Article

Public Water Supply and Sanitation Authorities: A Sustainable Domestic Water Management Strategy in Tanzania

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Abstract: Water supply is a mandatory service for Tanzanians from respective legal public water utilities, and their sustainability reflects implementations of best management strategies at a local level. The objective of this study was to assess current approaches used in water quality and quantity management in Tanzania. This was achieved through secondary water data tends, on-site water quality assessments, visits of respective water supply and sanitation authorities, and assessment of their performances. It was observed that water supplied in rural-based authorities was quite different from that supplied in an urban setting as far as quality and quantity is concerned, urban-based supplies being of assistance to users over rural ones. A new strategy on water management is presented for sustainable water supply in Tanzania; it is based on controlling groundwater abstractions and preference of surface water in public water supplies. Rural water supply management must learn several practices realized at urban supplies for the betterment of respective majority water users.

Keywords: Community owned water supply organization (COWSO); Domestic water management strategy; Water Quality; Water Quantity; Water supply and sanitation authority (WSSA).

1. Introduction

Globally, Water is considered to be conserved by the hydrological cycle [20, 66] and covers 75% of the planet earth in which only 2.5% is freshwater [80]. The freshwater portion under conservation concept is rather diminishing due to an increased demand through global population growth over time [15, 33], major sectors being agriculture, industries and domestic water supplies [31, 82] that are essential for economic growth. Apart from stable ice-locked water and paleo-groundwater, freshwater flows and its interaction within the hydrologic cycle does not guarantee availability at its origin point i.e unevenly distributed [45, 69]; consequently, freshwater becomes scarce [26, 28, 29, 66] and a common good [52] where business intervenes [4, 64, 79]. While all countries are trying to account for freshwater sustainability dilemma [51, 61, 65, 68, 85, 87], international policies favors virtual water exploitation as all countries are relatively economically interdependent [36, 83, 84, 89].

Tanzania is also facing a similar situation [42] where agricultural sector is the backbone of the country's economy [41, 43, 44, 67, 77] that supports 80% of Tanzanians occupation and 95% for food [1, 37, 49]. Freshwater use has been given first priority for basic human needs under domestic water supply, and the environment receives a second priority, but other sectors including agriculture are periodically given other priorities based on their real-time socio-economic significance [72]. Even with firsthand prioritization of Water for domestic use, many Tanzanians receive limited freshwater due to poor water resource management [30, 63]. While many water sources used for domestic water supply becomes insufficient due to poor managements, it has been a common practice on seeking for alternative water source to supplementing the existing ones; this idea threatens the second water priority for the environment over domestic favor, and leaving agriculture together with other sectors to experience the worst scenario. Many successful water supply projects are utilizing fresh surface water sources under gravity driven water supply, but when this option is not available in other communities, pumping of either available ground or surface water source is preferred; unfortunately the cost for supplied treated and electrically pumped water is unbearable to low-income individuals residing in rural settings [11]. Water quality is another criterion for freshwater source suitability in domestic use; currently groundwater is much preferred over surface water due to a general perceived good water quality [33, 57] regardless of potential existence of chemical pollutants [10, 17, 21, 23]; Since much efforts are devoted to fresh surface waters, no attention in Tanzania laws and policies on the promotion and regulation of groundwater use have been effectively emphasized [32]. Thus, it has become a common practice where those who can afford to drill have legal and illegal access to groundwater, irrespective of critical issues such as compromising aquifer composition and content leading to groundwater pollution as well as overexploitation that mismatches recharge rates [86]. Since surface and ground waters are greatly interrelated [62], it is meaningless to solely put efforts on surface water sources management; furthermore, it has been evident that groundwater is greatly advocated for agricultural practices [14, 24, 54, 76] that makes freshwater vulnerable to pollution and overexploitation as contrasted from the water resource use priorities by [72]. Rainwater harvesting is a mature technology used for sustaining agricultural activities [6] but due to an increased freshwater crisis, it is currently receiving many credits as a potential alternative and a management Strategies for Sustainable Water Supply [25, 46, 56]. However, since its availability is not evenly allocated to all places during the entire rainy season, and the fact that it is vulnerable to pollution [53], it cannot reliably and exclusively be preferred in all areas with freshwater demands. Hence different management approaches that can supplement it and other sectors in a sustainable manner must be explored and implemented accordingly.

This paper considers public water supply and sanitation authorities as a management strategy for freshwater resource in Tanzania. The management concept is clearly addressed in terms of water quality and quantity aspects using Iringa region as a case study. It is anticipated that, when this option is taken into consideration by relevant regulatory bodies under respective policies and regulations, it will be a potential preference in the toolbox towards the management of freshwater resources for integrated sectors and enable them to operate sustainably.

2. Materials and Methods

2.1 Study area

Iringa region was used as a case study where key Urban and Rural water supply and sanitation authorities from available four districts (Iringa Municipal, Iringa Rural, Mufindi, and Kilolo) were covered. This reflected an operational and functional performance reality that relates to the potential opportunities for water management strategies in Tanzania.

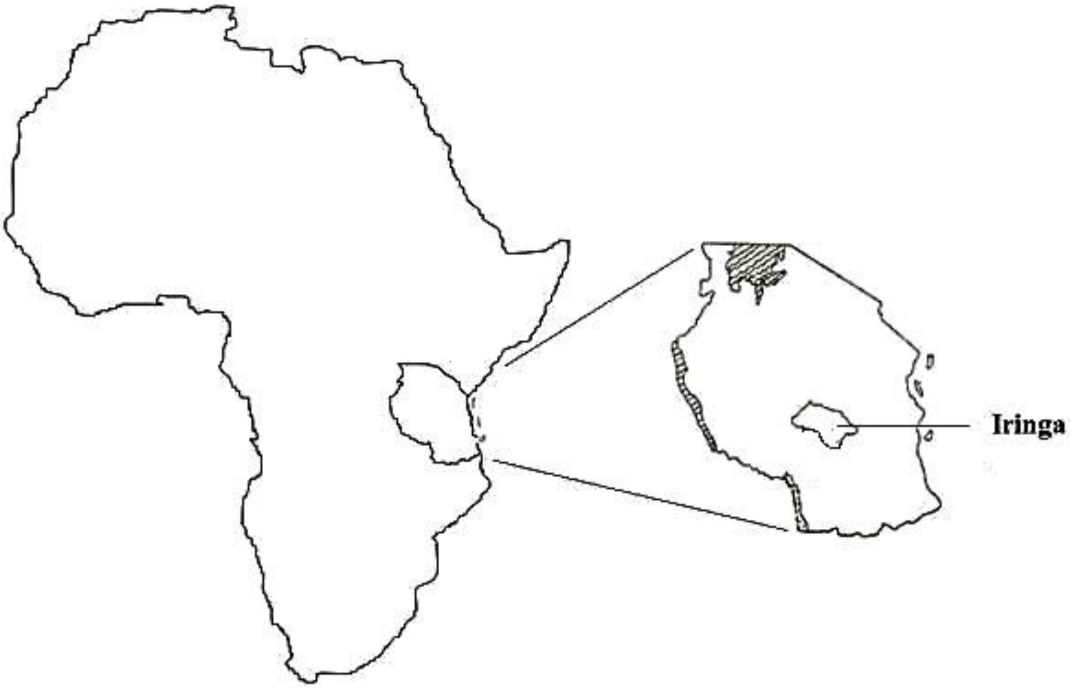

Figure 1: A Sketch map showing the Locality of Iringa region (Modified from [47])

2.2 Water Quality

2.2.1 Water quality Assessment - Heavy metals

Inductively Coupled Plasma (ICP) was used to assess the level of Heavy metals content in Raw and treated water samples from little Ruaha River which is the major source of public water supply in Iringa Municipal. Other samples analyzed were from Kibwabwa Borehole and Kitwiru spring, which altogether supplements the Iringa Urban Water Supply and Sanitation Authority (IRUWASA) supply. All water quality samples were collected, preserved and analyzed in accordance with the Standard method for the examination of water and wastewater [3].

2.2.2 Water Quality Trends

Secondary data from Iringa Water Quality Laboratory (IWQL) database were used to study the long term (2015 to 2018) behavior of surface (rivers, streams, dams, ponds, wetlands, and wastewaters) and ground (deep wells, shallow wells, and springs) water qualities across Iringa region. These data were mostly based on monthly and quarterly water quality monitoring programmes; however, semi-annual and annual monitoring programmes were also considered. Non-complying Physico-chemical and microbial parameters were used for trend analysis, whereas parameters that consistently complied with available national guidelines [78] for the trend period were not considered. Seasonal variations (Dry and Wet) were also taken into consideration for the entire trend.

