Long term hydrochemical analysis and quality assessment of five dams in Lesotho, Southern Africa

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Abstract: Lesotho, is a mountainous country located within South Africa. Water is one of the major export earnings. One of the major dams in Lesotho is called Mohale Dam built at a cost of US$1.5 billion. It has five inflow dams at: Bokoaneng, Bokong, Likalaneng, Jorodane and Senquyanne. There is sparse data on water quality of these dams, hence, data were collected between 2009 and 2012 to monitor and assess the water quality for drinking using these parameters: Na, K, Ca, Mg, electrical conductivity (EC), pH, total hardness (TH) and turbidity. These were compared with the WHO standard for drinking water. Data were analysed using these procedures: means (PROC MEANS) and cluster (PORC CLUSTER) of Statistical Analysis Systems, and trilinear plots/Piper diagram. Results showed that across sites, these variables (i.e. pH, EC, Ca, Na, K, Mg, TH, and turbidity) fluctuated across sites and years and still far lower than the critical limits of the WHO as drinking water quality. The only parameter that was relatively high, when compared to the stringent water quality of APHA, AWA and WEF [25] standard for drinking was the mean turbidity which ranged between 1.32±0.27 (Bokoaneng) and 4.70±1.26 (Jorodane). However, when compared to the WHO [2] standard for drinking water quality of 5.00 NTU [23], it is still acceptable. The Piper diagram classified the water as sulfate-chloride dominated, though when compared to the critical values of WHO limits of 250mg/L (Cl\(^-\)) and 400 mg/L (SO\(_4\)\(^{2-}\)) it is still very low as these values are still ≤ 5 mg/L. As at the time of data collection, there was no source of contaminants. However, the aforementioned values were the highest for a dam located at Likalaneng. As, such, it is imperative that sources of the “seemingly” high values should be identified as this might build up over the years.

1. Introduction
Lesotho lies within Republic of South Africa (RSA) and has a total land area of 30,350km\(^2\) with four agro-ecological zones (AEZ). Most of the land in Lesotho is fragile because of its topography, rainfall patterns, erodibility of its soils and land use patterns. The topography is mountainous with sharp terrains ranging in elevation from 1460 meters above sea level (asl) in the west to 3400 meters above sea level in the Northeast. The country lies within the summer rainfall area of Southern Africa and more than 85% of the annual rainfall occurs in the seven months from

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October to April. Mean annual rainfall range from less than 600mm in the lower Senqu valley to 1000mm along the mountain ranges. Inter-annual variations in rainfall are significant with prolonged dry or wet periods occurring. At higher altitudes, winter nights are very cold and even in the low-lands, frost occurs on over 80 days of the year. In the mountains areas with elevations exceeding 3000m, frost can occur on over 250 days in the year. Water is a resource that Lesotho has in relative abundance. Lesotho's water resources far exceed its possible future requirements, even allowing for possible future irrigation projects and for general development and improvement of living standards. The average total available water in Lesotho is about 150m$^3$/s and current national consumption is not more that 2m$^3$/s [1-2].

There is a close linkage between climate systems and freshwater resources [3-8], as such; climate change (CC) will be a factor that will seriously impact on the quantity and quality of water resources in the sub-Saharan Africa (SSA) and especially Lesotho. Furthermore, CC will affect water availability and the hydrological cycle [9]. Pollution of surface waters is closely linked with human activities of agricultural, urban and industrial sources. Due to increase in the activities of human in these areas, surface water quality can be compromised if care is not taken [10] as well as [11] demonstrated that increase in air temperature in some parts of the world impacted negatively on the water quality. These authors reported that global warming resulted in increased temperature of surface water which resulted in higher nutrient levels, decrease in dissolved oxygen coupled with the enhancement of the growth of phytoplankton. In addition, [11] also reported that seasonal changes in precipitation affected seasonal distribution of stream flows and nutrient loads. In Lesotho, [12] reported that increase in anthropogenic impact on wetlands and stream water quality is increasing the pollutant loads that may end up in major and minor rivers in the country.

