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Dynamics of Potable Well Water Quality in Key Mining Chiefdoms in Kono District, Eastern Sierra Leone

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Abstract

Groundwater is increasingly being used due to its universal availability and generally good quality. However, the risk of contamination of groundwater due to various human activities such as mining is equally increasing across the globe. In this study, the physical parameters of potable well waters in the key mining areas in Nimikoro and Tankoro Chiefdoms in Kono District were analyzed for compliance with drinking water quality standard. To do this, both unpurged and purged well water samples were collected once every month for a period of one year. Some of the well water properties like temperature, Total Dissolved Solids (TDS) and Electrical Conductivity (EC) were measured on site and others determined in the laboratory. The data collected from the laboratory analyses were statistically analyzed in MS Excel, SPSS and ArcGIS environments for quality trends in time-space fabric. The results showed that well water quality in the study area generally fell short of drinking water quality standards of Sierra Leone and WHO. There were high temperature and turbidity during the dry season and then high TDS and EC during the rainy season. Temperature and turbidity also significantly influenced well water quality in the study area, much more than TDS and EC. The implications for drinking water of lower quality than the standard could be huge for the local population and therefore needs the attention of stakeholders in the study area and decision makers in the country.

Keywords

Temperature, Total Dissolved Solids, Turbidity, Electrical Conductivity, Water Quality

1. Introduction

Water is the second most important element for life after air. While water covers some two-thirds of the Earth's surface and it is available almost everywhere beneath the surface of the Earth, its use for any purpose is limited by its quality. Water quality is the state of its physical, chemical and biological characteristics [1] [2]. It is the measure of the properties of water relative to the established standards for a given use [3] [4]. Next to medical uses is drinking in terms of water quality standards. Unfortunately, however, some 2.2 billion people do not still have access to safe drinking water [5]. Further worse is the fact that over half of this number are in the global south, including Sub-Saharan Africa and South Asia [5]. Studies show that while up to 84% of the urban population has access to safe drinking water, only 32% is the case for the rural areas of Sierra Leone. While also the 32% relies on water wells, the vast 68% risks it out with various sources of water for drinking. Some 50% use surface water, 9% unsafe well water and 9% unsafe spring water [6]. In the hinterlands of the country, mechanically-pumped hand-dug wells are predominantly used [7].

Water quality can be classified as potable water, palatable water, contaminated water and infected water. Potable water: Is safe to drink, pleasant to taste, esthetic sight and fit for domestic use. Palatable water: Contaminated water contains unwanted physical, chemical, biological and radiological substances and therefore unfit for drinking or domestic purpose. Infected water contains pathogenic organism [8].

As a key requirement for public health [9], water quality can be assessed from physical, chemical and biological properties [1] [10]. Physical properties refer to such things as temperature, turbidity, total dissolved solids (TDS), electrical conductivity (EC), pH, etc. Physical properties affect mainly the aesthetic look of water, including clarity, color, taste, odor, etc. [11]. However, properties like temperature and pH can very much influence a whole lot of other properties of water.

Cool water is much cleaner than warm water because heat increases the dissolution of a range of substances in water, affecting its quality, taste, etc. The growth of microorganisms in water increases with increasing temperature, in turn affecting taste, odor, color and corrosivity of water [12] [13]. Higher temperatures increase sedimentation and chlorination processes, in turn affecting biological oxygen demand (BOD) and biosorption of dissolved heavy metals in water [14]-[16]. Warm spring water with average temperature of 26.5˚C is likely to have high count of pathogens [17]. Geothermal temperature increases steadily with increasing well depth [18].

Turbidity is caused when suspended materials such as clay, silt and organic matter accumulate in water [3]. Particulates shield microorganisms from the effects of disinfectants and thereby stimulate their growth [12] [15] [19]. Suspended particles provide the surfaces for the adsorption of heavy metals and hazardous organic pollutants [20]. Groundwater generally has low turbidity because of inherent filtration processes as water penetrates through the soil [10] [21].

Solids, as either solution or suspension, are generally referred to as TDS when in water and consist mainly of inorganic salts and traces of organic matter. In drinking water, TDS could come from the dissolution of rock minerals, sewage, urban runoff and industrial wastes [13] [22].

The water quality analysis in this study was limited to physical properties such as temperature, turbidity, TDS and EC. Although the study was limited (in scope of properties analyzed, area covered and data collection time span), it was still very much important due to its health implication for the local population.

2. Methods and Materials

2.1. Study Area

Kono District is located in Eastern Province of Sierra Leone at latitude 8˚44'02.44" and longitude 10˚58'48.00" (**Figure 1**). There are 14 chiefdoms in the district, two (Nimikoro and Tankoro) of which were covered in this study. These are the notorious mining belt, but subsistence agriculture is the next main stay of the local people.