2.2.3 Water Quality Perception

During site visits, the management and technical part of WSSA staff, as well as majority water users, were informally requested to provide their water quality perception based on daily water use experience. Comments were noted with respect to available treatment practices and seasonal variation issues.

2.3 Water Quantity

2.3.1 Assessment of WSSA current practices

Study area visits were implemented over 11 WSSAs (One Municipal/Urban, Three Small town/District, and Seven Rural based Community Owned Water Supply Organizations - COWSO) where information regarding Population served, treatment practices, Number of meter/private connection, water use tariff and payment modalities (e.g flat rate or as per quantity consumed) were captured in relation to water management strategies.

3. Results and Discussion

3.1 Limitation of the study

Several observations were noted to have potential influence on this study; they included using secondary water quality data from a competent laboratory. Here qualification and disqualification of water samples was based on East African potable water standards, which could be different from other countries guidelines. Furthermore, the case study is characterized by many surface water sources whereas other regions with droughts dominance may lack representations especially in the water quality section that can be characterized in a different manner than the one presented herein. Heavy metal assessment was done only at the urban based water supply authority due to analytical cost implications; rural based supplies were not accomplished on this case and could have established another compelling relationship. Rural based supplies selected in this study were based on recent developed projects (≤ 1 year) which could have presented unique information compared to old projects that still operates at the same level and locality; their choice was also a function of availability of a treatment practice i.e Chlorination.

3.2 Quality Aspect

3.2.1 Water Testing

3.2.1.1 Private owned water sources

The concept behind WSSA as a water resource management strategy extends itself to quality issues that strictly define the suitability of any secured freshwater source for domestic use. Currently, all WSSA in Tanzania are legally established and recognized by [75] as an amendment of [74], which continues to address internal and external requirements on regular water quality monitoring; thus, water supplied by these entities are of known quality which is accountable for public health protection. In urban settings, water supplies are perceived to be relatively expensive compared to rural areas; this is due to multi-step treatment expenses of polluted surface water sources from rivers and streams. Individuals and institutions that are financially sound tend to opt for user permits over deep groundwater sources as they are economically feasible to operate once established. Furthermore, their quality is observed to be superior when compared to treated surface water supplies which are believed to contain residual treatment chemicals that could affect their health. Majority with limited financial capacities are also interested for shallow groundwater sources; fortunately [73] has a free of permit room for individuals utilizing groundwater within a few meters deep. Individuals and institutions located far from WSSA networks are usually securing their own permitted water from nearby running surface waters, and or groundwater abstractions. However, almost all of these privately owned water sources are not tested and or monitored for water quality status in their entire operational periods; in rare cases, water test is realized only when it is a regulatory requirement that is accompanied with an inspection from a compliance body.

What is urged here is that, water quality tests are too technical and very expensive among private owned water users; furthermore, Tanzania government has only sixteen (16) regional water laboratories for this task, thus it becomes even more expensive to arrange necessary logistics for remote and on-site testing with respect to transport and technical staff per diem [58]. The following are technical suggestions based on water quality assessment experience towards alleviating unnecessary setbacks and thus facilitating convenient and smooth water testing means for all privately owned water sources:-

- Water samplings are greatly emphasized at sources or intakes rather than existing domestic points. It takes a long time to visit remote surface water source intakes for the same water available near resident or easily accessible areas; on the other hand, it presents increased cost (e.g per diem) to the technical staff during monitoring sessions that private water source owners find it higher than the analysis cost. Thus samples shall only be taken at point of use, and for a new source, a closet downstream point shall be preferred as its quality would be a representative of the source intake to a large extent unless point source of pollution is identified to interfere.
- Water sampling and preservations prior laboratory conveyance for microbial assessment shall be taken by private water sources owners using guidelines presented by [48]. Glass bottles that require an autoclave for sterilization can be replaced by locally sold bottled water as their cleanliness is assured by good manufacturing practices and regular factory and market monitoring by legal Tanzania quality regulatory bodies.
- Water quality testing laboratories should employ the concept presented by [40] where Electric conductivity (EC) shall be the basis on omitting unnecessary chemical parameters that could only increase analytical expenses, which is a burden and one of the critical reasons as to why the majority do not prefer water testing.

3.2.1.2 Public owned water sources

While WSSAs are strictly obliged to test and monitor their water quality supplies, rural-based WSSA with limited financial and analytical technical capabilities are experiencing a similar scenario comparable to that of privately owned water sources. Thus, solutions presented for private owned water sources on enhancing regular water quality testing following proposed cost-effective sampling in 3.2.1.1 above can be adopted here. Unlike privately owned water sources, WSSA legal water quality compliances are required for reporting to respective regulatory authority i.e The Energy and Water Utilities Regulatory Authority (EWURA). The current paradigm of respective WSSA to directly report on EWURA is questioned based on regular EWURA monitoring programs where results are quite different from regular reported trends by most WSSAs [19]; there are possible incidences that results are direct entered over online platforms even without realizing any water quality monitoring programme. In order to avoid this, analytical results shall be directly entered by a respective water quality laboratory that executed the analytical task, and the same should be declared if not done. Furthermore, since compliance is an issue here, WSSA implementing the proposed private owned water sources sampling option shall be accompanied by another legally accountable and nearby available qualified staff (e.g Regional, District and or Town Environmental/Water Engineers, Scientists and Technicians).

Currently, most WSSAs are implementing Chlorination practices to public-supplied water as a safeguard step towards endemic diseases following recent Cholera outbreaks throughout the country [50, 81]; however, majority citizens utilizing such treated water are complaining about this new chemical to their historical pristine domestic water and they claim it to be unbearable on use (complaints observed includes bad water test, believed to be established for birth control by destroying male reproductive systems, and carcinogenic upon prolonged use). The main reason arises from all WSSA (except IRUWASA) having only chlorination step towards treatment, and the fact that gravity based water supplies have an uncontrolled water flow rate, thus manual chlorine set doses becomes sporadically unstable. Higher flows are noted at night and morning with relative clear waters whereas low flows are noted during a day and evening with higher turbidities (mostly due to involvement of water for agricultural activities upstream), thus chlorine demand dramatically changes in response to these changes, thereby exposing domestic water users to extreme events of high and low chlorine doses. With these constraints, many WSSA are unofficially opting to reduce chlorine set dose while other prefers not to use it at all for the sake of political issues and majority water user reactions. Thus, the aims of establishing chlorination treatments are compromised, and a sustainable solution is urgently required to this matter.

