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Research Paper

Understanding anthropogenic and geogenic controls on major elements of water quality in arid and semi-arid areas in Africa: A review

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ABSTRACT

The global dry-lands constitute a unique ecological system which is primarily characterized by low rainfall, high rate of evaporation and scanty vegetation cover. These in conjunction with environmental and land-use changes, exert heavy pressure on water resources. The objective of this review is to assess the influence of natural geogenic and anthropogenic activities on the hydrochemical composition of streams and aquifers in drier parts of Africa. Water quality studies were scrutinized, in order to identify the natural geogenic and anthropogenic origin of ions in water. Results indicated that the hydrochemical composition of streams and aquifers is controlled by natural geogenic processesas well as anthropogenic activities. Also, the current environmental change has further worsened the water quality situation through declines in annual rainfall with its resultant consequences on the over-abstraction of groundwater aquifers, which has led to saltwater intrusion in coastal aquifers. Thus, it is difficult to separate natural geogenic and anthropogenic controls on water quality. This is because ions that are derived naturally from rock minerals are increasingly being added into the environment through human activities. Hence, the rationality for establishing the origin of ions in streams and aquifers proved to be very difficult. Consequently, water quality results must be interpreted within the framework of the existing environmental conditions, land use types and regularly essential standard application for reporting water quality in the literature.

Key words: Anthropogenic inputs, geogenic processes, groundwater depletionsurface water quality; municipal and industrial sewage, agrochemicals.

INTRODUCTION

Anthropogenic activities such as mining, agriculture, industry and urbanization create pollutant that threatened water quality in arid and semi-arid areas(Jia et al., 2019; Li et al., 2017; Wu and Sun, 2015). Likewise, oxidation of sulfide minerals in mining waste and tailings and geochemical weathering creates a long-term threat to the surface water bodies and the underlying aquifers (Gomes et al., 2018). Contingent on their location and ecological setting, they present opposing chemical, physical and hydrological controls on the fate and transport of pollutants (Geissen et al., 2015). Anthropogenic activities such as agriculture and industry together with mining activities introduce a high level of sulfate and toxic metals, which pose a threat to water quality (Gomes et al., 2018; Jia et al., 2019).The generation of pollutants from the natural geogenic processes through rock weathering and anthropogenic inputs may alter the quality of freshwater sources by introducing contaminants that can render water sources unfit for human, agricultural and industrial use. Because water is a valuable natural resource, understanding the controls on water quality in an arid environment (Kolahchi and Jalali, 2007; Masoud et al., 2016; Wanke and Wanke, 2007), is necessary for the sustainability of the ecosystem, economic growth, human

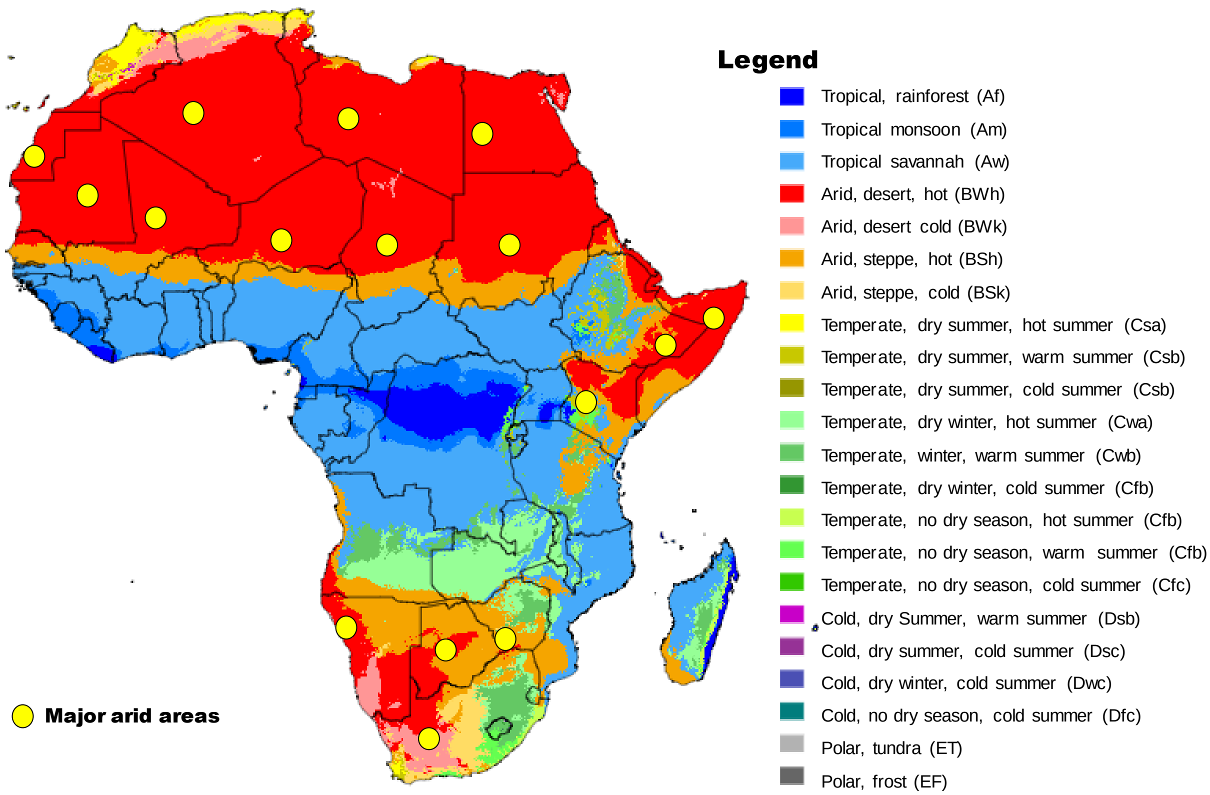

Figure 1: KÖppen-Geiger climate classification maps at 1-km resolution, Scientific Data 5:180214, doi:1038/s data.2018.214(2018). Retrieved from https://scholar.google.com/ on 29/4/2019.

health and wellbeing. Global environmental change, for instance, will result in fluctuations of rainfall, water shortages, high frequency of flooding and drought (Phillips, 2016). Accordingly, these would impact the agriculture and the livelihood in arid and semi-arid areas around the world. The surface and groundwater networks would be threatened due to improper sewage disposal from industry, urban areas and application of agrochemicals in irrigation fields (Lerner and Harris, 2009). Therefore, thorough analyses of the hydrochemical composition of surface and groundwater in arid and semi-arid areas are required for sustainable water use and protection of water sources from contamination, under extreme climatic conditions, which threatened the availability and quality for water in these areas(Gomes et al., 2018; Mahlknecht et al., 2018; Xue et al., 2016).

