PAPER 10

EFFECTS OF RAINFALL TEMPORAL VARIABILITY ON GROUNDWATER PHYSIO-CHEMICAL AND MICROBIAL QUALITY: A CASE STUDY OF THE MTHATHA RIVER CATCHMENT

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ABSTRACT
Water quality in the Mthatha River Catchment (MRC) in the Eastern Cape Provinceof South Africa, continues to be degraded by nature and anthropogenic activities of municipal wastewater discharge, industrial waste, and agricultural runoff. Improving the health status of water bodies, represents good surveillance in minimising the public health entities for groundwater quality assessment. This study aimed at evaluating the variability of groundwater quality with respect to monthly rainfall temporal changes at the MRC. A systematic sampling method in selecting 10 sampled borehole sites in the area was employed. Consequently, a historic data comprising 21physico-chemical parameters were collected monthly between the period 2000 to 2020 and analysed. Autocorrelation statistical technique was used to evaluate the effects of rainfall temporal variability (RTV) on the groundwater physio-chemical and microbial quality. The normalized probability test statistic (Zy) was used to determine the level of significance exhibited while the Mann-Kendall (MK) tool was used in identifying trend patterns. The RTV results on the water quality parameters showed a positive autocorrelation range of 0.010 – 0.538 for all the parameters with a good fit analysis while MK concentration of turbidity, Iron, dissolved oxygen, total viable count, and total coliform counts parameters revealed increasing trends along the MRC. In general, the groundwater was not always of pure quality as perceived and various factors may be attributed to the fluctuating water quality in the catchment. These maybe very useful to decision-makers or managers in monitoring and detecting the quality of groundwater in the aquifer for pumping.

Keywords: aquifer scale, contaminants, groundwater, temporal variability, water quality.

1. INTRODUCTION

Groundwater may not always be as pure as perceived in many areas. Several phenomena affect the continuous health entities of groundwater quality either through contaminants from a variety of places including municipal wastewater, industrial waste, and agricultural runoff resulting in degrading the groundwater quality (Diamantini et al., 2018; Rey et al., 2018; Kumar et al., 2020). Also, understanding a catchment's underlying geomorphometric and physical mechanism impacts the natural processes of precipitation, runoff, and effluent discharge of a place at a particular time (Liu et al., 2022). Moreso, with a changing climate, incidents such as droughts and human migration will exacerbate the pressure to tap into groundwater resources as an alternate source of water. Therefore, the evaluation of the variability of the groundwater quality parameters witnessed in an area will assist in monitoring and improving the quality of groundwater available in the aquifer for pumping permission.

Groundwater pollution is a critical problem worldwide (Makungo & Odiyo, 2018), and South Africa is not an exception (Le Maitre & Colvin, 2008; Mokoena et al., 2020). The country is classified as a water-stress country. Moreso, most of the country's terrain is made up of hard rock formations that do not contain major aquifers that can be used for storage on a national scale (Mpofu & Gwavava, 2020). Thus, understanding the conjunctive uses of surface water and groundwater was necessary to get the best management of the resources. Although several groundwater studies have been carried out previously in South Africa and the area by private and government organisations that are aimed at enhancing the rural and municipal water supply augmentation scheme (Fatoki et al., 2001; Fatoki et al., 2002; Zamxaka et al., 2004; Mofokeng, 2017; Owolabi et al., 2020; Owolabi et al., 2020a; Gintamo et al., 2021). However, most of these studies either focused on the quantification of the resource or assessed the quality, but rarely on both. Most previous studies had contributed significantly to the background information on groundwater development and its potential as an alternate source of water for the area (MRC). Among the notably employed methods for monitoring the groundwater are the aquifer tests, recharge estimation, geophysical and geological logging which had been carried out at several sites as part of the method to model the groundwater quality and for the recharge estimation (Xu & Beekman, 2003; Sibanda et al., 2009; Mpofu et al., 2020; Owolabi et al., 2020). Most of the employed methods for monitoring the groundwater resources had assessed climatic impacts on groundwater quantity while paying little attention to other determinant factors that affect the quality or control the groundwater interaction with pollutants (Sibanda et al., 2009; Simmers 2013; Li et al., 2016; Kumar et al., 2019; Mepaiyeda et al., 2020). Moreso, there is currently no consensus on how varied external catchment systems inputs such as recharge and/or base flow variation, drainage area, average daily maximum temperature, precipitation, evapotranspiration, land-use type, topography, slope, and percentage of sand in the soil impact groundwater quality (Kumar et al., 2019; Kumar et al., 2020; Mepaiyeda et al., 2020). With a changing climate incident, factor like frequency, intensities of precipitation affect flow patterns (Lisboa et al., 2020), sinequano other morphometric factor contributes to flow regime impacts in characterising the water quality abstraction status in a given site. In addition, scholars differ on how temporal variability of rainfall impacts and propagates through the complex hydrogeological systems of the aquifer. Therefore, it is critical to understand both the general and specific impacts of varying rainfall magnitude on pollutants' strength in characterising any river catchment and assessing their impact on groundwater quality. Thus, this study analysed the trends in the monthly monitored groundwater quality;

