Analysis of water quality of selected irrigation water sources in northern Ghana
Davie Kadyampakeni, Richard Appoh, Jennie Barron and Enoch Boakye-Acheampong

ABSTRACT
Small-scale irrigation continues to cushion the food security gap in sub-Saharan Africa. Irrigation is largely governed by water availability, soil type and crop water requirements, among other factors. Thus, a study was conducted to assess the suitability of various water sources for irrigation in northern Ghana. Specifically, the study sought to assess quality of water sources in the Savelugu, Kasena-Nankana East, and Nabdam districts for small-scale irrigation development. The water quality parameters used were: pH, electrical conductivity (ECw), sodium adsorption ratio (SAR), sodium percent (Na%), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelley’s ratio (KR), total hardness (TH), chloride (Cl), Escherichia coli, and fecal coliforms. While we found most of the irrigation water sources, including small reservoirs, dams, wells and rivers suitable, few unsuitable irrigation water sources were also identified. Overall, the study found that opportunities for scaling small-scale irrigation exist in all the sites. The knowledge generated from this study will guide irrigation water use, and agricultural policy for sustainable smallholder irrigation development in the region.

Key words | irrigation development, shallow wells, small reservoirs, salinity, water quality, Ghana

INTRODUCTION
The agriculture sector plays a key role in the economies of many sub-Saharan African (SSA) countries. Ghana’s economy remains largely agro-based even though the service and industry sectors have overtaken agriculture as the highest contributors to gross domestic product (GDP). The agriculture sector has been and remains the largest employer of the active labour force, employing in 2010 up to 42 percent (Ghana Statistical Service 2012). It accounted for about 40% of export revenues between 1997 and 2011 (Dzanku & Aidam 2013), and contributed 22.4% to the GDP of Ghana in 2013 (Ghana Statistical Service 2015). Agriculture in Ghana is predominately rainfed, and heavily reliant on variability and patterns of rainfall. Due to this variability, water is the key limiting factor for agricultural production in northern Ghana. The region is characterized by a uni-modal rainfall regime lasting 3–4 months and a long dry period lasting 6–7 months in a year (Gyau-Boakye & Dapaah-Siakwan 1999; Kizito et al. 2014; Kadyampakeni et al. 2017). Nearly 70% of annual rainfall in the region occurs during the 3 months of July, August and September, with little or no rainfall between November and March. The agricultural sector remains highly relevant to the growth of the economy due to its significant contributions to foreign exchange earning, employment, food security and poverty reduction, especially among the rural poor.

Over the years, there has been a significant reduction of rainfall and highly variable climate in the Volta Basin where northern Ghana is located (Gyau-Boakye & Tumbulto 2000, 2006; Opoku-Ankomah 2000; L’hôte et al. 2002; Owusu et al. 2008; McCartney et al. 2012; Mul et al. 2016). van de Giesen et al. (2001) noted that rainfall is becoming an unreliable source of water for agriculture in the Volta Basin due to
its high spatial and temporal variability. There is high uncertainty in the onset of the rainy season (Laux et al. 2008; Mul et al. 2016). Climate change is also projected to exacerbate the problem of diminishing rainfall in the basin (de Condappa et al. 2009; McCartney et al. 2012). The rainy season is also characterized by dry spells of varying duration, which can have serious effect on crop yields (Rockström & De Rouw 1997; Rockstrom 2000; Mul et al. 2016).

Under these conditions of long dry season, dry spells during the rainy season, reduction in total rainfall, high spatial and temporal variability in rainfall, and uncertainty in the onset of the rainy season, irrigation development offers the promise of food security in northern Ghana during the dry season. Without irrigation, there is virtually no agricultural activity outside the rainy season.

Irrigation development in northern Ghana has revolved around river pumping, and gravity-fed reservoir systems and shallow wells. Several small, medium and large reservoirs have been constructed in the basin primarily to ensure a year round crop production, livestock watering and domestic water use (Liebe et al. 2005; Hagan 2007; de Condappa et al. 2009; Venot & Krishnan 2011; McCartney et al. 2012). The network of rivers forming the Volta River System is also used for irrigation. The use of shallow wells for irrigation is common in the region, especially in areas with a high groundwater table (Ofosu 2011).