3.2.2 Water quality trends

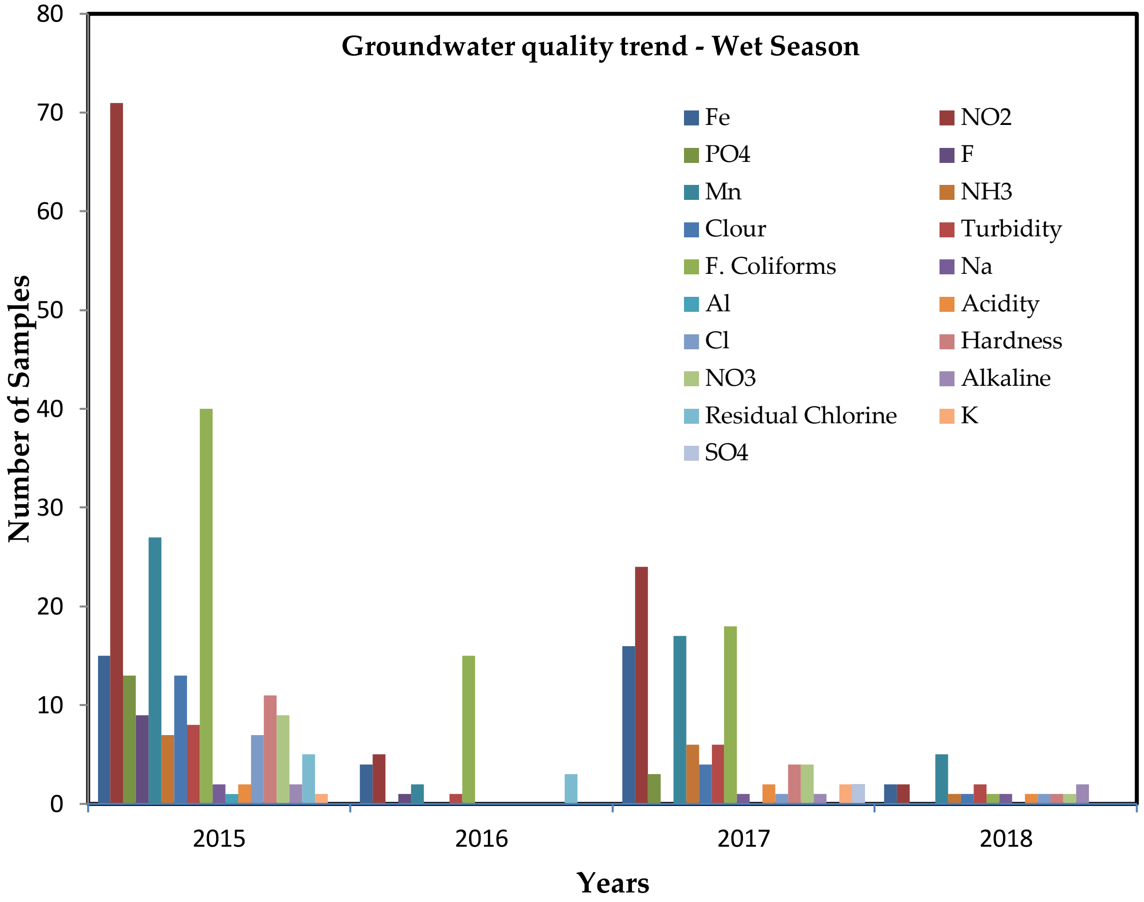

Figure 2: Groundwater Quality Variations during Wet Season from 2015 to 2018 (Number of non-qualifying parameters, n = 19)

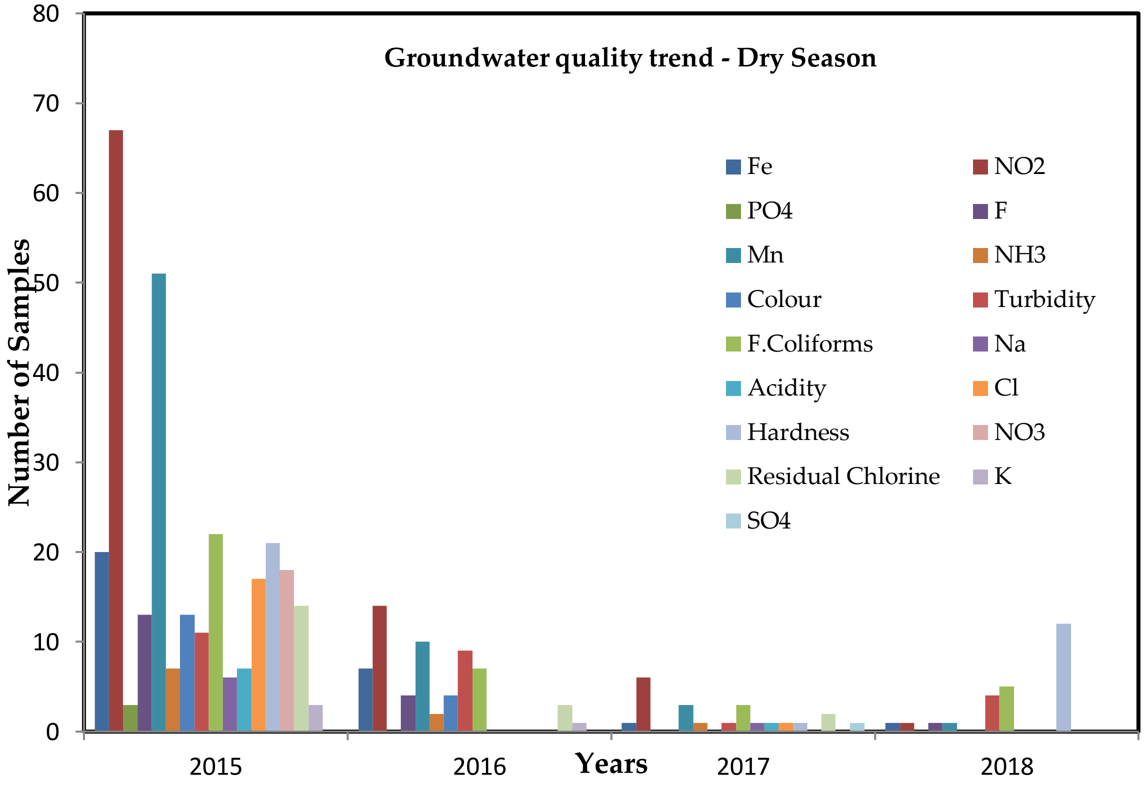

Figure 3: Groundwater Quality Variations during Dry Season from 2015 to 2018 (Number of non-qualifying parameters, n = 17)

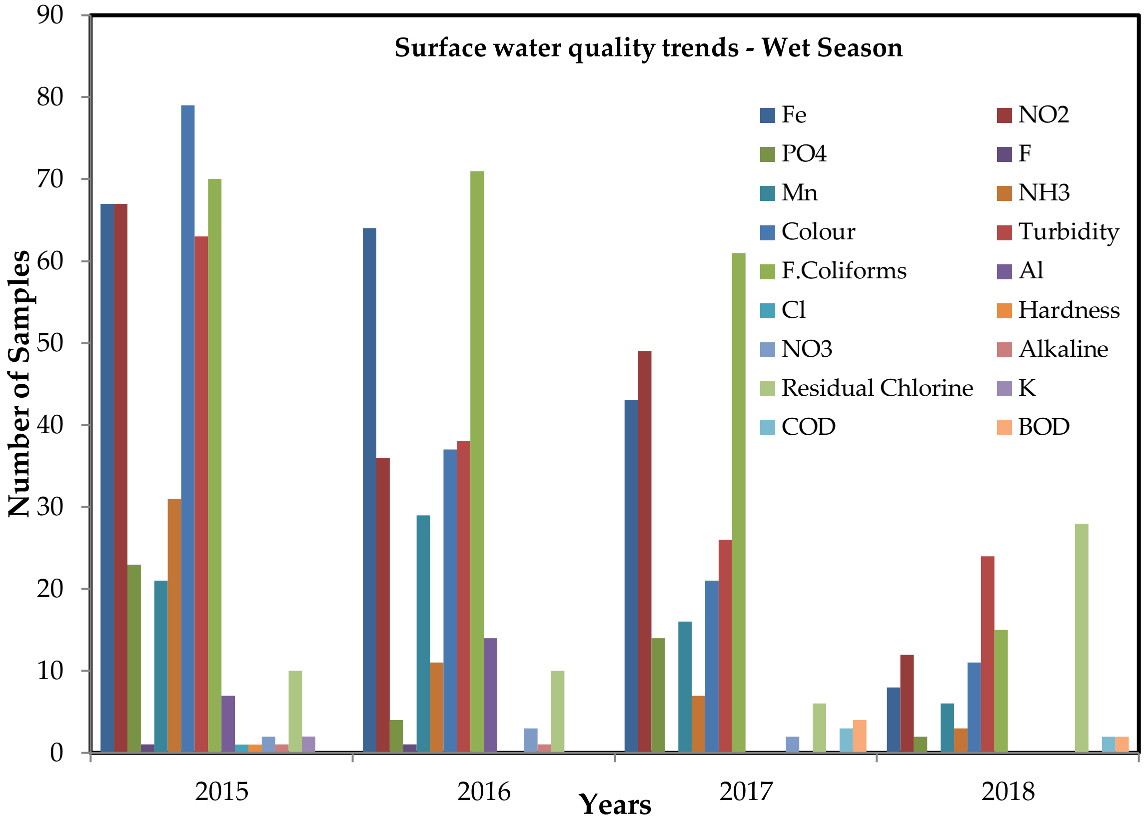

Figure 4: Surface water Quality Variations during Wet Season from 2015 to 2018 (Number of non-qualifying parameters, n = 18)