assess the effects of rainfall temporal variability on groundwater physio-chemical and microbial quality.

The remaining sections of this paper are arranged as follows. Section 2 describes the materials and methods, section 3 presents the results and discussions while section 4 presents the conclusion and recommendations.

2. MATERIALS AND METHODS

2.1 Study area description

The Mthatha River rises in the Eastern Cape Province of South Africa's plateau region, roughly halfway between the Drakensberg escarpment and the Indian Ocean. The river's catchment is 100 kilometers long and 50 kilometers wide (Amoo et al., 2023). The Ngqungqu River is the main tributary of the Mthatha River, and it enters the main river on the right bank around 27 kilometers from the coast. With a steep cliff near the headwaters, the watershed is generally undulating, hilly, and broken towards the shore. The river flows through a vast plain with a flat grade in the neighbourhood of Mthatha. Between Mthatha Dam and Mthatha town, the Cicira River meets the Mthatha River from the west (DWAF, 2009; DWS, 2018). Figure 1 depicts the map of the study area.

FIGURE 1: *Map of the study area (DWS, 2018)*

The Mthatha River is divided into three branches (upstream, midstream, and downstream). There are three Plantation forests, which help to quantify plantations and settlements upstream that have an impact on river water quality. Likewise, In the Tabase area, there are exist additional informal communities with their various human activities that have impacted the quality of the River water. The Mthatha Dam, located in the middle of the river also negatively impacts the river's water quality. Finally, there is a Norwood Bridge and the Mthatha Sewage Works effluent discharge point at downstream length which also have a significant negative impact on the quality of the river's water (Fatoki et al. 2001). Domestic, and agricultural i.e livestock watering, aquatic ecosystem use, and recreational swimming water use are some of the main users of water in the catchment with irrigation water that constitutes the most frequent user of conjunctive water for the area.

2.2 Research Methodology

This study uses a descriptive research approach which allows for large research data collection which is to be analysed in a systematic manner that sheds more light on greater scrutiny of the information (Lynn,2017). The choice of the selected ten (10) boreholes sample points was based on a strategic desktop selection that entails a 5km radius distance along the Mthatha River on both sides to depict fair uniform boreholes site selection for the area. The year 2000-2020 represents the common base for the available data (monthly rainfall (depth), streamflow data, and water quality parameters) which were used for this study. However, it was observed that the month of April till June has missing data for all years used. The water quality parameter was collected from the Department of Water and Sanitation, Mthatha while the meteorological data (rainfall) was sourced from the South Africa Weather Services (SAWS). In all, 21 water quality parameters consisting of TBD=turbidity, pH at 25ºC, NH_4=Ammonia, Ca=Calcium, Cl=Chloride, Fl=Fluoride, Mg=Magnesium, K=Potassium, Na=Sodium, SO_4=Sulphate, Zn=Zinc, Al=Aluminium, Cu=Copper, Cyanide, Fe=Iron, Pb=Lead, Mn=Manganese, Ni=Nickel, E. coli=EC, total Coliforms, and TDS=total dissolve solid were carefully analysed to show the effects of rainfall variability shift on the catchment's mean monthly water quality parameters.

