HYDROCHEMISTRY OF KUPINDE LAKE AT THE LESSER HIMALAYA IN KARNALI PROVINCE, NEPAL

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ABSTRACT

Hydrochemical assessment of the freshwater lakes provides important insights into the sources of dissolved ions, geochemical processes, and anthropogenic activities taking place in the environment. This study focuses on the assessment of hydrochemistry and water quality of Kupinde Lake, Karnali Province, Nepal. Surface water samples were collected from 24 different locations of the lake in October 2021 and analyzed for 18 different physico-chemical parameters. The pH, temperature, electrical conductivity and total dissolved solids were measured on-site, and concentration of major ions (Ca$^{2+}$, Mg$^{2+}$, Na$^+$, K$^+$, NH$^+_4$, HCO$_3^-$, Cl$^-$, SO$_4^{2-}$, PO$_4^{3-}$, NO$_3^-$), including hardness and free CO$_2$ were measured in the laboratory. The results revealed that lake water was alkaline with abundance of the major ions in the following order: Ca$^{2+}$ > Mg$^{2+}$ > Na$^+$ > K$^+$ > NH$^+_4$ and HCO$_3^-$ > Cl$^-$ > SO$_4^{2-}$ > PO$_4^{3-}$ > NO$_3^-$ for the cations and anions, respectively. The lake water was dominated by Ca-HCO$_3^-$, indicating calcium carbonate dominated lithology in the area. Gibb’s plot and Piper diagram illustrated rock weathering as the most dominant process in controlling the hydrochemistry of the lake basin. The suitability of water for drinking and irrigation was determined using geochemical indices and WHO standards. The results indicated that the Kupinde Lake water could be used for drinking and irrigation purposes in terms of measured hydrochemical variables.

Keywords: Hydrochemical facies, hydrochemistry, multivariate analysis, irrigation parameters, water quality

INTRODUCTION

Wetlands are natural or man-made landscapes like swamps, marsh, fen, lakes, and streams (Keddy, 2010). These areas are located between the terrestrial and aquatic systems and serve as a habitat for birds, amphibians, fish, and reptiles (Bhandari, 2009). Wetlands are unique ecosystems, and they provide a variety of ecosystem services including climate regulation, carbon storage, water reservoirs, runoff containment and flood risk reduction (Cimon-Morin & Poulin, 2018). Wetlands also support a high amount of biodiversity compared to their space by providing a habitat for a diverse range of flora and fauna (Kingsford et al., 2016). Despite their importance, wetlands are disappearing at alarming rates around the world, with up to 71 percent of global wetland area converted to other land-cover types since 1900 (McCarthy et al., 2018).

Wetlands in the Himalayas are suffering from global climate change and rampant development, which are threatening their ecological health (Pant et al., 2021). Specially, the hydrochemistry and water quality of these pristine wetlands has been altered due to human encroachment and contamination of various pollutants including excessive use of various chemical fertilizers and pesticides (Hey et al., 2012). In order to be suitable for a particular use, water must meet a variety of biological, chemical, and physical characteristics (Pfister et al., 2011; Gorde & Jadhav, 2013). In lesser Himalayan lakes such as Begnas and Phewa lakes in Nepal, major ions, such as Ca$^{2+}$, Mg$^{2+}$, and HCO$_3^-$, were found in higher concentrations (Khadka & Ramanathan, 2013; Khadka & Ramanathan, 2021). These major ions are also dominant in high altitude Himalayan Rara lake (Kaphle et al., 2021). There is also evidence that it contains a high concentration of Ca$^{2+}$, Mg$^{2+}$, and HCO$_3^-$ in the Rewalsar Lake in the Lesser Himalaya, India (Gaury et al., 2018). The concentration of major ions in lake water determines its suitability for drinking and irrigation (Gaury et al., 2018, Pant et al., 2021) as well as providing valuable insight into the sources of dissolved ions, weathering, and hydrogeochemical processes (Singh et al., 2016). The chemistry of lakes is influenced by many factors, including rocks and soils in the catchment area, atmospheric gases, aerosols, basin morphology, climate, fauna, and flora in the area, and human activities (Hey et al., 2012; Gaury et al., 2018). The pollution of Himalayan lakes is due to rock weathering and human activities in the catchment (Das & Kaur, 2001; Gaury et al., 2018; Kaphle et al., 2021). Thus, wetland ecosystems are facing the most serious problem worldwide, and impact on water quality is recognized as one of the key environmental issues (Amankwaa et al., 2020).