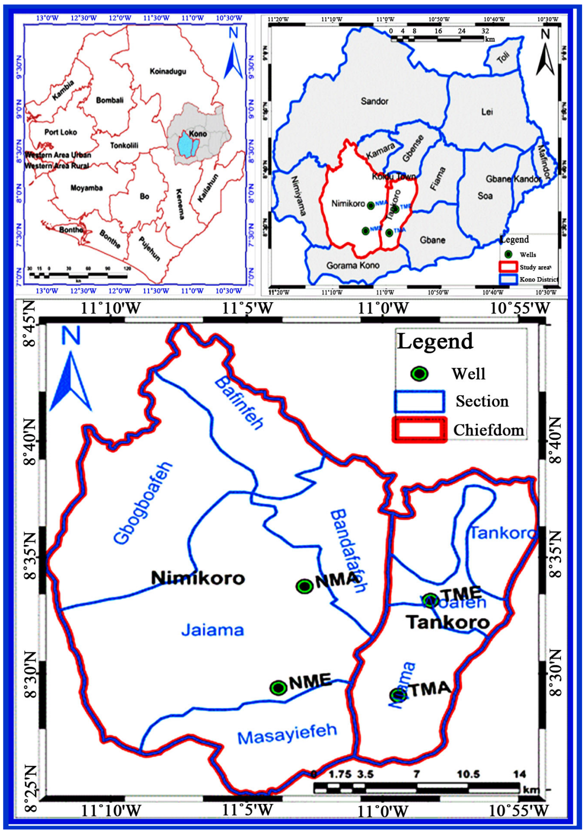


Figure 1. A map of Sierra Leone showing Kono District and the Nimikoro and Tankoro Chiefdoms where the study was conducted. *Note: NMA = manually dug and operated well in Nimikoro Chiefdom; NME = mechanically drilled and operated well in Nimikoro Chiefdom; TMA = manually dug and operated well in Tankoro Chiefdom; and TME = mechanically drilled and operated well in Tankoro Chiefdom.*

Diamond mining started in these chiefdoms since the 1930s and have to date continued to attract a huge influx of youths. Small-scale artisanal mining is scattered everywhere across the chiefdoms too, seeking precious diamonds and dust gold. The mode of artisanal small-scale mining practiced is called alluvial mining. This started in Yengema village (Nimikoro Chiefdom) in the 1930s and later extended over to Tankoro Chiefdom. There are today established estates of multi-national mining companies doing even deep-earth (Kimberlite) mining in the region.

The climate in the study area is humid, with a unimodal precipitation [7]. The annual average temperature, precipitation and relative humidity are respectively 24.4˚C, 1694 mm and 87.3% [23]. In Nimikoro Chiefdom, the mechanically-drilled hand-pumped well was located at 8˚26'38.409"W and 11˚1'21.021"N, and then the manually-dug hand-drawn well at 8˚36'38.739"W and 11˚1'22.669"N. In the contiguous Tankoro Chiefdom, the mechanically-drilled hand-pumped lied at 8˚37'53.500"W and 10˚59'24.200"N, and then the manually-dug hand-drawn well at 8˚37'56.000"W and 10˚59'28.400"N. The average depth of the machine-driven wells in the study area was 31.95 m and that of the hand-dug wells was 15.65 m. It suggested that the machine-driven wells were on average twice as deep as the hand-dug wells in the region.

2.2. Well Water Sampling

For the well water quality study, water samples were taken on the 15th of every month for the period of 12 months in 2021. A set of water samples were collected per well, one before purging and another after purging [24].

For the hand-dug and hand-drawn wells, a sampling bottle (the main bottle) and string were used to collect the water sample. Before each use, the main bottle was thoroughly rinsed in distilled water. Each collected water sample from the main sampling bottle was turned into a total of 3 small glass-bottles each of volume of 15 ml. A total of 6 small glass-bottles were used per well (3 before purging and another 3 after purging). All the small water sample glass-bottles were also thoroughly rinsed in distilled water and labeled correctly. Then for the hand-pumped wells, the small glass-bottles (prepared as described above) were used to collect the water samples directly at the pump. Thus, for the 4 water wells covered in the study, a total of 24 samples of water were collected per month and 288 water samples for the year. The collected well-water samples were kept off from the sun ray, packed in an insulated cooler at a regulated temperature of not above 4˚C ± 2˚C and then taken to the laboratory for analyses.

The well water temperature reading was done on-site using a hand-held thermometer. The measurement was done from the main sampling bottle for the hand-drawn wells, and at the mouth of the pump for the hand-pumped wells. The other physical properties of the collected well water samples were measured in the laboratory using the UV-Vis spectrophotometer.