Since water quality data is frequently not normally distributed due to intra-annual variations, outliers, and undetected missing data. The nonparametric tests: Mann-Kendall, Sen slope, and Spearman correlation were used to explore the water quality and hydro-climatic data trends in the catchment. The non-parametric approach- the Mann-Kendall test for trend is functionally identical to Kendall's (tau) test for correlation and with the associated slope estimate were usually adopted (Li et al. 2014; Ravichandran, 2003; Singh et al. 2004; Tabari et al. 2011). It is mostly used for identifying trends and patterns in time series data. It compares the relative magnitudes of sample data rather than the data values. The major benefit of this test is that the data need not conform to any particular distribution. Thus, if $X_1, X_2, \ldots$, Xn represents n data points where Xj represents the data point at time j. then the Mann-Kendall statistic (S) is given by

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sgn\left(X_j - X_i\right) \quad (1)$$

$$Sgn(X_i - X_i) = \begin{cases} +1, & X_j > X_j \\ 0, & X_j = X_j \\ -1, & X_j < Xj \end{cases} \quad (2)$$

Then, the computed probability associated with S and the sample size n is used to statistically quantify the significance of the trend (Ndione et al. 2017). The quantification of the variance of S, (σ^2) is computed by using Equation 3

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g}(t_p - 1)(2t+5)\right] \quad (3)$$

Where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value), and tp is the number of data points in the P_{th} group. Computation of a normalized test statistic Zy is shown in Equation 4

$$Zy = \begin{cases} (S-1)/\sigma & for\ S \rangle 0 \\ 0 & for\ \ S = 0 \\ \frac{S+1}{\sigma} & for\ \ S \langle 0 \end{cases} \quad (4)$$

The test statistics Zy is used as a measure of trend significance. In fact, this analysis is used to test the null hypothesis. Ho: that there is no monotonic trend in the data if Zy| is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (usually 5% with $Z_{0.025} = 1.96$), thus, the null hypothesis is invalid meaning that the trend is significant which implies that the trend has a causative factor and did not occur by chance.

TABLE 1: *The Pettit's SNHT Test for sample.*

Variables	K	(S)	p-value (Two-tailed)	99% confidence interval on the p-value	
MaxT	2221.000	279	0.597	[0.584,	0.609]
MinT	3311.000	98	0.158	[0.148,	0.167]
Rain	5358.000	148	0.003	[0.001,	0.004]
Streamflow	-0.234	92586	<0.0001	[0.627,	0.651]

where MaxT-maximum temperature, MinT-minimum temperature

Hence, preliminary tests for normal distribution and other internal consistency tests were performed to identify the possible reliability of the datasets, which were performed in the XLSTAT statistical software and Microsoft Excel tools. The effects of rainfall pattern shift on the catchment's mean monthly water quality parameters were analysed graphically by correlations. Thereafter, the coefficient of autocorrelation was used to evaluate the effects of rainfall temporal variability (RTV) on the groundwater physio-chemical and microbial quality. The normalized probability test statistic (Zy) was used to determine the significance level exhibited, while Mann Kendall was used to determine the trend pattern.