Before harnessing water sources for human, agricultural and industrial uses, it is essential to understand the tailings dissolution, hydrogeochemical reactions, types of human activities and transportation of effluents in surface and groundwater in response to environmental change (Egboka et al., 1989; Zhu and Schwartz, 2011). Understanding how climate interacts upon human activities in dry-lands is essential for management of water resources to meet the societal demand (Abbaspour et al., 2009; Piao et al., 2010; van Dijk et al., 2013). Therefore, understanding water quality is required as it provides the bases for a healthy living. However, water quality is potentially extremely vulnerable to rainfall fluctuation (or climate change) (Bucak et al., 2018; Woodward et al., 2016). This is particularly desirable owing to the exacerbation of the interactions already happening in the local environmental systems, as well as the development of new interactions concerning human systems and their subsequent impact on availability and quality of water sources. High concentrations of ions in surface and groundwater threaten human health and constitute a high priority environmental concern worldwide, especially in arid and semi-arid countries in Africa such as Western Sahara, Mauritania, Morocco, Algeria, Libya, Egypt, Sudan, Chad, Niger, Mali, Namibia, South Africa, Botswana, Northern part of Nigeria, Northern Burkina Faso, Northern Guinea, and Eastern Ethiopia (Figure 1). In these countries, there is a continuous shift from surface to groundwater, consequent of climate/environmental change (drought). Understanding the quality status of surface and groundwater is an essential step towards efficient water resources management. Currently, the hydrochemical characteristics of surface and groundwater in arid and semi-arid areas, are extensively reported (Acworth et al., 2016; Adelana et al., 2008; Adimalla et al., 2018; Alarcon-Herrera et al., 2013; Amare et al., 2018; Ammar et al., 2017; Bretzler et al., 2018;

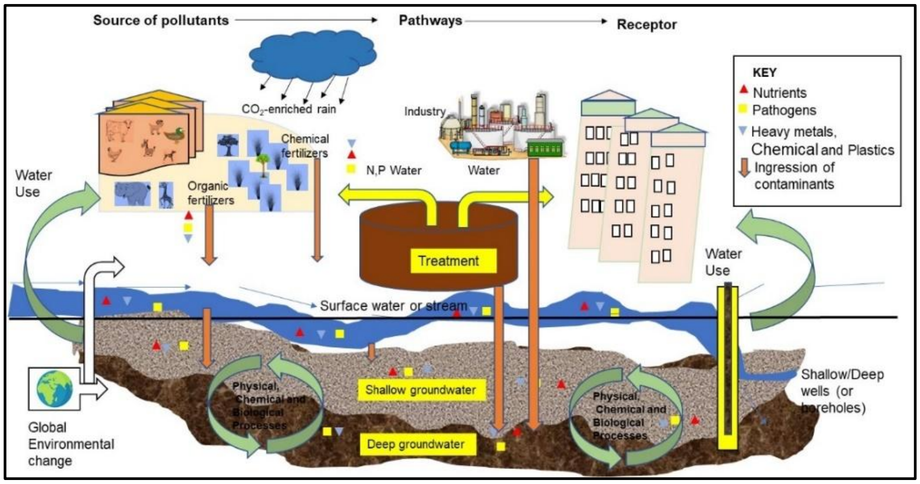

Figure 2: Natural geogenic and anthropogenic controls on water quality. After Andrade et al. (2018)

Carlson et al., 2011; Chamtouri et al., 2007; Chaves et al., 2019; Dehbandi et al., 2019; El Alfy et al., 2017; Gutierrez et al., 2018; Hammouri et al., 2016; Jalali, 2008; Karroum et al., 2017; Lamontagne et al., 2005; Masoud et al., 2016; Murgulet et al., 2016; Newman, 2019). Results from these studies showed the influence of both the natural geogenic and anthropogenic processes on water quality. Also, these studies have helped the advancement of relevant fields in hydrogeochemistry, making it a valuable tool in water contamination control and management of water resources. It is against this background that this review aimed at identifying the primary controls on water quality in arid and semi-arid areas in Africa.

CONTROLS ON WATER QUALITY

The global freshwater budget is strongly influenced by ecosystem's water availability, storage, biophysical and geochemical processes that modify the hydrochemical composition of surface and groundwater over different ecological systems(Bernal et al., 2018; Fekete et al., 2002; Niinemets et al., 2017; Safeeq and Fares, 2016; Stanley et al., 2012; Wood et al., 2011). While dissolved oxygen from atmosphere represents a fundamental source of hydrogeochemical processes in water bodies(Cirelli, 2004; Puntoriero et al., 2015; Rose and Long, 1988), rock weathering (Reimann et al ., 2009; Shiller and Mao , 2000; Singh et al ., 2007; Singh et al ., 2005), and anthropogenic activities(Hudon and Carignan , 2008; Mendiguchía et al ., 2004; Wu et al., 2009)also constitute major components of global hydrochemical cycle. Though surface water bodies are typically effluents collectors at basin scales (Chang, 2008; Petelet-Giraud et al., 2009; Shen et al., 2015), groundwater aquifers are also the dominant recipient of contaminants from surface water (Bakyayita et al., 2019; Kibuye et al., 2019; Lehosmaa et al., 2018). Therefore, it is quite challenging to understand the role of surface and groundwater in the global freshwater budget, because of large disparities found in bottom-up and top-down estimates of interaction between surface and groundwater (Cuthbert et al., 2019; Grogan et al., 2017; Marruedo Arricibita et al., 2018). This is particularly the case for arid and semi-arid areas, where inundation, soil moisture, precipitation and temperature are incredibly variable. Hydrochemical transformation in rivers and groundwater aquifers in dry-lands present a thought-provoking topic(Cartwright et al., 2019; Kattan, 2018; Szczucińska et al., 2019), owing to difficulties involved in understanding the interaction between surface and groundwater and biogeochemical processes in rivers and groundwater (Figure 2).

