives the difference between the skewness and kurtosis before and after transformation for each parameter.

Table 1: Descriptive Analysis of the groundwater (Wells/Hand Pump) Hydrological Parameters

No	Hydrological Parameters	# of Data	Min	Max	Mean	St. Dev	Skewness	Kurtosis
1	TDS	43	14	590	89.3	99.2	3.42	16.9
	TDS[a]	43	2.64	6.38	4.13	0.82	0.46	2.84
2	PEROXIDE	43	0.3	25	7.68	7.01	1.32	4.13
3	pH	43	3.4	6.4	5.3	0.81	-0.62	2.43
	pH[a]	43	1.22	1.86	1.66	0.16	-0.88	2.90
4	TH	43	25	425	172	101	1.33	4.09
	TH[a]	43	3.22	6.05	4.99	0.58	-0.32	4.14
5	TA	43	0	720	73.2	117	4.14	22.8
6	NITRATE	43	0.23	80	15.9	16.2	2.08	8.11
7	TEMP	43	26	32	29.1	1.67	0.21	2.36
	TEMP[a]	43	3.26	3.47	3.37	0.057	0.097	2.38

[a] Transformation using logarithm

Groundwater Classification in the Study area

The groundwater is classified based on the analysis of samples collected from the water infrastructure. The water sample was analyzed in the field using the HACH DR 900 handheld equipment for the chemical and physical parameters. From Table 1, the concentration of the water parameters from the 43- water infrastructure varies. Figures 3 to 6 provide information on the distribution of the water parameters from geostatistical analysis using the Ordinary Kriging tool. Figure 3 gives the distribution of the water infrastructure in the study areas.

Nitrate & Peroxide. Figure 4 shows the distribution of nitrate and peroxide. The concentration of nitrate (Table 1) varies from 0.23 to 80ppm with the average concentration of 15.9 ± 16.2 ppm. From the WHO 2017 drinking water guidelines, nitrate accepted range is 50ppm. Therefore some of the water infrastructures were above the allowed range of nitrate in drinking water. 6.98% approximately 7% (coordinates: 6.268167, -10.660633 (Shara); 6.273983, -10.671867 and 6.274133, -10.671667 (Cow Field)) of the water infrastructure constructed between 2010 – 2015 was above the WHO drinking water guidelines for nitrate. The type of water infrastructure was two opened or unprotected well and a covered or protected well.

The nitrate and peroxide concentrations reduced to the north of the study area and distributed randomly central of the study area. However, the concentration of the peroxide range (Table 1) between 0.3 to 25ppm and the average peroxide concentration is 7.68 ± 7.01ppm.

Nitrate a univariate anion interfere with the intake of iodine by thyroid resulting to the reduced production of thyroid hormones. In previous epidemiological studies, investigators a correlates nitrate contamination in water supplies[11] and thyroid dysfunction and thyroid disease. In a cross-sectional study of school children l in areas of Slovakia with increased levels of nitrate concentration exposure via drinking water, experience increased thyroid disease [12]. The presence of nitrate in groundwater where the used of fertilizer may be rare could be associated with decaying organic matter and sewage[13] leakage.

Nitrate itself is a compound of low toxicity but reduced to nitrite, the toxic form relating human health, [14] which can cause infantile methemoglobinemia. The reduction reaction is biochemical in the human system that released an oxygen atom from the nitrate (NO_3) compound to produce nitrite (NO_2).

Total Dissolved Solids & Total Hardness. Figure 4 shows the distribution of the total dissolved solid and total hardness in the water infrastructure in the study area. The total dissolved solids (TDS) vary between 14 – 590ppm with the average concentration of 89.3 ± 99.2 ppm. The total dissolved solids reduced towards the north of the study area, the Soul Clinic Diamond Creek community. However, 6 (14%) of the 43-water infrastructure constructed between 2006 – 2014 in the Shara and Cow Field communities was above the WHO drinking water guidelines. The six WI include one hand pump in Shara and four – open well, one covered well in the Cow Field community. The accepted total dissolved solids in drinking water are 150ppm.