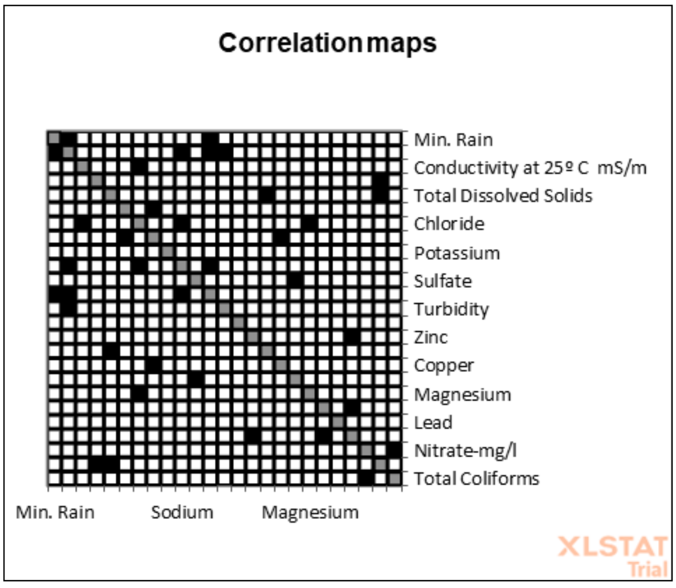

FIGURE 2: *MRC water quality correlation maps with rainfall*

3. RESULTS

The results of the preliminary data analysis for the homogeneity, and consistency tests are as presented in Table 1. A Pettit Standard Normal Homogeneity Test (SNHT) is used to check whether two samples are from the same population, likewise for the detection of change point or abrupt points in time series. The Pettit's Homogeneity test indicates that the meteorological data is uniformly distributed and that there exists no date in which the data exhibit anomaly since their p-value exceeds the significance level alpha=0.05 except for rainfall and streamflow which exhibits a non-significant decreasing trend.

The effects of rainfall temporal variability on the borehole water quality physio-chemical and microbial were hereby presented.

3.1 Datasets and Analyses

Table 2 depicts the 21-year monthly summary of the hydro-meteorological data (2000- 2020) while Table 3 depicts the descriptive statistical summary of the catchment's water quality parameters.

The minimum, maximum, mean, and standard deviation in the water quality parameter is 2.00, 6.00, 3.667, and 1.966 for pH (unit). This depicts a sample means with heterogeneous variability. The various water quality mean samples have lower standard deviation values of 1.97, 3.46, 0.55, and 3.25 for pH, turbidity, Zinc (Zn), Magnesium (Mg), and Total Coliforms to indicate the sample is more diverse.

3.2 Autocorrelation Trend and Discussions

Figure 2 depicts the Spearman autocorrelation matrix plot for the borehole water quality parameters with rainfall. The correlation coefficient value range from positive 0.010 – 0.538 for all the parameters with a good fit analysis. This implies a weak correlation for most of the physio-chemical and biological parameters observed in the area. The bold value indicates strong autocorrelation while the positive sign depicts dilution with rainfall and vice versa. This also corresponds with core principles of hydrogeology and other hydro-climatic changes (Kourakos et al., 2019; Gintamo et al., 2021).

TABLE 2: *A 20-years synopsis of meteorological data (2000- 2020)*

Variables	Unit	Maximum	Minimum	Std. dev	Mean
MaxT	°C	33.170	14.400	3.442	4.408
MinT	°C	20.620	-5.000	4.942	10.392
Rain	mm	353.200	0.000	61.918	64.394
Streamflow	m^3/s	123.639	2.018	26.216	26.217

3.3 Mann-Kendall and Sen's Slope Autocorrelation Results

Table 4 depicts the results of the water quality statistics summary with the Mann-Kendall trend analysis. The Mann-Kendall (S) analysis identifies the trend pattern. A Kendal's tau of zero (0) indicates that no trend exists. Likewise, by implication, a significantly high positive value of the Mann-Kendall test is a sign of an "increasing trend" whilst a very low negative value signals a "decreasing trend". If the probability normalized test statistic (Zy) is ($Z_{0.025}$=1.96), this means that the trend is significant. A positive statistical significance (Zy) illustrates the likely trend to continue. A Sen's Slope value is less significant when it is closer to zero, while a positive Sen's Slope signifies an increasing trend and vice versa.

As the computed p-value is greater than the significance level alpha=0.05, we conclude that ties have been detected in the dataset. This implies that most of the physio-chemical and microbial parameters exhibit varied significant trends composition for the groundwater parameters. Thus, the varied changes observed in the water quality parameters depict the response of the aquifer to rainfall percolation. A strong positive correlation among water quality parameters exposed the weathering of carbonate rocks, evaporites, soil salts, and the interaction of halite with groundwater as the common sources of increase in values of these ions in groundwater (Edokpayi et al., 2020). Conversely, negative values indicate the items tend to be monotonic in trend correlation and vice versa.