Nepal occupies 745,00 hectares (5% of the total area) of freshwater ecosystem, which include rivers, lakes, ponds, wetlands, reservoirs, and irrigated rice fields, that support diverse flora and fauna (Sharma, 2008). Hydrochemistry of freshwater lakes, especially in western Nepal, has received
limited scientific investigation. Kupinde Lake is located in the Salyan District of western Nepal and is one of the most popular tourist destinations in the region. The lake’s most significant features are its ecological, religious, and social values, as well as its recreational importance (Sunar et al., 2022). There is ongoing construction and improvement of roads around the lake area, as well as the development of a large tourist complex. In the area, domestic tourists have increased over the past few years due to the improvement of the access roads. As a result, the lake could experience increased anthropogenic impacts, threatening its ecosystem services and unique biodiversity. However, there is no scientific study conducted on the physicochemical characteristics and water quality of the lake. Therefore, in order to understand the hydrochemistry and water quality of the lake, this investigation was carried out. The main objective of the study was to reveal the hydrochemistry and status of water quality for drinking and irrigation in Kupinde Lake, Salyan District, Nepal.

MATERIALS AND METHODS

Study Area
The Kupinde Lake is located in the Salyan District of Karnali Province, Nepal (Fig. 1). It lies 28°24’56.64”N and 82° 3’26.10”E and at an elevation about 1153 m above sea level and 15 km² away from the district headquarters. Salyan District is a hilly area covering an area of 1462 km² with a population of 238,515 (CBS, 2021). The district is bounded by Rolpa on the east, Surkhet and Bardiya on the west, Rukum and Jajarkot on the north and Dang and Banke on the south. The district has a sub-tropical to temperate climate with maximum temperature of 31°C and minimum of 3°C and annual average rainfall is of 1100 mm (Rawal & Joshi, 2022). Kupinde Lake is situated in the south-eastern region of Salyan District and is one of the most popular tourist destinations and natural water resources in the district. It occupies 0.24 km² which is surrounded by forest and agriculture land (Sunar et al., 2022).

Figure 1. Map of the study area showing sampling sites. (A) Map of Nepal showing Salyan district, (B) map of Salyan district showing Kupinde Lake (C), and map of Kupinde Lake showing sampling points.

Sampling and Laboratory Analysis
A total of 24 sampling points were selected from the lake for the spatial analysis of water quality in October 2021. The water samples were collected systematically from the periphery and middle of the lake using a boat. The location of the water sample was recorded with a Garmin e-trex10 GPS (Garmin, Chicago, IL). Water samples were collected in high density polyethylene (HDPE) bottles and were carefully transported and stored under freezing conditions before further analysis. Out of 24 samples, 20 were taken from the periphery and four
were from the inner area of the lake (Fig. 1). The physical parameters like pH, temperature, total dissolved solids (TDS) and electric conductivity (EC) were measured onsite. The other chemical parameters were analyzed in the laboratory as per the standard methods prescribed by APHA (APHA, 2005). Alkalinity (HCO$_3^-$) was analyzed by acid-base titration. Total hardness (TH) and calcium hardness were analyzed titrimetrically using EDTA titration. Magnesium hardness was calculated as the differences between total hardness and calcium hardness. Chloride (Cl$^-$) was determined by AgNO$_3$ titration. Sodium (Na$^+$) and potassium (K$^+$) were determined using flame photometric method. In addition, chemical parameters like ammonium (NH$_4^+$), nitrate (NO$_3^-$), and phosphate (PO$_4^{3-}$) were analyzed by phenate, brucine and stannous chloride method, respectively using UV-visible spectrophotometer in the laboratory at the Central Department of Environmental Science, Institute of Science and Technology, Tribhuvan University (CDES-TU), Kathmandu, Nepal.