The distribution of total hardness in the study area was randomly distributed (figure 4). The total hardness concentration varies from 25 to 425ppm with average means of 172 ± 101 ppm. 4 (9%) of the water infrastructure above the WHO drinking water guidelines. The drinking water guideline for total hardness from the WHO 2017 guidelines is 270 ppm. The four water infrastructures are in Shara (one-hand pump and two opened well) and Cow Field community (one-opened well) constructed between 2003 to 2015.

pH and Total Alkalinity. Figure 5 depicts the distribution of the acidity and alkalinity of the water sample from the 43-water infrastructure in the study area. The distribution shows that the water was more acidic associated with the dissolution of metal in the soil. The pH range between 3.4 to 6.4 and from the accepted WHO 2017 drinking water guidelines, the pH range is 6.8 to 8.5. None of the water source meets the WHO guideline for pH level in drinking water. The average pH value is 5.3 ± 0.81. For the total alkalinity, about 95% of the water infrastructure was between 0 – 180 ppm with the highest value of 720ppm from a hand pump in Shara community. The average of the total alkalinity was 73.2 ± 117ppm. The pH is a critical parameter for predicting the amount of dissolved CO_2, the precipitation of carbonates in the pore spaces, and the release of trace metals from the reservoir rocks [15]. Contaminated groundwater typically has chloride and alkalinity levels ranging from micro- to millimole, and pH from neutral to extremely high concentrations impacted by the base activation of persulfate. Alkalinity and pH mainly affect the surface complexation of containing aquifer soluble minerals.

Higher alkalinity favors the formation of unreactive surface carbonate complexes, while higher pH favors the formation of reactive surface hydroxy complexes and accelerates remediation efforts [10]. In an acidic media, both reduction and oxidation of Fe microbially catalyzed, and available evidence suggests that microbial Fe redox cycling takes place across a diverse wide range[16] of modern natural environments.

Total Coliform Bacteria & Temperature. Figure 6 shows the distribution of total coliform bacteria and related temperature value from the water source. The total coliform bacteria were positive in 93% of the 43 water infrastructures water sample tested. The total coliform analysis for the study was based on the qualitative analysis using the either presence or absence of total coliform bacteria in the water sample. The total coliform bacteria was determined using LaMotte total coliform kit. The average temperature was 29.1 ± 1.67^{0}C and range from 26 to 32^{0}C. A study conducted in Nigeria showed that 85% of wells tested was acidic that is below WHO standard for pH[9]. The study also had similar results with all the 43-water sources pH range was between 3.3 to 5.5.

Drinking water contamination risk reflects the increased vulnerability of groundwater sources to surface contamination, particularly in flood area. A study conducted in Bangladesh revealed fecal contamination due to flood. Tube well water samples in the flooded areas were contaminated with total coliforms (41%, n = 85), thermotolerant coliforms (29%, n = 60) and E. coli (13%, n = 27). Only four samples had E. coli contamination >100 CFU 100 ml) [17]. The study area does experience flood during the rainy season affecting groundwater infrastructure. Relatively high groundwater table within flood areas exposed to fecal organisms.

Maintaining a high-quality drinking water is one of the fundamental goals of health or public health authorities in many countries. Thus, the establishment of the legislature of the drinking water quality guideline, in developed and developing nations aid in the production of quality water for drinking and domestic work [4].

Geostatistical Analysis

Figure 7 depict scatter plots or semi-variogram around the model indicated by blue line or average. Table 2 illustrates the suitable semivariogram models for the hydrogeological parameters from the 43-wells water sample. The range from table 2, is the distance where the design flattens and varies among the parameters. The sill and the nugget provide information relating to attainment of range and interception of the y-axis respectively.

The ratio of the nugget to the sill correlates the spatial dependences of groundwater quality. The proportion of the nugget per skill has three classifications: less than 25% high spatial dependence, in the range of 25% to 75% moderate spatial dependencies and greater than 75% weak spatial relationships[18]. From Table 2 nitrate concentration, total hardness, and the temperature showed a moderate to high spatial dependence.