TABLE 3: *Descriptive statistics of MRC-monthly selected water quality parameters (2000- 2020)*

Water quality parameters	Units	Minimum	Maximum	Mean	Std. deviation
Conductivity at 25° C	mS/m	5.00	170.00	116.00	83.68
pH at 25° C	pH units	2.00	6.00	3.67	1.97
Total Dissolved Solids	mg/L	1.50	1200.00	404.75	616.01
Calcium	mg/L	1.50	1000.00	303.48	391.81
Chloride	mg/L	100.00	1200.00	500.00	477.49
Fluoride	mg/L	1.50	500.00	117.42	193.54
Potassium	mg/L	1.50	2000.00	1056.92	1034.93
Sodium	mg/L	1.00	1200.00	317.00	448.79
Sulphate	mg/L	1.50	1000.00	416.92	342.66
Aluminium	mg/L	1.00	2000.00	436.83	779.14
Turbidity	NTU	1.00	10.00	6.00	3.46
Ammonia	mg/L	1.00	300.00	52.50	121.30
Zinc	µg/L	0.90	10.00	5.15	2.89
Manganese	mg/L	10.00	400.00	218.33	157.53
Copper	mg/L	1.50	2000.00	816.92	923.68
Iron	mg/L	300.00	2000.00	1550.00	731.44
Magnesium	mg/L	1.00	2.00	1.50	0.55
Cyanide	mg/L	10.00	1200.00	470.00	571.80
Lead	mg/L	8.00	400.00	74.67	159.38
Nickel	mg/L	0.90	200.00	65.30	73.10
Nitrate	mg/L	0.90	500.00	170.63	255.17
E-coli	Count per 100 mL	1.00	200.00	38.83	79.09
Total Coliforms	Count per 100 mL	1.00	10.00	7.17	3.25

3.4 RAINFALL VARIABILITY CORRELATION WITH WATER QUALITY PARAMETERS

A frequency trend analysis of the water quality parameters variation of the catchment helps in understand the prevailing underlying physio-chemical mechanism occurring in the catchment. Figures 3-13 depict the different water quality mean monthly value correlation with minimum and maximum rainfall depth.

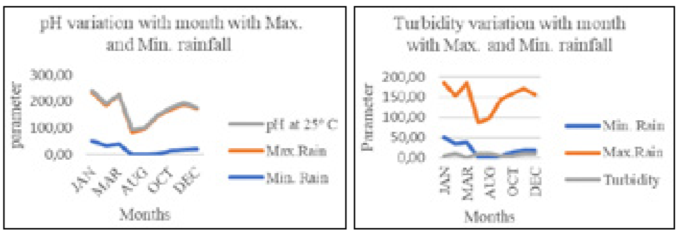

FIGURE 3: *pH and Turbidity water quality parameter for different months between the years (2000- 2020)*

Although, figure 3 witnessed a similar pattern of observation both in pH and turbidity but at different magnitude. The pH follows the same pattern with maximum rainfall, while turbidity relate well with the minimum precipitation but at different the months. The month of January and March witnessed a high percentage of turbidity that is witnessed over the catchment. An average value of 100 NTU Turbidity occur in December and July with a minimal low value of less than 50.

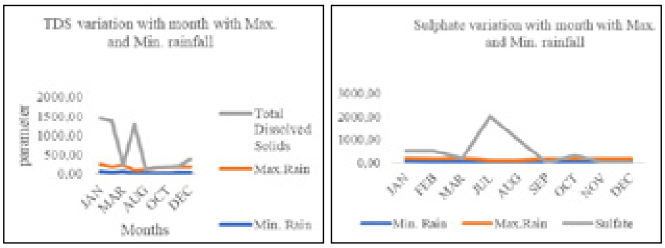

FIGURE 4: *TDS and Sulphate water quality parameter for different months between the years (2000- 2020)*

Figure 4 explains the TDS and sulphate water quality patterns. Most of these parameters exhibit a Zig-zag linear plot from the beginning of the year (January) till July before the gradual decline in magnitude values.

