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RESEARCH ARTICLE

RATIONAL INTEGRATION OF PRINCIPAL COMPONENT ANALYSIS IN SOLICITING SPATIAL 'LANDMARK-CONTAMINANTS' OF TANZANIA GROUNDWATER

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ABSTRACT

Background: Regional landscapes createnatural barriers which restrict movements of groundwater within tectonic plates. This forms a vague groundwater containment which is likely affected by evaporations, fissures, and mineral dissolution. The effect is localized in such it accumulates certain kinds of chemicals resulting in a temporal build-up of unique contaminants. The unique or landmark contaminants destabilize the physicochemical and microbial composition of groundwater, resulting in the considerable risks upon consumption of such water. **Methods:** In order to establish spatial landmark contaminants, physicochemical, heavy metals and microbial content of selected water wells from Temeke and Nkuhungu wards were analyzed according to EPA Ireland methods. It was then, followed by bivariate correlation and principal component analysis (PCA) for data analysis. **Results:** It was observed that Temeke had a strong association between electrical conductivity and hardness while Dodoma had slightly higher alkalinity, pH values and coliform counts as compared to Temeke. A perfect linear relationship between electrical conductivity and total dissolved salts was further observed in Dodoma. The first principal component was electrical conductivity followed by dissolved salts merely from Temeke. The third and last principal components were respectively alkalinity and hardness from Dodoma.PCA proved to be a perfect tool for regional solicitation of landmark contaminants. **Conclusions:** The overall findings of this study identified that slightly high alkalinity and pH values were unique properties of Nkuhungu ground water as compared to low pH values and high electrical conductivity of Temeke ground water.

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INTRODUCTION

The complexity of landscapes is a phenomenological aspect which reflects the facets of a particular heterogeneous environment. When coupling the environmental forces with terrestrial and wetland productivity, an essential component of water balance emerges. Destabilization of the hydro-geo-chemical cycles without considerable resource mobilization is a threat to the lively hood and balancing of groundwater(Raven & Priestley 2016). The misbalancing of the groundwater flowing patterns subject to tremendous exploitation of groundwater than its recharging rates merely favor leaching and seawater intrusion (Fantong *et al*. 2016).Yet, the movement of contaminated groundwater through features as well as the dissolution of bedrocks may contribute to the deterioration of groundwater quality too.

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The regional topographical, geological and aquifer confinement marginalize the preferential landmark characteristics of particular groundwater (Pittalis *et al*. 2016). A relative groundwater tastes among distinctive geographical areas constitutes ambiguity, essentially require scientific interventions. Groundwater is an inevitable choice of domestic water supply in the coastal and semi-arid regions (Aderemi *et al*. 2014; Pastore 2015; Thakur *et al*. 2016), yet this doesn't proof its safety (Boateng *et al*. 2015). The temporal recharge via seawater intrusion together with groundwater movements to unsaturated zones induce ion exchange reactions which alter the groundwater chemistry (Okeke *et al*. 2015). As groundwater serves as a subsurface receiver, nevertheless, it can store and transport contaminants, thus persuades water scarcity by interfering hygienic and agricultural practices (Namwata *et al*. 2015) (Mohamed *et al*. 2016). The retrospective and prospective case studies show that seawater intrusion scenarios exist, while descriptive case study lacks circumstantial isotopic evidence of the saline intrusion along the coastal regions of Tanzania. Similarly, experimental evidence of sources of alkalinity of water in the central Tanzania is yet clear either originating from bedrocks or otherwise. The current cross-sectional study applied correlation and PCA between two distinctive geographical regions for solicitation of salt-like-taste causing contaminants.

MATERIALS AND METHOD

Study Area: Dodoma municipal is a lowland area located at 6°10′23″S 35°44′31″E at the centre of Tanzania. It is about 486 kilometers west of Dar es Salaam, at the altitude of 1120 m. Dodoma is a semi-arid region without any permanent river, characterized by red loamy surface soil and black clay subsurface soil (UNDP and FAO 1983; Batakanwa *et al.* 2015). Some parts of Dodoma are crossed with the rift valley thus experiences faults and fracture (British Geological Survey 2000), which may serve as natural canals for transporting sodic water from northern regions. Water samples were collected from Mdalasapla, Mutulang’ondo, Muhanga and Msugale streets at Nkuhungu Ward, Dodoma.