Regardless of its source, irrigation water contains some dissolved salts. The quality of irrigation water varies greatly depending on the source and quantity of dissolved salts. The suitability for irrigation water is assessed in terms of the presence of undesirable constituents. The most important characteristics that determine the suitability of irrigation water are: pH; total concentration of soluble salts assessed through electrical conductivity (EC); relative proportion of Na to other cations such as Ca and Mg, referred to as the sodium adsorption ratio (SAR); concentration of boron and other elements that may be toxic to plants; concentration of carbonates and bicarbonates as related to the concentration of Ca and Mg, referred to as residual sodium carbonate (RSC); content of anions such as chloride, sulphate and nitrate (Haritash et al. 2014). As a tool for assessing the suitability of water quality for irrigation, guidelines have been developed by irrigation and water resources authorities in a number of countries and by international organizations such as the FAO (Ayers & Westcot 1985). These guidelines contain threshold values based on criteria such as optimum crop yield, crop quality, soil suitability, and maintenance of irrigation equipment (Ayers & Westcot 1985).

The primary goal of irrigation water analysis is to examine the effect of the water on the soil, and ultimately on the plants grown (Adamu 2013). Poor irrigation water quality is currently a major environmental issue worldwide (Millennium Ecosystem Assessment 2005). Poor quality irrigation water affects both soil quality and crop production adversely. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers & Westcot 1985).

Monitoring irrigation water quality is crucial to the sustainability of crop production and productivity. Few studies have been conducted to assess the quality of irrigation water in northern Ghana (Cobbina et al. 2012).

This study was conducted to assess the suitability of various water sources for irrigation in northern Ghana. Specifically, the study sought to assess the physico-chemical quality of water sources in the Savelugu, Kasena-Nankana East, and Nabdam districts for smallholder irrigation development. The water quality parameters used were pH, electrical conductivity (ECw), sodium adsorption ratio (SAR), sodium percent (Na %), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelley’s ratio (KR), total hardness (TH), chloride (Cl), Escherichia coli, and fecal coliforms. The knowledge generated from this study will guide irrigation water use, and other stakeholders, on agricultural policy for sustainable smallholder irrigation development in the region.

MATERIALS AND METHODS

Description of study area

The study was conducted in northern Ghana (Table 1). The area is fairly flat, with an average slope of less than 1% (Forkuor et al. 2013). The vegetation consists predominantly of grassland with sparsely distributed drought-resistant trees such as shea, baobab and acacia. The climate is relatively dry, with a single rainy season that begins in May and
The dry season starts in November and ends in April, with maximum temperatures occurring towards the end of the dry season (March-April) and minimum temperatures in December and January. Poverty is widespread in the region. The Ghana poverty mapping report (Ghana Statistical Service 2012) indicates that the districts located in the region are the poorest in the country. Northern Ghana has been the poorest part of the country because of its vulnerability to climate change and precarious climatic conditions, such as a long dry season of about 7 months followed by just a 5-month rainy season with recurrent, intermittent droughts and/or floods in the rainy season.

### Water sampling and analysis

Water samples were collected from 30 shallow wells, 10 deep wells, three small multi-purpose reservoirs, one river and one big irrigation dam across six communities. Ten shallow wells each are located in Dimbasinia and Zanlerigu in the Upper East Region, and Duko in the Northern Region. All the 10 deep wells are located in Nyangua in the Upper East Region. The three small multi-purpose reservoirs are located in Dimbasinia, Zanlerigu and Nyangua, and the big Tono irrigation dam is located in Navrongo, in the Upper East Region. The river is located in Bihinaayili in the Northern Region. Sampling was designed to cover both the wet and dry seasons. Wet season samples were collected in April 2015 and April 2016, and dry season samples in October 2015 and