While pollutant wash-off, municipal and industrial sewage, agriculture and mining dominate pollutants pools (Shajib et al., 2019; St-Hilaire et al., 2015), streams and catchments, floodplain flows and infiltration of water during and after rainfall event dominate pollutant source to groundwater aquifers(Bonneau et al., 2017; Kløve et al., 2017; Vrzel et al., 2018). Even though, the interaction between surface and groundwater is well deliberated in the literature (Cuthbert et al., 2019; Freitas et al., 2019; Fuchs et al., 2019; Hokanson et al., 2019), yet why the hydrochemistry of surface and groundwater is so diverse in arid and semi-arid environments? The status and knowledge of Africa's freshwater sources in arid and semi-arid areas have increased recently with a greater understanding of their distribution, hydrogeochemical and anthropogenic controls. Though considerable amounts of research were undertaken in Africa's dry-lands, most of these studies focussed on specific hydrochemical evaluations such as the impact of climate, land use, urbanization, the industry as well as the natural biogeochemical and physical processes (Table 1).

Table 1: Example of literature reports on natural geogenic and anthropogenic controls on water quality in arid and semi-arid areas in Africa.

S/no	Country/region	Objectives	Natural controls	Anthropogenic controls	Reference
S1	Khenchela City (Eastern Algeria	To determine the quality of groundwater supply meant for drinking in Khenchela city.	Water mineralization and a surplus of organic minerals contents.		Benrabahet al. (2016)
S2	Ain Azel plain (Algeria)	Application of multivariate statistical methods to groundwater quality analysis.	Rock weathering		Belkhiri et al. (2010)
S3	Northern Gafsa basin Central Tunisia	To classify the main recharge zones, the groundwater condition, the mineralization and the effect of changing the climate on groundwater.	Geogenic processes		Mokadem et al. (2016)
S4	Chtouka-Massa, Morocco	Effect of over-abstraction, drought, intrusion of saltwater on quality and availability of groundwater.		The water table was exposed to a gradual decline	Malki et al. (2017)
S5	Bahira plain, Morocco	To describe the chemical characteristics of the groundwater and to evaluate the processes governing the groundwater composition.	Evaporation and water-rock interaction		Karroum et al. (2017)
S6	Poura, Burkina Faso	Impact of high geogenic arsenic (As) levels (>10 mg/L) stemming from the sulfide minerals oxidation minerals in mineralized regions.	The proximity to mineralized regions		Bretzler, et al. (2017)
S7	Northern Morocco	Surface water quality and toxicity of contaminated Rivers.		Industry and urbanization.	Koukala et al. (2004)
S8	Murzuq basin, SW Libya	Evaluation of quantity and quality of irrigation water.		Improvement in the efficiency of water use	Shaki and Adeloye (2006)
S9	Bou-Areg, NE Morocco	To determine the primary factors and mechanisms controlling the groundwater chemistry and salinity of the unconfined aquifer.	Salinization in both the littoral and the upstream areas, and the dilution of groundwater by recharge		Yaouti et al. (2009)
S10	Bou-Areg, North Morocco	To identify the key processes initiating groundwater salinization.		Agricultural return flow	Sacchi et al. (2009)
S11	Souss Basin, Morocco	To identify the chemical characteristics and the origin of groundwater.	Rock weathering		Dindane et al. (2003)
S12	Cap Bon Peninsula Tunisia	Variation in quality of groundwater in a coastal aquifer.		Susceptibilities to human activities.	Charfi et al. (2013)
S13	Tazoghrane, Tunisia	To identify the sources and processes that affects the groundwater composition.		Farming activities	Moussa et al. (2014)
S14	Nouakchott, Mauritania	Impacts of climate change and human activities on groundwater resources		High abstraction and absence of wastewater nets	Mohameda et al. (2017)
S15	Niamey, Niger	Qualitative and quantitative depiction of surface water, groundwater, and aggregates.		Local singularities of contamination	Lasagna et al. (2015)
S16	N'djamena Chad	To examine the water quality of River Nile at Rosetta branch and five main drains located on its sides.		predisposition to drains ejection	Kadjangaba et al. (2017)