Temeke is one among the three municipals of Dar es Salaam city, located at 6°48' S, 39°17' E. The eastern part of the city is bordered to the Indian Ocean at the coast of Africa, covered with sandy beaches. Temeke features tropical wet and dry climate, with two different rainy seasons ranging between 1,100-1900 mm. Contrarily, Dodoma receives an average of 500 mm (Mtoni *et al.* 2012; Tanzania Bureau of Statistics and Macro International 2010). Water samples were collected from Keko, Tandika and Charambe wards at Temeke municipal. These places were chosen because of high dependence on shallow wells as well as their distinct geographical locations.
Materials. A total of 31 samples each of 1 L were collected from April to May 2014 from both areas, followed by analysis of physicochemical and bacteriological parameters. Temperature, pH, TDS, Conductivity, TSS, turbidity, alkalinity, hardness, and coliforms were respectively analyzed by using a thermometer, pH meter, gravimetric, electrometric, gravimetric, turbidimeter, titrimetric and most probable number methods. All samples were handled and analyzed based on the standard procedures and guidelines as per EPA Ireland methods (EPA Ireland 2001).

RESULTS AND DISCUSSION

The *temperature* of groundwater varies with season, weather of the day and time of sample collection. Water samples were collected during morning hours of April to May which is moderate to cool weathers in Tanzania. The findings from Chart 1 shows Temeke samples had high temperature compared to Dodoma. The facts for this observation are; foremost Temeke is located at the sea level, thus experiences high temperature than Dodoma which is about 1120 m above the sea level(Wikipedia 2016). Second; Temeke is highly urbanized thus the soils experience little winds that cool groundwater compared to bare and less urbanized lands of Dodoma.

In addition Temeke soil is mainly sand which conducts heat quickly thus warm groundwater compared to Dodoma soil which is luvisols. Luvisols is characterized by subsurface clay soil which is overlain by sandloam soil (Mlingano Agricultural Research Institute, 2006). The recorded temperatures were within an atmospheric temperature range of these places (Mtoni *et al.* 2012; Rwebugisa 2008). No local existing standards for water temperature, nevertheless high water temperature reduces the amount of oxygen in the water, increase anaerobic and reaction processes, increases algal growth and this interferes with aquatic lives. The *average pH* values of Dodoma was higher than Temeke values, with most values fall within accepted TBS and WHO guideline of 6.5 - 8.5.As shown in Chart 2, water with pH less than 6.5 may be due to dissolution of minerals and toxic metals that could make water tastes bitter, metallic and corrosive. In other hand water with pH value greater than 8.5 resulted from the dissolution of carbon dioxide and soda minerals feel slippery, sodataste and tend to deposits. The high pH values of Dodoma is a common phenomenon since the lake Hombololocated in Dodoma is slightly saline and alkaline too (UNDP and FAO 1983). The corrosiveness of salty groundwater of Temeke and soda taste, as well as depositions of Dodoma groundwater, is physically observed. These properties render groundwater unfit for drinking even if boiled.

The amount *of total dissolved salts,* TDS from Temeke samples was twice higher than Dodoma as indicated in Chart 3. The most important justifications are the possibility of bottom feeders of saline waters and high rate of evaporations which concentrates ions in the groundwater. Also, the nature of Temeke soils allows maximum infiltration of surface water which washes and carry some ions with it (Walraevens *et al.* 2014).The smaller TDS values resulted from less dissociation of inorganic salts in water. Some ions which contribute into TDS include calcium, magnesium, potassium and sodium, which are all cations, and carbonates, nitrates, bicarbonates, chlorides, and sulfates, which are all anions. Increased concentrations of dissolved solids can produce hard water, so as to Temeke water. The overall TDS rating of Temeke water in Table 1 is fair to unacceptable compared to Dodoma which is excellent to fair.