2.3. Data Analysis

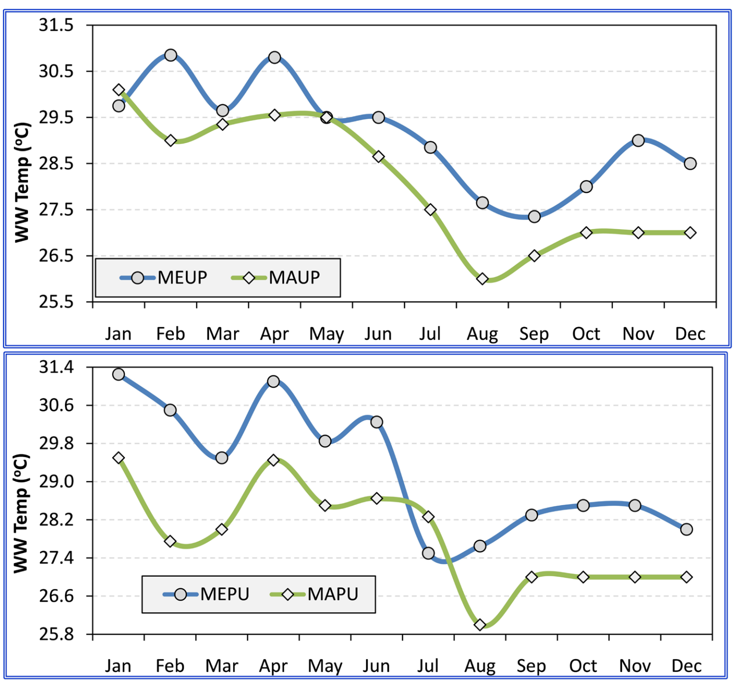
The collected water quality data obtained both field measurement and laboratory analyses were statistically analyzed in MS Excel, SPSS (Statistical Package for Social Sciences) and ArcMap GIS (Geographic information System) environments. The well water quality was determined from the degree of occurrence of selected water properties, including temperature, turbidity, TDS and EC.

The coefficient of variation (CV) was used to assess the data variability, coefficient of determinant (r^2) to determine the interdependence of the variables and *t*-test to determine the significance of any correlation at $p < 0.05$. Then the results were plotted in time-series and spatial distributions to aid understand the subsequent discussions.

3. Results

3.1. Time Trend of Temperature

For both the mechanically-drilled and manually-dug wells in the study area, temperature of was generally higher for unpurged well water than purged well water. Temperature was also higher for mechanically-drilled than for manually-dug well water (**Figure 2**). In time, well water temperature was on average highest in January and lowest in August. For mechanically-drilled wells (which were generally deeper than manually-dug ones), the average water temperature was highest in February and lowest in September. There was on average on month delay in temperature trend from mechanically-drilled well to manually-dug well in the study area. While (except for the early months of the year) the well water temperature was hardly above the standard value (30˚C), it was generally above the ideal value (20˚C).



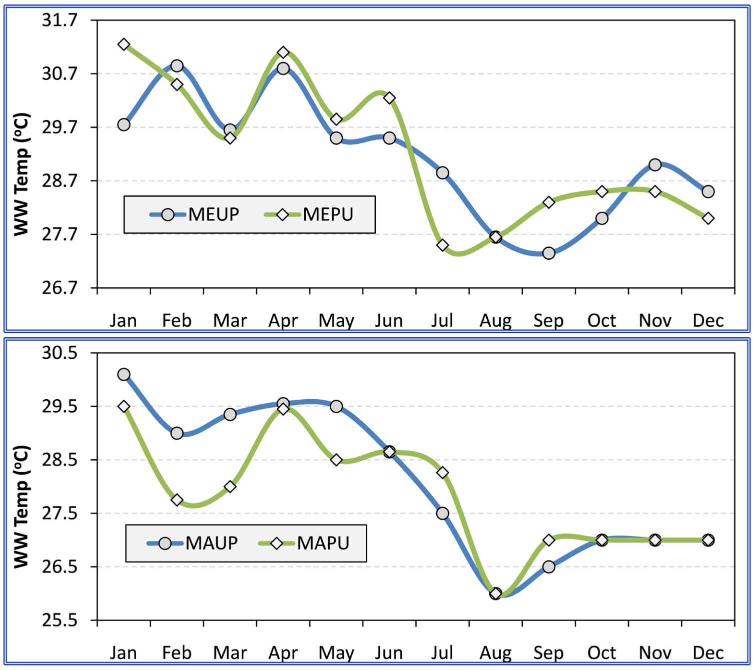
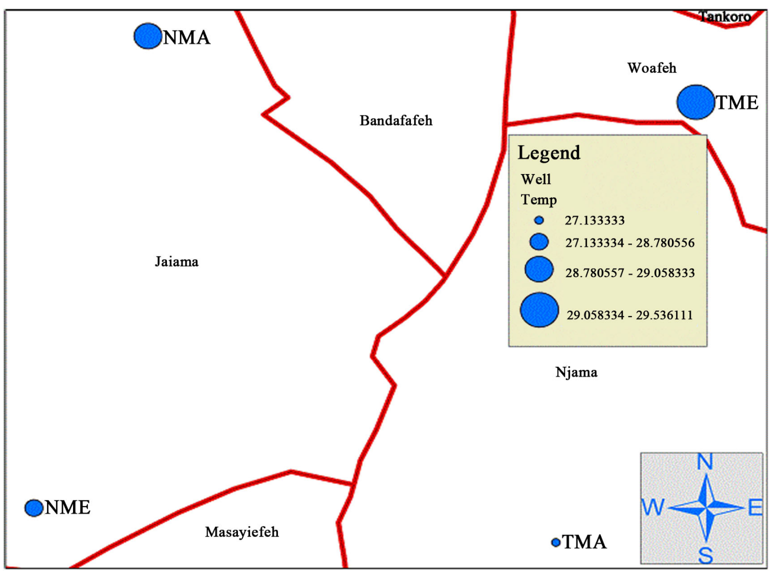


Figure 2. Time-series of monthly water temperature (Temp.) before (UP) and after (PU) purging of manually-dug (MA) and mechanically-driven (ME) wells in the study area (Ideal value = 20˚C; Standard value = 30˚C).