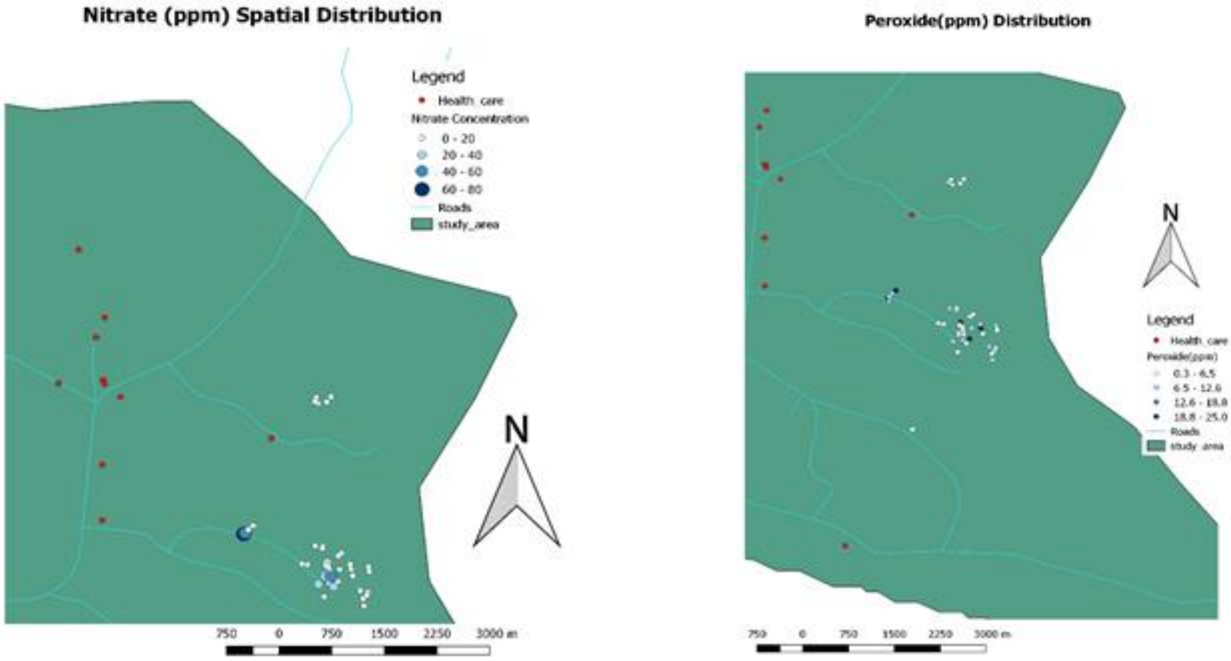

Figure 3: Distribution of Nitrate (Left) and Peroxide (Right) concentration in the study area