The *electrical conductivity* of water in Chart 4 has a similar pattern to TDS because they both depend on the amounts of dissolved salts. That is to say, the electrical conductivity in water usually measures the ionic concentrations of water. High ionic concentration/salinity or indirectly chloride concentration causes high electrical conductivity just like Temeke findings. This is a typical indication of contamination, which renders water a salty taste (Abila *et al.* 2012; Saleem *et al.* 2012). Chart 5 and 6 clearly indicate high levels of *turbidity* and *suspended solids* in water from shallow wells located at Dodoma. These were highly contributed by bareness of Dodoma lands and strong continuous winds which carry small to large particulate organic and inorganic matters into shallow wells. Soil erosion, algae growth, silt, finely dissolved organic and inorganic material and microorganisms such as bacteria and viruses contribute into turbidity. Also, human activities like agriculture and grazing at Dodoma are common with significant contributions. Contrary to Temeke, least amounts of organic matters and winds exist. Nearly zero agriculture practices since salts water kill vegetation and absence of soil erosions due to lack of domestic animals. Suspended solids and turbidity of water change color and taste and interfere light passage and water treatments. They also favor microbes growth, thus lowers water quality (Kahler *et al.* 2016). The *alkalinity* of waters measures the concentration of carbonate and bicarbonate present in the water.

Figure 1. Tanzania Map Showing Study Areas

Table 1. Classification of Amounts of TDS/Hardness in the Water

TDS (ppm)	Rating	Hardness (ppm)	Rating
Less than 300	Excellent	Below 60 mg/L	Soft
300 - 600	Good	60 – 120 mg/L	Moderate hard
600 - 900	Fair	120 – 180 mg/L	Hard
900 - 1,200	Poor	Above 180 mg/L	Very hard
Above 1,200	Unacceptable	Concentration	Relative hardness

Table 2. Variation of Physicoparameters Between Selected Points

source	Temp. ℃		pH		TDS		EC		TSS		Turb		Alkal		Hard	
	TMK	DOM	TMK	DOM	TMK	DOM	TMK	DOM	TMK	DOM	TMK	DOM	TMK	DOM	TMK	DOM
AS/S1	36	25	6.02	7.76	570	592	857	993	10	822	0	20.9	21.95	580	26.92	155
SS/S2	30	24	5.07	6.3	1020	108.7	1810	179.4	0	226	0	40	7.98	97	78.18	52
CS/S3	32	23	7.33	6.14	1040	111.4	2240	185.3	0	25	2	37	211.47	200	101.25	63
RS/S4	32	25	5.06	6.94	610	115.1	1105	192.2	20	44	0	45	95.76	198	44.86	54
S5		24	6.2	6.24		110.5		184.4		168		49		95		56
TBS-L									500		5				500	
TBS-H									2000		25				600	

Table 3. Variation of Concentration of Selected Metals

source	Cu		Pb	
	TMK	DOM	TMK	DOM
AS/S1	0	1.922	0	0.6156
SS/S2	0.004982	0.9924	0	0.3713
CS/S3	0	0.7188	0	0.31
RS/S4	0	0.9288	0	0.105
S5	Nil	0.7813	Nil	0.1631
TBS-L	3	Nil	0.1	Nil
TBS-H	Nil	Nil	Nil	Nil

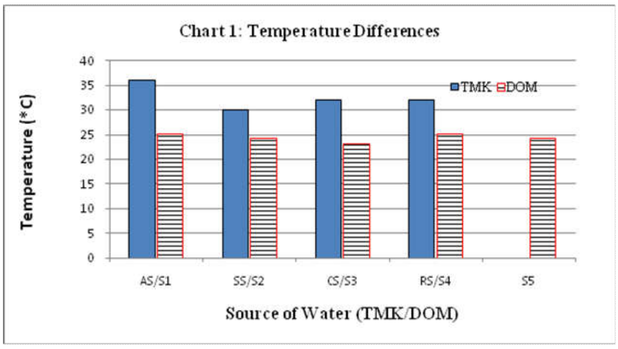


Chart 1: Temperature Differences
Temperature (*C)
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
Source of Water (TMK/DOM)