### Table 1 | Locations of study communities in northern Ghana

<table>
<thead>
<tr>
<th>Community</th>
<th>GPS location</th>
<th>Irrigation water source</th>
<th>Water source code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimbasinia</td>
<td>10°53’15.5” N; 1°4’13.0” E</td>
<td>Small reservoir</td>
<td>DM1</td>
<td>Water samples were collected from a small reservoir. The water from the reservoir is used for irrigation, livestock watering, construction and domestic water supply.</td>
</tr>
<tr>
<td></td>
<td>10°54’12.5” N; 1°1’9.7” E</td>
<td>Shallow wells</td>
<td>DM2</td>
<td>These are water samples from temporal shallow wells constructed behind the Dimbasinia reservoir wall. Water from these shallow wells is pumped mainly for irrigation in the dry season.</td>
</tr>
<tr>
<td>Nyangua</td>
<td>10°57’13.1” N; 1°5’35.0” E</td>
<td>Small reservoir</td>
<td>NY1</td>
<td>Water samples were collected from a small reservoir. The water from the reservoir is used for irrigation, livestock watering, construction and domestic purposes.</td>
</tr>
<tr>
<td></td>
<td>10°56’26.8” N; 1°4’16.3” E</td>
<td>Shallow wells</td>
<td>NY2</td>
<td>Water samples were collected from shallow wells constructed behind the Nyangua reservoir wall. Water from these shallow wells is pumped mainly for irrigation in the dry season.</td>
</tr>
<tr>
<td>Zanlerigu</td>
<td>10°48’12.3” N; 0°43’16.9” E</td>
<td>Small reservoir</td>
<td>ZN1</td>
<td>Water samples were collected from a multi-purpose small reservoir. The water from the reservoir is used for irrigation, livestock watering, construction and domestic uses.</td>
</tr>
<tr>
<td></td>
<td>10°47’11.9” N; 0°43’48.5” E</td>
<td>Shallow wells</td>
<td>ZN2</td>
<td>Water samples from shallow wells constructed behind the Zanlerigu dam wall, and other locations within the community. Water from these shallow wells is collected with watering cans for irrigation in the dry season.</td>
</tr>
<tr>
<td>Bonia</td>
<td>10°52’48.1” N; 1°8’57.3” E</td>
<td>Irrigation dam</td>
<td>TN3</td>
<td>Water samples from the Tono irrigation dam. This is the biggest irrigation dam in northern Ghana.</td>
</tr>
<tr>
<td>Bihinaayili</td>
<td>9°34’23.0” N; 0°50’29.9” E</td>
<td>River</td>
<td>LI4</td>
<td>Water samples from excess water running off the fields and in the spillway of the Libga irrigation scheme. Farmers downstream of the irrigation scheme divert this excess water into ponds constructed in fields near the water channel to their fields to irrigate in the dry season.</td>
</tr>
<tr>
<td>Duko</td>
<td>9°34’23.0” N; 0°50’30.0” E</td>
<td>Shallow wells</td>
<td>DK2</td>
<td>Water samples were collected from shallow wells near a stream. Water from these shallow wells is collected with watering cans for irrigation in the dry season.</td>
</tr>
</tbody>
</table>
November 2016. For each sampling event, one water sample was taken from each of the well water sources and 10 water samples each from the small reservoirs, big irrigation dam, and river water sources for analysis.

The sampling and analytical procedures followed Standard Methods for the Examination of Water and Wastewater (APHA 2005) and the Global Environmental Monitoring Systems/Water Operational Guide (WHO/UNEP/UNESCO/WMO 1988; Mensah 2011). Samples were collected and filtered into 1.5 L acid pre-cleaned high-density polyethylene bottles and sterilized bottles containing sodium thiosulfate preservative (a chlorine neutralizer) in the case of microbiological parameters. The samples were sealed and stored in ice-chests with ice to maintain a low temperature (<4 °C) and transported to the Environmental Chemistry Laboratory of the Water Research Institute for analysis.

EC and pH measurements were made using EC and pH meters, which were calibrated prior to taking the readings. A flame photometric method was used to determine sodium and potassium, while ethylenediaminetetraacetic acid (EDTA) titration was used to determine Ca and Mg. Fluoride was determined using the SPADNS method recommended by the US Environmental Protection Agency, while Fe and Al were measured by flame atomic absorption spectroscopy (AAS). Chloride was analyzed using the argentometric method, while E. coli and fecal coliform concentrations were determined by the membrane filtration method.

Sodium adsorption ratio (SAR) was calculated using Equation (1) (USDA 1954):

\[
SAR = \sqrt{\frac{Na^+}{Ca^{2+} + Mg^{2+}}} \times 100
\]

where all the concentrations of the cations are expressed in meq/L (milliequivalent per liter).