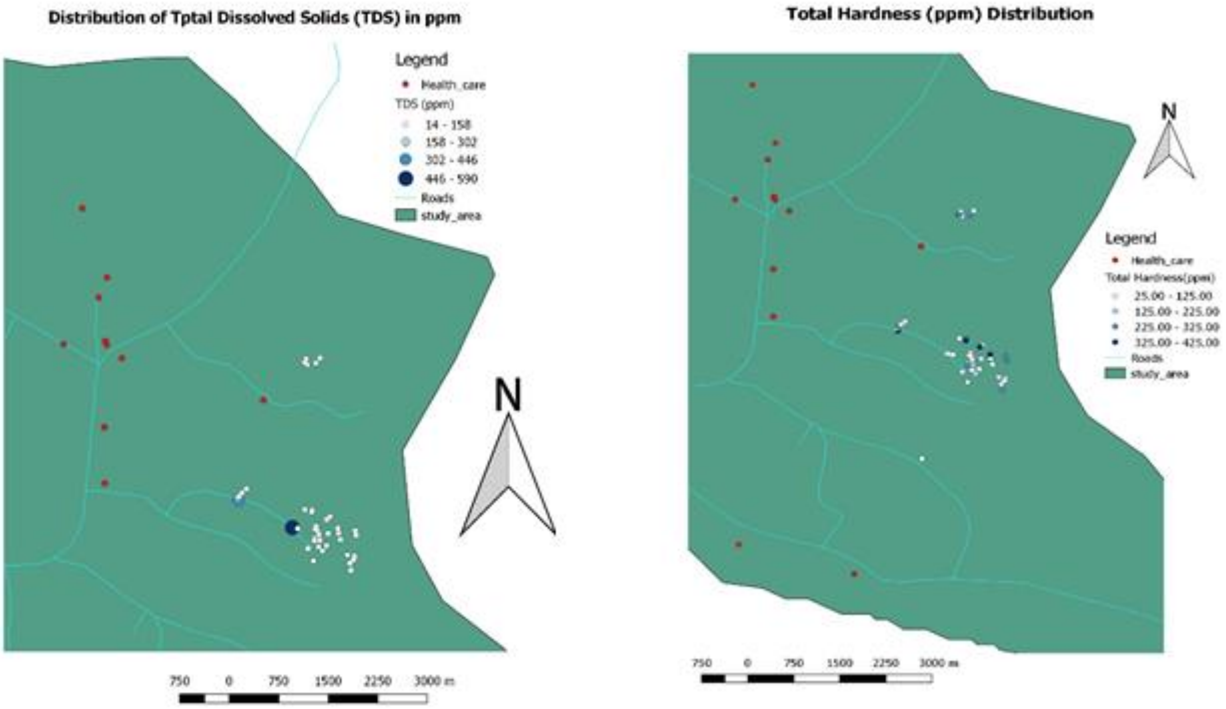

Figure 4: Distribution of TDS (Total Dissolved Solids) (Left) and TH (Total Hardness) (Right) concentration in the study area.

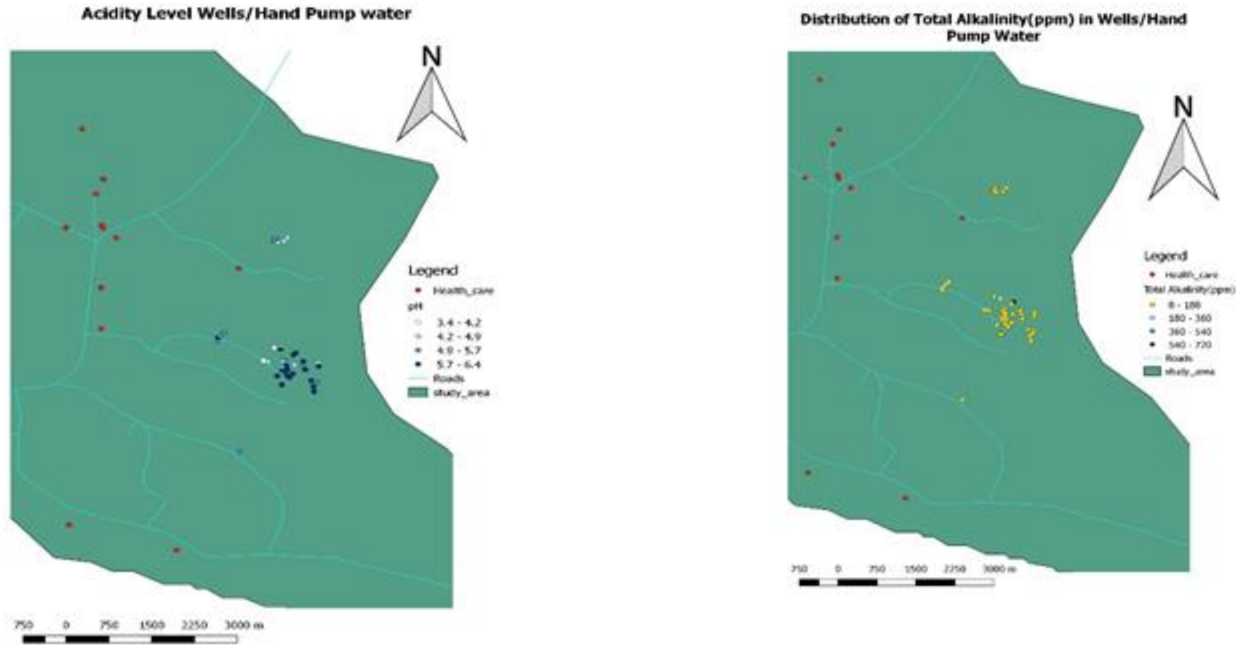

Figure 5: Distribution of pH (Left) and TA (Total Alkalinity) (Right) concentration in the study area