1. Sodium absorption ratio (SAR) = \[
\frac{Na^+}{\sqrt{(Ca^{2+}+Mg^{2+})/2}}\]
2. Sodium percentage (Na %) = \[
\frac{Na^+}{(Ca^{2+}+Mg^{2+}+Na^+)}\]
3. Kelly’s ratio (KR) = \[
\frac{Na^+}{(Ca^{2+}+Mg^{2+})}\]
4. Permeability index (PI) = \[
\frac{(Na^+ + \sqrt{HCO_3^-})}{Ca^{2+}+Mg^{2+}+Na^+}\]
5. Magnesium Hazard (MH) = \[
\frac{Mg^{2+} \times 100}{Ca^{2+}+Mg^{2+}}\]
6. CROSS = \[
\frac{Na^+ + 0.56K^+}{\sqrt{(Ca^{2+}+0.6Mg^{2+})/2}}\] (Richards, 1954)

Data Analysis
For analyzing the data, the overall hydrochemistry, source identification, and grouping the similar sampling points, the multivariate statistical analysis was done. The descriptive statistics (maximum, minimum, mean, and standard deviation), correlation matrices and Shapiro-Wilk test were also performed for testing the elaborating the dataset using IBM SPSS v.25 software. Correlation matrix (corrplot) was generated in R environment using RStudio software (R-Core Team, 2022). In the multivariate analysis, the principal component analysis (PCA) and cluster analysis were performed. For the PCA, the sample adequacy was examined by Kaiser-Meyer-Olkin (KMO) and the Bartlett Sphericity, and the outcomes were found to be satisfactory. In addition, the Piper plot, Gibb’s plot and the Mixing diagram were used for the understanding of hydrochemical characteristics and source identification of the chemical variables. Furthermore, the irrigation suitability of the lake water was determined by using the following equations.

RESULTS AND DISCUSSION
Hydrochemistry of Kupinde Lake
The mean temperature of Kupinde Lake was 22.58°C and varies over a range of spatial and temporal scales (Table 1). The pH of Kupinde Lake water was 8.16, ranging from 7.9 to 9.2, indicating the lake is slightly alkaline. A variety of factors affect the pH of freshwater, including regional geology, hydrology, climate, anthropogenic factors, rainfall, and soil type (Feng et al., 2017; Zhu et al., 2022). The pH of lake water was found to be alkaline for all the sampling sites and shown to be within the permissible limit of the World Health Organization (WHO, 2011). The pH values in this study are consistent with the previous studies Chandra Tal Western Himalayan, India, Rara lake in Mugu and Beeshazar and associated lakes in Chitwan Nepal (Singh et al., 2016; Gurung et al., 2018; Pant et al., 2021). The mean EC was found to be 136 μS/cm with range from 129 to 143 μS/cm and TDS was 68 μS/cm with range from 64 to 72 mg/L. The EC of Rara Lake (193 μS/cm) are comparatively higher (Kaphle et al., 2021), whereas Ramaroshan (67 μS/cm) and Rajarani (54 μS/cm) are comparatively lower (Adhikari et al., 2020; Dangol et al., 2022). The EC is the parameter which indicates the mobility of the ions and is directly related to the total dissolved solids (TDS). Minerals, salts, metals, ions, and organic matter dissolved in water constitute TDS. EC and TDS were substantially associated among hydrochemical parameters. As a result, the highest and lowest EC and TDS values were found in the sample locations K18 and K20. The highest concentration of EC and TDS are most likely owing to road construction, whereas the lowest concentrations are most likely due to the Kailubarah Temple at the sampling points. Obtaining relatively low levels of TDS in this area could be possible due to the religious belief that people should not dispose of their garbage near temples. Both EC and TDS were found to be below WHO acceptable limits (WHO, 2011). Hence, the water of the lake is suitable for drinking as well as for sustaining aquatic ecosystems. In this study, Ca$^{2+}$ is the dominant cation, with a mean concentration of 27.97 mg/L, and ranges from 22.4 to 36 mg/L. The mean concentration of Mg$^{2+}$ is 11.23 mg/L with a range from 4.39 to 20.5 mg/L. Factors influencing the concentration of Ca$^{2+}$ and Mg$^{2+}$ in surface water include geological
Concentration in mg/L were consistent with Rara Lake > Mg mg/L. Range of 0.09 to 0.44 mg/L with a mean value of 0.11 mg/L with a mean value of 3.47 mg/L. NH mean value of 7.38 mg/L. K hardness varied from 18 to 84 mg/L with mean 46 mg/L. 56 to 90 mg/L with mean 69.92 mg/L. Magnesium hardness varied from 18 to 84 mg/L with mean 69.92 mg/L. Calcium hardness varied from 6.5 to 8.5 mg/L with a mean value of 7.38 mg/L. K+ varies between 2.4 and 4.9 mg/L with a mean value of 3.47 mg/L. NH4+ was in the range of 0.09 to 0.44 mg/L with a mean value of 0.11 mg/L. The dominance order of the major cations was Ca2+ > Mg2+ > Na+ > K+ > NH4+; These findings in Kupinde Lake were consistent with Rara Lake (Kaphle et al., 2021).