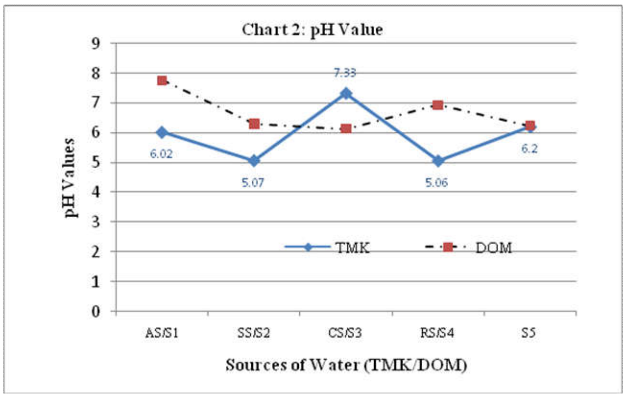


Chart 2: pH Value
pH Values
7.33
6.02
5.07
5.06
6.2
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
Sources of Water (TMK/DOM)

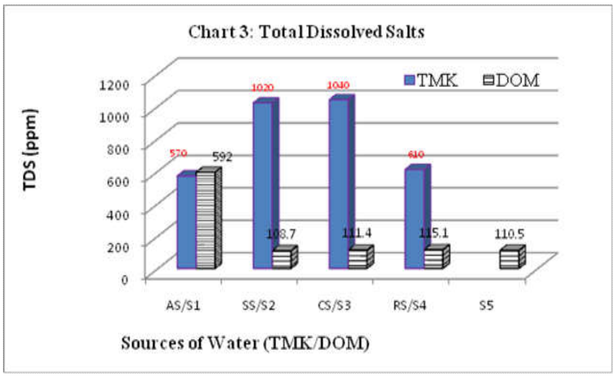


Chart 3: Total Dissolved Salts
TDS (ppm)
TMK
DOM
570
592
1020
1040
610
108.7
111.4
115.1
110.5
AS/S1
SS/S2
CS/S3
RS/S4
S5
Sources of Water (TMK/DOM)

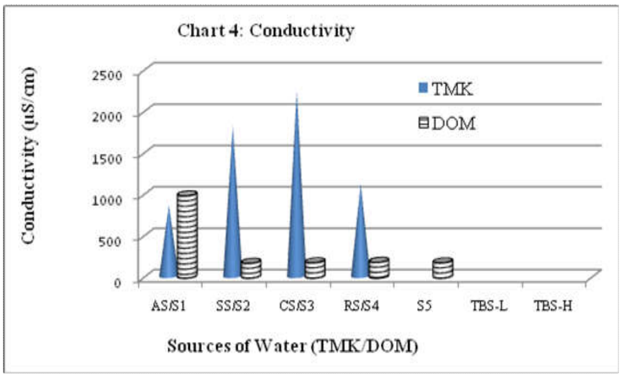


Chart 4: Conductivity
Conductivity (µS/cm)
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
TBS-H
Sources of Water (TMK/DOM)

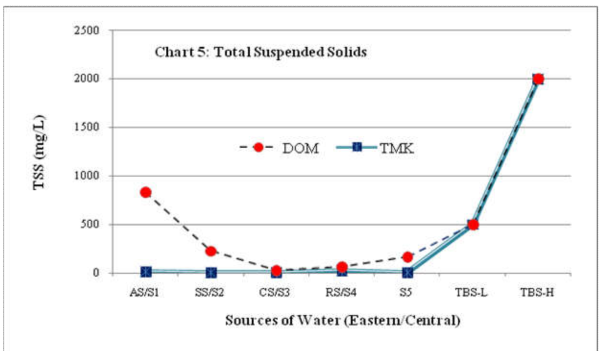


Chart 5: Total Suspended Solids
TSS (mg/L)
DOM
TMK
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
TBS-H
Sources of Water (Eastern/Central)