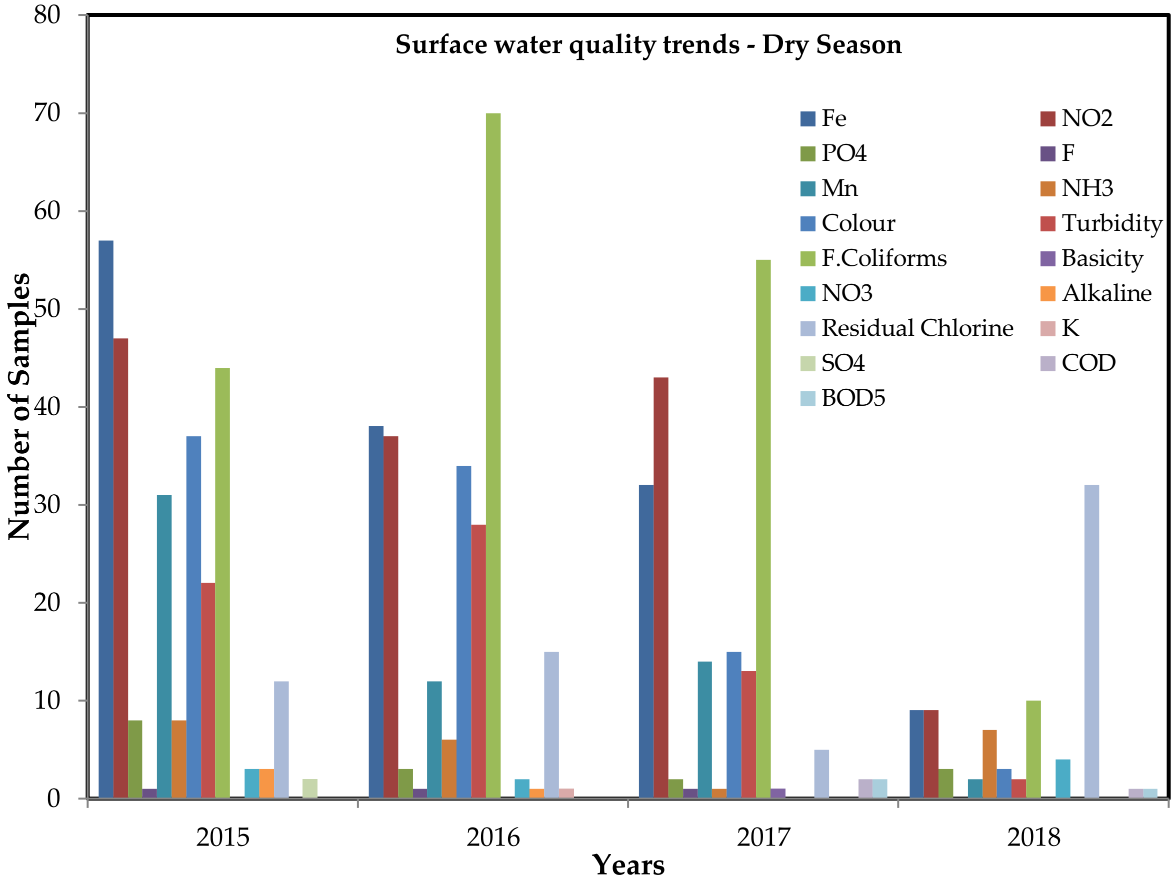

Figure 5: Surface water Quality Variations during Dry Season from 2015 to 2018 (Number of non-qualifying parameters, n = 17)

In all water quality trend plots, groundwater is observed to have less number of samples and hence a low number of non-qualifying parameters as contrasted from surface waters. Limited groundwater samples are attributed by private owned boreholes that are negligibly tested for water quality; few groundwater sources noted are due to regulatory requirement assessment over several private companies that usually require compliance confirmation to their accrediting organizations. Parameters noted to exceed in groundwater sources were mostly the same on surface water sources, however, several unique parameters existed on either source. While the wet season was observed to have a dilution effect on groundwater sources by presenting less non-qualifying parameters as contrasted by their dry season statistics, surface water sources are characterized by high non-qualifying parameters during the wet season due to interaction with mostly terrestrial rain surface run-off. Useful information obtainable from these plots includes:-

i. Microbial quality: Most groundwater sources present limited microbial pollution in both seasons, but surface water sources guarantee microbial pollution in both seasons. Current water quality practices are emphasizing efforts on assessing microbial quality in new and developed sources, while these parameters requires strict analytical precautions, it can be concluded that they are of no importance on their analysis in surface water sources (unless it intends to assess a microbial treatment practice efficiency) but rather significant on groundwater sources. Many water supply projects are constantly established based on funds and funders availability, hence when surface water sources are preferred, efforts on microbial assessment should be avoided and treatment practices shall be a mandatory part of the project infrastructure. State monitoring programmes that realize on-site water quality assessment can omit microbial analysis in untreated surface water sources/supplies as it increases complications while the reality is always valid for this source category on being vulnerable and contaminants existence.

ii. The trend shows the dominance of certain parameters in either surface or groundwater sources. Since regional water quality laboratories are focusing on their legal sphere of services and the fact that they aim to be accredited, it can be concluded that such laboratories better focus on accrediting respective non-qualifying parameters as a basic criterion. Furthermore, heavy metal assessments can be preferred over mostly qualifying parameters when there is limited analytical scope coverage window.

3.2.3 Water Quality Remediation practices

3.2.3.1 Heavy Metal Issues

Irrespective of any domestic water source origin (Ground or surface; public or private), quality is a pre-requisite criterion over its suitability conformity. Heavy metals are encountered in environmental setting due to their geological conservation, thus groundwater sources are vulnerable to a large extent. On the other hand, human development has encouraged heavy metal contamination in water sources in a number of ways, these include (i) Fertilizer application in irrigation water that interact with aquifers and or becomes transported downstream where domestic applications are realized (ii) rainwater harvesting through various roof materials (iii) corrosion of metallic-based water supply networks [18]. [48] Clearly demonstrates the significance of assessing heavy metals due to their increasing impacts on public health [22, 27, 39]. Like other chemical pollutants, heavy metals are bio-accumulated in body tissues and will present their effect at chronic levels [8]. The table below shows the status of heavy metals in different sources based on IRUWASA tested water sources.

Table 1: Heavy Metals concentration (mg/L) in different water sources supplied by IRUWASA

S/N	Parameter	Raw water at	Borehole at	Spring water	Treated water*

		Little Ruaha River	**Kibwabwa**	**at Kitwiru**	
1	Aluminium	0.000	0.000	0.000	0.004
2	Arsenic	0.000	0.000	0.000	0.000
3	Barium	1.000	0.000	1.000	0.000
4	Cadmium	0.010	0.000	0.030	0.010
5	Chromium	0.000	0.000	0.000	0.000
6	Cobalt	0.410	0.000	0.320	0.000
7	Copper	0.000	0.010	0.000	0.010
8	Iron	0.100	0.010	0.030	0.020
9	Lead	0.002	0.000	0.004	0.000
10	Manganese	0.025	0.007	0.045	0.000
11	Mercury	0.001	0.000	0.000	0.000
12	Molybdenum	0.010	0.090	0.050	0.010
13	Nickel	0.000	0.034	0.147	0.000
14	Selenium	0.005	0.001	0.042	0.000
15	Silver	0.020	0.000	0.000	0.000
16	Zinc	0.050	0.000	0.030	0.000

* Treated water is a blend of (i) Treated Little Ruaha River water, 85% (ii) Spring water, 14% and (iii) Borehole water, 1%.

Table 1 presents heavy metal results with 0.000 mg/L concentration which implied to be below the analytical detection limit. A high concentration of heavy metals was detected in the order of Raw water from little Ruaha river > spring water > Borehole >>>> Treated water. Since the high volume of treated little Ruaha raw water contributes much on blended final water, it was observed that treatment practices employed to eliminate higher river water turbidities (Coagulation-flocculation and sedimentation) were also responsible for concurrent elimination of heavy metals [60]. Thus, it can be noted that, while IRUWASA is struggling with turbidity elimination using flocculants, they are also realizing heavy metal remediation from the same water. Furthermore, when this water (85%) was mixed with that of spring (14%) and borehole (1%) which contained higher levels of several heavy metals, it resulted to an overall dilution effect and the new blended water is characterized with less to no detectable heavy metal content. What is learned here is that, while it has been observed as a curse for many WSSA in Tanzania on encountering very turbid raw water sources, it is now an advantage as making this water clear makes it free from heavy metals too.