The bicarbonate (HCO3-) was the most dominant among anions with the concentration ranging from 40 to 300 mg/L with a mean of 157.71 mg/L. It is formed primarily from the weathering and decomposition of organic matter in the catchment (Jha et al., 2009). Additionally, HCO3- is a major constituent of carbonate rocks containing calcite (CaCO3) and dolomite (CaMg(CO3)2) (Mallick, 2017). The Cl concentration ranged from 4.26 to 8.52 mg/L, with a mean of 6.04 mg/L, indicating that atmospheric inputs and anthropogenic sources have a minor influence on Cl input to the lake (Pant et al., 2021). Furthermore, SO42- varied from 0.13 to 2.28 mg/L with a mean 0.64 mg/L. Moreover, PO43- varies from 0.11 to 0.29 mg/L with mean value 0.19 mg/L. Limited amounts of NO3- are present in the present study varying from 0.05 to 0.06 mg/L with mean value 0.06 mg/L. Among the dissolved ions, Cl-, NO3-, and SO42- mainly come from anthropogenic sources, such as fertilizers applied to fields, industrial effluents, and atmospheric emissions (Sun et al., 2010). However, the area surrounding the lake shows less anthropogenic disturbance, indicating that it is less polluted. The dominance order of the major anions was HCO3- > Cl- > SO42- > PO43- > NO3-. Previous investigations in the Rajarani Lake (Adhikari et al., 2020), Jhilmila Lake (Pal et al., 2021), Ramaroshan Lake (Dangol et al., 2022), and Ghodaghodi Lake (Pant et al., 2021) indicated similar superiority of major anions except NO3 and PO43-.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>SD</th>
<th>WHO (2011)</th>
</tr>
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<tr>
<td>Temp</td>
<td>21.8</td>
<td>25</td>
<td>22.58</td>
<td>0.69</td>
<td>-</td>
</tr>
<tr>
<td>pH</td>
<td>7.9</td>
<td>9.2</td>
<td>8.16</td>
<td>0.29</td>
<td>6.5 - 8.5</td>
</tr>
<tr>
<td>EC</td>
<td>129</td>
<td>143</td>
<td>136</td>
<td>3.04</td>
<td>800-1000</td>
</tr>
<tr>
<td>TDS</td>
<td>64</td>
<td>72</td>
<td>68</td>
<td>1.67</td>
<td>500</td>
</tr>
<tr>
<td>F-CO2</td>
<td>4.4</td>
<td>11</td>
<td>7.43</td>
<td>2.13</td>
<td>-</td>
</tr>
<tr>
<td>Cl-</td>
<td>4.26</td>
<td>8.52</td>
<td>6.04</td>
<td>1.34</td>
<td>250</td>
</tr>
<tr>
<td>HCO3-</td>
<td>40</td>
<td>300</td>
<td>157.71</td>
<td>69.09</td>
<td>80-120</td>
</tr>
<tr>
<td>TH</td>
<td>86</td>
<td>174</td>
<td>115.92</td>
<td>27.67</td>
<td>-</td>
</tr>
<tr>
<td>Calcium hardness</td>
<td>56</td>
<td>90</td>
<td>69.92</td>
<td>10.82</td>
<td>-</td>
</tr>
<tr>
<td>Magnesium hardness</td>
<td>18</td>
<td>84</td>
<td>46</td>
<td>20.21</td>
<td>-</td>
</tr>
<tr>
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<td>36</td>
<td>27.97</td>
<td>4.33</td>
<td>100</td>
</tr>
<tr>
<td>Mg2+</td>
<td>4.39</td>
<td>20.5</td>
<td>11.23</td>
<td>4.93</td>
<td>50</td>
</tr>
<tr>
<td>PO43-</td>
<td>0.11</td>
<td>0.29</td>
<td>0.19</td>
<td>0.05</td>
<td>0.8</td>
</tr>
<tr>
<td>NO3-</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>NH4+</td>
<td>0.09</td>
<td>0.44</td>
<td>0.11</td>
<td>0.07</td>
<td>0.5</td>
</tr>
<tr>
<td>SO42-</td>
<td>0.13</td>
<td>2.28</td>
<td>0.64</td>
<td>0.5</td>
<td>250</td>
</tr>
<tr>
<td>K+</td>
<td>2.4</td>
<td>4.9</td>
<td>3.47</td>
<td>0.65</td>
<td>100</td>
</tr>
<tr>
<td>Na+</td>
<td>6.5</td>
<td>8.5</td>
<td>7.38</td>
<td>0.6</td>
<td>200</td>
</tr>
</tbody>
</table>