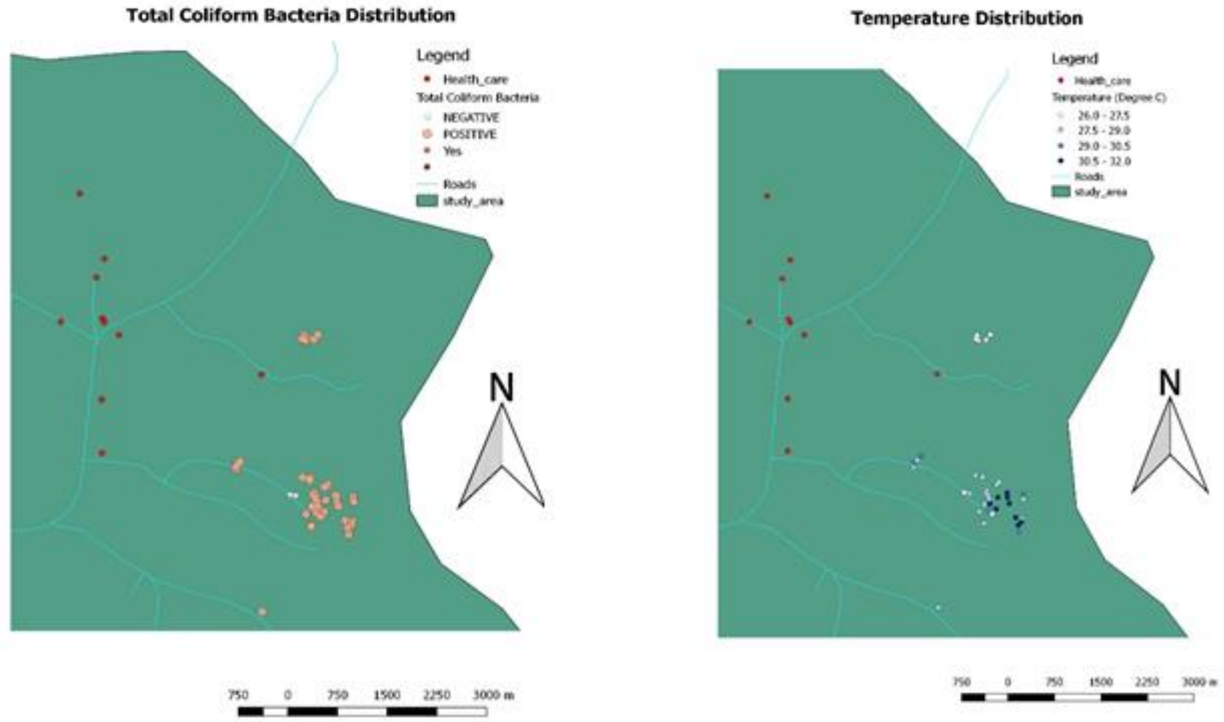

Figure 6: Distribution of Total Coliform Bacteria (Left) and Temperature (Right) concentration in the study area