3.2.3.2 Disinfection By-products (DBPs) Issues

Chlorination is a mandatory treatment stage to many water supply schemes in Tanzania, regardless of any pre-treatment means such as water clarification from elevated turbidity values. Even in advanced treatment practices that involve turbid water clarification prior chlorination, organic flocculants residuals play a key role in the formation of DPBs [7]. However, with such observation many remediation approaches are suggested towards combating DBPs issues; membrane technique being excellent [88], two stage or standard treatment as contrasted from rapid [2] in WSSA implementing clarification processes reduces DBPs levels, but the common and affordable one being household boiling of such treated water meant for drinking.

Table 2: DBPs (Regulated Trihalomethanes, THMs) remediation by boiling drinking water

S/N	DBP Species	Efficiency (%)	Reference
1	Chloroform (TCM)	69 - 97	[9, 34, 38]
2	Bromodichloromethane (BDCM)	68 - 98	[9, 34, 38]
3	Dibromochloromethane (DBCM)	51 - 100	[9, 34, 38]
4	Bromoform (TBM)	40 - 100	[9, 34, 38]
5	Sum of 4 THMs (THM4)	40 - 98	[9, 34, 38]

From Table 2, a variation on DPB decrease efficiency was attributed by different boiling appliances in all experiments within five minutes. Useful information in these observations is that, while the state recommends chlorination practices to all public water supplies in favor of preventing endemic disease eruption, individuals can avoid any potential health impact (especially for children and pregnancy) due to DBPs by boiling such water meant for drinking.

3.3 Quantity Aspect

3.3.1 Ground water

Tanzania has more than 48 known private groundwater drilling companies that competitively provide relatively affordable services than the government based drilling agency i.e Drilling and

Dam Construction Agency - DDCA. While DDCA has a remarkable record of on this service (Table 3), it can be concluded that groundwater has been adversely exploited under the operation of these companies that stick on profit maximization. In this case, groundwater quantification and hence accountability as a water resource becomes poorly manageable, water use permits that are legally granted by country basin water boards have not been successful as most private company and client on drilling normally find this step a setback. Therefore, a number of boreholes reported to have been drilled are not reflecting the reality, and many water users are then abstracting groundwater without any plausible use control. The government of Tanzania through the ministry of water should consider identification of such illegal drilled boreholes, and account them in available water sources and revenue channel on promoting equity water utilization among country dwellers.

Table 3: Boreholes and their yields since 1999 to 2015 (Modified from [16])

Financial year	**Successful Borehole**	**Average yield per Borehole per Day (m^3/d)**	**Total Yield per day ($x10^3$ m^3/d)**
1998/1999	427	163.44	69.8
1999/2000	503	120.24	60.5
2000/2001	352	179.04	63
2001/2002	331	140.88	46.6
2002/2003	358	123.12	44.1
2003/2004	417	136.32	56.8
2004/2005	423	123.45	52.2
2005/2006	401	150	60.2
2006/2007	401	242.13	97.1
2007/2008	419	228	95.5
2008/2009	380	133.8	50.8
2009/2010	254	142.10	36.1
2010/2011	219	102.00	22.3
2011/2012	226	249.3	56.3
2012/2013	205	137.66	28.2
2013/2014	116	142.95	16.6
2014/2015	285	166.85	47.6

Total	**5717**	**2681.28**	**903.7**

For the past 17 years (1999 to 2015), DDCA was able to accomplish 5,700 Boreholes in Tanzania with an average of 86% success rate capable of providing 903,700 m^3/d yields. It was declared that 27 to 200 liters per capita per day (0.027 to 0.2 m^3/d) are required for drinking, sanitation, cooking and bathing [59]; currently, there are about 61,000,000 Tanzanians [71] whom altogether would require a total of 1,647,000 to 12,200,000 m^3/d freshwater. Thus, an average of 6,923,500m^3/d freshwater is required to sustain the current daily demand. As of 2005, the ministry of water had a database of 9,242 drilled boreholes [5] in which DDCA contributed 2811 (30.4%); since private drilling companies are preferred by individuals due to their affordability (which is also suspected to affect the quality of the work), it can confidently be estimated that at least each year a total of 1,320 boreholes are accomplished (even though [5] estimated an annual requirement of at least 1,600 boreholes drilling). Using such estimation in the period of 1999 to 2018, at least 26,406 boreholes are available in Tanzania; in fact, as of 2009 private enterprise contributed about 9,000 boreholes from Dar es Salaam city alone [13]. Since boreholes are drilled to operate for 20 to 50 years [12], then a total of 4,174,060m^3/d is obtainable and capable of satisfying more than 60% current freshwater demands for all Tanzanians. This estimate excludes shallow wells and un-reported boreholes which significantly contribute to the water supply sector; in this case, a 25% reported as a contribution of boreholes in the domestic water supply [70] is rather due to poor management of abstracted groundwater.

During site visit, a number of hotels, lodges and guest houses were characterized by the possession of boreholes as a secondary water source i.e in addition to the one supplied by WSSAs; however, such groundwater sources were significantly preferred over public water supplies as they could meet customer requirements at an affordable cost. It was observed that individual guests were utilizing more water under the claim that they pay for it. Thus, groundwater resource is inequitably accessed by many Tanzanians in the business intervention model. Furthermore, since only WSSA are legally permitted to realize water supplies, many individuals with private well are unofficially doing the same under civilian support; the worst scenario arises from the government (Ministry of water) recent statement over an intention to authorization of free groundwater access at household uses, this contradicts WSSAs and Water Basin supply business/fraud and revenue collection respectively [32]. In fact, majority preferred groundwater due to clarity issues as WSSA utilizing surface water sources are significantly facing inadequate supply and poor quality (e.g very turbid water during rainy seasons; chemical residuals from treatment practices). Thus, this paper suggested that, no permit on groundwater abstraction shall be a setback in drilled and on-going drilling business, but for each borehole there shall be water abstraction control and charges by means of metering; well owners shall then not be prohibited to sell their water, but only agreed price must be used and collected to the governmental control body (e.g Basin Water Boards and WSSAs based on their legal spheres of influence). The same should be done to bottled water companies that maximize their profit on this common good. Groundwater abstraction for Irrigation shall be exempted due to the fate of irrigation waters [55], and the significance of agriculture to the country's economy unless otherwise aquifers get compromised in an undesirable manner that threatens domestic water supplies.

3.3.2 Surface water

Table 4: WSSA/COWSO current practices (as of April, 2019)

S/N	WSSA/COWSO	Source	Supply Mode	Treatment Practices	Population Served	Connection		Tariff (TShs/m^3)	
						Public	Private	Public	Private
1	IRUWASA - (M)	R, BH & Sp	P	F, SF, C & B	138,000	128	24553	1000	1685-2035
2	Kilolo - (D)	St	G & P	C	28,000	70	724	1000	485
3	Mafinga - Smt	St & Sp	G & P	C	72,000	1	3768	500	790-930
4	Ilula - Smt	St	G	C	40,700	56	1186	1500-2500	500-600
								1000^{FR}	5000^{FR}
5	Magubike - (R)	R	G	C	15,000	62	187	1500	1500
6	Ifunda - (R)	Sp	P	C	6,000	20	5	2500	2000
7	Kidabaga - (R)	R	P	C	2,300	13	40	2500	2500
8	Ng'uruhe - (R)	St	G	C	2,900	48	78	2000^{FR}	5000^{FR}
9	Ihimbo - (R)	St	G	C	2,700	18	66	1000	5000
10	Mgama - (R)	St	G	C	1,000	17	110	1000^{FR}	1667^{FR}
11	Irindi - (R)	St	G	C	2,400	16	27	1000	5000

M - Municipal, (D) - District, Smt - Small town, (R) - Rural, R - River, BH - Borehole, Sp - Spring, St - Stream, P - Pumping, G - Gravity, F - Flocculation, SF - Sand filtration, C - Chlorination, B - Blending, FR - Flat rate tariff payment per household on monthly basis (i.e not TShs/m^3).

