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Mary Kisaka and Rubhera Mato

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RESEARCH ARTICLE

Spatial Variation of Ground water Quality Parameters and its Suitability for Drinking at Makutopora Aquifer, Dodoma Municipality, Tanzania

Mary Kisaka[1,*] Rubhera Mato [2]

[1] School of Environmental Science and Technology, P.O. Box 11090, The University of Dodoma, Dodoma TANZANIA. [2] School of Environmental Science and Technology, P.O. Box 35176, Ardhi University, Dar es Salaam TANZANIA.

*Corresponding author
Tel : +255 76983 8539
E-mail : maykskO6@yahoo.com

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Abstract

A study was conducted to benchmark the ground water quality parameters and its spatial variation from Makutopora boreholes which are found 32 km from Dodoma town. A total of 90 samples (from both deep and shallow wells) were collected and analyzed for various quality parameters. The analysis results were interpolated using statistics and Inverse Distance Weighting tool in a Geographical Information System (GIS) environment to determine their spatial variation. The results indicated that all samples were within the permissible Tanzanian standards, except for two unused production boreholes which showed higher levels of total hardness, Electrical conductivity and total dissolved solids. However, gross pollution was found in community shallow wells of Chihanga and Veyula that showed high levels of nitrate (78-82 mg/l), Manganese (1.05 mg/l), low pH (5.98) and E. coli. (52/100 ml). It is quite clear from this study that the ground water supplied to Dodoma is still meeting the set drinking water standards in Tanzania although aquifer deterioration was noticed which demands an urgent innovative ground water management. The results obtained in this study will therefore be helpful for future monitoring and sustainable ground water quality management in the Makutopora sub basin.

Keywords: GIS, Sustainable Ground Water Management, Borehole, Electrical conductivity, Pollution

Introduction

Water is the one of the naturally occurring essential requirement of all life supporting activities (Alauddin, 2014). More than 70% of the globe is being covered by water but, only its fraction fits for domestic uses (WHO, 2008). Ground water resources play an important role in meeting demands on water supply due to insufficient surface water sources as well as its relatively low susceptibility to pollution when compared to surface water (Arzu & Fatma, 2013). Water said to be safe for drinking when it is free of pathogens, poisonous substances and excessive amounts of mineral and organic matter (Sabo & Christopher, 2014). The quality of it determined by its physical, chemical and biological parameters (Barut, 2015; Tikle et al., 2012). It is reported that millions of people especially young children tends to die every year due to water related diseases and mostly in developed countries (Sossou et al., 2016 and Saxena et al., 2015).

Ground water quality and quantity has noticeably been deteriorated in many countries due to overexploitation (Gazioğlu, et al., 2010, 2014; Venkatramanan et al., 2016). A report by US EPA (2000) explained that ground water contamination can occur as localized plumes emanating from specific sources such as leaking underground storage tanks, spills, landfills, waste lagoons, and/or industrial facilities. Rapid population growth has increased demand for essential services including accessibility of potable water (Wahome et al., 2014). Also Increasing human population, development, urbanization, coupled with changing land use and agricultural patterns may lead to increased releases of pollutants to shallow ground water aquifer which impair the quality of water (Mishra et al., 2014). Hence by

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studying the aquifer, hydraulic properties and also hyrdochemical characteristics of water is very crucial for ground water planning and management (Nosrat & Asghar, 2010).

In Tanzania ground water is a major source of water for many areas and actually the most viable alternative supplement in the central and northern parts of the country i.e the drought prone regions of Dodoma, Singida, Shinyanga, Tabora, Mwanza, Mara, Arusha, Coast and Southern Kilimanjaro, which is used for domestic water supply and to less extent for irrigation. Although ground water quality in Tanzania is considered potentially good and acceptable for most use faces problems such as, salinity, high fluoride, hardness, corrosion and nitrate (Mato & Mjwahuzi, 2010). Dodoma region is classified as semi desert area where surface water resources are limited, with the result, ground water from Makutopora sub basin has become a major source of supply to the population of Dodoma municipality. A study by the Japan-Tanzania Joint Research documented that, there were initial problems with water quality of the well field due to human settlement, farming, and livestock grazing. These activities raised the levels of nitrate to 144 mg/l in one of the borehole which is above the recommended WHO and Tanzanian Drinking Water Standards (Shindo, 1989, 1990, 1991). Such nitrate levels indicate serious aquifer degradation.

Although the Tanzania Government shifted human settlement from the basin in 2007, there has not been comprehensive assessment of the ground water quality recuperation, such information is necessary to determine long term ground water sustainability for the fast growing Dodoma Town and the adjacent villages within the Makutupora basin. Therefore this study aimed to assess ground water quality parameters and its suitability for drinking in Dodoma region.

Materials and Methods

Descriptions of the study area

Makutupora sub-basin is located in semi-arid central Tanzania in Dodoma region which is 32 km north of Dodoma town (Figure 1). According to the National Census of 2012 Dodoma has the population of 2,083,588 (URT, 2015).The current and future water requirement is likely to increase considerably due to the increased population (by birth and migration). Hydrologically makutpora lies within the Wami sub-basin (Kinyasungwe sub-catchment) in the Wami-Ruvu Water Basin at latitude 5º 36’59”S and 6º 14’50”S and longitude 35º 36’36”E and 37º 01’54”E.

The geology around sub basin is consist mostly crystalline basement rocks which are granites and gneiss of Dodoma system of Precambrian. Also it includes granite, hornblende, and biotitegneiss with development of foliation, pink pegmatite and basic dike. The rocks are highly fractured and intensively weathered, shows three pronounced faults, Mlemu (major) running NE-SW, Kitope (minor) crossing Mlemu at acute angle in the middle of the basin trending NNE-SSW and Kilungule fault (minor) trend parallel to Kitope with the offset of 10 km in the west. The area principally has Mountains and hills, uplands and lowlands range in scale from massive mountain bocks to small isolated inserbergs the most conspicuous mountain block (chenene hills with altitude up to 2,000 m (Shindo, 1989). A major part of the area is covered by soil and other detrital deposits which have been derived from granitic rocks which are generally silty and sandy. Superficial deposits consist of mbuga, clay, sand, and gravel and concretion limestone. The principal soil types are white sandy soil, red loam soil, and black clay soil (Shindo, 1991).

Meteorologically, the area under study is characterized by wet and dry season, has an average annual rainfall of 614 mm. The rainfall is unreliable and very variable in time and space even within the basin itself, resulting in insignificance or no recharge to the basin. The estimated recharge flux 22 ranges between 1 to 2% of the annual rainfall equal to 5 to 12 mm/yr (Rwebugisa, 2008). The average monthly maximum temperature for the period of ten years (2001-2011) is 31.4 ºC which occurs around November while the minimum temperature is 14.1 ºC which observed around July.