Soluble sodium percentage (SSP) was calculated using Equation (2) (Todd 1959):

\[
SSP = \frac{(Na^+ + K^+) \times 100}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}
\]

where all the concentrations of the cations are expressed in meq L⁻¹.

Magnesium adsorption ratio (MAR) was calculated using Equation (3). MAR values higher than 50 are considered harmful and unsuitable for irrigation (Raghunath 1987).

\[
MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100
\]

where all the concentrations of the cations are expressed in meq L⁻¹.

Kelley’s ratio (KR) was calculated using Equation (4) (Kelley 1963):

\[
KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \times 100
\]

where all the concentrations of the cations are expressed in meq L⁻¹.

Sodium percentage was calculated using Equation (5)

\[
\%Na = \frac{Na^+ \times 100}{Ca^{2+} + Mg^{2+} + Na^+ + K^+}
\]

where all the concentrations of the cations are expressed in meq L⁻¹.

The total hardness (TH) was calculated using Equation (6) (Raghunath 1987):

\[
TH = (Ca^{2+} + Mg^{2+}) \times 50
\]

where all cationic concentrations are expressed in mg L⁻¹.

Statistical analysis

All statistical analysis was performed using SPSS Statistics software. The water quality data were tested for normality with the Shapiro-Wilk test. The two-tailed Spearman rank correlation was used to determine the relationship among all the parameters (Quinn & Keough 2002).

RESULTS AND DISCUSSION

Water quality characterization

The measured chemical parameters of the irrigation water sources showed a general trend of higher levels in the
wells than the remaining water sources. A seasonal effect on the measured chemical parameters was apparent over the sampling period. The recorded levels of the chemical parameters were generally higher during the rainy season.

**pH**

The pH is an indicator of the predominant cations and anions. For example, irrigation water with a high pH indicates the potential for the precipitation of calcium carbonate salt, which can plug emitters in a drip system.

The pH levels for the Bihinaayili site ranged from 5.96 to 7.50 with a mean of 6.49 ± 0.41 (Figure 1). The minimum value recorded during the dry season (5.96) was below the acceptable FAO permissible limits for irrigation water (6.80 to 8.40) and therefore could be hazardous to crops. The maximum pH level recorded at the Dimbasinia small reservoir was 7.10, and the maximum recorded at the shallow temporal wells was 8.02. The mean pH levels recorded at the Dimbasinia small reservoir and shallow wells were 6.79 ± 0.18 and 7.26 ± 0.41, respectively. These were all within the acceptable FAO threshold of 6.80 to 8.40. The pH levels recorded at Zanlerigu sites ranged from 6.63 to 8.33 at all the sampling points. In addition, the average pH levels for Zanlerigu small reservoir and shallow wells were 7.10 ± 0.27 and 7.50 ± 0.53 respectively, and were acceptable within the FAO thresholds.

The recorded pH levels for the Duko site also range from 5.90 to 6.34 with an average of 6.12 ± 0.20. The minimum value recorded during the dry season (5.90) was below the acceptable FAO permissible limits for irrigation water and therefore could be hazardous to crops due to aluminium and iron toxicity at low pH.

The Tono irrigation dam recorded a pH ranging from 6.65 to 7.96. The pH values recorded were all within the acceptable threshold of FAO for irrigation water (6.80 to 8.40).

The pH range (6.42–8.02) observed at Nyangua perennial wells and dam sites were within the FAO acceptable irrigation water quality limit.

**Electrical conductivity**

EC is a good estimator of the total amounts of mineral salts dissolved in water (Warrence et al. 2003), and therefore is often used to measure salinity problems related to irrigation of crops. The EC levels of the water bodies of the sampled locations were within the FAO permissible limits of less than 1,000 μS cm⁻¹ and therefore pose no threat to crops (Figure 1). Comparison of the conductivity levels of the sampling sites indicated that Dimbasinia wells samples recorded the highest mean level of 463 ± 95 μS cm⁻¹. Overall, the conductivity of the sampled water bodies ranged from the lowest level of 56.2 μS cm⁻¹ at Bihinaayili River to the highest, of 641 μS cm⁻¹ at Dimbasinia. Moreover, higher values of conductivity were recorded in the rainy season than in the dry season.