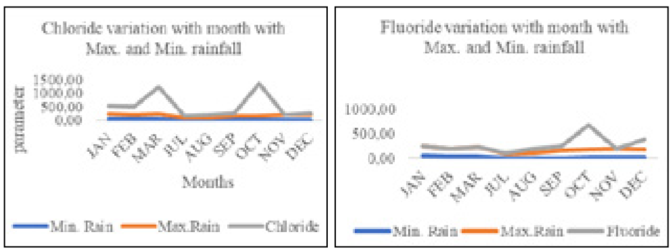

FIGURE 5: *Depicts the chloride and Fluoride plots.*

TABLE 4: *The autocorrelation Mann Kendall's trend nature and trend significance*

Series\Test	Kendall's tau	p-value	Sen's slope	Trend nature	Trend significance (Zy)
Min. Rain	-0.255	0.454	-4.309	Decreasing	Yes
Max.Rain	0.000	1.000	-0.950	Decreasing	Yes
Conductivity	0.178	0.667	0.000	Decreasing	Yes
pH at 25° C	-0.154	0.700	-0.071	Decreasing	Yes
Total Dissolved Solids	-0.591	0.070	-90.107	Decreasing	No
Calcium	0.265	0.447	43.950	Increasing	Yes
Chloride	-0.222	0.530	-36.500	Decreasing	Yes
Fluoride	0.386	0.248	14.600	Increasing	Yes
Potassium	0.000	1.000	0.000	Decreasing	Yes
Sodium	-0.222	0.530	-13.679	Decreasing	Yes
Sulphate	-0.371	0.258	-68.690	Decreasing	Yes
Aluminium	-0.309	0.369	-44.881	Decreasing	Yes
Turbidity	0.000	1.000	0.000	Decreasing	Yes
Ammonia	0.038	1.000	0.000	Decreasing	Yes
Zinc	0.403	0.232	1.125	Increasing	Yes
Manganese	-0.519	0.102	-46.190	Decreasing	Yes
Copper	-0.386	0.248	-181.768	Decreasing	Yes
Iron	0.356	0.316	0.000	Decreasing	Yes
Magnesium	0.477	0.170	0.225	Increasing	Yes
Cyanide	0.113	0.800	1.000	Increassing	Yes
Lead	0.081	0.894	0.000	Decreasing	No
Nickel	0.038	1.000	0.000	Increasing	Yes
Nitrate	0.340	0.311	110.025	Increasing	Yes
E-coli	0.371	0.258	0.929	Increasing	Yes
Total Coliforms	-0.309	0.371	-0.500	Decreasing	Yes

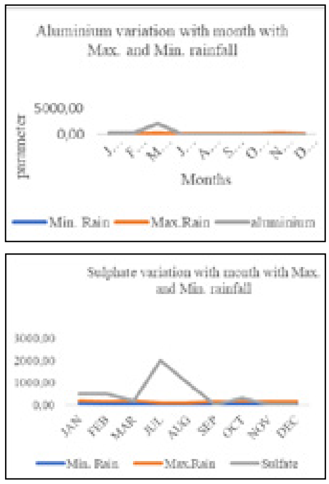

FIGURE 7: *Aluminium and manganese water quality parameter for different months (2000- 2020)*

Figure 7 is quite different from the preceding graphs. The Aluminium figure depicts a high value of 2000 (mg/l) witnessed in March and a relatively uniform value was witness across the rest months (July to December). This could be due to the low rainfall that is usually witnessed in this period while the Manganese concentration is relatively related to the trend and pattern of maximum precipitation across the months.

Figure 8 correlation plot explains how the ammonia and zinc suggests an increasing trend with the climax in August month for ammonia and July, November accounting for Zinc. Although, there is strong influence of maximum rainfall occurrence. Figure 9 depicts the copper and iron monthly trend variation.

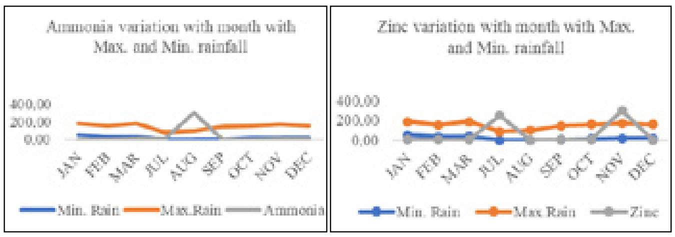

FIGURE 8: *Ammonia and Zinc water quality parameter for different months*

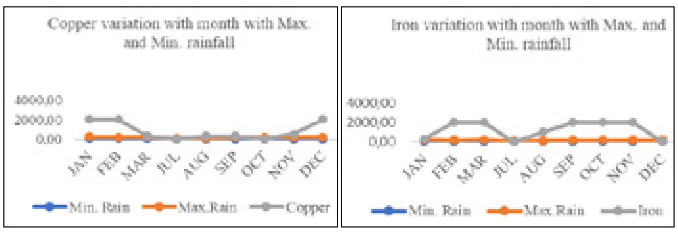

FIGURE 9: *Copper and Iron water quality parameters monthly trend variation observed for different months*