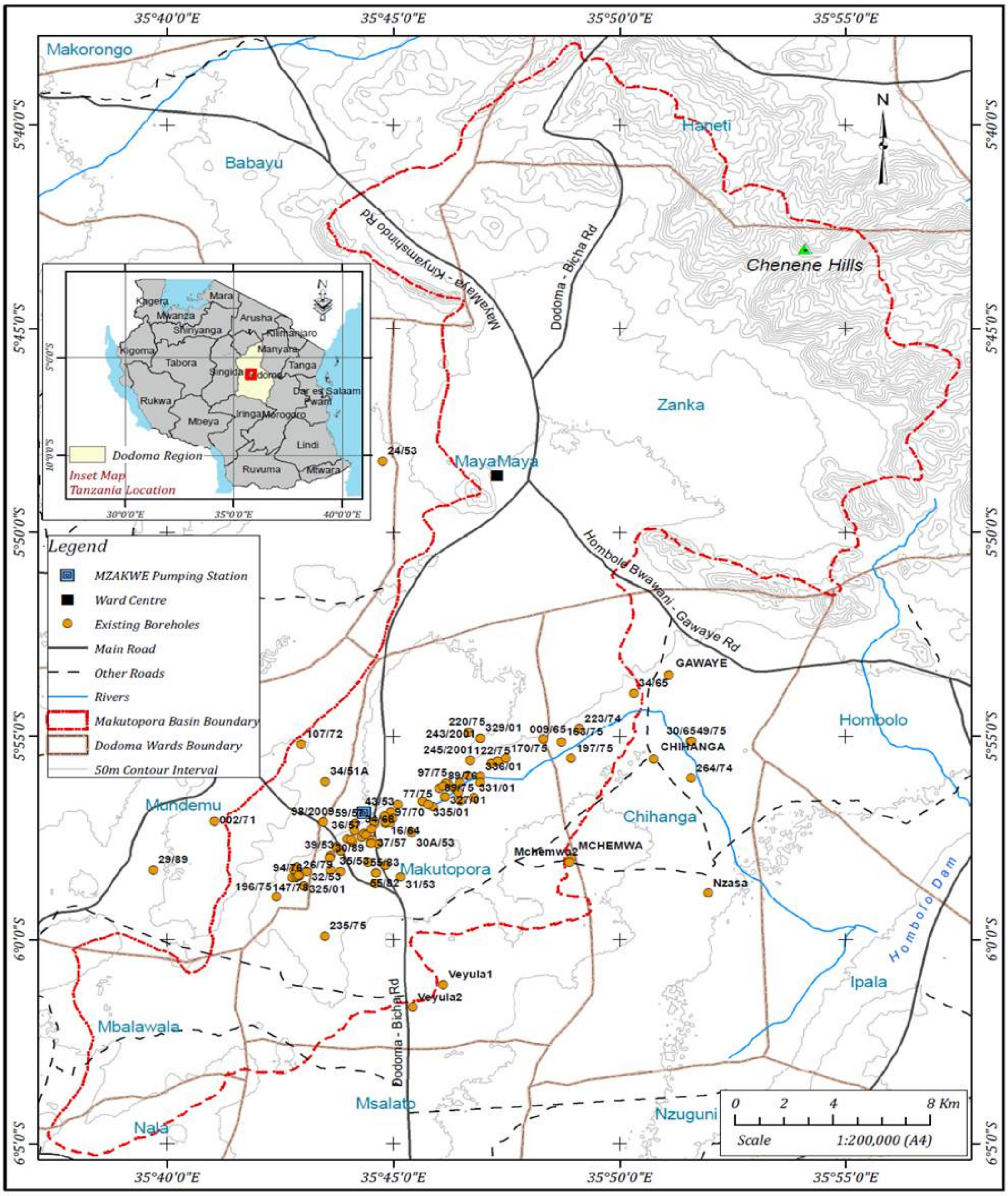

Figure 1: Makutopora location Map (Source: Dodoma water resource office 1996)

Sample collection

In this study a total of 90 ground water samples from 30 different sites were collected, of which 25 samples were collected from the well field, four (4) samples from four nearby villages (Gawaye, Mchemwa, Nzasa, and Veyula) and one (1) from shallow well at Chihanga village. The sampling process was conducted three times, October, November 2012 and January 2013.A numbers of boreholes were selected depending on the sample availability.

Ground water samples were analyzed for different parameters, physical (pH, Electrical conductivity, Salinity, Turbidity), chemical (calcium, magnesium, sodium, potassium, chloride, bicarbonate, sulfate, nitrate, nitrite, iron, phosphate and total alkalinity) and microbiological (Fecal and Total coliform) parameters which were analyzed immediately after sampling. All the results were compared with standard limits recommended by Tanzanian and World Health Organization (Table 2). This was achieved using the standard methods as suggested by the American Public Health Association of 1995 (Table1).

Statistical analysis

Ground water Quality Variation

Spatial variations in ground water quality and its suitability in the Makutopora aquifer have been studied using geographic information system (GIS) technique. Spatial data of each borehole were imported into GIS software and combined with attribute data showing ground water quality parameters. Each ground water parameter was interpolated using IDW spatial analyst tool to produce GIS layer that shows spatial variation in ground water quality over the entire area. Such GIS layers were standardized to a common scale of nine (9) ranging from one to nine to show ground water suitability basing on individual parameters. Finally, all standardized GIS layers of such ground water quality parameters were combined using weighted overlay spatial analyst tool to determine overall ground water suitability.

Table 1: Showing Ground water parameters analyzed and the method adopted

Analysis	Method/Instruments
PH	Digital pH meter
Alkalinity	Digital Titrator
Electrical conductivity (EC)	Digital conductivity meter
Turbidity	DR/890 Calorimeter
Total hardness (TH) & calcium Hardiness (CaH)	Digital titration
Sodium (Na), Potassium(k)& magnesium (Mg)	Atomic absorption spectrophotometer
Iron (Fe)	Spectrophotometer
Chloride (Cl)	Spectrophotometer
Sulphate (SO_4)	Spectrophotometer
Phosphate (PO_4)	Spectrophotometer
Nitrate (NO_3)	Spectrophotometer
Manganese (Mn)	Spectrophotometer
Ammonium -Nitrogen (NH_3-N)	Spectrophotometer
Nitrite-Nitrogen ($N0_2$-N)	Spectrophotometer
Fluoride (F)	Iron electrode
Faecal & Total coliforms	Membrane filtration technique

Test for spatial pattern

The Geary's C statistic was used to test for a significant spatial pattern (spatial autocorrelation) among the observed ground water quality parameters, Geary's C is defined as

$$C = \frac{(N-1)\sum_i \sum_j w_{ij}(X_i - X_j)^2}{2W\sum_i (X_i - \bar{X})^2}$$

Where N is the number of spatial units indexed by i and j; X is the variable of interest; $\overline{X}$ is the mean of X; w_{ij} is a matrix of spatial weights; and W is the sum of all w_{ij} .