Concentration in mg/L except pH, Temp, (°C) and EC in μS/cm
Hydrogeochemical Facies

Piper plot (Piper, 1944) was used for the characterization and source identification of major ions. The milli-equivalent percentage of major ions was plotted in the trilinear diagram as shown in (Fig. 2). A water type is classified and named based on previous studies (Pant et al., 2021). Most of the samples were placed in the lower left corner of the cation triangle indicating a high concentration of Ca\(^{2+}\) and in the lower left corner of the anion triangle showing high concentration of HCO\(_3^-\). The alkali earth metals Ca\(^{2+}\) and Mg\(^{2+}\) dominated the alkali metals (Na\(^+\) and K\(^+\)) and weak acids (HCO\(_3^-\)) dominated the strong acids (Cl\(^-\) and SO\(_4^{2-}\)). On the Piper diagram, both cations and anions fall into the Ca-HCO\(_3^-\) type in the central diamond field. Carbonate dominated lithology was identified as the dominant mechanism that regulates the hydrogeochemistry of the Kupinde Lake. The finding of this study was similar to Phewa Lake in the lesser Himalaya (Khadka & Ramanathan, 2021), Ghodaghodi Lake (Pant et al., 2020) and Rara Lake (Kaphle et al., 2021).

Controlling Mechanism of the Hydrochemistry

Gibb’s diagram can be used to determine the major chemistry-controlling mechanisms of the water bodies (Gibbs, 1970). The effects of hydrochemistry on the surface water environment include precipitation, rock weathering, and evaporation (Pant et al., 2018). The lower concentration of TDS and higher ratios of Na\(^+\)/ (Na\(^+\) + Ca\(^{2+}\)) and Cl\(^-\)/ (Cl\(^-\) + HCO\(_3^-\)) suggest precipitation influences which lie in the lower right corner. Generally, rock weathering occurs when the TDS concentration is moderate and the ratios of Na\(^+\)/ (Na\(^+\) + Ca\(^{2+}\)) and Cl\(^-\)/ (Cl\(^-\) + HCO\(_3^-\)) are lower on the left. Likewise, the upper right corner of the diagram represents dominance of evaporation which influences the concentrations of TDS with high of Na\(^+\)/ (Na\(^+\) + Ca\(^{2+}\)) and Cl\(^-\)/ (Cl\(^-\) + HCO\(_3^-\)) ratios (Pant et al., 2018). The concentration of TDS and ratios of Na\(^+\)/ (Na\(^+\) + Ca\(^{2+}\)) and Cl\(^-\)/ (Cl\(^-\) + HCO\(_3^-\)) are plotted in the diagram (Fig. 3). The majority of the samples exhibited moderate TDS and low ratios of Na\(^+\)/ (Na\(^+\) + Ca\(^{2+}\)) and Cl\(^-\)/ (Cl\(^-\) + HCO\(_3^-\)) showing a dominant influence of rock weathering in the lake water. All the sampling sites are mainly affected by carbonate type rock weathering. This is evidenced by the increased concentration of major cations Ca\(^{2+}\), Na\(^+\) and anions HCO\(_3^-\) and Cl\(^-\) in the lake catchment. This finding is similar to those of previous studies, which have shown that rock weathering significantly impacts Himalayan lakes (Pant et al., 2020; Kaphle et al., 2021; Kaushik et al., 2021).