Generally, Table 4 shows that rural water supplies are very expensive compared to urban-based WSSAs services. Furthermore, while Public domestic point connections are aimed at serving many people at an affordable cost, the opposite is observed due to most points having higher or comparable cost with those of private based. These observations were attributed by many rural-based WSSAs on ensuring availability of funds for sustainable water supply operations; hence relative higher tariff was to be subjected to the large public-oriented community. In fact, private connections are much preferred as their revenue are exclusively collected by WSSAs management, whereas public connection requires a public kiosk operator who must receive 20 to 50% share of the collected tariff. Water supply through pumping mode in rural areas had higher tariff compared to rural gravity-based water supplies, in these WSSAs water management is improved and financial collections reflect operation and maintenance expenses. On the other hand, gravity-based water supplies are facing difficulties in financial collections as majority public water users believe water is for granted, and that operating costs are far low compared to current tariff; hence management of rural gravity-based water supplies becomes deprived and threatens the sustainability of these projects. Such management practices are further related to water losses in most parts of the supply network in these highly numbered gravity water supplies, making losses of permitted water quantities for abstraction and subjecting downstream users to water scarcity vulnerabilities; the situation becomes worse in flat rate tariff oriented WSSAs, where water management is extremely poor. Since water treatment and supply modes presented by urban WSSA are very advanced and characterized by highest operation cost, and yet the supplied water for town dwellers is relatively cheap compared to a rural setting, then a lesson can be learned here and propagated in all rural based WSSAs for effective safe water provision at an affordable cost.

4. Conclusions

- Groundwater abstraction shall be controlled through metering and hence charging reasonable tariff that will consider owner on invested well infrastructure, and shall be permitted to sell such water to neighbors for enhancing service while controlling abstraction charges.

- Treatment of turbid surface water sources shall be preferred as the process concurrently eliminates heavy metals in the final water; furthermore, other polluted sources can be subjected to blending practices using treated water to acceptable final contaminant limits prior supply.

- Water quality assessment can be enhanced among private water source owners if water sampling is done by such an owner using a simplified procedure presented and a sampling protocol from the ministry of water.

- Rural-based WSSAs/COWSO must learn and implement best practices from urban WSSAs that irrespective of higher operation and maintenance expenses they still provide water to urban communities at relative low tariff compared to rural water supplies.

- The diversity of water quality laboratories shall be eliminated in order to improve management and minimize operations expenses while maximizing analytical capabilities. Only three to five fully furnished water laboratories are satisfactory in Tanzanian; this is possible if offices at regional and or district level are established on facilitating in-situ analysis of non-preservable parameters and sample preservations for transportation to such designated laboratories.

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References

1. Alam, F., Myovella, G. (2017): Causality between Agricultural Exports and GDP and its implications for Tanzanian economy. Journal of Economics, Finance and Accounting, 3(1), 1-18. https://doi.org/10.9790/5933-0806013649
2. Ali, S. I., Arnold, M., Liesner, F., & Fesselet, J. F. (2019). Characterization of Disinfection By-Products Levels at an Emergency Surface Water Treatment Plant in a Refugee Settlement in Northern Uganda. *Water*, *11*(4), 647. https://doi.org/10.3390/w11040647
3. American Water Works Association, American Public Works Association, Water Environment Federation (2017). Standard methods for the examination of water and wastewater. ISBN(s):9781625762405.
4. Barlow, M., & Clarke, T. (2017). *Blue gold: the battle against corporate theft of the world's water*. Routledge. https://doi.org/10.4324/9781315096216
5. Baumann, E., Ball, P., & Beyene, A. (2005). Rationalization of Drilling Operations in Tanzania. *Review of the Borehole Drilling Sector in Tanzania*. https://sswm.info/sites/default/files/reference_attachments/BAUMANN%20et%20al%202005%20Rationalization%20of%20Drilling%20Operations%20in%20Tanzania.pdf

6. Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L. (2012). Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review. *Physics and Chemistry of the Earth, Parts A/B/C*, *47*, 139-151. https://doi.org/10.1016/j.pce.2011.08.015
7. Bolto, B., & Gregory, J. (2007). Organic polyelectrolytes in water treatment. *Water research*, *41*(11), 2301-2324. https://doi.org/10.1016/j.watres.2007.03.012
8. Bungudu, J. I., Shuaibu, L., Mohammed, U. F., & Alkali, M. (2018). Heavy Metals Analysis in Human Body (Toenail, Fingernail and Hair Samples) and Drinking Waters of Santa Fe Region, Argentina. *Asian Journal of Applied Chemistry Research*, 1-14. http://www.journalajacr.com/index.php/AJACR/article/view/9582
9. Carrasco-Turigas, G., Villanueva, C. M., Goñi, F., Rantakokko, P., & Nieuwenhuijsen, M. J. (2013). The effect of different boiling and filtering devices on the concentration of disinfection by-products in tap water. *Journal of environmental and public health*, *2013*. http://dx.doi.org/10.1155/2013/959480
10. Chacha, N., Njau, K. N., Lugomela, G. V., & Muzuka, A. N. (2018). Hydrogeochemical characteristics and spatial distribution of groundwater quality in Arusha well fields, Northern Tanzania. *Applied Water Science*, *8*(4), 118. https://doi.org/10.1007/s13201-018-0760-4
11. Chumbula, J. J., & Massawe, F. A. (2018). The role of local institutions in the creation of an enabling environment for water project sustainability in Iringa District, Tanzania. *Environmental & Socio-economic Studies*, *6*(4), 1-10. https://doi.org/10.2478/environ-2018-0023
12. Danert, K., Armstrong, T., Adekile, D., Duffau, B., Ouedraogo, I., Kwei, C. (2010). Code of Practice for Cost Effective Boreholes. Rural Water Supply Network. https://www.ircwash.org/sites/default/files/Danert-2010-Code.pdf
13. Danert, K., Carter, R. C., Adekile, D., & MacDonald, A. (2009). Cost-effective boreholes in sub-Saharan Africa. http://nora.nerc.ac.uk/id/eprint/9185
14. de Bont, C., Komakech, H. C., & Veldwisch, G. J. (2019). Neither modern nor traditional: Farmer-led irrigation development in Kilimanjaro Region, Tanzania. *World Development*, *116*, 15-27. https://doi.org/10.1016/j.worlddev.2018.11.018
15. Dilling, L., Daly, M. E., Kenney, D. A., Klein, R., Miller, K., Ray, A. J., ... & Wilhelmi, O. (2019). Drought in urban water systems: Learning lessons for climate adaptive capacity. *Climate Risk Management*, *23*, 32-42. https://doi.org/10.1016/j.crm.2018.11.001
16. Driling and Dam Construction Agency - DDCA: Performance Report 1999-2015 http://www.ddca.go.tz/storage/app/uploads/public/58e/393/f8b/58e393f8b6394101742489.pdf
17. Elisante, E., & Muzuka, A. N. (2016). Assessment of sources and transformation of nitrate in groundwater on the slopes of Mount Meru, Tanzania. *Environmental earth sciences*, *75*(3), 277. https://doi.org/10.1007/s12665-015-5015-1
18. Elumalai, V., Brindha, K., & Lakshmanan, E. (2017). Human exposure risk assessment due to heavy metals in groundwater by pollution index and multivariate statistical methods: a case study from South Africa. *Water*, *9*(4), 234. https://doi.org/10.3390/w9040234
19. Energy and Water Utilities Regulatory Authority (2018). Water utilities performance review report for the FY 2917/18. Regional and National project water utilities. 21-22.