The value of Geary's C lies between 0 and 2. 1 means no spatial autocorrelation. Values lower than 1 demonstrate increasing positive spatial autocorrelation, whilst values higher than 1 illustrate increasing negative spatial autocorrelation. This test was performed using SAS software (version 9.4), with 5% level of significance.

Results

Descriptive statistics

The various physico-chemical and bacteriological characteristics were analysed for ground water from 30 different sampling stations. The details of the results were summarized for their Mean ± Standard deviation in Table (2 and 3).

Cations: The concentrations of the major cations namely sodium, potassium, calcium, magnesium and manganese ranged from 27.75 to 684.47, 3.15 to 241.40, 67.33 to 509.33, 3.23 to 88.78 and 0.1 to 2.85 mg/l with a mean of 149.44, 13.79, 156.06, 33.80 and 0.34 mg/l respectively

Anions: The anions, chloride, sulphate, phosphate, nitrate, and nitrite had the following range of concentrations: 4.90 to 178.75, 1 to 335, 0.05 to 0.76, 1.33 to 82.78 and 0.05 to 7.75 with mean values of 23.47, 55.22, 0.28, 16.29 and 0.46, mg/l respectively.

Table 2: Summary statistics of the analytical data of the physical and biological parameters in the Makutopora aquifer (N=30)

Variable	Mean ± SD	Min.	Max.	Tanzanian Standards	WHO Standards
Temperature (^{0}c)	27.32 ± 0.56	26.47	28.43	Nm	Nm
pH	7.23 ± 0.50	5.98	7.91	6.5-9.2	9.2
Conductivity (µs/cm)	1030.90 ± 778.90	366.00	4260.00	Nm	1000
Total dissolved solid (mg/l)	503.46 ± 382.08	179.67	2083.67	Nm	1000
Salinity (mg/l)	0.52 ± 0.41	0.17	2.23	Nm	Nm
Turbidity (FAU)	39.67 ± 68.06	1.00	288.50	5-25	5
Faecal coliform/100ml	14.99 ± 14.49	1.00	52.00	0	0
Total coliform/100ml	56.33 ± 53.52	4.33	256.67	0	0
Nm-Not mentioned					

Trace metals: Iron concentrations in the ground water ranged from 0.01 to 2.32 mg/l with mean value of 0.31 mg/l

Microbiological parameters: the bacteriological analyses showed total coliform ranged from 4.33 to 256.67 counts per 100 with mean value of. 56.33 while faecal coliform ranged between 1 to 52 with a mean value 14.99.

Test for spatial pattern

The results of Geary's C statistic revealed that, there was significantly strong evidence of a positive spatial pattern in Total dissolved solid (C=0.2823, p < 0.0001), Salinity (C=0.2719, p<0.0001), EC (C=0.2796, p<0.0001), Turbidity (C=0.3202,p=0.0011),Total hardness (C=0.2963, p<0.0001), Cl (C=0.2796,p.<0.0001), NH3-N (C=0.3152,p=0.0001), Fe2+ (C= 1.0134,p=0.0048), SO42- (C= 0.5097, p=0.0056), Na (C=0.323788,p=0.0001), K (C=0.206,p<0.0001), Ca (C= 0.3348,p= 0.0002) Mg (C=0.4683,p=0.0027),Mn (C=0.44521,p= 0.0073), and Total Alkalinity (C=0.2744,p<0.0001). However, the spatial pattern of pH (p=0.7726), temperature (p=0.5446), NO2-N (p=0.9397), NO3_N (p=0.8961), NO3- (p=0.8971), F (p=0.7619), Fecal coliform (p=0.4805) and Total coliform (p=0.7749) were not statistically significant. The details of Geary's C statistic for spatial autocorrelations of physical –chemical and biological parameters are shown in table (4).

Table 3: Summary statistics of the analytical data of the chemical parameters in the Makutopora aquifer (N=30)

Parameters	Mean ± SD	Minimum	Maximum	Tanzanian Standards	WHO Standards
Total Alkalinity (mg/l)	216.81 ± 200.64	40.67	1207.67	600	500
Total Hardness (mg/l)	293.26 ± 169.63	135.33	975.33	500-600	500
Cl-(mg/l)	23.47 ± 31.75	4.90	178.75	200-800	250
Fe^{2+}	0.31 ± 0.53	0.01	2.32	0.3-1.0	0.3
SO_4^{2-}(mg/l)	55.22 ± 60.97	1.00	335.00	200-600	250
PO_4-(mg/l)	0.28 ± 0.16	0.05	0.76	Nm	Nm
F-(mg/l)	1.06 ± 0.27	0.50	1.55	1.5-4.0	1.5
K-(mg/l)	13.79 ± 43.24	3.15	241.40	Nm	Nm
Na-(mg/l)	149.44 ± 109.76	27.75	684.47	Nm	200
Ca-(mg/l)	156.06 ± 85.02	67.33	509.33	75-300	200
Mg-(mg/l)	33.80 ± 18.45	3.23	88.78	10-100	150
Mn-(mg/l)	0.34 ± 0.62	0.10	2.85	0.1-0.5	0.1
NO_3-(mg/l)	16.29 ± 17.68	1.33	82.78	10-75	50
NH_3-N(mg/l)	1.78 ± 4.63	0.13	24.10	Nm	Nm
NO2-N(mg/l)	0.46 ± 1.41	0.05	7.75	Nm	3
NO_3-N(mg/l)	3.68 ± 3.99	0.30	18.70	Nm	Nm
Nm-Not mentioned					

Hydro chemical Facies

The chemical laboratory results (Cations and anions results) for all sampled points, required by piper diagram were imported into AQUACHEM V 2011 software.

Results showed that the ground water in the basin is highly mineralized with calcium, sodium and magnesium as cation and bicarbonate as anion. However bicarbonate was observed as dominant anion while calcium was the dominant cation, indicating that the water type of the basin is CaHCO3 (Figure2).