The figures differ in trend for the parameters but follow the same trend for both minimum and maximum rainfall observed for the years of

Figure 5 explains how chlorine follows the same monthly pattern as fluorine. The months of March and October are the highest. A greater percentage of the observed month's maximum rainfall does not relate well with chlorine except in Nov-Dec and January to July for fluoride. Figure 6 depicts the monthly plotted potassium and calcium value data.

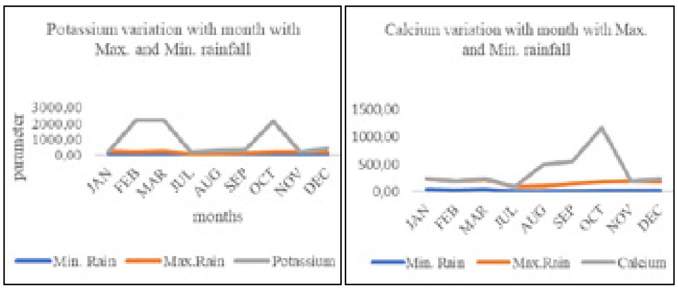

FIGURE 6: *Potassium and Calcium water quality variables observed for different months (2000- 2020)*

The calcium water quality parameters follow a linear plot from the beginning of the year (January) till July before the irregular. This could be a result of high rainfall which usually occurs in the months while the potassium with high failure values for the drinking water occurs intermittently in the catchment. Figure 7 depicts the plotted monthly Aluminium and Manganese pattern and trend.

observation. Both copper and iron parameters follow the same monthly pattern with the months of July and November being the lowest. Figure 10 depicts the magnesium and cyanide monthly trend variation.

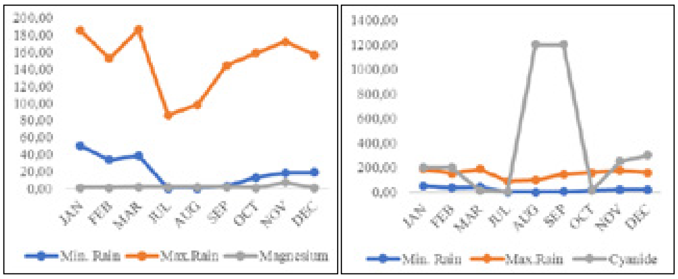

FIGURE 10: *Magnesium and Cyanide water quality parameter across the different months of the years*

Figure 10 depicts the magnesium and cyanide parameter variation trend. The magnesium plot is quite different from the cyanide graphs with a high value of 200mg/l witnessed in March and November. This could be due to the low rainfall that is usually witnessed in this period. However, cyanide has a relatively uniform value for both maximum and minimum rainfall across months July to October. Figure 11 depicts the lead and nickel concentrations value with rainfall magnitude in groundwater.

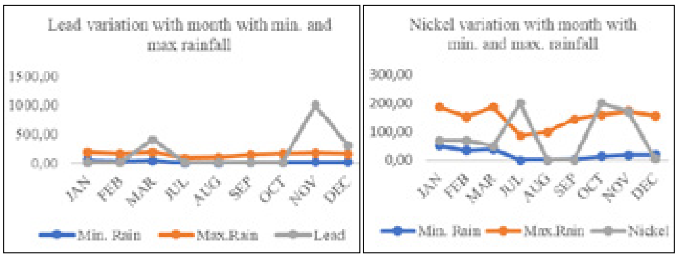

FIGURE 11: *Lead and Nickel water quality parameter across the different months of the years (2000- 2020)*

The lead trend results value is noted to be higher in October (the month with minimum rainfall depth) than in the month of September (the month with maximum rainfall depth) while Nickel relates well with maximum rainfall (Figure 11). Figure 12 depicts the E-coli and total coliform (microbial concentrations) in the boreholes.