Table 1: Cont

S17	River Nile, Egypt	Assess chemical and biological pollution.		Anthropogenic contamination issues are frequent	Ezza et al. (2012)
S18	Bamako, Mali	To characterize the recharge and factors controlling the quality of groundwater.		Susceptible to contamination during the recharge time.	Orange and Palangié (2006)
S19	Ain Azel plain, Algeria	We are defining the main controls on the hydrochemistry at the direct scale.	Rock weathering		Belkhiri et al. (2010)
S20	Tahoua, Niger	Evaluation of quality of groundwater in parts of Tahoua region.	Weakly mineralized water due to decreased recharge		Ikpokonte et al. (2007)
S21	Nyos, Cameroon	To characterize the recharge process of the shallow groundwater leaking in the splintered rock.	The speedy circulation and the truncated solubility lead to little mineralization.		Kamtchueng et al. (2015)
S22	Sétif, Algeria	Assessment of temporal variations of quality of surface water.	Salinization and organic pollutants		Bouguerne et al. (2017)
S23	Ain Azel, Algeria	To highlight the hydrochemical processes of groundwater.	Rock weathering		Belkhiri et al. (2012)
S24	Ain Djacer, Algeria	Impacts of onsite wastewater ejection structures on the groundwater aquifer.	Salinization based on flow direction		Bencer et al. (2016)
S25	Sfax, Tunisia	Assess water-rock interaction and geochemistry of groundwater.	The consumption of CO_2 and dissolution of rock mineral.	Increased urban groundwater levels and anthropogenic pollution	Chamtouri et al. (2008)
S26	Kankara, NW Nigeria	To determining groundwater geochemical facies and suitability of water for drinking.	Water–rock interaction t stimulates of groundwater composition.		Abusu (2019)
S27	Kano, Nigeria	To examine the level of groundwater pollution.		Domestic, industrial and agricultural effluents	Amoo et al. (2018)
S28	Katsina, Nigeria	We are assessing the Groundwater quality in Basement complex formation.	Natural filtration process		Danhalilu et al. (2018)
S29	Sokoto, Nigeria	To determine water quality using standard methods.	Seasonal variability		Raji et al. (2015)
S30	Qus City, Upper Egypt	Possible effects of groundwater and surface water pollution in an urban zone.		Urbanization	Abdalla and Khalil (2018)
S31	Ethiopian Aquifers	Assess the hydrogeological framework and occurrence of groundwater in the Ethiopian aquifers.	Geologic influence/ rock weathering		Ayenew et al. (2008)
S32	Kadugli, Sudan	To assess the ^{238}U, ^{226}Ra, ^{222}Rn, and ^{232}Th activity concentrations	Rock weathering		(Osman et al., 2008)
S33	Windhoek aquifer, Namibia	Impact of human activities on soil and groundwater quality.		Industrial pollution	Mapani and Schreiber (2008)
S34	Semi-arid Kalahari of Botswana	To determine recharge conditions, and to define the regional scale hydrogeochemical evolution of groundwater.	Mixing between aquifers		Stadler et al. (2010)
S35	Bangui, Central African Republic	Assessing the type and quality of the groundwater resources of the Bangui region of the Central African Republic.	Water table depth		Djebebe-Ndjiguim, et al. (2013)

Natural geogenic controls

Studies on water quality carried out in North Africa such as Dindane et al. (2003); Yaouti et al. (2009); Benrabah et al. (2016); Belkhiri et al. (2010); Karroum et al. (2017); Bretzler et al. (2017); and Karroum et al. (2017), indicates that the natural geogenic processes such as rook weathering, water mineralization and surplus of organic minerals contents, evaporation and water-rock interaction, proximity to mineralized regions, salinization in both the littoral and the upstream areas, and the dilution of groundwater by recharge are the dominant mechanisms controlling water chemistry in Algeria, Tunisia, Morocco and Libya (Table 1). Similarly, in East Africa, natural geogenic processes were reported from Ethiopia and Sudan (Ayenew et al., 2008; Osman et al., 2008). In Tahoua, Niger (West Africa), weakly mineralized water due to decreased recharge was observed by Ikpokonte et al. (2007), perhaps driven by reduced precipitation (climate change). Also, in Northern Nigeria, in Kastina, Kankara and Sokoto water quality is significantly influenced by the infiltration process and seasonality (Amoo et al., 2018; Danhalilu et al. 2018; Abusu, 2019). A similar condition was reported from the Central African Republic and Chad by Djebebe-Ndjiguim et al. (2013); and Kadjangaba et al. (2017). In the southern part of Africa, for instance, in Botswana mixing between groundwater aquifers was discovered by Stadler et al., 2010). The significant difficulty related to the study of rock weathering using dissolved load in-stream is that lithology is the primary control of solute chemistry and that stream. This is also influenced by evaporite and carbonate weathering. Consequently, the only active physical weathering of continental rocks appears to be able to sustain high chemical weathering rates and actual rates of CO2intake (Gaillardet et al., 1999). However, a variation of water quality in coastal aquifers in Tunisia, indicate susceptibilities to human activities (Charfi et al., 2013).

Anthropogenic controls

Anthropogenic activities such as agriculture, industry, mining and urbanization exert influence on water in arid and semi-arid regions. For instance, in Morocco, over-abstraction of groundwater consequent of drought, which led to intrusion of saltwater and water table declines in aquifers (Malki et al., 2017). Also, groundwater quality was further impaired by agricultural activities in Morocco (Moussa et al., 2014). In Nouakchott, Mauritania, the impacts of climate change and human activities result in over-abstraction of groundwater. This, coupled with a dearth of wastewater disposal networks, has led to the degradation of water quality (Mohameda et al., 2017). In Qus City, Upper Egypt urbanization has significantly impacted water quality (Abdalla and Khalil, 2018). The account of recharge and factors controlling groundwater quality showed that aquifers are susceptible to pollution during recharge period, as contaminants of anthropogenic origin are added into aquifers by in filtering surface water (Orange and Palangié, 2006). Conversely, in Windhoek aquifer, Namibia, industrial pollution was the major influential factor controlling groundwater quality (Mapani and Schreiber, 2008). A similar, condition was observed by Amoo et al. (2018), in Kano, Northwestern Nigeria. Overall, the natural geogenic processes, seasonality, environmental change and other forms of human activities such as industry, agriculture, mining, and urbanization appeared to be the key factors controlling water quality, in arid and semi-arid areas in Africa. The impact of anthropogenic activities on water quality includes the introduction of ions that are naturally derived from rock-minerals into streams and aquifers. This can best be evaluated through the analysis of physical andchemical elements of water quality.

The physical elements

pH, Eh, acidity, temperature and electrical conductivity

Physical parameters such as pH, Eh, temperature and electrical conductivity (EC) are the main parameters used in water quality analysis. For instance, pH is essential for the reason that it is used to classify water as neutral, alkaline or acidic. In this review, pH synthesis from showed at least 33/35 of studies had attempted some pH analyses. If possible, the pH level in drinking water should not be greater than 8; though, lower-pH water (~7 or less) is more likely to be corrosive (WHO, 2011). At least 3/35 studies have pH less than 6.5, whereas, the remaining 33/35 studies have pH less than 8.5. Therefore, it can be inferred that freshwater sources in arid and semi-areas are relatively neutral-alkaline. Similarly, redox potential (Eh) is a measure of the ability of water to receive or denote electrons (Søndergaard, 2009). In water quality studies it is typically employed to describe the oxidizing or reducing capacity of a river or an aquifer, naturally in an anoxic or close to the anoxic setting as, for instance, the surface sediments of the lake, stream, marine, or estuarine environments (Søndergaard, 2009).