In Lesotho, Mohale Dam is the second dam, under Phase 1B of the series of dams of the proposed Lesotho Highlands Water Project (LHWP) built at a cost of US$1.5 billion [13]. Its height is about 145 metres (476 ft); length of 700 metres (2,300 ft) and the dam volume is 7,500,000 m$^3$. There is sparse data on water quality of dams that feed into Mohale Dam. Hence, data were collected between 2009 and 2012 from five dams (i.e. Bokoaneng, Bokong, Likalaneng, Jorodane and Senquyanne). The objective of the investigation was to monitor and assess the water quality of these dams and compare with the WHO standard for drinking water. To identify if any, dam(s) with highest with the water quality parameters.

2. Materials and Methods
2.1 Geology and location of study areas
Lesotho is a small mountainous country located within the Republic of South Africa with a total land area of 30,350 km$^2$. The altitude varies from 1,500 m to 3,482 m. Lesotho is divided into four agro-ecological zones (AEZ) and these are:

- The mountain AEZ which occupies about 59% (or 17,906.50 km$^2$) of the total land area of the country at an elevations of ≥2,000 m above sea level (asl);
- The foothills AEZ covering about 15% (or 4,529 km$^2$) situated at an elevation of between 1,800 m to 2,000 m asl.
- The lowland AEZ covering 17% (or 5,094 km$^2$) and is situated at an elevation of ≤1,800 m; and
- The Senqu River Valley covering about 9% (or 2,690 km$^2$). The Senqu (Orange) River penetrates deep into the Maluti Mountains; elevations vary from mountains to lowlands.

Lesotho is generally underlain by sedimentary rocks (Karoo), igneous (volcanic basalt and intrusive dolerite) and alluvium (figure 1). In addition, the cliff forming Clarens Formation is the youngest of the sedimentary deposits and is prominent as the tan colored cliffs and plateaus of the lowlands. Maseru soil series originate from the Burgersdorf, Molteno and Elliot formations characterized by nearly level to gentle sloping terrain [16].
Figure 1: Location of Lesotho in South Africa and geology

The study was carried out in the Mohale Catchment in Maseru Lesotho. The Catchment carries the Mohale Dam and the stretches of the following rivers: Jorodane (29° 26' 00" S; 28° 07' 00" E); Likalaneng (29° 27' 54" S; 28° 05' 52" E); Bokoaneng (29° 25' 00" S; 28° 08' 00" E); Bokong (29° 28' 50" S; 28° 39' 08" E) and Senquyanne (30° 01' 59" S; 28° 10' 26" E) and it is approximately 938 km² in size. The climate of the site is described as semi-arid and the summer rainfall that is concentrated in seven months from October to April and the mean annual rainfall is 1000 mm (Figure 2).

2.2 Water sampling, preservation and analyses
Water samples were collected into a stopper-fitted polyethylene bottles in triplicates on a monthly basis between 2009 and 2012 into a 500ml (Table 1)
Figure 2: Mean monthly climate data in Maseru, Lesotho (2005-2015)
(Source: http://www.lesotho.climatemps.com/)

The pH and electrical conductivity (EC) were determined immediately after sampling using a portable pH meter (EC-PH5PLS02 K, Eco-scan made).

Table 1: Sampling Dates across months and years

|     | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2009|     |     |     |     |     |     |     |     |     |     |     |     |
| 2010|     |     |     |     |     |     |     |     |     |     |     |     |
| 2011|     |     |     |     |     |     |     |     |     |     |     |     |
| 2012|     |     |     |     |     |     |     |     |     |     |     |     |