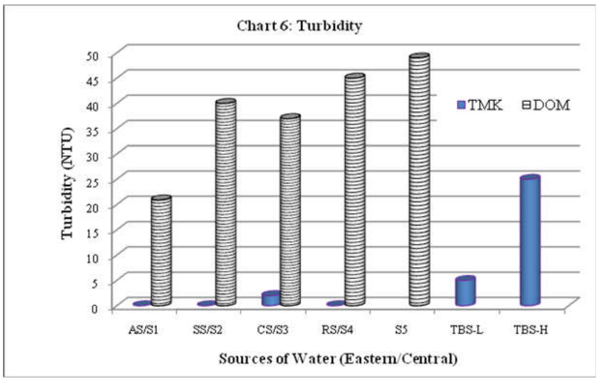


Chart 6: Turbidity
Turbidity (NTU)
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
TBS-H
Sources of Water (Eastern/Central)

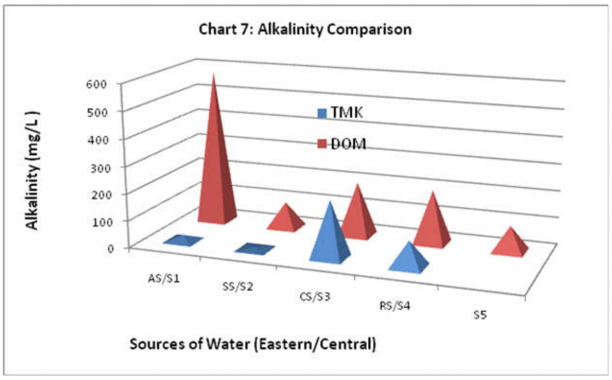


Chart 7: Alkalinity Comparison
Alkalinity (mg/L)
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
Sources of Water (Eastern/Central)

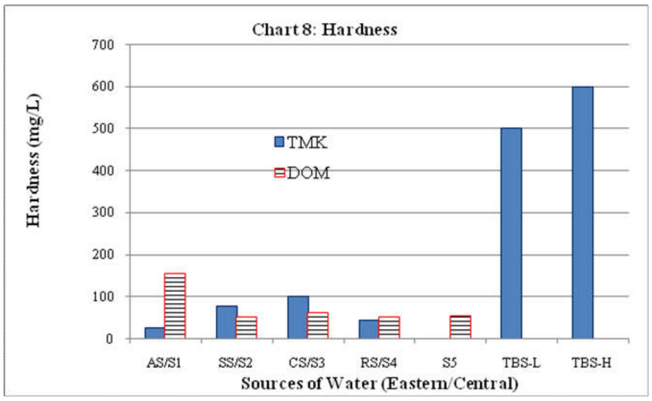


Chart 8: Hardness
Hardness (mg/L)
TMK
DOM
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
TBS-H
Sources of Water (Eastern/Central)

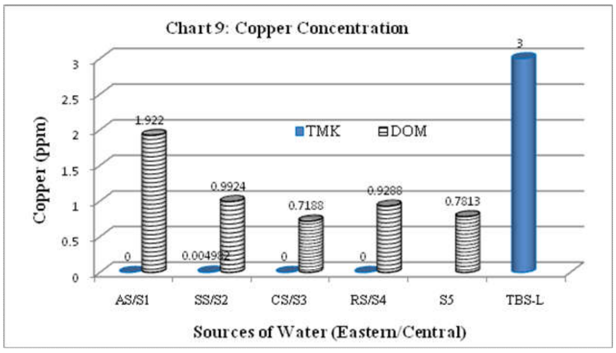


Chart 9: Copper Concentration
Copper (ppm)
TMK
DOM
3
1.922
0.9924
0.7188
0.9288
0.7813
0
0.004962
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
Sources of Water (Eastern/Central)