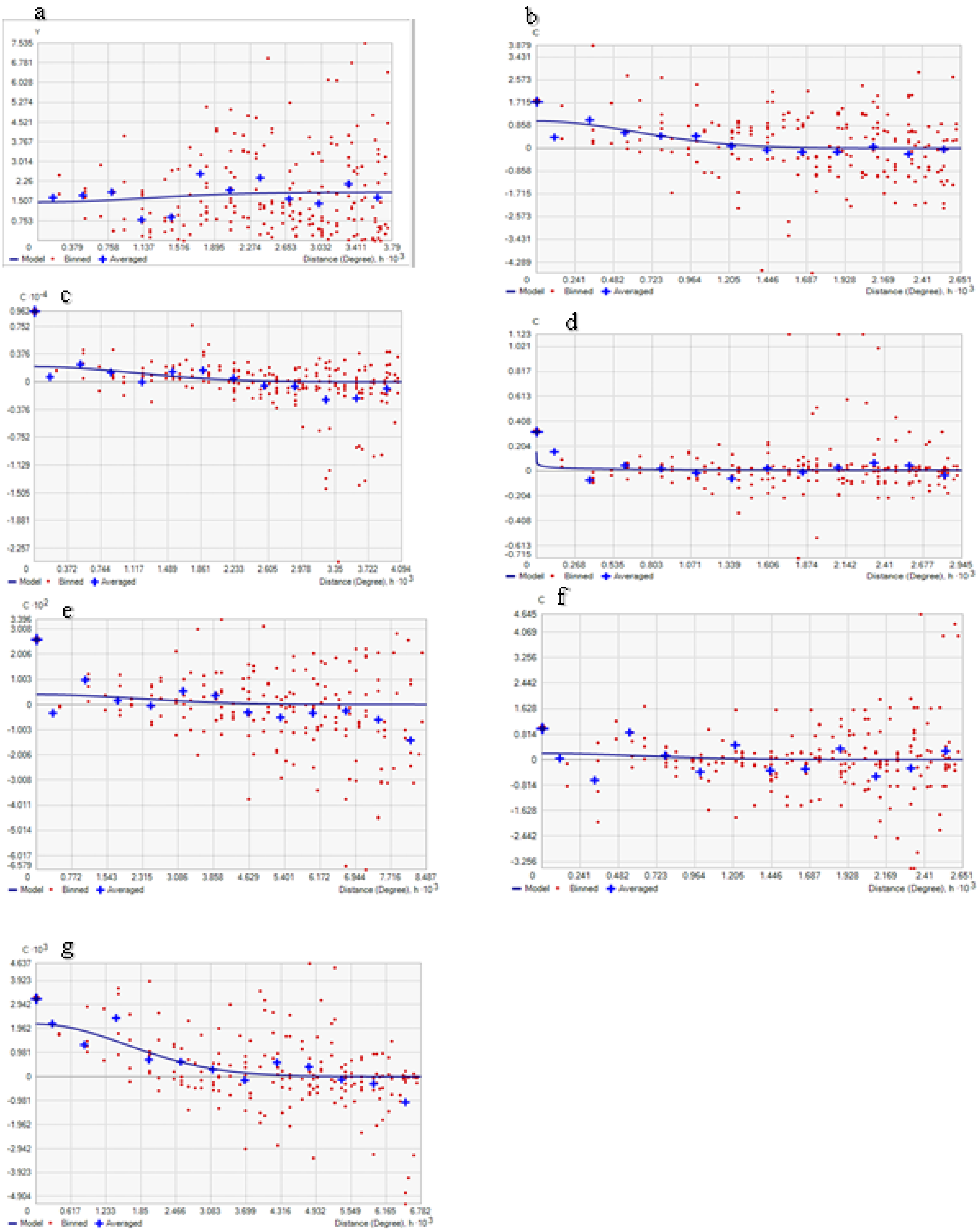

Figure 7 : Fitting Semivariogram models for the Groundwater Hydrogeological parameters, i.e., a=peroxide, b=nitrate, c=Total Dissolved Solids, d=Total Hardness, e=pH, f=Total Alkalinity, g=Temperature

Table 2 : Semi variogram Characteristics for Map generation

Hydrogeological Parameters	# of Data	Transformation	Number of Lag	Lag Size	Nugget	Sill	Partial Sill	Range(M)	Nugget/Sill	Nugget/Sill
Peroxide	43	Normal	12	0.00038	1.43	1.481	0.051	0.0023	0.966	Weak
TDS	43	Logarithm	12	0.00034	7,521	9,641	2,093	0.0027	0.780	Weak
TH	43	Logarithm	12	0.00025	0.164	0.323	0.159	0.0021	0.508	Moderate
TA	43	Logarithm	12	0.00022	0.802	1.00	0.198	0.0016	0.802	Weak
Temp	43	Logarithm	12	0.00057	0.001	0.003	0.0021	0.0039	0.333	Moderate
Nitrate	43	Normal	12	0.00022	0.741	1.771	1.03	0.0015	0.418	Moderate
pH	43	Logarithm	12	0.00071	0.022	0.026	0.004	0.0054	0.846	Weak

Table 3: Global Moran's Index Analysis for the hydrogeological parameters

Hydrogeological Parameters	Moran's Index	P – Value	Z- Score
Nitrate	0.240	0.000082**	3.94
Peroxide	0.066	0.203	1.27
Total Alkalinity	-0.00027	0.731	0.343
Total Hardness	0.032	0.560	0.584
pH	0.059	0.25	1.15
Temperature	0.376	0.000001**	5.55
Total Dissolved Solids	0.068	0.11	1.60

** = Statistically Significant

Table 4: Water Quality data from the three selected communities – Soul Clinic Diamond Creek and the Duport Shara and Cow Field communities

CODE	LAT	LONG	COM	INF	HOM	TDS (ppm)	TEMP (0C)	PH	TH(ppm)	TA (ppm)	PEROXIDE (ppm)	NO3 (ppm)	Total COLIFORM
W1	6.269883	-10.6644	SHARA	HP	20	590	27	3.8	120	0	5	15.5	NEGATIVE
W2	6.26975	-10.6636	SHARA	HP	10	130	28	4.5	120	40	2	19.9	NEGATIVE
W3	6.27235	-10.6627	SHARA	OW	8	31	29	3.9	125	0	10	20	POSITIVE
W4	6.272283	-10.6617	SHARA	OW	10	42	29	3.4	250	40	5	20.1	POSITIVE
W5	6.272017	-10.6617	SHARA	HP	15	109	29	6.1	425	240	10	2.3	POSITIVE
W6	6.271367	-10.6593	SHARA	HP	15	141	29	6.3	150	720	5	0.98	POSITIVE
W7	6.270983	-10.6597	SHARA	OW	5	68	29	6	425	120	0.6	1.98	POSITIVE
W8	6.270067	-10.6611	SHARA	CW	4	42	28	5.3	120	0	25	22.9	POSITIVE
W9	6.26965	-10.6613	SHARA	OW	6	52	28	3.8	120	0	0.5	17	POSITIVE