Discussion and Conclusion

Physico-chemical parameters and the ground water quality

The pH: Indicates the acidic or alkaline material present in the water (Kumar & Kumar, 2013) The pH of the ground water samples in the study area ranges from 5.98 to 7.91 of which indicates that generally the ground water in the aquifer is slightly alkaline in nature, except water from Chihanga village which is weakly acidic. The minimum value of pH at Chihanga could be due to the geology of the aquifer which has few carbonate rocks (example sandstones, metamorphic granitic schists and gneisses; volcanic rocks, etc.) indicating acidic nature. Figure 3a shows how suitability varies within the basin, in the eastern and western side suitability is very low compared to the central party of the study area.

Turbidity: The turbidity value for ground water ranged from 1 to 288.50 FAU with an average value of 39.67 FAU.The maximum value which is above the Tanzanian permissible limit of 25FAU observed in more than 20% of the boreholes, however the suitability observed to be low in the western side and small area in the northeast as shown in Figure 3d .This could be due to most of observation, and unused production boreholes are not sealed/coved above, hence a lot of external particles (suspended matter such as clay, silt, and fine particles of organic and inorganic matter, and other microscopic organisms) get access into.

Table 4: Geary's C statistic for spatial autocorrelation among Physical, chemical and biological parameters

Variable	Observed C	Expected C	Standard deviation	Z-Value	P-Value
Total dissolved solid	0.2823	1	0.177	-4.054	<0.0001
Salinity	0.2719	1	0.177	-4.113	<0.0001
Electical conductivity (EC)	0.2796	1	0.177	-4.069	<0.0001
pH	0.9488	1	0.177	-0.289	0.7726
Turbidity	0.3202	1	0.207	-3.277	0.0011
Temperature	0.893	1	0.177	-0.606	0.5446
Total hardiness	0.2963	1	0.177	-3.975	<0.0001
Cl^-	0.2796	1	0.177	-4.069	<0.0001
NH_3- N	0.3152	1	0.177	-3.868	0.0001
NO_2	1.0134	1	0.177	0.0757	0.9397
Fe^{2+}	0.5008	1	0.177	-2.820	0.0048
SO_4^{2-}	0.5097	1	0.177	-2.769	0.0056
Na	0.323788	1	0.177	-3.820	0.0001
K	0.206	1	0.177	-4.485	<0.0001
Ca	0.3348	1	0.177	-3.758	0.0002
Mg	0.4683	1	0.177	-3.003	0.0027
Mn	0.44521	1	0.207	-2.685	0.0073
Total Alkalinity	0.2744	1	0.177	-4.099	<0.0001
NO_3-N	0.977	1	0.177	0.13060	0.8961
NO_3^-	0.9771	1	0.177	0.12934	0.8971
F	0.946	1	0.177	-0.303	0.7619
Feacal coliform (FC)	0.8362	1	0.232	-0.706	0.4805
Total coliform (TC)	1.0506	1	0.177	0.286	0.7749

Electrical Conductivity (EC) and Total Dissolved Solids (TDS): TDS describes all solids (usually mineral salts) that are dissolved in water. The TDS and the electrical conductivity are in a close connection. The more salts are dissolved in the water; the higher is the value of the electric conductivity (Iyasele et al., 2015) in the study area EC varies with water sample and ranges between 366.00 and 4260 µS/cm. The TDS amount ranges between averages of 2083.67 mg/l maximum 179.6 mg/l minimum. Knowing that the maximum limit of EC and TDS for drinking water is prescribed as 1,000 µS/cm. all the values are within the WHO water quality standards permissible limit except for borehole 234/75 (4260 µS/cm) and 01/2009 (3130 µS/cm) which make also their suitability to be low as shown in Figure 3c. High levels of EC for boreholes 234/75 and 01/2009 is due to high concentration of TDS (1532.67 mg/l and 2083.67 mg/l respectively), the higher TDS values could be due to solubility of minerals present in the rock or soil.

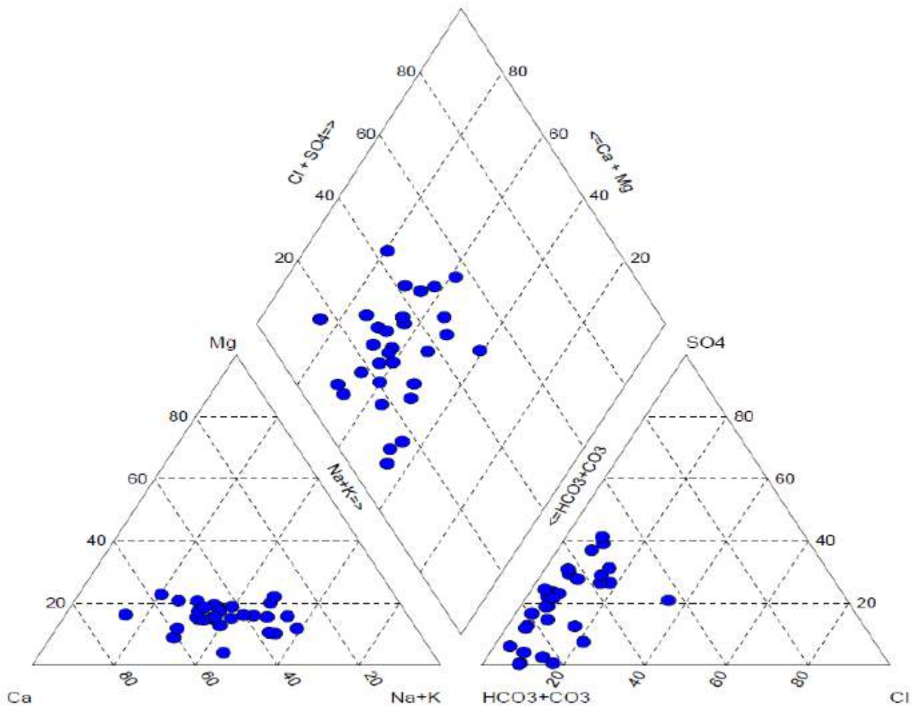

Figure 2: Piper diagram showing major ions chemistry in the groundwater at the study area

Nitrate content: Results from the added nitrogenous fertilizers, decay of dead plants and animals, animal urines etc (Tikle et al., 2012). They are all oxidised to nitrate by natural process and hence nitrogen is present in the form of nitrate (Ramakrishana & Ranibai, 2015).Regarding to all samples taken from the production boreholes within the protected Makutopora aquifer, nitrate concentrations ranged between 2.44 mg/l and 27.22 mg/l which fall within the permissible Tanzanian standards. From the observation wells the values of nitrate ranged from 1.35 mg/l and 45.08 mg/l level that is below the health guidelines, but to some extent indicate aquifer deterioration.