3.2. Temperature Spread in Space

The spatial spread of well water temperature in the study area is plotted in Figure 3. The temperature was generally lower in the south than in the north of the study area. In fact, well water temperature was lowest for the manually-dug well in the southeast and highest for the mechanically-driven well in the northeast. The distribution was not necessarily consistent with well type, suggesting that the location and geoformation more strongly influenced well water temperature in the study area.



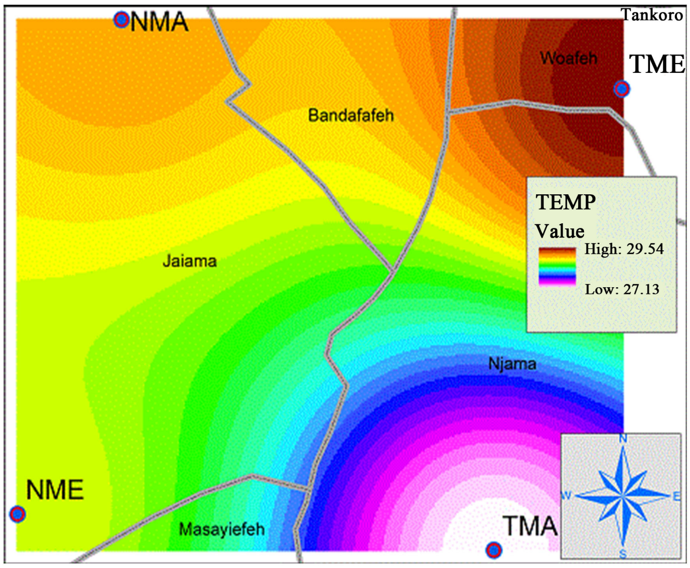
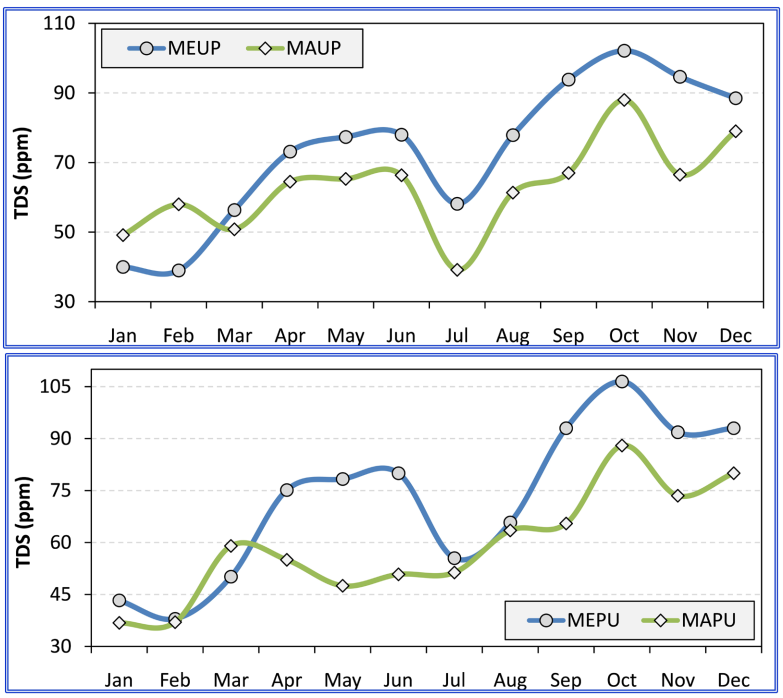


Figure 3. Spatial distribution of well water temperature (Temp.) in the study area.

3.3. Time Trend of Total Dissolved Solids

Like temperature, well water TDS was generally higher for unpurged wells than purged wells, consistent for both mechanically-drilled and manually-dug wells in the study area (Figure 4). It was also higher for mechanically-driven wells than manually-dug wells. The TDS concentration was highest in October and lowest in February, a near-reverse of temperature. Furthermore, the trend in TDS increased with the coming of the rains in the study area. TDS occurred in well water in the study area in concentration below both the ideal (500 ppm) and standard (1000 ppm) values.