W10	6.2694	-10.661	SHARA	CW	10	38	29	5	120	0	5	12.6	POSITIVE
W11	6.2689	-10.6608	SHARA	OW	15	47	29	5.8	120	40	5	17.8	POSITIVE
W12	6.26835	-10.6614	SHARA	HP	14	18	28	4.1	50	0	5	20.7	NEGATIVE
W13	6.268083	-10.6614	SHARA	OW	20	92	29	6.4	250	120	0.5	40	POSITIVE
W14	6.26615	-10.6569	SHARA	HP	5	130	32	5.8	120	40	10	5.9	POSITIVE
W15	6.265967	-10.6559	SHARA	HP	13	58	29	5.4	180	40	5	20.1	POSITIVE
W16	6.2655	-10.6561	SHARA	HP	14	120	31	5.1	50	40	10	4.12	POSITIVE
W17	6.265033	-10.6565	SHARA	HP	12	42	32	5.7	120	40	5	4	POSITIVE
W18	6.264083	-10.6564	SHARA	OW	3	150	30	6.1	250	120	10	0.23	POSITIVE
W19	6.268217	-10.6578	SHARA	HP	17	120	32	5.7	120	0	0.3	0.67	POSITIVE
W20	6.267433	-10.6598	SHARA	OW	12	150	32	6	120	80	25	1.8	POSITIVE
W21	6.267033	-10.6622	SHARA	CW	15	38	29	5.7	120	40	10	20.5	POSITIVE
W22	6.265383	-10.6615	SHARA	CW	20	36	30	5.7	120	40	2	3.9	POSITIVE
W23	6.265333	-10.6615	SHARA	CW	18	34	28	5.9	120	40	5	2	POSITIVE
W24	6.26725	-10.6608	SHARA	OW	10	53	30	6.2	120	40	10	20.5	POSITIVE
CODE	LAT	LONG	COM	INF	HOM	TDS (ppm)	TEMP (0C)	PH	TH(ppm)	TA (ppm)	PEROXIDE (ppm)	NO3 (ppm)	Total Coliform
W25	6.266717	-10.6603	SHARA	OW	25	30	27	5.8	140	80	0.5	20.9	POSITIVE
W26	6.268167	-10.6606	SHARA	OW	18	73	31	6.4	130	40	5	50.9	POSITIVE
W27	6.2691	-10.6595	SHARA	HP	15	24	32	4.4	120	0	10	3.4	POSITIVE
W28	6.269117	-10.6581	SHARA	OW	15	40	32	5.3	120	180	25	5.6	POSITIVE

W29	6.269767	-10.6581	SHARA	OW	13	95	31	6.4	425	120	10	3.6	POSITIVE
W30	6.269483	-10.6558	SHARA	CW	15	26	30	4.9	250	80	10	19.4	POSITIVE
W31	6.268833	-10.6557	SOUL CLINIC	OW	5	79	28	6.2	250	80	2	19.8	POSITIVE
W32	6.29235	-10.6628	SOUL CLINIC	CW	10	14	28	4.7	250	40	0.5	4.9	POSITIVE
W33	6.292833	-10.6625	SOUL CLINIC	HP	25	22	26	5.3	120	40	2	5	POSITIVE
W34	6.2921	-10.6623	SOUL CLINIC	CW	25	26	27	4.1	120	40	0.4	17	POSITIVE
W35	6.292267	-10.6612	SOUL CLINIC	OW	15	28	27	4.7	250	80	2	18	POSITIVE
W36	6.292967	-10.6606	SOUL CLINIC	CW	20	28	27	4.3	120	0	5	10	POSITIVE
W37	6.292317	-10.6627	SOUL CLINIC	OW	10	120	26	5.4	250	40	10	15	POSITIVE
W38	6.273583	-10.6718	COW FIELD	OW	20	340	29	5.1	425	120	10	15	POSITIVE
W39	6.273983	-10.6719	COW FIELD	CW	15	153	29	4.9	120	0	25	80	POSITIVE
W40	6.274133	-10.6717	COW FIELD	OW	20	154	30	5.7	250	250	10	60	POSITIVE
W41	6.274617	-10.6713	COW FIELD	CW	25	27	29	5.6	125	80	10	18	POSITIVE
W42	6.275157	-10.6707	COW FIELD	HP	15	140	30	5.4	75	40		20	POSITIVE
W43	6.252967	-10.6682	COW FIELD	HP	10	88	28	5.6	25	0	2	20	POSITIVE