Subsequently, the samples were taken to the laboratory, where they were filtered using 0.45millimicron WHATMAN filter paper (No 42) and refrigerated (DEFY fridge, South Africa) at a temperature of 4°C. Water samples were analyzed for chemical constituents such as Na, K, Ca, Mg, Chloride, bicarbonates, carbonates, sulphate, nitrate, total dissolved solids (TDS) in the laboratory using the method recommended by the American Public Health Association [15]. Ca²⁺, Mg²⁺, HCO₃⁻, CO₃²⁻, Cl⁻ and TDS were analyzed by volumetric titrations. Concentrations of Ca²⁺ and Mg²⁺ were estimated titrimetrically using 0.05N EDTA and 0.01N H₂SO₄ was used to determine the concentrations of HCO₃⁻ and CO₃²⁻. The AgNO₃ was used to estimate Cl⁻. The Flame Photometer (Sherwood Model 410) was used to estimate the concentration of Na⁺ and K⁺ ions. The SO₄²⁻ concentration was determined using Atomic Absorption Spectrophotometric (AAS) techniques (Perkin Elmer, 3110). The accuracy of the chemical analysis was verified by calculating ion-balance errors where the errors were generally around 10%. The TDS, major ions are in m l⁻¹, whereas conductivity is given in deci-Siemens per meter (dS/m) and pH in standard units. The Determination of Turbidity was by using Nephelometer (Ecotech- Aurora 2000 Nephelometer) and expressed as Nephelometric Turbidity Units (NTU) [16]. The instrument shines a beam of light through water sample and this measures the amount of light that passes through the water.
compared to the amount of light that reflects off particles in the water. Turbidity can range from less than 1 NTU to more than 1,000 NTU. At 5 NTU, water is visibly cloudy; at 25 NTU, it is murky. The total hardness of the water was calculated using the formula given as:

\[ \text{TH (as CaCO}_3\text{)} \text{ mg/l} = (\text{Ca}^+ + \text{Mg}^+) \text{ meq/l} \times 50. \]

Results are presented only for pH, Ca, Mg, Na, K, Turbidity, and total hardness (TH). However, for the trilinear diagram/Piper, other parameters (i.e. HCO$_3$-, CO$_3^{2-}$, Cl$^-$, and SO$_4^{2-}$) were used. Long term rainfall data (1896-2007) were collected from the Lesotho Meteorological Services.

2.3 Statistical Analyses

Data collected were subjected to descriptive statistics (N, mean, range, maximum (Max), minimum (Min), standard error (SE) and standard deviation (SD) and coefficient of variation (CV) across sites and these were compared with the World Health Organization (WHO) guidelines for drinking water quality [17]. And all these were calculated using the means procedure (PROC Means) of Statistical Analysis System (SAS) [18]. Data across sites were subjected to Cluster analysis using Proc Cluster [19]. The Box plots of the means of the selected water quality variables were generated using Box plot procedure [20]. Water across the five dams was classified using trilinear plots otherwise called Piper diagram. The Piper diagrams or trilinear diagrams [21] are drawn by plotting the proportions (in equivalents) of major cations (Ca$^+$, Mg$^+$, (Na$^+$ & K$^+$)) on one triangular diagram, the proportions of the major anions (Alkalinity (CO$_3^{2-}$+ HCO$_3^-$), Cl$^-$, SO$_4^{2-}$) on another, and then the information is combined from the two triangles on a quadrilateral. The positioning of this plotting will show relative composition of water in terms of the cation-anion pairs that correspond to four vertices of the field [22]. The anions and cations data were used to generate the piper diagrams across the five dams.

3. Results and discussion

The summary statistics of selected chemical properties of the dams sampled between 2009 and 2012 is presented in Table 2 in terms of means, range, maximum, minimum, standard deviations) and these were compared with the WHO guidelines for drinking water quality. Results showed that all the five dams (Bokoaneng, Bokong, Likalaneng, Jorodane and Senquyanne) had contents of pH, Ca, Mg, K, Na, electrical conductivity (EC), total hardness (TH), was lower that the critical limits of the guidelines for drinking water quality (Table 2). The only parameter that was relatively high, when compared to the stringent water quality of Canada standard for drinking was mean turbidity as this value was found to be between 1.32±0.27 NTU (Bokoaneng) and 4.70±1.26 NTU (Jorodane). However, when compared to the WHO [23] standard for drinking water quality of 5.00 NTU [23], it is acceptable. Most natural waters have turbidity of < 50 NTU, but often times, values range from <1.0 to 1000 NTU [24]. When the stringent standard of APHA, AWA and WEF [25], was applied and compared with the reported values for these dams, it showed that the dams contains some dissolved materials (e.g. clay, silts, and finely divided organic and inorganic matter). This must have been the reason why the dam in Jorodane has slightly elevated levels of 4.70 NTU. An increase in turbidity has been shown to reduce light penetration in lakes and this is associated with decreased production and abundance of plant material (primary production), decreased abundance of fish food organisms (secondary production), and decreased production and abundance of fish [26].
### Table 2: Summary statistics of selected water quality parameters across sites