The Kupinde Lake water chemistry is influenced by the chemical weathering of rock. Generally, carbonates, silicates, and evaporates are the dominant sources of rock weathering and Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\), K\(^+\), HCO\(_3^-\), SO\(_4^{2-}\), and Cl\(^-\) influenced chemical rock weathering in hydrogeochemical composition (Pant et al., 2018). The Na-normalized hydrochemistry of Kupinde Lake revealed that most of the samples were found between the carbonate and silicate end-members, indicating the lake has both types of rock weathering (Fig. 4). The weathering process for carbonate rock is more rapid than that for silicate rocks (Fan et al., 2014). Carbonates and silicates are formed based on the amount of TDS and CO\(_2\) in water (Fan et al., 2014). Based on the results of this study, the dominant tendency of TDS has affected the formation of carbonates. In contrast, the lowest trend of CO\(_2\) has affected the formation of silicates.
Associations among Physicochemical Parameters
The pH showed a strong positive correlation with NH4+ (Fig. 5). A majority of the NH4+ in rivers and lakes originates from atmospheric deposits, fertilized and manured agricultural land, and urban wastewater. These sources contribute significantly to the rise in pH (Schuurkes & Mosello, 1988). The physical parameters EC and TDS show a strong positive correlation with one another. Typically, the higher the concentration of chemical ions in water or the dissolved salts, the higher the conductivity. As a result, conductivity is correlated with the amount of total dissolved solids and the amount of chloride ions in the solution. Similar, strong positive correlation between EC and TDS was observed in Rudra Sagar Lake (Pal et al., 2015). The association between TH-Magnesium hardness and TH-Mg has a significant positive
correlation with each other (Fig. 5). It is evident that these chemicals have a common origin, which may be derived from carbonate weathering (Singh et al., 2016). Hydrogen ion concentration (pH) is negatively correlated with free \( \text{CO}_2 \) and \( \text{Na}^+ \). Water's pH is negatively correlated with \( \text{CO}_2 \) due to \( \text{CO}_2 \) reduction during photosynthesis (Zhang et al., 2018). In the same way, \( \text{K}^+ \) tends to be negatively correlated with temperatures.

The hierarchical agglomerative clustering approach using the major ions (\( \text{HCO}_3^- \), \( \text{Ca}^{2+} \), \( \text{Mg}^{2+} \), \( \text{Na}^+ \), \( \text{K}^+ \), \( \text{Cl}^- \), \( \text{SO}_4^{2-} \), \( \text{NO}_3^- \), \( \text{PO}_4^{3-} \) and \( \text{NH}_4^+ \)) clustered 24 samples into five main clusters with low distance criterion from 0 to 5 (Fig. 6). Cluster-1 was formed by six samples (4, 5, 6, 17, 18, and 20) from lesser disturbance areas towards the side of large rocky mountain. Samples 17 and 18 were located close to dense forest, and sampling site 20 lies near the Kailubarah Temple. The cluster-2 (sites 19 and 21) was formed of the samples from disturbed area near the road and lobby. Cluster-3 and 4 were formed of samples taken from the periphery of the lake and are connected by a road and small path. The cluster-3 was composed of seven samples (1, 2, 3, 7, 13, 14, and 23) and cluster-4 was composed of two samples (sites 9 and 10). Cluster-5 was formed by the samples of inlet and center point of sampling sites (8, 11, 12, 15, 16, 22, and 24).