However water from the community wells which are outside the protected Makutopora catchment (Gawaye, Chihanga, Nzasa, Veyula and Mchemwa), most of them are found south east of the sub basin. The level of nitrate observed to range from 8.19 to 82.78 mg/l, the higher level which is above the recommended standards found at Chihanga shallow well as well as veyula village. The higher nitrate concentration at Chihanga shallow well is related to the agriculture activities which accompanied with application of fertilizer, surface runoff, animal grazing as well as poor protection of the well, and the, raised level of nitrate at veyula village could be due to vegetable cultivation activities that are taking place there.

These areas need special attention because nitrate is very dangerous for human health; it contributes to the illness known as methenglobinemia in infants (Curşeu, 2010). The responsible authorities must control or restrain all anthropogenic activities that affect the ground water quality. Figure 5g shows the nitrate concentration variation and its suitability in different site visited.

Total iron: Despite Iron and manganese being as one of the abundant elements in the earth crust, but also may result to inconvenience to users such as giving coloration or impart metallic taste to water (Zogo et al., 2010). Iron concentrations in the ground water ranged from 0.01 to 2.32 mg/l with mean value of 0.31 mg/l. Generally all bore holes fall within the Tanzanian guideline of 1 mg/l, with the exception of two observation boreholes. Suitability observed to be low in the central part and small area in the western side as shown in Figure 4l. The raise level of iron could be due to the development of rusting along the borehole casing, most of observation wells are open therefore it is easy for rusting to take place along the pipe.

Manganese: Concentrations in the ground water ranged from 0.1 to 2.85 mg/l with mean value of 0.34 mg/l. All boreholes fall within the permissible Tanzanian standards of 0.5Mg/l, except for borehole 234/75,131/75 and Chihanga shallow well as shown in Figure 3f. Manganese occurs naturally in many surface water and ground water sources and in soils that may erode into these waters (WHO, 2004). However, human activities are also responsible for much of the manganese contamination in water in some areas.

Total alkalinity (TA): Total alkalinity concentrations in the ground water ranged from 41mg/l to 1208 mg/l with mean value of 217 mg/l. Therefore the suitability observed to be much lower in the western side and high in the eastern side as shown in Figure 3b the high alkalinity in the study area is increased due to the action of carbonates on the basic materials in the soil.

Total Hardness (TH): Ranged from 135 mg/l to 975 mg/l with the average of 293 mg/l .30% of ground water samples analyzed exceed the maximum Tanzania water quality standards (600 mg/l). The suitability is low in southwest of study area while in the northern side have high suitability as shown in Figure 5m. The raised values could be due to natural accumulation of salts (calcium and magnesium, and of anions such as carbonate, chloride and sulfate) contacting with soil.

Chloride: Chloride in natural water may results from agricultural activities, industries and chloride rich rocks (Ramakrishana & Ranibai, 2015). Chloride concentration in the study area ranged from 4.9 mg/l to 178 mg/l with an average of 24 mg/l. The results obtained shows that all the sampling stations are well within the permissible limit of 800 mg/l guided by Tanzanian guidelines for drinking water quality. Figure 3h shows chloride suitability in the basin.

Sulphate (SO42-): The sulphate ion is one of the important anion present in natural water which produces catharsis, dehydration and gastrointestinal irritation effect upon human beings when it is present in excess (Sarala & Ravi, 2012). Concentration in the study area ranged from 1 mg/l to 335 mg/l with an average of 55 mg/l. Results showed that the values from the study area are all within the permissible limit of 600 mg/l guided by Tanzanian standards for drinking water purpose. Sulphate may come into ground water by industrial or anthropogenic additions in the form of Sulphate fertilizers. Figure 4k shows sulphate suitability within the basin.

Microbiology and the Ground water quality

Microbiological contamination observed to be the microorganisms that could originate from different sources such as human or animal excreta, wastewater, landfills, or wastewater treatment stations, (Mostafa et al., 2014) The bacteriological analyses showed total coliform range of 4.33 to 256.67 counts per 100 with mean value of 58.52 while the Faecal coliforms ranged between 1 to 52 with a mean value of 11.08. WHO and Tanzanian safety guideline value for both faecal and total coliform is zero (0) counts per 100 ml. However suitability observed to be low in the observation, unused production boreholes and some of the wells from the village, all are found in the eastern side and small area in the central part of the basin as shown in Figure 5o and 5p.