Changes in the Eh as, for instance, within the sediment-water boundary of ponds where the rate of O2 is high, are significant for the total holding and release of phosphorus (P) from iron. While both pH and Eh are essential parameters for understanding water quality, the latter can be ignored from multivariate statistical analysis to avoid peculiarity with pH in response to near-perfect correlation (Lin et al., 2012). This perhaps explained the poor reporting of this parameter in water quality studies from Africa. Conversely, 12/35 studies have measured temperature. Examination of temperature is essential during water analysis since the variability of temperature can be very critical, especially where biochemical reactions are concerned. An increase of temperature by 10oC in streams or aquifers may lead to doubling of chemical reactions (EPA, 2001; Wali. et al., 2018). Likewise, the solubility of gasses, ion exchange capacity, redox reaction, sorption processes, complexation, speciation, EC and pH level are all affected by variations in temperature (Ngabirano et al., 2016). The significance of easily achieved measurements of conductivity is apparent using EC, as this parameter is related to the ionic content of the water sample, which is derived from the dissolved ionizable solids absorption. Even though a certain amount of the dissolved solids will not be ionized for several surface glasses of water, the following calculation will apply:

EC (μS/cm) x 2/3 = TDS (mg/l)

In water samples derived from a source which is frequently tested, a rapid EC analysis may be a suitable replacement for other longer determinations.Studies that measured EC exclude S3, S19, S20, S22, S24, S25, S28, S31, S32, and S33, indicative of the extent to which EC has been reported. In arid and semi-arid areas, EC is widely tested during water quality analyses, which provide an alternative measurement of salinity (EPA, 2001).

Total dissolved solids, total hardness, turbidity and salinity

Consequently, salinity was poorly reported. Possible reasons may be that EC measurements are used in place of salinity. The significance of salinity in water quality analyses is well discussed in the literature (Foster et al., 2018; Graham et al., 2006; Rivett et al., 2019). The TDS is also poorly reported (5/35).Natural sources of drinking water having TDS concentrations <500 mg/l are considered essential for drinking (Wali. et al., 2018). Total hardness (TH) on the other hand, was reported by S5, S7, S26, S29, and S31. Sources of freshwater having TH <75 are classified as soft, 75-150 (moderately hard), 150-300 (hard) and above 300 (very hard). Based on a few reports on TH, it will be challenging to make any inference relating to the range into which hardness is likely to fall in water sources from dry-lands of Africa. Alkalinity is also poorly studied (5/35). Possible reasons for low reporting of alkalinity may include pH measurements, since pH value >7, denotes alkaline condition (Wali. et al., 2018). The significance of assessing turbidity is as a result of the adverse effects it has on the ecosystem (Parra et al., 2018; Tai et al., 2012).

Biological oxygen demand, chemical oxygen demand and dissolved oxygen

There are few reports of BOD (S17, 21 and 28) and COD (S17, S21, and S28). S29 reported total suspended solids (TSS). Similarly, Soluble Solids (SS) was also poorly reported (S19 and S29), and acidity was captured only by S29. While reports on acidity from arid and semi-arid areas of Africa are relatively scanty, perhaps as a result of pH analysis, which is used as a measure of acidity and alkalinity in water quality analyses, there is increasing studies on acid generation in water bodies, both in arid and non-arid regions around the world (Karimian et al., 2017; Leyden et al., 2016). In water bodies, the volume of DO is affected by the volume of BOD and this result in rapid depletion of oxygen in surface and groundwater thus depleting the volume of oxygen obtainable by aquatic organisms in the water. The general range for BOD in sewage is 100-400 (Thatai et al., 2019). Aquatic organisms are further influenced by DO, which represents a vital parameter to access water quality. The volume of DO in water depends mainly on pressure, salinity and temperature. Reductions in oxygen often accompany the decline in temperature. Also DO decreases consequent of rising salinity and pressure (Thatai et al., 2019). Overall, there is poor reporting of BOD, COD and DO from arid and semi-arid areas of Africa.

Dissolved organic carbon, total suspended solids, soluble solids and acidity

Recently, one of the major concerns arising from increased precipitation is the quantity of DOC that flows into surface water. While DOC is primarily derived from terrestrial sources, it enters aquatic ecosystems through the surface, ground and soil waters (Huntington et al., 2019; Warner and Saros, 2019). Changes in rainfall intensity, duration and frequency which are well pronounced in arid and semi-arid regions, in addition to transport by overflow from the watershed to surface water bodies contribute to higher DOC levels in water (Huntington et al., 2019; Warner and Saros, 2019). Of significance concern are solids that will not pass via a 0.45-micron filter which are known as TSS (McCarthy et al., 2012; Simpson, 2017).Despite the weight of soluble solids (SS) in water quality analyses, it is poorly reported. Solids from different sources are dissolved and these contribute to water quality degradation, especially in irrigation fields where chemicals like phosphorus (P) are used. Poor management of P fertilization and inefficient irrigation coupled with high permeability of sandy soils may be connected to greater P concentrations in aquifers. Generally, the higher the level of P concentration in an aquifer, the closer the solution is to equilibrium about the more soluble calcium-phosphate minerals (Jalali, 2008).