**Figure 5.** Corrplot showing the correlation among physicochemical parameters of the Kupinde Lake. Corrplots with blue and red colors indicate positive and negative correlations. The full blue represents \( r = 1 \) and the full red represents \( r = -1 \), all values were significant at \( p < 0.05 \)

PCA is one of the powerful tools for hydrochemical studies which attempts to explain the variance of a large dataset of inter-correlated variables with a smaller set of independent variables and thus reduces the dimensionality of the large datasets. In this study the PCA was applied to TDS and the major cations and anions. A total of five principal components have been extracted (Table 2). The five components explained 76.05 % of the total variance. To assess PCA, an eigenvalue greater than one has been considered. In the definition of factor loadings, a factor loading is graded as strong, moderate, or weak when it is greater than 0.75, between 0.75 and 0.50, and between 0.50
and 0.30 (Pant et al., 2020). The first principal component (PC1) explains 24.78% of the variance in the data, and Calcium hardness, Magnesium hardness, Mg$^{2+}$, and Ca$^{2+}$ are strongly positively loaded, which might be due to common sources of ions (Singh et al., 2016). Silicates and carbonates containing calcium and magnesium are the main sources of these parameters (An et al., 2020). PC2 shows strong positive loadings with Cl$^-$ and NO$_3^-$ whereas HCO$_3^-$ displays moderately negative loadings, which explains about 14.43% of total variance in the results. The influences of rainfall and anthropogenic inputs on lakes could be responsible for this association (Mu et al., 2014; Singh et al., 2016). In addition, natural waters contain a high level of HCO$_3^-$ due to CO$_2$ dissolution, weathering of carbonate minerals, and carbonate-rich geological formations (Jha et al., 2009; Fan et al., 2014; Mallick, 2017). In PC3, PO$_4^{3-}$ had a moderately positive loading and SO$_4^{2-}$ had a moderately negative loading, which accounts for 13.08% of the variance in the result indicating less polluted lake water. Similarly, it was observed that NH$_4^+$ is moderately loaded in PC4 and Na$^+$ is strongly negative loaded, which accounts for 12.09% of the variance. The NH$_4^+$ and Na$^+$ could be originated from diverse sources. The majority of ammonium pollution originates from anthropogenic sources including industrial emissions, sewage, and fertilizer leachate (Du et al., 2017) whereas Na$^+$ is released from the dissolution of evaporates and the weathering of silicate rocks (An et al., 2020). The TDS is strongly negative loaded and the K$^+$ is moderately positive loaded, explaining 11.66% of the total variance in PC5.

**Water Quality Status**

All sampling points were found excellent in the EC’s categorization, and the Kupinde Lake water was deemed suitable for irrigation (Table 3). Irrigation water can be classified into five types in terms of Na$^+$ (Acharya et al., 2020). Similarly, the average value of Na% is 15.53, categories as excellent with compare standard value. The sodium adsorption ratio (SAR) was 0.30, which is divided into three categories depending on SAR content, with lowest SAR content indicating ideal for irrigation. The Wilcox diagram (Fig. 8) exhibited plotted water samples of Kupinde Lake into C1S1 section, indicating excellent category for irrigation. In addition, KR values were within the safe category for irrigation, the lake water is suitable for irrigation. Irrigation water was divided into three categories based on the PI values. The average PI value indicated that the water was of good quality. In this investigation, the CROSS values of the lake water are excellent category. Kupinde Lake water was suitable for drinking as it was within the range of given guidelines for pH, EC, TDS, and all the cations and anions (WHO, 2011). However, we acknowledge that this study has not analyzed the microbial parameters of water.

![Figure 6. Dendrogram of the hydrochemical variables in the Kupinde Lake based hierarchical cluster of sampling sites](image)

Figure 6. Dendrogram of the hydrochemical variables in the Kupinde Lake based hierarchical cluster of sampling sites
Table 2. Varimax rotated component matrix of Kupinde Lake