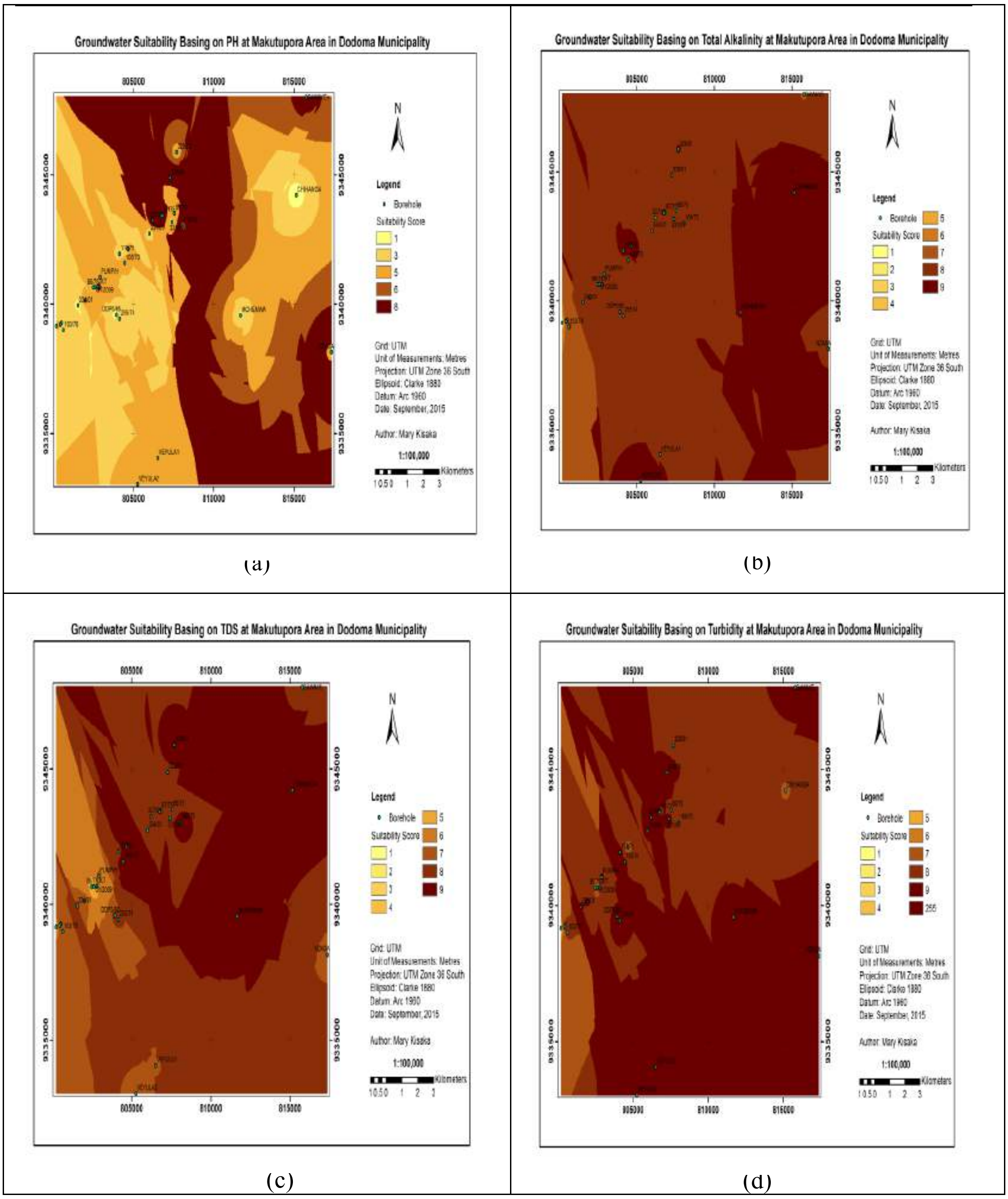

Figure 2: a, b,c & d, Showing Ground water suitability basing on pH, Total alkalinity, TDS & turbidity at the Makutopora basin

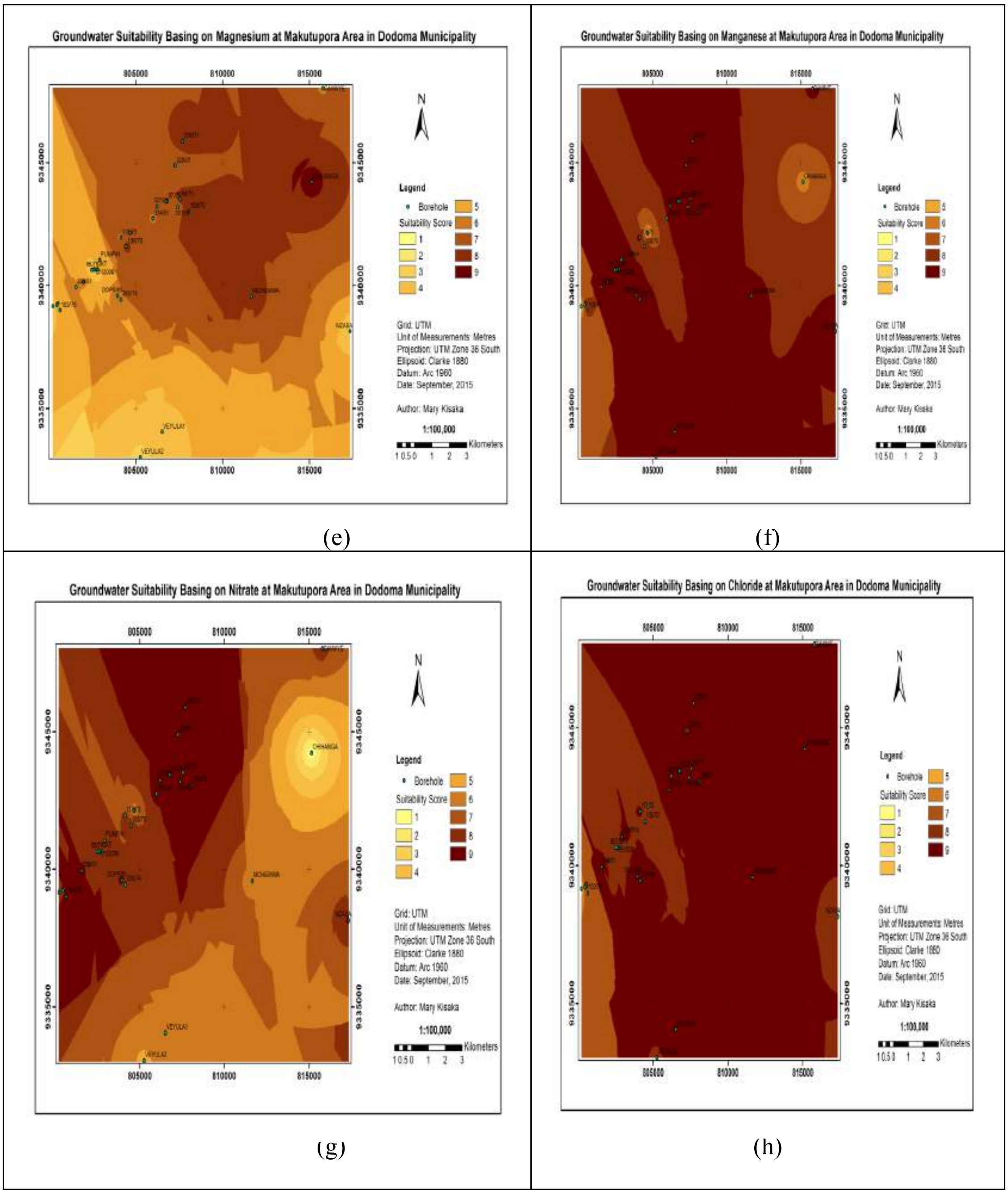

Figure 3: e,f,g &h, Showing Ground water suitability basing on Magnesium, Manganese, nitrate & chloride at Makutopora basin.