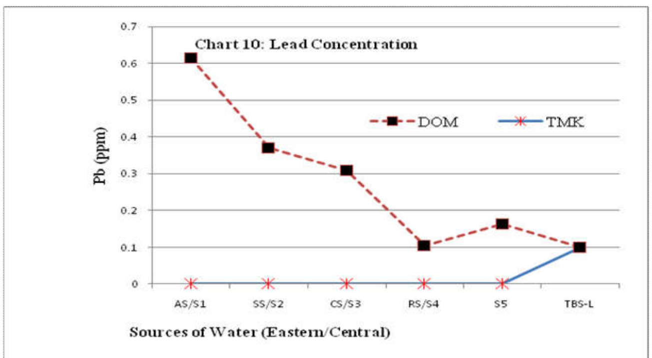
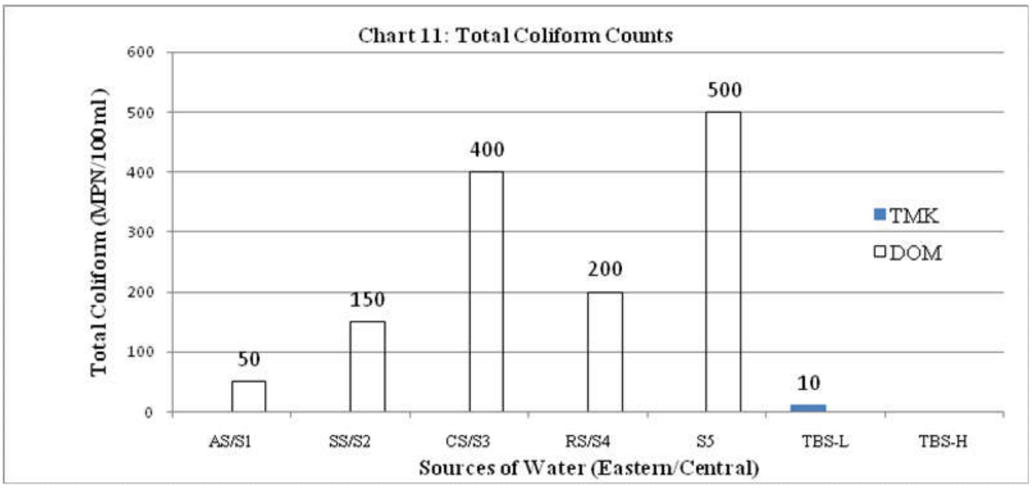
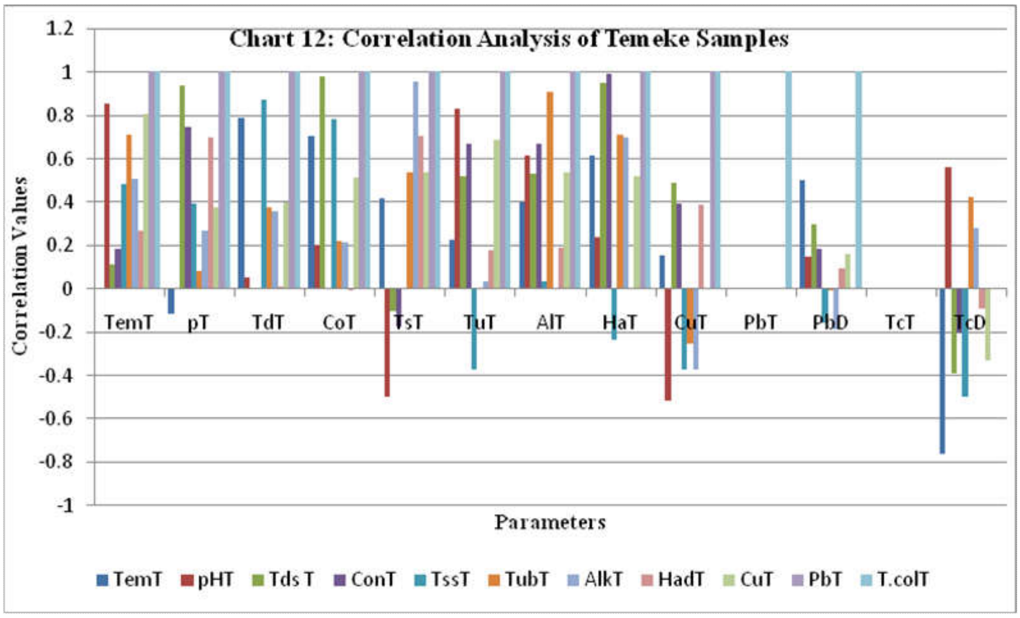
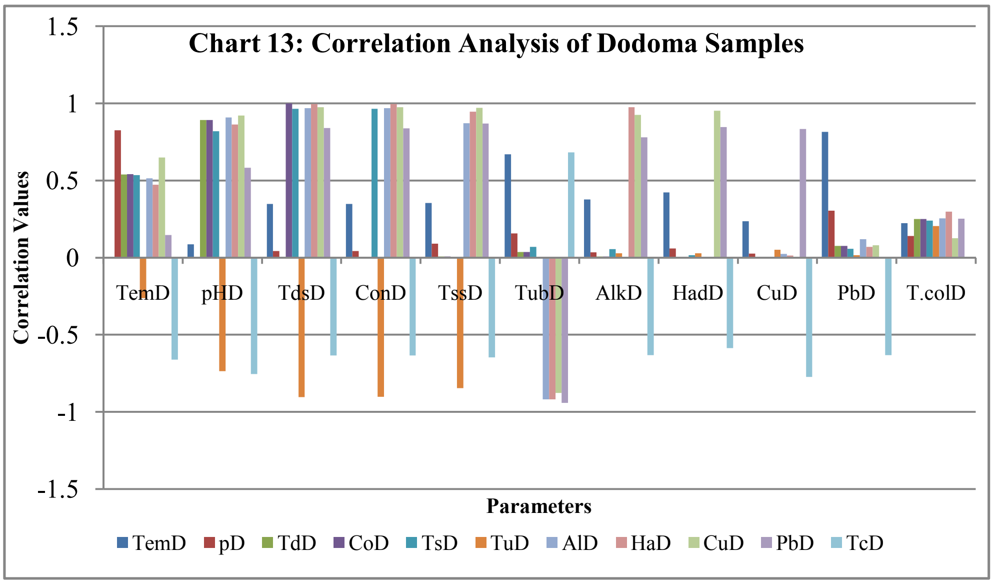