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Component</th>
<th></th>
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<tbody>
<tr>
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<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>TDS</td>
<td>-0.15</td>
<td>0.23</td>
<td>0.03</td>
<td>0.08</td>
<td>-0.79</td>
</tr>
<tr>
<td>Cl⁻</td>
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<td>0.76</td>
<td>-0.09</td>
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</tr>
<tr>
<td>HCO₃⁻</td>
<td>0.01</td>
<td>-0.60</td>
<td>-0.55</td>
<td>0.09</td>
<td>0.21</td>
</tr>
<tr>
<td>Calcium hardness</td>
<td>0.93</td>
<td>-0.05</td>
<td>-0.03</td>
<td>-0.19</td>
<td>-0.15</td>
</tr>
<tr>
<td>Magnesium hardness</td>
<td>0.77</td>
<td>0.12</td>
<td>0.41</td>
<td>0.20</td>
<td>0.27</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>0.93</td>
<td>-0.05</td>
<td>-0.03</td>
<td>-0.19</td>
<td>-0.15</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>0.77</td>
<td>0.12</td>
<td>0.41</td>
<td>0.20</td>
<td>0.27</td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>-0.01</td>
<td>-0.06</td>
<td>0.73</td>
<td>0.04</td>
<td>0.20</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>0.03</td>
<td>0.82</td>
<td>-0.19</td>
<td>0.33</td>
<td>0.09</td>
</tr>
<tr>
<td>NH₄⁺</td>
<td>0.16</td>
<td>-0.08</td>
<td>-0.10</td>
<td>0.68</td>
<td>-0.31</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>-0.28</td>
<td>0.10</td>
<td>-0.64</td>
<td>0.03</td>
<td>0.06</td>
</tr>
<tr>
<td>K⁺</td>
<td>-0.26</td>
<td>0.39</td>
<td>0.23</td>
<td>0.01</td>
<td>0.68</td>
</tr>
<tr>
<td>Na⁺</td>
<td>0.33</td>
<td>-0.07</td>
<td>-0.12</td>
<td>-0.80</td>
<td>-0.19</td>
</tr>
<tr>
<td>% of Variance</td>
<td>24.78</td>
<td>14.43</td>
<td>13.08</td>
<td>12.09</td>
<td>11.66</td>
</tr>
<tr>
<td>Cumulative %</td>
<td>24.78</td>
<td>39.21</td>
<td>52.30</td>
<td>64.39</td>
<td>76.05</td>
</tr>
</tbody>
</table>

Figure 7. Factor loading plot of the principal component analysis
Table 3. Classification of water samples for irrigation based on various parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Average value</th>
<th>Category</th>
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</thead>
<tbody>
<tr>
<td>EC</td>
<td>136.54</td>
<td>Excellent</td>
</tr>
<tr>
<td>Na%</td>
<td>15.53</td>
<td>Excellent</td>
</tr>
<tr>
<td>SAR</td>
<td>0.30</td>
<td>Excellent</td>
</tr>
<tr>
<td>MH</td>
<td>38.38</td>
<td>Suitable</td>
</tr>
<tr>
<td>KR</td>
<td>0.14</td>
<td>Safe</td>
</tr>
<tr>
<td>PI</td>
<td>74.74</td>
<td>Class I</td>
</tr>
<tr>
<td>CROSS</td>
<td>0.38</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

CONCLUSIONS

The hydrochemical analysis of the Kupinde Lake revealed slightly alkaline and moderately hard water with its EC and TDS lying within WHO guidelines. The major cations are abundant in the order \( \text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+ > \text{NH}_4^+ \), while anions are abundant in the order \( \text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{PO}_4^{3-} > \text{NO}_3^- \). Based on the results of this study, all physicochemical parameters were within the WHO permissible limits. The dominant hydrochemistry of the Kupinde Lake water was carbonate weathering. The hydrochemistry of Kupinde Lake water is primarily influenced by carbonate rock weathering. Based on the irrigation parameters of Kupinde Lake water, all samples fell within the excellent category, thus the lake water is an excellent irrigation resource. This study provides a set of reference values for assessing the potential impacts of ongoing development around the lake in the future.

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AUTHOR CONTRIBUTIONS
CBS: performed field work, laboratory analysis, data analysis and prepared manuscript; LK: conceptualized the study, revised, and finalized the manuscript, supervised the study; RRP: analyzed data, revised the manuscript; BT: performed field sampling, laboratory analysis and revised the manuscript; BC: performed field work, revised the manuscript.

CONFLICT OF INTEREST
There is no conflict of interest between the authors in this publication.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

REFERENCES