**Elemental concentrations**

Similar to the trend observed for the chemical parameters, the measured metals levels of the irrigation water sources showed...
a general trend of wells recording higher levels than the other irrigation water sources. The variations of the metals analyzed at the various sampling locations are outlined in Table 2.

Potassium (K) levels in the small reservoir and dam samples were higher than the wells and the river. The measured levels of K in the small reservoir samples were found to be between 0.7 and 8.9 mg L$^{-1}$. The K concentration of the sampled water bodies of different sampling sites ranged from 0.4 mg L$^{-1}$ at Bihinaayili river site to 12.8 mg L$^{-1}$ at Nyangua small reservoir. Moreover, the highest mean concentration recorded was 8.6 ± 4.2 mg L$^{-1}$ at the Nyangua small reservoir site, while the lowest mean concentration was 1.2 ± 1.84 mg L$^{-1}$ at the Zanlerigu shallow well site. However, all recorded concentrations at Bihinaayili, Dimbasinia, Zanlerigu, Nyangua and Tono which were above the acceptable limits FAO of 5 mg L$^{-1}$ could pose a threat to vegetable production. In addition, the potassium concentration recorded higher values in the rainy season than in the dry season.

The Na level recorded in Bihinaayili sites ranged from 7.3 to 15.7 mg L$^{-1}$ for all the sampling periods. The mean Na level recorded was 10.40 ± 2.59 mg L$^{-1}$. The maximum Na levels recorded for Dimbasinia sites at both the small reservoir and the shallow wells during the sampling periods were 12.1 and 65.0 mg L$^{-1}$, while the minimum Na levels recorded were 4.0 and 15.4 mg L$^{-1}$, respectively. The mean Na levels for Dimbasinia small reservoir and shallow well sites were 6.9 ± 5.5 and 21.1 ± 14.6 mg L$^{-1}$, respectively, with no anticipated problems to vegetable production. In addition, the Na levels recorded for Zanlerigu sites range from 6.9 to 30.0 mg L$^{-1}$ for the small reservoirs and shallow wells. The average Na levels for Zanlerigu small reservoir site and shallow wells were 15.3 ± 9.1 and 14.9 ± 5.5 mg L$^{-1}$, respectively and were acceptable within the FAO permissible range of 0 to 50.0 mg L$^{-1}$.

Recorded concentrations that were greater than the 50 mg L$^{-1}$ of the FAO acceptable threshold at certain sampling points at Dimbasinia, Nyangua, could be hazardous to vegetable production due to salinity and sodicity concerns.

Recorded calcium (Ca) levels in most of the wells at different sampling locations were variably higher than the other water sources sampled. Mean calcium concentrations of the water sources of different sampling sites ranged from a high level of 45.5 ± 3.7 mg L$^{-1}$ at Zanlerigu well site to the lowest level of 4.2 ± 3.1 mg L$^{-1}$ at Duko well site. All the Ca