Cation chemistry

Calcium, Magnesium, Sodium, and Potassium

Calcium (Ca), Magnesium, Sodium (Na) and Potassium (K) constitute the major cations reported in water quality studies. At least 33/35 studies have reported on Ca, Mg and Na, whereas, 32/35 studies have assessed K, indicative of broader reporting of these elements. Elevated Ca in drinking water is beneficial, but excessive concentration is often related to hardness (Wali. et al., 2018). Contingent on pH and alkalinity, total hardness (TH) above 200 mg/l can lead in scale deposition, mainly on heating. Soft waters with a TH level less than 100 mg/l tend to have a low buffering capacity and maybe more eroding to water pipes. However, there are some signs that very soft waters may harm mineral balance (Wali. et al., 2018). Potassium is not restricted in drinking water, though high ingestion may lead to health risk. While it is an indispensable element of many non-natural fertilizers, it is controlled in lakes when the assessment of nutrients consequence is being carried out. Naturally, Na concentration in freshwaters is low. Even though it is a nutritional requirement, it is imperative to regulate Na in drinking water for the reason that it exercises combined effects with SO4 (Wali. et al., 2018). Magnesium is an important water quality parameter for the fact that it is the second major component of hardness (CaCO3). As a result of the central role played by these elements, it is often difficult to ignore these elements in any water quality analysis. More details on the significance of Ca, Mg, Na, and K is fully discussed (EPA, 2001, 2014; NSDWQ, 2007; WHO, 1997, 2006, 2008, 2011, 2018).

Aluminium, Boron, Bromine and Cobalt

There is poor reporting of Aluminium (Al), Boron (B), Bromine (Br) and Cobalt (Co) from arid and semi-arid areas in Africa. Only 8.6% (3/35) of the studies have measured Al. Boron was captured by only two studies (S6 and S10). Bromine was reported by S5, S6, S10, and S14. S5, S6, and S17 reported cobalt. While Al is the most widely distributed element and constitutes 8% of the Earth's crust, it is limited to 0.9 mg/l in drinking water (WHO, 2018). The increasing rate of Al uses as in water purification as coagulants to lessen organic matter, colour, turbidity and microorganism levels have led to increased rates of more Al ingestion by humans. Many health studies have linked increased Al exposure to vagaries related with brain ageing and neuro deterioration - Alzheimer's disease (Bondy, 2014; Flaten, 2001; Srinivasan et al., 1999; Wang et al., 2016). Naturally, Br is found in groundwater, but its occurrence in the surface water is often a consequence of the ejection of treated sewage effluent, in which it is derived from the use of detergents, soaps and flame retardants. The provisional reference value is 0.5 mg/l (WHO, 2008). Although detailed evidence on effects of high Br ingestion in drinking water is lacking, the only available data showed that severe exposure is related with short-term irritant effects of the upper respiratory tract (Yazbeck et al., 2005). During decontamination of water that holds bromide ions and organic matter, brominated acetic acids are formed. These ions mainly exist in water distribution networks at an average concentration >5 mg/l. The significance of Br analysis lies with the fact that both aqueous chlorine (HOCl/OCl-) and bromine (HOBr/OBr-) react with organic matter during water treatment (Westerhoff et al., 2004).S6, S7, and S17 reported cobalt (Co). This element occurs primarily in ores. Cobalt is also found in water as a result of sewage discharges. Due to the low level of occurrence, this element is of little significance in water quality analysis. The lack of reference value for Co reflects the negligible hazard and perhaps, this could explain why Co is not well reported from the arid and semi-arid areas of Africa. However, the determination of Co during water analysis may be demanding (Hu et al., 2002; Qiu and Zheng, 2009).

Copper, Cadmium, Iron^{++} and Iron^{+++}

Copper is reported by S6, S7, S17, S18, and S33. Copper is both an indispensable nutritional requirement and a drinking-water contaminant (WHO, 2018). Copper is limited in drinking water (2 mg/l) because unfriendly tastes can occur at concentrations above one mg/l. The Cu concentrations in natural water vary between ≤ 0.005 to > 30 mg/l, chiefly due to the corrosion of interior copper plumbing. Mean Cu levels were above the WHO reference value in Burkina Faso, Morocco and Namibia. The underlying reasons for high Cu in these countries remain at large and whether this applies to other countries in dry parts of Africa is still poorly known. Cadmium was reported by S6, S7, S17, and S27, implying that only 11.4% of water quality studies in dry regions of Africa have measured Cd concentrations in water. Although Cd is primarily derived from rock mineral, this metal is continuously added into the environment by the steel industry and in plastics. Also, Cu compounds are extensively used in batteries. Sewage and diffuse pollution caused by pollution from fertilizers and local air pollution are significant drivers of Cd in water bodies. The concentration of Cu is limited to 0.00 mg/l in drinking water, as high ingestion may be associated with kidney disease (Panhwar et al., 2016). There is also poor reporting of iron. Only S34 measured the Fe2+ which represents the soluble (or reduced) ferrous. However, Fe3+ was reported by nine (9) studies. Iron in natural waters is found at concentrations ranging from 0.5 to 50 mg/l. This element is limited in drinking water (2 mg/l), as a result of problems related to the taste and appearance of water below this level (WHO, 2011). Iron is primarily derived from rock minerals under reducing conditions, sewage ejections and acid drainage (EPA, 2001). Consequently, large amounts of iron may be present in aquifers (EPA, 2011).

Fluorine, Lithium, Silicon, and Vanadium

Studies on fluorine (F) are relatively scanty. This element is widely distributed on the Earth's crust and occurs in the form of fluorides in many minerals such as fluorapatite, cryolite, and fluorspar. Drops of fluorides are available in several water bodies, having elevated levels often related to groundwater aquifers. Groundwater may contain up to 10 mg/l of fluoride, even though much higher levels can be found. In aquifers, concentrations vary with the type of rock mineral but then do generally not surpass 10 mg/l. This element is regulated in drinking water (1.5 mg/l) because epidemiological studies show that at a level above 1.5 mg/l (WHO, 2018), there will be an increased risk of developing dental fluorosis and that increasingly elevated levels in drinking water may lead to high risks of skeletal fluorosis. Lithium (Li), is seldom reported by water quality studies. Surface water usually contains only 3 ppb, although Li levels in aquifers may vary between 0.05 to 1 mg/l. Lithium analyses are mostly carried out under epidemiological studies relating Li ingestion to dementia and suicide mortality (Helbich et al., 2015; Kessing et al., 2017; Vita et al., 2015). Primary anthropogenic source of Li in the environment is through batteries. Currently, no reference value for Li was proposed. Reports on Silicon (Si) in drinking water are also few. After O2, Si is the most abundant element on the Earth. Substantial quantities of Si are present in many parts of the world and it is available in oceans and both surface and groundwater as silicic acid. These compounds are derived from slow dissolution of silica in water. Silicon is further added into the environment from anthropogenic sources (industrial wastes and tip-head leachates). Currently, there is no proposed guideline value for Si. Most studies on Si are related to borne status in human and animals (Choi and Kim, 2017; Sgavioli et al., 2016). Synthesis of Vanadium (V) showed that the element is poorly reported in the literature. Vanadium is abundant in rocks and minerals. The health significance of high V ingestion is related to some objectionable physiological effects such as ear, nose and throat irritation, but no risk of significant concern in drinking water. While V is naturally found in large quantity, a relatively substantial amount of V is added into the environment from industrial sources and other related human activities. Currently, there are efficient methods for V decontamination or removal in drinking water (Chiavola et al., 2019; Roccaro and Vagliasindi, 2014).