20. Environmental Protection Agency, EPA (2015): The Water Cycle and Water Conservation: https://www.epa.gov/sites/production/files/2015-08/documents/mgwc-gwa1.pdf
21. Figoli, A., Bundschuh, J., & Hoinkis, J. (2016). Fluoride, uranium and arsenic: occurrence, mobility, chemistry, human health impacts and concerns. In *Membrane Technologies for Water Treatment* (pp. 3-19). CRC Press. https://doi.org/10.1201/b19227
22. Ghaderpoori, M., Kamarehie, B., Jafari, A., Ghaderpoury, A., & Karami, M. A. (2018). Heavy metals analysis and quality assessment in drinking water-Khorramabad city, Iran. *Data in brief*, *16*, 658-692. https://doi.org/0.1016/j.dib.2017.11.078
23. Goeller, D. (2017). *Investigation of Water Quality and Availability in Rural Tanzanian Villages* (Doctoral dissertation, The Ohio State University). http://hdl.handle.net/1811/80691
24. Gudaga, J. L., Kabote, S. J., Tarimo, A. K., Mosha, D. B., & Kashaigili, J. J. (2018). Groundwater users' awareness of water institutions in Tanzania: A case study of Mbarali District, Mbeya Region. http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/2076
25. Han, M. Y. (2016). *Rainwater Harvesting Potential and Management Strategies for Sustainable Water Supply in Tanzania* (Doctoral dissertation, 서울대학교 대학원). http://hdl.handle.net/10371/118728
26. Hertel, T., & Liu, J. (2019). Implications of water scarcity for economic growth. In *Economy-Wide Modeling of Water at Regional and Global Scales* (pp. 11-35). Springer, Singapore. https://doi.org/10.1007/978-981-13-6101-2_2
27. Hofman-Caris, R., Bertelkamp, C., de Waal, L., van den Brand, T., Hofman, J., van der Aa, R., & van der Hoek, J. P. (2019). Rainwater Harvesting for Drinking Water Production: A Sustainable and Cost-Effective Solution in The Netherlands?. *Water*, *11*(3), 511. https://doi.org/10.3390/w11030511
28. Hu, T., Pang, C., & Zhou, X. (2018, July). Say No to the Thirsty Planet: Too Few Freshwater for the Daily Life of Human Beings. In *IOP Conference Series: Earth and Environmental Science* (Vol. 170, No. 2, p. 022116). IOP Publishing. https://doi.org/10.1088/1755-1315/170/2/022116
29. Jedd, T. (2018). Management of Transboundary Water Resources under Scarcity. https://doi.org/10.1162/GLEP_r_00450
30. Jiménez, A., & Pérez-Foguet, A. (2010, May). Building the role of local government authorities towards the achievement of the human right to water in rural Tanzania. In *Natural Resources Forum* (Vol. 34, No. 2, pp. 93-105). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/j.1477-8947.2010.01296.x
31. Johnson, H., South, N., & Walters, R. (2017). Eco-crime and fresh water. In *Greening Criminology in the 21st Century: Contemporary debates and future directions in the study of environmental harm* (pp. 133-146). Taylor and Francis. https://doi.org/10.4324/9781315585949
32. Komakech, H. C., & de Bont, C. (2018). Differentiated access: Challenges of equitable and sustainable groundwater exploitation in Tanzania. *Water Alternatives*, *11*(3), 623. http://www.water-alternatives.org/index.php/alldoc/articles/vol11/v11issue3/457-a11-3-10/file
33. Kooy, M., Walter, C. T., & Prabaharyaka, I. (2018). Inclusive development of urban water services in Jakarta: The role of groundwater. *Habitat International*, *73*, 109-118. https://doi.org/10.1016/j.habitatint.2016.10.006

34. Krasner, S. W., & Wright, J. M. (2005). The effect of boiling water on disinfection by-product exposure. *Water research*, *39*(5), 855-864. https://doi.org/10.1016/j.watres.2004.12.006
35. Kummu, M., Guillaume, J. H. A., de Moel, H., Eisner, S., Flörke, M., Porkka, M., ... & Ward, P. J. (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Scientific reports*, *6*, 38495. https://doi.org/10.1038/srep38495
36. Le Vernoy, A. (2017). *The trade and water nexus* (No. 669). ADBI Working Paper Series. http://hdl.handle.net/10419/163168
37. Leyaro, V., Morrissey, O., & Boulay, B. (2014). Food crop production in Tanzania: Evidence from the 2008/09 National Panel Survey. http://hdl.handle.net/20.500.12018/2680
38. Liu, J., Zhang, X., & Li, Y. (2015). Effect of boiling on halogenated DBPs and their developmental toxicity in real tap waters. *Recent advances in disinfection by-products*, 45-60. https://doi.org/10.1021/bk-2015-1190.ch003
39. Liu, Q., Han, W., Han, B., Shu, M., & Shi, B. (2018). Assessment of heavy metals in loose deposits in drinking water distribution system. *Environmental monitoring and assessment*, *190*(7), 388. https://doi.org/10.1007/s10661-018-6761-9
40. Lufingo M (2019). The fate of water quality sector in developing countries. International Journal of Advanced Research and Publications (IJARP), Volume 3 - Issue 4, April 2019 Edition, 86-90 #ijarporg. http://www.ijarp.org/online-papers-publishing/apr2019.html
41. Lugendo, P., Tsegaye, T., Wortman, C. J., & Neale, C. M. (2017). Climate Variability Implications for Maize Yield Food Security and Rural Poverty in Tanzania. *Available at SSRN 3233487*. http://dx.doi.org/10.2139/ssrn.3233487
42. Lyakurwa, F. S., Song, G., & Chen, J. (2014). Quantitative modeling of freshwater stress in the nine water basins of Tanzania. *Chinese Journal of Population Resources and Environment*, *12*(4), 309-315. https://doi.org/10.1080/10042857.2014.953742
43. Lyatuu, E. T., Nie, F., & Fang, C. (2016). Implication of the economic stability on the poverty-agriculture development nexus in Tanzania. *International Journal of Agricultural and Food Research*, *4*(3). https://www.sciencetarget.com/Journal/index.php/IJAFR/article/viewFile/509/169
44. Makulilo, A. B. (2017). Against Foreign Capital: The Populist Temptation in Tanzania. *Whitehead J. Dipl. & Int'l Rel.*, *18*, 49. http://blogs.shu.edu/diplomacy/files/2018/02/Against-Foreign-Capital-The-Populist-Temptation-in-Tanzania.pdf
45. Marion, P., Bernela, B., Piccirilli, A., Estrine, B., Patouillard, N., Guilbot, J., & Jérôme, F. (2017). Sustainable chemistry: how to produce better and more from less?. *Green Chemistry*, *19*(21), 4973-4989. https://doi.org/10.1039/C7GC02006F
46. Marwa, J., Lufingo, M., Noubactep, C., & Machunda, R. (2018). Defeating fluorosis in the East African Rift Valley: Transforming the Kilimanjaro into a rainwater harvesting park. *Sustainability*, *10*(11), 4194. https://doi.org/10.3390/su10114194
47. Matojo, N. D. (2015). Rastapodidae fam. nov. of "Harrowfoot Frogs"(Anura: Neobatrachia) inferred from Breviceps mossambicus re-description (formerly in Brevicipitidae) from Tanzania. *Journal of Biology and Nature*, 200-205. http://www.ikprress.org/index.php/JOBAN/article/view/1393

48. Ministry of Water and Irrigation MoW (2018) National Guideline on Drinking Water Monitoring and Reporting. Vol 3: Main Document. http://maji.go.tz/uploads/publications/sw1552468165-National%20Guideline%20on%20Drinking%20Water%20Quality%20Monitoring%20and%20Reporting.pdf
49. Mkonda, M., & He, X. (2018). Vulnerability assessment of the livelihoods in Tanzania's semi-arid agro-ecological zone under climate change scenarios. *Climate*, *6*(2), 27. https://doi.org/10.3390/cli6020027
50. Mohamed, H., Brown, J., Njee, R. M., Clasen, T., Malebo, H. M., & Mbuligwe, S. (2015). Point-of-use chlorination of turbid water: results from a field study in Tanzania. *Journal of water and health*, *13*(2), 544-552. https://doi.org/10.2166/wh.2014.001
51. Mooney, H., Cropper, A., & Reid, W. (2005). Confronting the human dilemma. *Nature*, *434*(7033), 561. https://doi.org/10.1038/434561a
52. Murray, K., Roux, D. J., Nel, J. L., Driver, A., & Freimund, W. (2011). Absorptive capacity as a guiding concept for effective public sector management and conservation of freshwater ecosystems. *Environmental management*, *47*(5), 917-925. https://doi.org/10.1007/s00267-011-9659-7
53. Mwamila, T. B., Han, M. Y., & Katambara, Z. (2016). Strategy to Overcome Barriers of Rainwater Harvesting, Case Study Tanzania. *J. Geosci. Environ. Protect*, *4*, 13-23. http://dx.doi.org/10.4236/gep.2016.49002
54. Nakawuka, P., Langan, S., Schmitter, P., & Barron, J. (2018). A review of trends, constraints and opportunities of smallholder irrigation in East Africa. *Global food security*, *17*, 196-212. https://doi.org/10.1016/j.gfs.2017.10.003
55. National Research Council. (1993). *Soil and water quality: an agenda for agriculture*. National Academies Press. https://doi.org/10.17226/2132
56. Ndé-Tchoupé, A. I., Tepong-Tsindé, R., Lufingo, M., Pembe-Ali, Z., Lugodisha, I., Mureth, R. I., ... & Rahman, M. A. (2019). White teeth and healthy skeletons for all: The path to universal fluoride-free drinking water in Tanzania. *Water*, *11*(1), 131. https://doi.org/10.3390/w11010131
57. Ngasala, T. M., Masten, S. J., Phanikumar, M. S., & Mwita, E. J. (2018). Analysis of water security and source preferences in rural Tanzania. *Journal of Water, Sanitation and Hygiene for Development*, *8*(3), 439-448. https://doi.org/10.2166/washdev.2018.169
58. Nkamleu, G., & Kamgnia, B. (2014). Uses and abuses of per-diems in Africa: a political economy of travel allowances. *African Development Bank Group, AfDB Working Paper*, *196*. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Working_Paper_196_-_Uses_and_Abuses_of_Per-diems_in_Africa-_A_Political_Economy_of_Travel_Allowances.pdf
59. Nkonya, L. K. (2011). Realizing the human right to water in Tanzania. *Human Rights Brief*, *17*(3), 5. https://digitalcommons.wcl.american.edu/cgi/viewcontent.cgi?article=1130&context=hrbrief
60. Phan, H. L., Tessier, C. (2008). *U.S. Patent Application No. 11/463,439*.
61. Rahaman, M. M., & Varis, O. (2005). The ethical perspective of water: dilemmas and future challenges. *Sustainable Development of Energy, Water and Environment Systems*, 2, 39-51. https://www.researchgate.net/profile/Muhammad_Rahaman2/publication/267793654_THE_ETHICAL_P