| Variables | N  | Mean  | Range    | Max    | Min    | Std Dev | Std Error | Desirable Limits* |
|-----------|----|-------|----------|--------|--------|---------|-----------|-------------------|
|           |    |       | Bokoaneng |        |        |         |           |                   |
| Ca (mg/L) | 62 | 6.35  | 13.00    | 13.00  | 0.45   | 4.58    | 0.58      | 75                |
| EC (dS/m) | 63 | 6.19  | 46.60    | 46.60  | 2.56   | 6.58    | 0.83      | 400               |
| K (mg/L)  | 64 | 0.14  | 0.54     | 0.54   | 0.34   | 0.13    | 0.02      | 12                |
| Mg (mg/L) | 62 | 2.13  | 4.20     | 4.20   | 1.23   | 1.54    | 0.19      | 50                |
| Na (mg/L) | 63 | 1.58  | 3.90     | 3.90   | 1.18   | 1.28    | 0.16      | 250               |
| pH        | 63 | 5.55  | 9.45     | 9.45   | 6.8    | 3.83    | 0.48      | 7-8.5             |
| Turbidity | 62 | 1.32  | 14.00    | 14.00  | 0.20   | 2.09    | 0.27      | 0.1-1.0‡          |
| TH (mg/L) | 62 | 24.51 | 47.81    | 47.81  | 0.34   | 17.65   | 2.24      | 100               |
|           |    |       | Bokong    |        |        |         |           |                   |
| Ca (mg/L) | 47 | 7.69  | 11.20    | 16.00  | 4.80   | 1.99    | 0.29      | 75                |
| EC (dS/m) | 46 | 6.76  | 7.12     | 10.53  | 3.41   | 1.83    | 0.27      | 400               |
| K (mg/L)  | 47 | 0.21  | 0.51     | 0.56   | 0.05   | 0.11    | 0.02      | 12                |
| Mg (mg/L) | 47 | 2.48  | 4.10     | 5.40   | 1.30   | 0.76    | 0.11      | 50                |
| Na (mg/L) | 47 | 1.71  | 2.77     | 3.50   | 0.73   | 0.87    | 0.13      | 250               |
| pH        | 47 | 8.17  | 2.56     | 9.65   | 7.09   | 0.56    | 0.08      | 7-8.5             |
| Turbidity | 47 | 1.86  | 12.70    | 13.00  | 0.30   | 2.60    | 0.38      | 0.1-1.0‡          |
| TH (mg/L) | 47 | 29.24 | 37.31    | 54.53  | 17.22  | 7.50    | 1.09      | 100               |
|           |    |       | Jorodane  |        |        |         |           |                   |
| Ca (mg/L) | 46 | 8.92  | 10.20    | 15.00  | 4.80   | 1.88    | 0.28      | 75                |
| EC (dS/m) | 46 | 7.71  | 10.10    | 13.30  | 3.20   | 1.87    | 0.28      | 400               |
| K (mg/L)  | 46 | 0.22  | 0.48     | 0.53   | 0.05   | 0.12    | 0.02      | 12                |
| Mg (mg/L) | 46 | 3.04  | 2.80     | 4.10   | 1.30   | 0.60    | 0.09      | 50                |
| Na (mg/L) | 46 | 2.04  | 3.25     | 3.50   | 0.25   | 0.81    | 0.12      | 250               |
| pH        | 46 | 8.14  | 1.88     | 8.95   | 7.07   | 0.50    | 0.07      | 7-8.5             |
| Turbidity | 46 | 4.70  | 41.75    | 42.00  | 0.25   | 8.55    | 1.26      | 0.1-1.0‡          |
| TH (mg/L) | 46 | 34.62 | 32.13    | 49.35  | 17.22  | 6.70    | 1.00      | 100               |