Manganese, Molybdenum, Nickel and Strontium

Studies on Mnare relatively low in the literature (6/35). Manganese is an extensively dispersed component of ores and rocks (EPA, 2001). Ingestion of Mn via drinking water is limited to 0.1 mg/l, as Mn levels above 0.1 mg/l in water supplies may cause an objectionable taste and stains sanitary ware and laundry. However, Mn has no specific toxicological implications; the objections to Mn, like Fe, are aesthetic and this may explain the poor reporting of Mn in the literature. The primary sources of Nickel (Ni) in water are minerals and industrial wastes. This element is restrained in drinking water (0.07 mg/l), because of probable carcinogenicity as far as humans are concerned. This element is of little environmental concerned as such water quality studies poorly report it. Similarly, Mo and Sr are not well reported in the literature. The Mo concentrations in potable water are typically < 0.01 mg/l, yet concentrations as high as 0.02 mg/l have been informed in areas near mining sites (WHO, 2018). While Sr is an alkaline earth metal which has high reactivity and mobility, data on Sr concentration in drinking water is scarce. In most natural systems, Sr level tends to be very low. The guideline proposed value is 0.03 mg/l. Very scanty data on Sr removal from drinking water is available. Consequently, there is an instant need for treatment facts (O'Donnell et al., 2016).

Arsenic, Zinc, Selenium and Tin

Arsenic generally exists in natural waters at levels below 0.01-0.02 mg/l. However in streams or aquifers having sulfide mineral formations and sedimentary rocks driven from volcanic rocks, the concentrations can be high. A significant reason for regulating arsenic in drinking water is that excessive ingestion may be linked to some forms of cancer (Brahman et al., 2016).Zinc was reported by S6, S7, S17, S27, and S32. High Zn concentration can be toxic to aquatic animals. At concentrations ranging from 3 to 5 mg/l, water may look opalescent and can form an oily film after boiling (EPA, 2001; Wali. et al., 2018).Water quality studies hardly report selenium and Tin. Selenium occurs in Earth's crust and often in connection with sulfur-containing minerals. While it is an essential trace element found in foodstuffs, Se levels are limited to 0.04 mg/l. High ingestion of inorganic selenium through drinking water may be dangerous to the human and long term exposure may be related to some forms of cancer (Vinceti et al., 2016). Tin is primarily derived from ores, sewage from Tin-plating and Alloy production. It is typically found in low concentrations in water and only in trace concentrations. No standard reference values have been proposed for Sn. While these parameters can be toxic, their concentrations in natural water systems tend to be very low.

Lead, Barium, Lanthanum and Uranium

Studies reporting Pb include S6, S7, S17, S19, S23, and S33. Lead is regulated because of the risk of poisoning in children. While the element is derived naturally from ores, there is an increasing risk of lead exposure via drinking water from old pipes (Harvey et al., 2016). Studies on Ba are also insignificant 2/35. Barium is a naturally occurring element derived from ores, which has been mined in many parts of the world. In natural surface water systems Ba concentration is expected to be low as traces of Ba will react with SO4 available to form the exceedingly insoluble barium sulfate. Barium is limited to 0.7 mg/l (WHO, 2011).Uranium is primarily derived in the environment from the leaching of natural deposits. Uranium usually occurs in water in the form of minerals, but at no time as a metal. It is derived in water from effluents from processing plants, leaching from rocks and soil, coal combustion and other fuels, application of phosphate fertilizers that contain Uranium (WHO, 2018). Uranium ingestion through the air is considered insignificant and studies have shown that ingestion through food varies between 0.001 and 0.004 mg/day. Likewise, ingestion through drinking water is tremendously low; though, in environments in which uranium is existing in sources of drinking water, the ingestion is large via drinking-water. Lanthanum is mainly occurring in rock and soil deposits. This element has a tremendously truncated solubility in water. Lanthanum is added into the environment as the zeolite catalysts applied in the petroleum industry since they calm the zeolite at extreme temperatures. It is also used in significant amounts in rechargeable batteries made from nickel-metal hydride. No guideline value is proposed by for this element.

Argon, Chromium, Thallium and Tungsten

Argon (Ar), Chromium (Cr), Thallium (Tl) and Tungsten (W) is occasionally reported in water quality analyses. Argon occurs in water by radioactive decay of the 40K isotope in several potassium minerals. The health and sanitary significance of Ar is mostly unimportant. Consequently, this element is not well captured in water quality studies. Data on Cr is also scarce (S6 and S7). It is naturally derived from ores, but Cr arises in surface water through effluents discharges from dyeing plants, paint, textile, tanning and electroplating. Owing to health concerns, 0.05 mg/l was proposed as a guideline value for total Cr concentration in drinking water (WHO, 2011). Assessment of Cr ingestion in drinking water as presented by Naz et al. (2016) showed that the total additive average cancer risk and non-cancer risk (Hazard Quotient) was found to be 2.04E-03 and 1.37 in male and 1.73E-03 and 1.16 within the female population, respectively, that indicated 'very high' cancer risk and 'medium' non-cancer risk. Other parameters of little importance in water quality analyses are Thallium (Tl) and Tungsten (W).Their toxicity to humans is measured analogous to that of Pb, Cd or Hg (Ghezzia et al., 2017).To date, studies on the toxicity of W and potential role as a carcinogen has produced varied results (Lemus and Venezia, 2015).