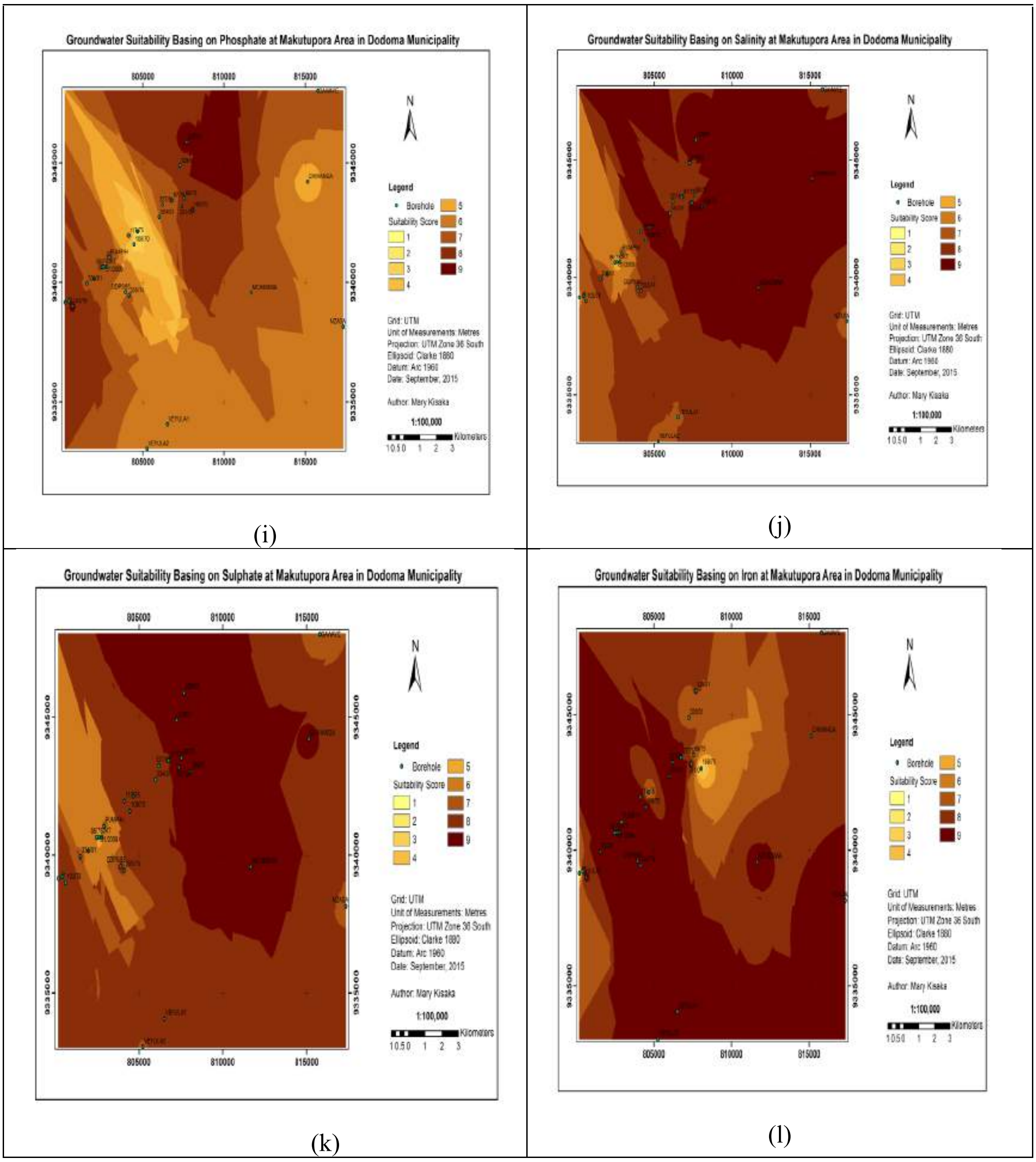

Figure 2: i, j, k & l, Showing Ground water suitability basing on phosphate, salinity, sulphate and iron at Makutopora basin