### Table 2: Water characteristics for the water sources across the three watersheds

<table>
<thead>
<tr>
<th>Water source</th>
<th>Cu (μg L$^{-1}$)</th>
<th>Fe (μg L$^{-1}$)</th>
<th>Al (μg L$^{-1}$)</th>
<th>Mg (mg L$^{-1}$)</th>
<th>Na (mg L$^{-1}$)</th>
<th>K (mg L$^{-1}$)</th>
<th>Ca (mg L$^{-1}$)</th>
<th>F (mg L$^{-1}$)</th>
<th>NO$_3$ (mg L$^{-1}$)</th>
<th>SO$_4$ (mg L$^{-1}$)</th>
<th>PO$_4$ (mg L$^{-1}$)</th>
<th>EC (μS cm$^{-1}$)</th>
<th>FS (%)</th>
<th>Cfu 100 mL$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI4</td>
<td>11.61 ± 1.05</td>
<td>2.22 ± 1.16</td>
<td>2.71 ± 1.57</td>
<td>34.8 ± 2.78</td>
<td>1.35 ± 0.64</td>
<td>0.16 ± 0.07</td>
<td>2.22 ± 1.26</td>
<td>1.95 ± 0.92</td>
<td>5.83 ± 0.79</td>
<td>1.84 ± 0.73</td>
<td>4.53 ± 0.78</td>
<td>455.50 ± 362.7</td>
<td>– – –</td>
<td>– – –</td>
</tr>
<tr>
<td>DM1</td>
<td>8.65 ± 1.42</td>
<td>1.62 ± 0.64</td>
<td>2.09 ± 0.57</td>
<td>16.5 ± 3.25</td>
<td>3.68 ± 1.57</td>
<td>1.17 ± 0.07</td>
<td>4.62 ± 2.91</td>
<td>2.90 ± 2.07</td>
<td>3.47 ± 0.64</td>
<td>4.7 ± 0.13</td>
<td>0.10 ± 0.03</td>
<td>453.50 ± 307.5</td>
<td>– – –</td>
<td>– – –</td>
</tr>
<tr>
<td>DM2</td>
<td>9.54 ± 1.65</td>
<td>2.59 ± 1.05</td>
<td>2.56 ± 1.12</td>
<td>34.8 ± 2.78</td>
<td>1.35 ± 0.64</td>
<td>0.16 ± 0.07</td>
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</tr>
<tr>
<td>ZN1</td>
<td>3.26 ± 1.01</td>
<td>1.84 ± 0.64</td>
<td>2.09 ± 0.57</td>
<td>16.5 ± 3.25</td>
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<td>– – –</td>
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</tr>
<tr>
<td>ZN2</td>
<td>10.26 ± 1.84</td>
<td>1.62 ± 0.64</td>
<td>2.09 ± 0.57</td>
<td>16.5 ± 3.25</td>
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<tr>
<td>TN3</td>
<td>10.26 ± 1.84</td>
<td>1.62 ± 0.64</td>
<td>2.09 ± 0.57</td>
<td>16.5 ± 3.25</td>
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<td>453.50 ± 307.5</td>
<td>– – –</td>
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</tr>
</tbody>
</table>
values recorded were within the acceptable FAO limits for irrigation.

Almost all the Mg concentrations recorded for samples were within the acceptable limits of FAO standards for irrigation, with few samples falling outside the acceptable standards. The concentrations recorded in the sampled water sources ranged between 0.3 and 65 mg L\(^{-1}\). The mean levels recorded at the different sampling locations were lowest (0.82 ± 0.33 mg L\(^{-1}\)) at the Tono dam site and highest at Dimbasinia well sites (23.3 ± 14.9 mg L\(^{-1}\)). The recorded values at the Dimbasinia well sites exceeding 24 mg L\(^{-1}\) were considered above the FAO acceptable threshold and could limit vegetable production due to elevated pH and lack of some nutrients to crops.

Similar to the Ca concentrations recorded at the sampling locations, the recorded levels of F were within the acceptable limits of FAO for irrigation. The measured levels of F in most wells were higher than the levels of the other remaining water sources. The mean fluoride concentrations of the sampled irrigation water sources ranged from the highest level of 0.56 mg L\(^{-1}\) at Zanlerigu small reservoir site to the lowest level of <0.005 mg L\(^{-1}\) at Nyangua small reservoir site. Moreover, most of the recorded values at the various sampling sites showed fairly low concentrations of iron during the sampling period with few deviations outside the FAO acceptable permissible threshold of 5 mg L\(^{-1}\).

The Fe concentrations recorded in the water sources sampled ranged between 0.08 and 14 mg L\(^{-1}\). The mean iron levels ranged between 1.36 ± 2.5 mg L\(^{-1}\) at Zanlerigu small reservoir site to 18 ± 17 mg L\(^{-1}\) at the Nyangua small reservoir site. The highest level recorded for Fe was not acceptable within the threshold of FAO values of 5 mg L\(^{-1}\). Higher Fe levels could be a problem to vegetable production, and in excess could compete with other nutrients like phosphorus.