Anion chemistry

Chloride, Sulfate, Nitrate and Bicarbonate

Chloride (Cl) was extensively studied (33/35). The Environmental and health significance of Cl lies with the fact that Cl is derived primarily from soil and rocks mineral, but recent studies show that a large amount of Cl is added to water sources from anthropogenic activities. At levels,>250mg/lin drinking water salty palate will occur. Though, a variation of Cl level by 5 mg/l at one sampling site in comparison with other sites may lead to the suspicion of groundwater contamination from sewage, mainly if levels of ammonia are also raised (EPA, 2001; Wali. et al., 2018). Like Cl, sulfate (SO4) also have received significant attention in the literature (33/35). At elevated levels (>250 mg/l), SO4 is reduced to sulfide, consequently producing noxious odours.Nitrate (NO3), was considerably studied. The significance of NO3 in water quality analyses lies with the fact the NO3 can be derived from anthropogenic sources (manure slurries and chemical fertilizer) since NO3 is derived from the oxidation of ammonia and agricultural fertilizer (EPA, 2001). Similarly, reporting on HCO3 was substantial (30/35). The significance of this element is that when HCO3 and CO3 are joined with Ca and Mg carbonate hardness is formed. Overall, these elements are considerably reported in the literature owing to the central role they play in understanding the sources and processes shaping water chemistry. Even though these elements are primarily derived from ores, there is increasing evidence to show that Cl, SO4, and NO3 are continuously added into freshwater from anthropogenic activities (Gutierrez et al., 2018; Wali. et al., 2018).

Phosphate, Ammonia and Silicon Dioxide

A large amount of PO4 is derived from organic wastes. High PO4 and NO3 in surface water, support plant and algal progressions, subsequently, initiating variation of diurnal blooms, dissolved oxygen and littoral slimes (EPA, 2001; Wali. et al., 2018). Ammonia including both the ionized (NH4) and non-ionized (NH3) originates from industrial, agricultural, and metabolic activities and disinfection with chloramine. Naturally, the concentration of ammonia in surface and groundwater is typically <0.2 mg/l. However, anaerobic aquifers can contain up to 3 mg/l. In surface water, high ammonia levels can be derived from intensive livestock farming. The NH3, which represents the non-ionized ammonia, is reported by S17, whereasS7, S14, and S29 reported NH4. While ammonia levels did not vary considerably in surface water between regions, it varied widely in groundwater as a result of geological heterogeneity (Fu et al., 2012).There were few studies on silicon dioxide (SiO2). Silicon (as silica) is the most copious element available in Earth's crust and it is always available in natural waters. The consequent renewal of silica is mostly derived from runoff. Although there is no proposed guideline value for this element, epidemiological studies have shown that high silica ingestion in drinking water can cause Alzheimer's disease or cognitive impairment (Rondeau et al., 2009).

CONCLUSION

The literature is unanimous on the importance of understanding of the origin of elements in streams and aquifers in drylands of Africa. These areas constitute a unique ecological system which is mainly characterized by low rainfall, high rate of evaporation and low availability of vegetation cover. These, coupled with environmental and land-use changes, exert heavy pressure on the available water resources. There is no doubt that human activities have impacted surface and groundwater aquifers by the introduction of chemical pollutants through irrigation, municipal and industrial water demand, and sewage ejections. Relating literature report with the above drivers of water use and water quality in arid and semi-arid areas of Africa results in the following remarks:

i. The regional outlook of water quality studies in drylands areas of Africa are focusing on the understanding of significant processes controlling water quality from different and their suitability for drinking, agricultural and industrial uses.
ii. Environmental factors such as geology, climate and land use are central to understanding the hydrochemistry of surface and groundwater including those located along with saline coastal environments.
iii. However, the objectives and parameters studied by individual water quality studies are often influenced by the environmental setting, i.e. climate, geology and land use.
iv. These factors have led to the increased exploitation of water sources to provide for the competing demand by agriculture, industry and municipal supplies.
v. Despite the relatively extreme environmental conditions, the current environmental change has further worsened the situation of water quality through declines in annual rainfall or frequent flooding events, which have made it difficult to separate environmental and anthropogenic controls on water quality.
vi. Such factors like drought, rainfall intensification, mining activities and overexploitation of water sources are also highly variable over drylands areas of Africa. They pose a severe hindrance to understanding the significant sources and process shaping the hydrochemistry of water sources.
vii. Further, these problems are manifested in the lack of a universal approach to regional water quality analyses; no standard parameters for evaluating water quality either at the local, basin or regional scale is available.
viii. Some water quality studies in drylands areas of Africa are also driven by epidemiology, geochemistry, environmental sciences, urbanization, agriculture, etc. making parameter selection too specific to address the objective of the study.
ix. Apart from these limitations, water quality studies in African drylands are further characterized by regular analyses of certain elements such as Mg, Ca, Na, K, NO_3, Cl, SO_4, and PO_4, suggesting either the availability of easy field and laboratory methods for analyses, or are prioritized to address certain prevailing environmental conditions.x. Also, most of the analyzed studies, lack a multi-source approach, as most of the water quality studies do not compare surface and groundwater in their analyses. More so, shallow groundwater is seldom integrated for a joint analysis with surface water and deep aquifers.
Consequently, water quality studies are mostly varied both in terms of temporal and spatial scopes as well as their coverage of elements of water quality. While there is significant reporting on water quality in arid and semi-arid areas of Africa, water quality investigations are primarily influenced by the geology, climate, land use and prevailing environmental conditions as well as anthropogenic activities. Therefore the rationality for establishing controls on water quality in arid and semi-arid areas of Africa proof to be complicated. Hence, water quality reports must be interpreted within the framework of the existing environmental conditions, land use types, time and resource constraints and regularly essential standard application for reporting water quality in the literature.

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