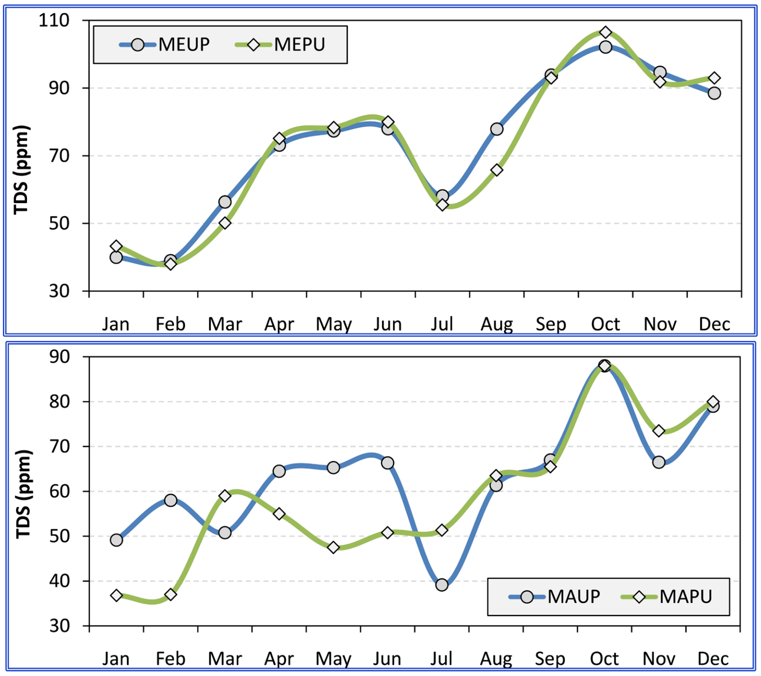


Figure 4. Time-series of monthly Total Dissolved Solids (TDS) of water before (UP) and after (PU) purging for manually-dug (MA) & mechanically-driven (ME) wells in the study area (Ideal value = 500 ppm; Standard value = 1000 ppm).

3.4. Total Dissolved Solids Spread in Space

The spatial spread of TDS in well water in the study area is also a near-reverse of temperature (**Figure 5**). It was generally low in the north and high in the south, lowest for manually-dug well in the northwest and highest again for manually-dug in the southeast. It then suggested that although TDS was more active for shallow wells than deep wells, it was generally an element of the location and geoformation of the study area.

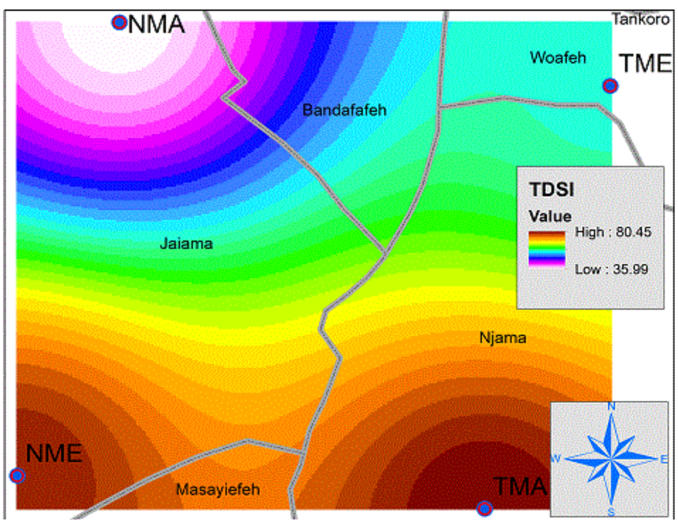


Figure 5. Spatial distribution of Total Dissolved Solids (TDS) in well waters in the study area.

3.5. Time Trend of Electrical Conductivity

Like temperature and TDS, the EC of well water in the study area was vastly higher for unpurged wells than purged wells. This trend was consistent for both mechanically-drilled and manually-dug wells in the study area (**Figure 6**). The well water EC was also highest in October and lowest in May, much the same as TDS. There were outlier values for the month of May for both the mechanical and manual wells after purging. Generally, however, well water EC in the study area was above the ideal value (50 µS/cm), but below the standard value (400 µS/cm).