|           |    |       | Likalaneng |      |        |         |           |                   |
| Ca (mg/L) | 29 | 12.63 | 10.40    | 19.00  | 8.60   | 2.83    | 0.53      | 75                |
| EC (dS/m) | 29 | 9.98  | 19.77    | 21.47  | 1.70   | 3.46    | 0.64      | 400               |
| K (mg/L)  | 29 | 0.21  | 0.38     | 0.53   | 0.16   | 0.11    | 0.02      | 12                |
| Mg (mg/L) | 29 | 4.61  | 3.80     | 6.60   | 2.80   | 1.00    | 0.19      | 50                |
| Na (mg/L) | 29 | 2.44  | 3.85     | 4.60   | 0.75   | 0.87    | 0.16      | 250               |
| pH        | 29 | 8.59  | 2.00     | 9.59   | 7.59   | 0.59    | 0.11      | 7-8.5             |
| Turbidity | 29 | 4.59  | 32.11    | 32.70  | 0.59   | 7.24    | 1.35      | 0.1-1.0‡          |
| TH (mg/L) | 29 | 50.31 | 40.60    | 73.43  | 32.83  | 10.73   | 1.99      | 100               |
|           |    |       | Senquyanne |      |        |         |           |                   |
| Ca (mg/L) | 34 | 7.94  | 7.30     | 12.00  | 4.70   | 1.75    | 0.30      | 75                |
| EC (dS/m) | 33 | 7.27  | 10.56    | 14.62  | 4.06   | 1.76    | 0.31      | 400               |
| K (mg/L)  | 34 | 0.20  | 0.57     | 0.62   | 0.05   | 0.13    | 0.02      | 12                |
| Mg (mg/L) | 34 | 2.59  | 2.80     | 4.20   | 1.40   | 0.59    | 0.10      | 50                |
| Na (mg/L) | 34 | 1.66  | 2.95     | 3.20   | 0.25   | 0.80    | 0.14      | 250               |
| pH        | 34 | 8.06  | 3.07     | 9.55   | 6.48   | 0.70    | 0.12      | 7-8.5             |
| Turbidity | 34 | 1.52  | 6.00     | 6.30   | 0.30   | 1.46    | 0.25      | 0.1-1.0‡          |
| TH (mg/L) | 34 | 30.34 | 29.64    | 47.04  | 17.40  | 6.71    | 1.15      | 100               |
TH= Total hardness; * [23]; ‡ [25] ; [24].
It was also reported [26] that there is a strong relationship between turbidity and the concentration of suspended sediments. The EC values across all the five dams were lower than that recommended for drinking water quality by WHO [17] and the results was consistent with the values reported by [27] for Shashemene, Ethiopia. Thus, the results showed that the water across the five dams were not considerably ionized and has the lower level of ionic concentration activity due to small amount of dissolve solids. Generally, across the five dams considered which are inflow rivers into Mohale Dam, results presented showed that the concentrations of the constituent major cations (K, Ca, Mg, Na) and anions (NO$_3^-$, Sulfate, Cl) are low, though detail information on the latter were not presented. This result is typical for most rainwater resources in industrialized urban areas according to [28]. As such, the concentration of major cations and anions of the five inflow Rivers conform to the standard for safe drinking water as stipulated by the WHO [23].