ERSPECTIVE_OF_WATER_DILEMMAS_AND_FUTURE_CHALLENGES/links/54b502d10cf28ebe92e4aadf.pdf

62. Safeeq, M., & Fares, A. (2016). Groundwater and surface water interactions in relation to natural and anthropogenic environmental changes. In *Emerging Issues in Groundwater Resources* (pp. 289-326). Springer, Cham. https://doi.org/10.1007/978-3-319-32008-3_11
63. Saladi, J. A., & Salehe, F. S. (2018). Assessment of water supply and its implications on household income in Kabuku Ndani Ward, Handeni District, Tanzania. http://www.suaire.suanet.ac.tz:8080/xmlui/handle/123456789/2229
64. Shiva, V. (2016). *Water wars: Privatization, pollution, and profit*. North Atlantic Books. http://courseresources.mit.usf.edu/sgs/ang6469/canvas/module_7/read/The_Sacred_Waters.pdf
65. Song, X., & Ravesteijn, W. (2017). Dilemmas in water systems development in China. In *What is Sustainable Technology?* (pp. 213-234). Routledge. urn:nbn:se:kth:diva-49586
66. Spellman, F. R. (2018). *The science of water: Concepts and applications*. CRC press. https://doi.org/10.1201/b17484
67. Suleiman, R. A. (2016). Assessing and controlling bio-deterioration of maize in Tanzania. https://doi.org/10.31274/etd-180810-5444
68. Swain, A. (2016). Water and post-conflict peacebuilding. *Hydrological Sciences Journal*, *61*(7), 1313-1322. https://doi.org/10.1080/02626667.2015.1081390
69. Taks, J. (2018). Water-Worlds: How to Research Under the Umbrella of Sustainable Development Being Aware of Its Multiple Ambiguities?. In *Sustainable Development Research and Practice in Mexico and Selected Latin American Countries* (pp. 411-421). Springer, Cham. https://doi.org/10.1007/978-3-319-70560-6_26
70. Tanzania National Audit Office NAOT (2019): Performance Audit on the Management of Water Supply Projects from Borehole Sources in Tanzania: Report of the Controller and Auditor General of the United Republic of Tanzania. http://www.nao.go.tz/?wpfb_dl=296
71. Tanzania National Bureau of Statistics NBS (2019). http://worldpopulationreview.com/countries/tanzania-population/
72. Tanzania National Water Policy NAWAPO (2002). http://maji.go.tz/uploads/publications/sw1552315386-NAWAPO.pdf
73. Tanzania Water Resources Management Act of 2009. http://www.maji.go.tz/uploads/publications/en1547642040-THE%20WATER%20RESOURCES%20MANAGEMENT%20ACT%20NO.%2011%20OF%202009-compressed.pdf
74. Tanzania Water Supply and Sanitation Act of 2009. http://www.maji.go.tz/uploads/publications/en1547641391-THE%20WATER%20SUPPLY%20%20AND%20SANITATION%20ACT%20NO%2012%20OF%202009.pdf
75. Tanzania Water Supply and Sanitation Act of 2019. http://www.maji.go.tz/uploads/publications/en1547640088-1542978073-BILL%20THE%20WATER%20SUPPLY%20AND%20SANITATION%20ACT,%202018.pdf

76. Theis, S., Lefore, N., Meinzen-Dick, R., & Bryan, E. (2018). What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values*, *35*, 671-684. https://doi.org/10.1007/s10460-018-9862-8
77. Tibesigwa, B., Siikamäki, J., Lokina, R., & Alvsilver, J. (2019). Naturally available wild pollination services have economic value for nature dependent smallholder crop farms in Tanzania. *Scientific reports*, *9*(1), 3434. https://doi.org/10.1038/s41598-019-39745-7
78. TZS 789:2016 - EAS 12: 2014. Potable water specification, Tanzania Bureau of Standards
79. Vörösmarty, C. J., Hoekstra, A. Y., Bunn, S. E., Conway, D., & Gupta, J. (2015). What scale for water governance. *Science*, *349*(6247), 478-479. https://doi.org/10.1126/science.aac6009
80. Vörösmarty, C. J., Lévêque, C., & Revenga, C. (2005). Fresh Water. Ch. 7 in: Millennium Ecosystems Assessment, vol. 1 Ecosystems and Human Well-Being: Current State and Trends. https://www.millenniumassessment.org/documents/document.276.aspx.pdf
81. Wang, A. (2016). Notes from the field: chlorination strategies for drinking water during a cholera epidemic—Tanzania, 2016. *MMWR. Morbidity and mortality weekly report*, *65*. http://dx.doi.org/10.15585/mmwr.mm6541a6
82. Wang, X., Yang, H., Shi, M., Zhou, D., & Zhang, Z. (2015). Managing stakeholders' conflicts for water reallocation from agriculture to industry in the Heihe River Basin in Northwest China. *Science of the Total Environment*, *505*, 823-832. https://doi.org/10.1016/j.scitotenv.2014.10.063
83. White, D. J., Hubacek, K., Feng, K., Sun, L., & Meng, B. (2018). The Water-Energy-Food Nexus in East Asia: A tele-connected value chain analysis using inter-regional input-output analysis. *Applied Energy*, *210*, 550-567. https://doi.org/10.1016/j.apenergy.2017.05.159
84. Wichelns, D. (2015). Virtual water and water footprints do not provide helpful insight regarding international trade or water scarcity. *Ecological Indicators*, *52*, 277-283. https://doi.org/10.1016/j.ecolind.2014.12.013
85. Yadav, A., Das, A. K., Roy, R. B., Chatterjee, A., Allen, J. K., & Mistree, F. (2017, August). Identifying and Managing Dilemmas for Sustainable Development of Rural India. In *ASME 2017 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. V007T06A017-V007T06A017). American Society of Mechanical Engineers. http://sunmoksha.com/Publication/Ashok%20Das%202017%20DilemmaTriangle%20IDETC2017%202017-08.pdf
86. Yihdego, Y., & Paffard, A. (2016). Hydro-engineering solution for a sustainable groundwater management at a cross border region: case of Lake Nyasa/Malawi basin, Tanzania. *International Journal of Geo-Engineering*, *7*(1), 23. https://doi.org/10.1186/s40703-016-0037-4
87. Yihdego, Z. (2017). The Fairness 'Dilemma'in Sharing the Nile Waters: What Lessons from the Grand Ethiopian Renaissance Dam for International Law?. *Brill Research Perspectives in International Water Law*, *2*(2), 1-80. https://doi.org/10.1163/23529369-12340006
88. Zazouli, M. A., & Kalankesh, L. R. (2017). Removal of precursors and disinfection by-products (DBPs) by membrane filtration from water; a review. *Journal of Environmental Health Science and Engineering*, *15*(1), 25. https://doi.org/10.1186/s40201-017-0285-z

89. Zhao, X., Liu, J., Liu, Q., Tillotson, M. R., Guan, D., & Hubacek, K. (2015). Physical and virtual water transfers for regional water stress alleviation in China. *Proceedings of the National Academy of Sciences*, *112*(4), 1031-1035. https://doi.org/10.1073/pnas.1404130112