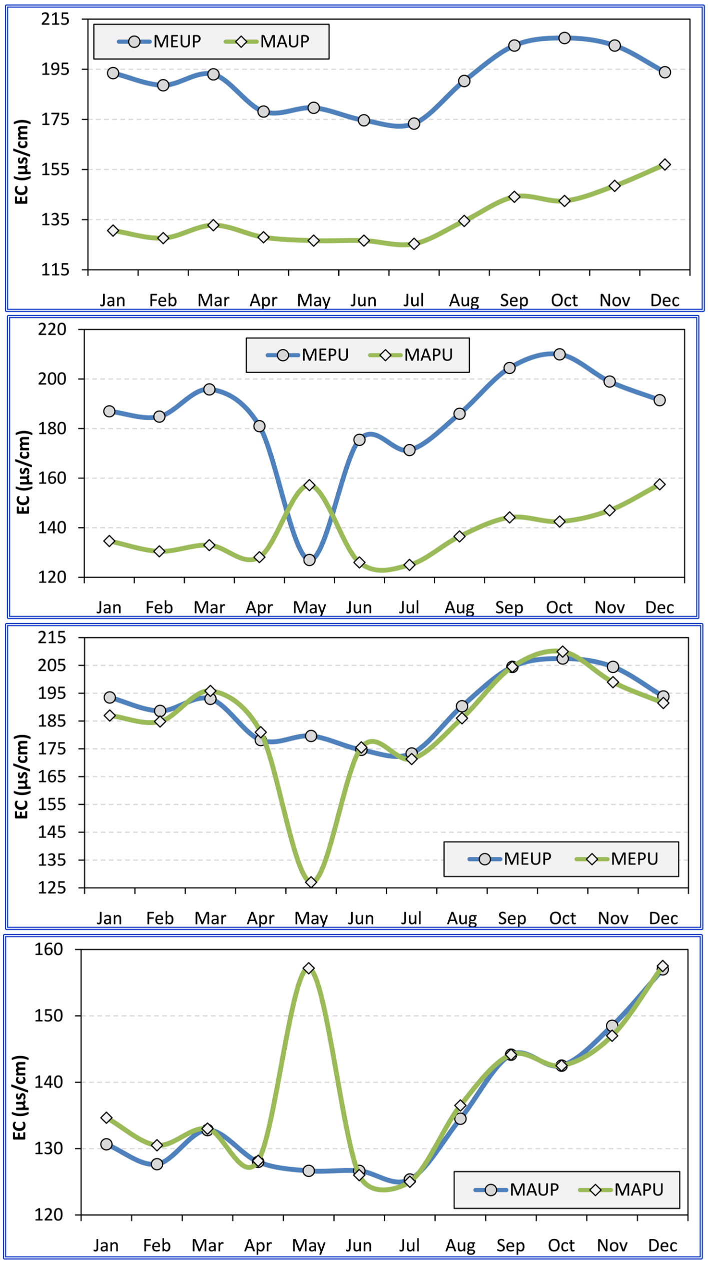


Figure 6. Time-series Electrical Conductivity (EC) of water before (UP) and after (PU) purging of manually-dug (MA) & mechanically-drilled (ME) wells in the study area (Ideal value = 50 µS/cm; Standard value = 400 µS/cm).

3.6. Electrical Conductivity Spread in Space

The spatial distribution of EC in well water in the study area is plotted in Figure 7, showing lower values in the north than in the south. Specifically, EC was lowest in the northwest and highest in the southwest. It showed that EC was not entirely driven by well type and therefore not by well depth. However, the well with the lowest TDS had the lowest EC too, suggesting some connection between TDS and EC in the study area.

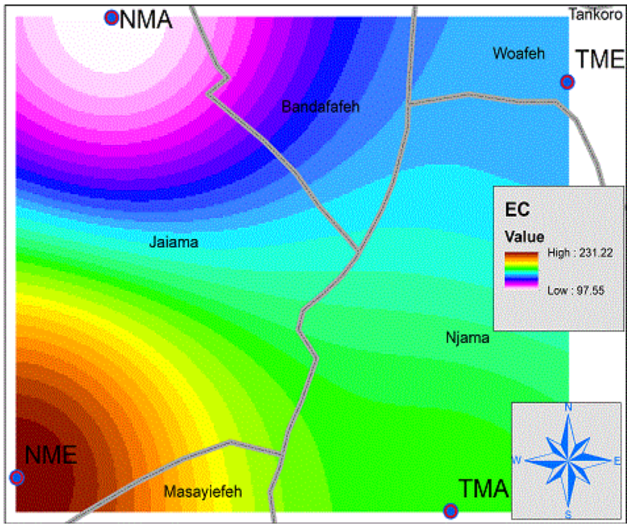
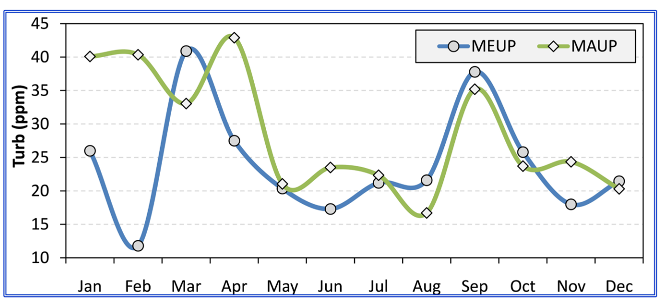


Figure 7. Spatial distribution of yearly average monthly Electrical Conductivity (EC) of well water in study area.

3.7. Time Trend of Turbidity

Turbidity was generally higher for unpurged than purged wells (Figure 8) for both mechanically-drilled and manually-dug wells in the study area. Although generally highly variable, turbidity was highest in March and lowest in August. March is the period when the water table is lowest, also when most of surface water bodies dry up in the study area. Thus, during this period, most people fall on well water especially for drinking and other domestic purposes. It implies that well water is constant disturbed in the study area, keeping lots of particles in suspension in the water during the period. Unlike most of the other measured properties, well water turbidity in the study area was generally above both the ideal (5 ppm) and standard (15 ppm) values.