Note: LAT = Latitude; LONG = Longitude; COM = Community; INF = Water Infrastructure; HOM = number of Homes per water infrastructure; TDS = Total Dissolved Solids; TEMP = Temperature; TH = Total Hardness; TA = Total Alkalinity; NO3 = Nitrated

Table 5: Number of homes collecting groundwater contaminated with Nitrate and Total coliform bacteria

	Covered Shallow Wells		Hand Pump		Opened Shallow Wells		Nitrate (ppm)		Number of Homes
	Total Coliform Results								
	Positive	Negative	Positive	Negative	Positive	Negative	Min	Max	
Diamond Creek/Soul Clinic	3		1		3		80	15	105
Duport Rd/Cow Field	2		2		2		50.9	0.23	392
Duport Rd/Shara	10		7	3	10		19.8	4.9	110

Spatial Autocorrelation (Spatial Analysis)

The spatial autocorrelation or Global Moran's Index is an inferential statistic tool with results interpreted within the context of the null hypothesis. For the Global Moran's Index statistic, the null hypothesis suggests that the water parameters are randomly distributed among water infrastructure in the study areas.

The Moran's Index uses the Getis-Ord General G to verify the null hypothesis. The G-statistic revealed a trend toward a concentration of high values with very high statistical significance in the selected sites indicating spatial autocorrelation [19]. The Getis-Ord statistic gives more natural results and better visual exploration and has the advantage of distinguishing high-value clusters or low value clusters[20].

From Table 3, the Moran's I index for the nitrate concentration and the temperature give a positive value, 0.240 and 0.376 respectively. The Z – score is 3.94 and 5.55 for nitrate and temperature respectively. Therefore, the spatial distribution of nitrate concentration and temperature whether high or low spatially clustered. The standard deviation of both nitrate and temperature is statistically significant at the 0.01 level. Which implies that there is less than 1% likelihood that the observed pattern of the nitrate concentration and temperature could have occurred by chance. The result indicates the observed pattern of nitrate and temperature have a significant impact on the water quality use for drinking in the study areas.

IV. CONCLUSION

From the results, it suggests that the 43-water infrastructure does not meet the drinking water guidelines, thus unfit for drinking. The three water infrastructures (Hand pump, Opened and Covered Wells) were above the accepted nitrate concentration and contaminated with total coliform bacteria located in the Shara and Duport Road - Cow Field communities. The nitrate contaminated water infrastructures served 53 homes with 66% from Duport Road Cow Field community and 33.9% from the Duport Road Shara community. For the distribution of contaminant, the parameters decreased towards the North of the study area; the Soul Clinic Diamond Creek community excepts for total hardness and acidity fluctuating concentration. Regarding chemical and physical parameters, the water sources in the North of the Study area are much better as compared to the Duport Road Shara and Cow Field communities. The three communities water infrastructure are contaminated with total coliform bacteria. Kriging method was used in the mapping prediction of contaminant concentration in the water infrastructure. A log transformation was applied for some hydrogeological parameters to enhance normalization of the concentration. The total dissolved solids, total hardness, pH, and temperature underwent the log transformation while the peroxide and nitrate concentration transformation were not applicable because the skewness and kurtosis were at the acceptable level. The semi variogram analysis varied for each hydrogeological parameters. The hydrogeological parameters concentration of a geological location, the nitrate concentration, and temperature have a moderate to high spatial dependence. All other parameters have a weak spatial dependence. The global Moran's Index results show that the nitrate concentration and temperature are statistically significant. The results imply that the 99% of the distribution of the nitrate concentration in the study area do not occur by chance may be either associated with environmental activity since agriculture activity that may require extensive use of fertilizer does not exist in the study area. Finally, the study results indicate that the water infrastructure located in the study area needs immediate attention and further research. Results from the Kriging and the Spatial Autocorrelation analysis show that the nitrate contaminant in the water infrastructure is an immediate public health and environmental issues in the study.

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