Chart 10: Lead Concentration
Pb (ppm)
DOM
TMK
AS/S1
SS/S2
CS/S3
RS/S4
S5
TBS-L
Sources of Water (Eastern/Central)

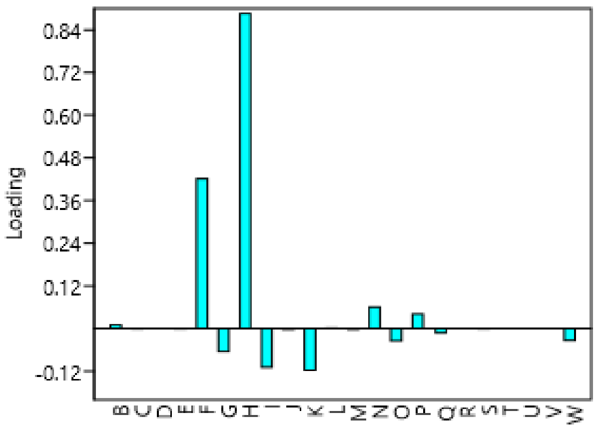






The average alkalinity of Dodoma shallow wells in Chart 7 was higher than Temeke. This observation indicates the presence of dissolved minerals from bedrocks of shallow wells. Apart from physical observation of depositions/scams of carbonates in the piping systems, several scholars have reported high amounts of carbonates of calcium and magnesium salts (R.J. Bowell, S. Mceldowney, A. Warren 1996).