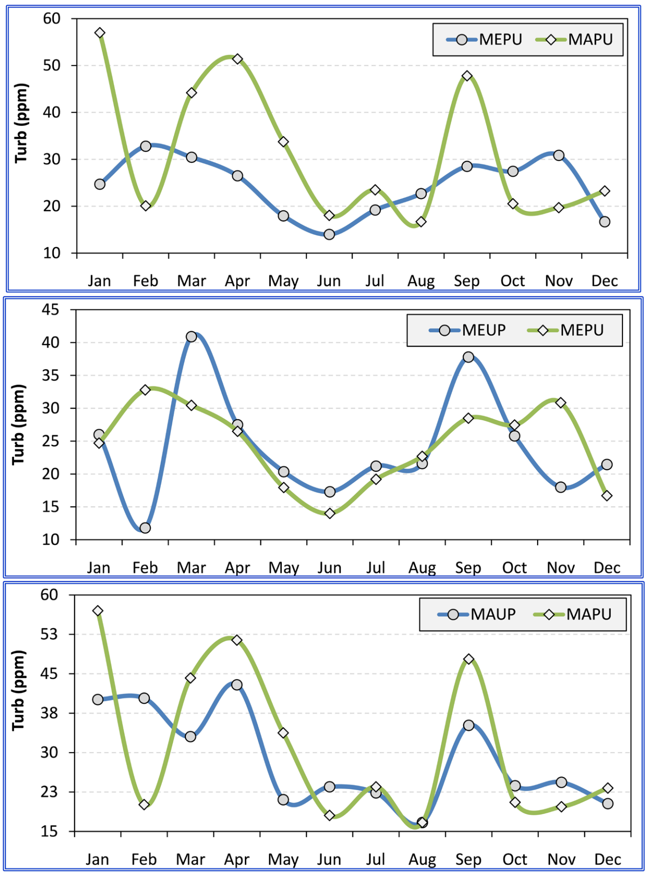


Figure 8. Time-series of Turbidity (Turb) of water before (UP) and after (PU) purging for manually-dug (MA) & mechanically-drilled (ME) wells in the study area (Ideal value = 5 ppm; Standard value = 15 ppm).

3.8. Turbidity Spread in Space

Both the highest and lowest turbidity were for manually-dug wells, with the highest value in the southeast and the lowest one in the northwest (Figure 9). This was quite unlike EC, but fairly like to TDS in terms of the degree but in spatial spread. This suggested that turbidity and TDS had more in common than EC. Also, both turbidity and TDS were within the limits of both the ideal and standard values of safe drinking water.

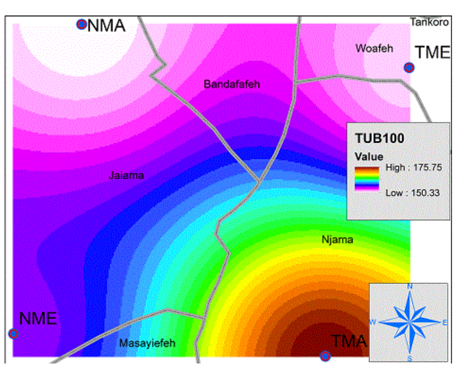


Figure 9. Spatial distribution of well water Turbidity (Turb) in the study area.

4. Discussions

4.1. Temperature

Several factors, including air temperature, can influence well water temperature. The soil formation within which well water occurs can influence well water temperature and quality, while air temperature in the study area is the highest in April and the lowest in December (data not shown). Then the well water temperature is highest in January and lowest in August. This is so because in the study area, meaning rains stop to fall in November, during which time the cold harmattan winds start to blow. During this time, there is no cooling effect of precipitation on the well water. Therefore, the temperature of the soil formation builds up; influence the temperature of the well water. The rains occur in June-September in the study area, creating a cooling effect on groundwater. Due to the cooling-effect of precipitation, well water is coolest in August, during which time rainfall in the study area is highest. There was therefore a near-inverse relationship between well water temperature and air temperature in the study area.

Temperature affects almost every property of water and therefore its quality. In the study area, well water temperature was negatively related with EC ($r = -0.63$), and turbidity ($r = -0.02$) but not with TDS ($r = 0.12$). Generally, solid dissolution in water increases with increasing temperature and vice versa. Pathogens survive in water within a given range of temperature, meaning that temperature indirectly affects water quality [25]. Well water temperature in the study area was highest for mechanically driven well, meaning that the water quality was potentially low for this type of wells in the study area. Well water temperature in the study area was within 27.13˚C - 29.54˚C, well within the ideal-standard values of water temperature of 20˚C - 30˚C. In a study in another district in Sierra Leone, [26] observed a similar trend in well water temperature.

4.2. Total Dissolved Solids

The rains fall during the period of high air temperature in the study area. This creates some warming effect of the soil formation. This in turn increases capacity of the percolating rainwater to dissolve and carry more soil minerals and particles into the well water. In the study area, TDS was highest in October (just after the pick rainy month of August) and lowest in February (among the driest months in the region). Then rains bring a significant amount of water and therefore dissolve or wash into the water a huge amount of soil minerals/particles [27]. Also, the acidic nature of the rainwater (well water pH = 5.92) makes it possible for the percolating water to dissolve and carry a lot of soil minerals/particles. As shallow wells are fist affected by the percolating rainwater, the hand-dug wells (which are relatively shallow) were more affected by the TDS surge in the rainy season. However, the 35.99 - 80.45 ppm of TDS concentration of the well water in the study area was within the ideal-standard range of 500 - 1000 ppm. Based on the TDS (and assuming that the TDS did not contain noxious substances), the well water was still good and safe for drinking. However, no analysis was done on the makeup of the TDS to see whether it was free of heavy metals and other toxic materials. Clearing this limitation will make the recommendation more conclusive.