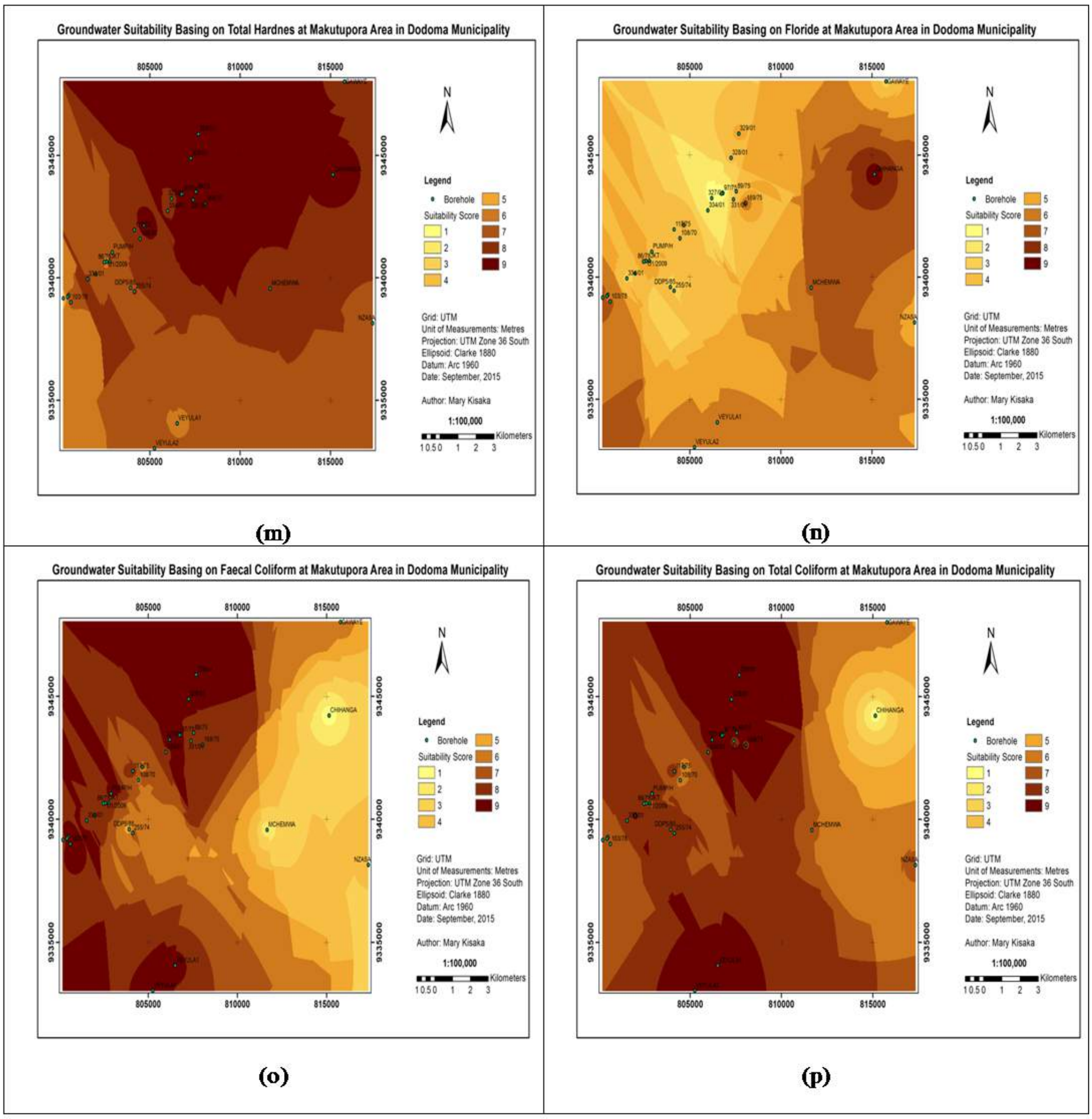

Figure 5: m,n,o & p, Showing ground water suitability basing on total hardness, fluoride, feacal and total coliform at Makutupora basin.

The presence of faecal and total coliform observed could be due to the reason that most of these boreholes are not sealed above, it's easily for these bacteria to act upon, improper sealing of the space between the well casing and the borehole, , and poor well seals or caps can allow sewage, surface water, or insects to carry coliform bacteria into the well. Therefore, the presences of the pit latrines, animal grazing, run off from agricultural land and poor management of the wells especially around the villages might have affected the quality of water in the aquifer.

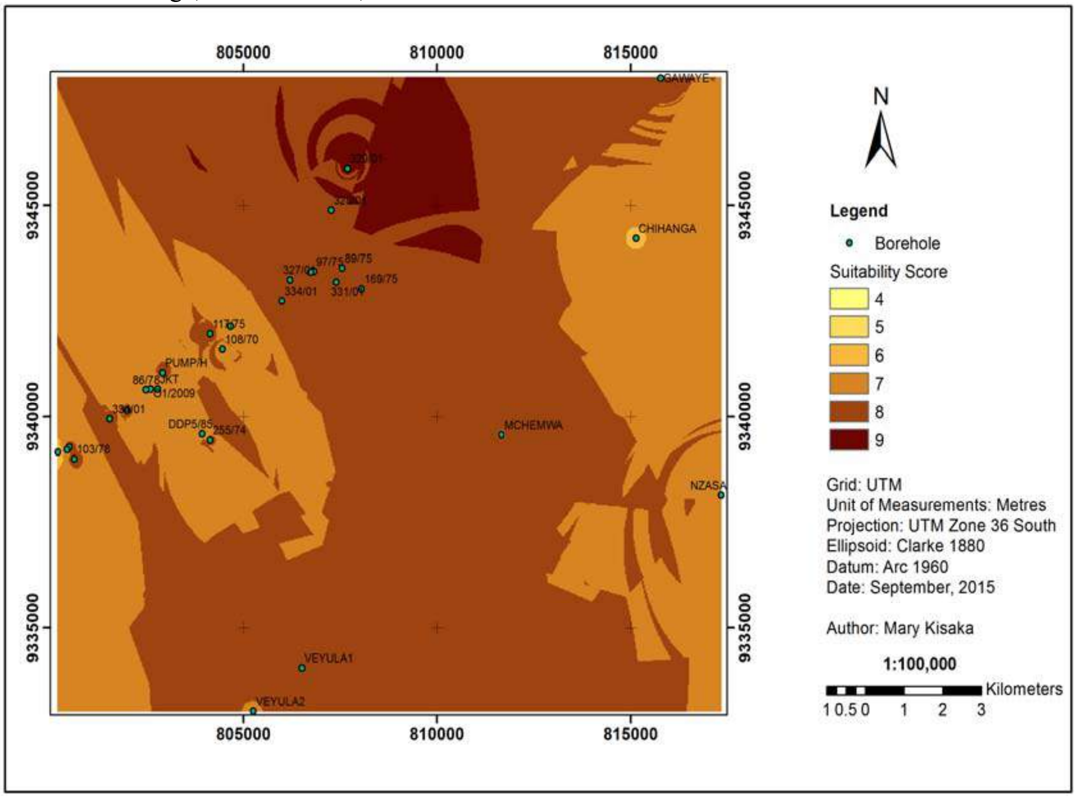

Figure 6: Showing the overall ground water suitability at Makutopora area

Overall Ground water suitability

Based on laboratory and GIS analysis, the suitability of ground water varies from one place to another within the basin. Generally, as observed in Figure 6 ground water overall suitability score ranges from 4 to 9 within the areas of study. Area with low suitability score indicates that the water is less suitable while those with large score indicate the water is more suitable. The overall ground water suitability is low in the western and eastern part of the study area when compared to the central part of the study area stretched from the southern to northern part. A small area within the central strip in the northern part of the study area is characterized with very high ground water suitability score.

Conclusively, Ground water quality in and around Makutopora aquifer has been analyzed in the present work. The concentration of physiochemical and biological constituents in the water samples were compared with the WHO and Tanzanian Standards to know the suitability of water. The ground water in the aquifer is slightly alkaline in nature, except water from Chihanga village which is weakly acidic. EC and TDS observed to be high in two boreholes (234/75 and 01/2009). 30 % of ground water samples analyzed for total hardness exceed the maximum Tanzania water quality standards. Manganese observed to be higher in borehole 234/75 and 131/75. Well Interpretation of hydrochemical analysis reveals that the type of ground water in study area is CaHCO3.

Generally, water samples from various method analysed indicated that ground water in the study area is suitable for drinking except in some areas as shown in Figure 6. Chihanga shallow well observed to be more polluted in terms of various parameters analyzed, therefore the government/responsible authority should take the immediate measures such as drilling another deep well, proper maintenance of the present well so as to save the health status of the present, and the coming generation. Although all human activities are prohibited at the Makutopora sub basin, still there is illegal grazing taking place there, therefore the present rules and regulation should be enforced accordingly to avoid the aquifer pollution problems.

Since the process of remediating the already contaminated ground water is much expensive, time consuming and sometimes very costful, it's obviously that prevention always is better than cure. For this purpose, spatial distribution and ground water suitability maps must be produced every now and then for purpose of monitoring and managing strategies of ground water quality.

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Author's contributions
The authors, Professor Rubhera Mato contributed to the supervision of the work, guidance professional /expert advice, proof reading, and correction of the manuscript and Mary Kisaka contributed to all steps leading to the production of this manuscript; Initial research preparation, data collection, data analysis and manuscript writing.

Competing interest
The author's declare that they have no competing conflict of interest.

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