The nature of water in Arusha and Manyara is typically alkaline too, thus since Dodoma is bordered to these regions, possibly their close proximity and rift valley fracture mix-up their waters. Temeke shallow wells are less affected compared to Dodoma likely because of the absence of alkaline minerals in the rocks and soils. The dissolved calcium and magnesium carbonate originating from minerals dissolution induce the total



Charts 14. Loadings Plot

hardness of the groundwater (Moyo 2013). Salts of magnesium, especially carbonates, and sulfate contribute lesser. The average hardness of water samples from Dodoma indicated in Chart 8 was higher 76 ppm than 64 ppm of Temeke. This observation is supported by findings on Chart 7, showing that alkalinity of Dodoma groundwater is caused by either/both mineral dissolution and/or an extension of alkaline/soda water from Northern volcanic-affected waters (Mlingano Agricultural Research Institue 2006). High values of domestic water hardness are associated with Atopic Dermatitis, skin-related effects (Perkin *et al*. 2016). Apart from the existing difference, all water samples met WHO and TBS standards as indicated in Table 2. The water hardness is mainly caused by the geological condition of the area (Kozłowski & Komisarek 2016). Various researches and studies proved that water with low magnesium can cause increased morbidity and mortality for cardiovascular disease, higher risk of motor neuronal disease, pregnancy disorders, and preeclampsia. Water with low in calcium may be associated with higher risk of fracture in children, certain neurodegenerative diseases, pre-term birth and low weight at birth. Lack of both calcium and magnesium in water can also cause some types of cancer.

Chart 9 and 10 indicate the quantified amounts of *copper and lead* in the waters collected from shallow wells. It is observed that the amounts of heavy metals at Dodoma were higher than Temeke. The obvious contributions apart from dissolution from bedrock minerals (Jurgen Hofmann 2014), blowing winds carry and transport particulate materials containing these metals into shallow water wells. Also, lack of surface protection and casing allows surface runoffs to contaminate them, as similarly reported by (Liddle *et al*. 2015).Geologically Dodoma region is partially crossed by rift valley thus most geological processes are common including deposition of metals and minerals. Just like the presence of uranium at Bahi district which is close to the study area. The higher values of lead may also result from brass plumbing fixtures, household items, and decoration house paints. The observed amount of copper was within acceptable range, whereas the amounts of lead were above the permissible limit of TBS and WHO of 0.1 and 0.01 ppm respectively. Through continuous accumulation and high levels of ingested heavy metals in humans is directly related and causes carcinogenic effects (Hu *et al*. 2015). The presence of high amounts of *coliform in* aquatic environments of Dodoma as shown in Chart 11 is an indication and proof of fecal contaminations. Grazing and free ranch system is widely practiced in Dodoma.

Also, fecal coliform originating from a human is unavoidable situation since during grazing and agricultural practices the possibilities of using bushes for open defecation is very high as supported by (Doni *et al*. 2016). Also, bacteria can enter into the well through direct discharge of waste from mammals and birds, from agricultural and storm runoff, and even from human sewage although the last is very low at Dodoma. The sampled shallow wells of Dodoma indicated that their water is not suitable for drinking as a number of coliforms exceed the allowable limit. The presence of coliform could results into cholera outbreak (Penrose *et al*. 2010).

Statistical Interpretation: Correlation analysis uses -1, 0 or +1 correlation coefficient values to establish any significant statistical similarity or differences between two data sets. Correlation analysis of Temeke samples from Chart 13 reveals most parameters are positively correlated, varying from weak to astrong association. This implies that variation of one parameter causes variation of another parameter provided that correlation values are greater than 0.5. Only total suspended solids, turbidity, Cu, Total coliform and little of lead had a negative correlation. On the other hand, most samples from Dodoma had moderate, weak to negative association among parameters. Electrical properties such as electrical conductivity, total dissolved salts and alkalinity have astrong association.

Principal Component Analysis (PCA): PCA is a multivariate form of data computation used to identify potential patterns existing among the data. It can compress data into lower dimension, highlight similarities and differences among data. As shown in Chart 14 below, the first principal component indicates that variable H which is electrical conductivity has the most contribution and stands as the unique characteristic. The second principle component is total dissolved salts while the rest has less impact. This observation depicts that electrical conductivity and alkalinity respectively are landmark chemical behaviors of Temeke Dodoma.

Conclusion

Both Dodoma and Temeke experience insufficient tap water supply, marginal public interventions and limited sanitation and protection practices. However the distinctive and potential landmark contaminants of Dodoma as revealed by PCA are alkalinity-based contaminants contrary to Temeke which had high electrical-based contaminants.

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