4.3. Electrical Conductivity

Electricity conductivity is another measure of water quality. In this study, EC was negatively related with temperature (r = −0.63) and positively with TDS (r = 0.86), but the correlation was not particularly strong for temperature. This suggested that temperature was not a dominant factor of well water EC in the study area. The composition of TDS (a factor of the soil makeup and other externalities) could also determine the strength of well water EC. In this study, however, well water EC (97.65 - 231.22 μS/cm) was above the ideal value (50 μS/cm) but within the standard value (400 μS/cm). It implied that the well water was somehow good for drinking by measure of the standard value of EC.

Based on the spatial plot, well water EC in the study area increased with well depth, stronger for boreholes than hand-dug wells. Of course, this again confirmed the effect of temperature on well water EC, in that the deep well water had lower temperature than the shallow well water. From the perspective of EC and temperature, it could be stated that high temperature in electrical conductivity suggests high resistivity to electricity flow. In other words, high temperature reduces flow of electric current, hence the inverse relation between EC and temperature. The above case suggests that well water with low temperature could be better than one with high temperature [26].

Again, however, if the well water EC is driven by TDS components from external impurities (rather than the internal geological makeup), then it makes the state of the water quality more difficult to assess. TDS contains minerals and organic molecules that provide benefits such as nutrients or poses risks such as contaminants of toxic metal and organic pollutant types [28]. This suggests that TDS could be more challenging if it is ladened with heavy metals and other toxic materials. This will make TDS more potent, even if EC and TDS concentration are well within the limits of the ideal values. It points to the need for further analysis of the makeup of the TDS of the well water, which was a limitation in this study.

4.4. Turbidity

Turbidity was both highest and lowest for mechanically-driven wells in the study area. However, it is good to note that both well types (machine-driven and hand-dug) were not hydrologically different as they were all seated in the surface aquifer. The depth range of the machine-driven wells was 7.99 - 11.49 m and that of the hand-dug ones was 4.36 - 5.18 m. Thus, the differences in well water quality properties measured in this study were largely due to the differences in specific makeup of the soil or in specifics uses of the water well, including mode of getting the water from the well. Generally, well water turbidity in the study area dropped with the coming of the rains, hitting the lowest level in August. The well water turbidity was by far much higher (150.33 - 175.55 ppm) than the range of the ideal-standard value of 5 - 15 ppm [12]. This was a major concern for all who used the well water for drinking in the study area.

Turbidity, like TDS, could also be caused by pathogens and toxic substances, which were analyzed for in this study. Also because TDS, turbidity and pH (not shown) increased with the coming of the rains [27], it was a strong indication of the occurrence of acid rain in the study area. The fall of acid rain substantially changed the makeup and therefore the quality of the well water in the study area. This suggested that air emissions as a result of mining activities affected rainwater quality (acidity), which in turn made season a key well water quality factor in the study area.

4.5. Water Property Correlativity

The correlativities of the measured water properties in the study are shown in **Table 1**, with highest of r = 0.86 (for EC and TDS) and the next value of r = 0.63 (for EC and water temperature). The lowest correlations were for TDS and turbidity (r = 0.02) and turbidity and well water temperature (r = −0.02). This showed that while TDS strongly affected well water EC, well water temperature also had a strong effect on well water EC. It suggested that well water EC in the study area was driven by both well water temperature and TDS. It also showed that while the relationship was negative for well water temperature, it was positive for well water TDS. Explaining interactive effects of the properties beyond the correlativity would require analysis of the makeup of well water TDS, which was not covered in this study. Other studies such as [29] have attempted to explain similar interactive relationships amount water properties, also see [30] and [31].

Table 1. List of correlativity of measured water quality properties in the study area.

r	WTEM	EC	TDS	TURB
WTEM	1.00	−0.63	0.12	−0.02
EC	−0.63	1.00	0.86	0.41
TDS	0.12	0.86	1.00	0.02
TURB	−0.02	0.41	0.02	1.00

5. Conclusions

Based on the selected water properties investigated in this study, well water in the key mining chiefdoms in Kono District were generally good for drinking. The key property of concern was turbidity, which occurred in concentrations above the values acceptable under both ideal and standard conditions. The study further showed that temperature influenced well water properties, which was the highest for EC. Hand-dug (shallow) wells were more or less in the same aquifer system with machine-driven (deep) wells, hence the similar well water quality.

Rainfall in the region was potentially acidic, affecting the properties of shallow well water more than deep well water. Also, the well water quality deteriorated with time over the rainy season, likely due to the acidic nature of the rainwater. It then suggested that although rainfall was the main source of groundwater replenishment, it also posed risk for well water quality in the region.

There are scores of measurable water properties (physical, chemical and biological) that should be comprehensively analyzed for a full understanding of portable water quality. In this study, not even all the physical properties were covered due to funding constraints. For a detailed understanding of well water quality in the study area, further studies are needed on the broader water quality properties/parameters; including the compositions of rainwater and particularly well water TDS. These studies should cover non-mining chiefdoms as well, to make it possible for comparisons and isolation of the effects of mining on the water (rainwater and groundwater) systems in the region. Stakeholders and decision-makers should also support confirmation studies to guide the development of policies to keep well water quality in compliance with drinking water standards in Sierra Leone and elsewhere.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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