However, in order to maintain the water quality of these five inflow rivers, it is important for the water quality to be monitored consistently in view of climate change. It is imperative that the community members can also participate at the local level in monitoring of river chemical composition by educating them on the importance of this natural resource in the country as well as the impact the poor water quality can cause over a long period of time. It should also be noted by the authorities of the government (i.e. the Lesotho Highland Water Authority), that water treatment facilities installed on these inflow rivers as well as in Mohale dams are vulnerable both to climatic extremes and to mechanical failure. Hence, these require proactive maintenance, since expertise available to repair them is limited, and delivery of equipment parts depends on seasonally available means of transportation. An observation of box plots of these variables across sites is presented in Figures 3a, b &c. Results showed that though these properties across sites were lower than that of the WHO guidelines for drinking Water quality, the values recorded at a dam called Likalaneng deserves attention. The contents of pH, Ca, Mg, K, Na, electrical conductivity (EC), total hardness (TH) were highest across sites. The reasons for the high values may be associated with the geology of the site. An examination of the graphs of these nutrients across years is presented in Figures 4a, b, c and d.
Figure 3a: Box plots of Turbidity and pH across sites

Figure 3b: Box plots of Ca and Mg across sites
Box Plots of EC (mS/m) across sites

Box Plots of Na (mg/L) across sites

Figure 3c: Box plots of EC and Na across sites
Figure 4a: Yearly contents of selected water quality parameters at Bokoaneng and Likalaneng.
Figure 4b: Yearly contents of selected water quality parameters at Bokong and Senquyanne.
Figure 4c: Yearly contents of selected water quality parameters at Jorodane
The Calcium and EC values were highest across the five years and K was the lowest, though below the WHO guidelines for drinking water quality. The CV of the selected hydrochemical properties considered was low across years and sites (Figures 5a, b, and c).

The concentrations of HCO$_3^-$, Cl$^-$, SO$_4^{2-}$, F$^-$, and TDS were not presented, but these were used in generation of the Piper Diagram (Figures 6a-c). The concentrations aforementioned parameters were low when compared to the WHO limits of 250mg/L (Cl$^-$), 400 mg/L (SO$_4^{2-}$), 1.50 mg/L (F$^-$), and 1500 mg/L (TDS). When the nutrient elements were plotted using Piper diagram [29], results showed that the waters in the five dams were sulfate-chloride dominated, though still lower than the WHO critical limits for drinking water consumption (Table 2). It was reported in the study [30] that, the use of Piper diagram may have some limitations. These authors used Cluster diagram to be able to elucidate the classification of hydrochemical variables. The Cluster analysis classified water in all five dams into three categories: (i) pH and Calcium dominated, (ii), Na, Mg & K and (iii) those with high turbidity. Dams that fall into category I are Jorodane and Likalaleling, those in category II are Likalaneng, Jorodane and Bokoaneng and category III is Likalaneng (Figure 7). The long term rainfall data showed that rainfall amount has been declining over the years (Figure 8). In their study on the impact on climate change on rainfall and temperature [31], it was reported that over Korea, temperature and rainfall had increased by 0.60º C and 9.1% respectively. The slight changes in these two parameters can result in unusual meteorological phenomenon such as drought and flood. In addition, a long-term change in these two parameters according to these authors could influence local water resources as was observed in the declining rainfall (Figure 8) over Lesotho. These could influence the quality of inflow dams as well as surrounding vegetation. Also, declining in the rainfall amount as was observed could also result in untold stress to the aquatic ecosystems [32].
Figure 5a: Coefficient of variations (CV) of selected hydrochemical properties, across five dams.
Figure 5b: Coefficient of variations (CV) of selected hydrochemical properties, across five dams
Figure 5c: Coefficient of variations (CV) of selected hydrochemical properties, across five dams.
Figure 6a: Piper diagram of water quality parameters at Bokoaneng and Bokong.
Figure 6b: Piper diagram of water quality parameters at Jorodane and Likalaneng.
Figure 6a: Piper diagram of water quality parameters at Senquyanne.
Figure 7: Cluster analysis (Dendrogram) of water quality parameters across the five inflow dams
4. Conclusions
Long term data (2009-2012) were collected across months and years for the following water quality parameters - pH, Ca, Mg, K, Na, electrical conductivity (EC) and total hardness (TH). Data analysed showed that these parameters were far lower than the critical levels recommended by the WHO for drinking water quality. Results showed that these five dams were sulfate-chloride dominated, though the values of the aforementioned parameters were still very low when compared with WHO standard. The only dam with seemingly elevated levels across years was Likalaleng, though these values are still lower than the critical levels of the WHO. It is recommended that there is a need to identify the source(s) of these elevated levels which may build-up over the years, hence impacting on the water quality of the main dam – Mohale.

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