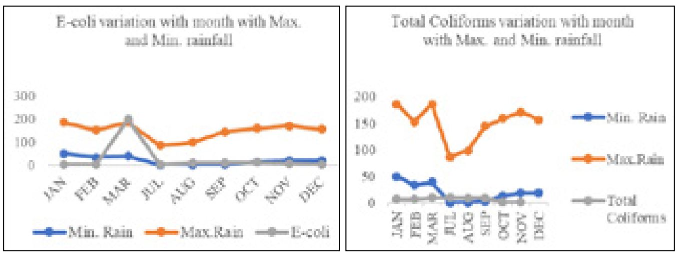

FIGURE 12: *E-coli and total coliforms water quality parameter for different months (2000- 2020)*

The microbial concentrations for the E-coli and the total coliforms value in the boreholes is noted to be higher in August - October (the month with minimum rainfall depth) than in the month of March (the month with maximum rainfall depth).

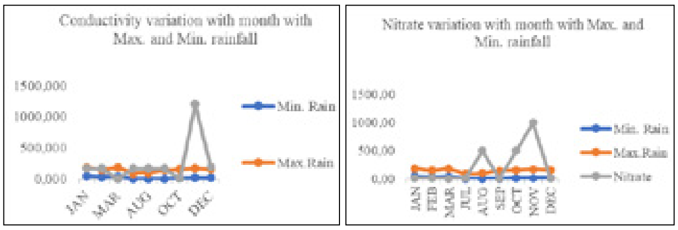

FIGURE 13: *Conductivity and Nitrate parameter for different months between the year (2000- 2020)*

Figure 13 reveals a fluctuating conductivity and Nitrate parameter with the lowest record between January to July and a gradual sharp increase from October before a gradual decline from November to December while Nitrate in particular witness irrational sharp increase from August to November before sharp decrease in December (the month with both minimum and maximum rainfall depth). In general, the lower region of the MRC has been experiencing a decline in water quality concentration with the lowest record values recorded between June and October with a gradual increase that usually occurred from November until January. This may be due to the minimum rainfall witnessed during the period, while the pH of most locations was found to be alkaline except for some downside sections, which may be due to the mixing of waste reactions.

4. CONCLUSIONS AND RECOMMENDATIONS

In summary, this study evaluates the effects of rainfall temporal variability (RTV) on groundwater physio-chemical and microbial quality. The study has highlighted the essence of maintaining acceptable standards for water quality even during unfavourable conditions. The correction to various groundwater quality parameters with RTV shows a weak correlation (0.010-0.537) value to the monthly rainfall magnitude. This implies there is a low chance that the physio-chemical and biological parameters react with the rainfall process. Hence, it can be deduced that most of the borehole contaminants variable occur monthly with a high-risk likelihood when recharge water carries dissolved pollutants down to the aquifer. Also, the primordial perception that groundwater/ boreholes are pure and pristine in nature, should not be generalised for all catchments without consideration to limiting factors such as topography terrain, underlying geological formation, and the varying climatic inputs variables. In all, decision-makers and water resource managers will find this study useful in recognizing the complexities of measuring boreholes/ groundwater quality as concerns for immediate attention and intervention. Hence, the study advocates government and non-governmental intervention in adequate finance of borehole water quality assessment and the need for a standardized routine monitoring programme for groundwater quality assessment.

5. LIMITATION OF THE STUDY

The study has ignored the complex strata of borehole nature and mechanisms like pollution retention, and/or dilution reaction of cleaner tributaries entering the aquifer. Furthermore, the study has disregarded changes in rainfall qualities in duration, intensity, frequency and seasonal pattern impact on boreholes' water quality. More research into these limitations would have been good, especially how they impact over the long-term. In general, the use of statistical hypothesis may be deceptive to subjective reasoning, thus real-time correlation of water quality parameters comparison with rainfall magnitudes may suggest a safe groundwater quality model's applicability for causes and mitigation suggestions.

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Conflict of interest

There are no conflicts of interest declared by the authors.

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