The Al levels of the irrigation water sources were within the acceptable thresholds of the FAO and therefore pose no threat to crops. Comparison of the Al levels of the sampling sites indicated that Nyangua small reservoir site recorded the highest mean level of 6 mg L\(^{-1}\), while the lowest mean level of 0.11 mg L\(^{-1}\) at Dimbasinia well site. Overall, the Al levels of the sampled water sources ranged from a low of 0.05 mg L\(^{-1}\) at Bihinaayili river site to a high of 2 mg L\(^{-1}\) at Zanlerigu small reservoir site. The Cl concentrations recorded in all the sampling points were within the acceptable threshold of the FAO. Zanlerigu well sites recorded the highest mean value of 12.2 ± 4.7 mg L\(^{-1}\), while Dimbasinia dam site recorded the lowest mean value of 5.96 mg L\(^{-1}\). The levels of nitrate and phosphate of the sampled water bodies were fairly low, and were within the acceptable thresholds of the FAO and posed no threat to vegetable production. However, only rainy season samples were analyzed for these parameters. Obuobie et al. (2013) reported reasonable values for physicochemical parameters in northern Ghana.

**Microbial contamination**

E. coli and fecal coliform counts were conducted in five irrigation water sources, namely, Bihinaayili River, Dimbasinia small reservoir and wells, and Zanlerigu small reservoir and wells (Table 2). On average, E. coli counts recorded at all the sampling sites were below the acceptable FAO threshold of 2.35 CFU mL\(^{-1}\) (235 CFU per 100 mL). However, a few extremely high values were recorded in some specific sampling points. For example, a count of 14.88 CFU mL\(^{-1}\) was recorded at one sampling point in the Dimbasinia small reservoir. Such extremely high E. coli counts could be detrimental to vegetable production. The fecal coliform counts recorded for all the sampling points were below the acceptable FAO threshold of 8 CFU mL\(^{-1}\), with the exception of one shallow well in Zanlerigu (9.70 CFU mL\(^{-1}\)). This well will require further monitoring, as the high fecal coliform level could pose a serious threat to vegetable production and human health.

**Sodium adsorption ratio**

SAR is the estimation of the degree to which sodium will be absorbed by the soil (Table 3). It reasonably predicts the degree to which irrigation water tends to enter into a cation–exchange reaction in the soil. High values of SAR imply a hazard of sodium replacing adsorbed calcium and magnesium ions, resulting in damage to the soil structure and plant roots. Irrigation water having high SAR levels can lead to the buildup of high soil Na levels over time, which can adversely affect soil permeability. Water having an SAR less than or equal to 10 is of excellent quality, 10
to 18 is of good quality, 18 to 26 is of doubtful quality and greater than 26 is of unsuitable quality for irrigation (USDA 1954). All the samples from the different water sources have SAR less than 10, indicating excellent quality water for irrigation.

**Soluble sodium percentage**

SSP is an important factor for studying the sodium hazard. Water with SSP greater than 50% may result in sodium accumulation that will cause a breakdown in the soil’s physical properties. It may also cause stunted growth in plants and reduce soil permeability (Joshi et al. 2009). All the water samples collected from the Tono dam, Dimbasinia small reservoir, Nyangua small reservoir, Duko wells, and Zanlerigu reservoir and wells had SSP values less than 50, indicating that they are good water sources for irrigation (Tables 3 and 4). Only one out of the 20 water samples taken from the wells in Dimbasinia had SSP values greater than 50%. Eight out of the 10 samples taken from the Nyangua wells in the dry season had SSP values greater than 50%, whereas none of the samples taken in the wet season had a high value of SSP. Eighty percent of the samples taken from the Bihinaayili River, runoff from the fields of the Libga irrigation project, had SSP values greater than 50%. Even the few (four) samples with SSP values less than 50% was in the range of 41 to 47, indicating that the water running off the Libga irrigation fields is not suitable for reuse as irrigation water without treatment. This may be due to the continuous use of chemical fertilizers on Libga irrigated rice fields.

**Kelley’s ratio**

Kelley’s ratio is used to find the suitability of groundwater for irrigation purposes. Groundwater having a Kelley’s ratio more than one has an excess level of sodium and therefore is considered not suitable for irrigation purposes (Kelley 1965). The Kelley’s ratio of all the

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**Table 3** | Water quality parameters including sodium adsorption ratio (SAR), soluble sodium percentage (SSP), magnesium adsorption ratio (MAR), Kelley’s ratio (KR), sodium percentage (%Na) and total hardness (TH) based on standard calculations

<table>
<thead>
<tr>
<th>Water source</th>
<th>SAR</th>
<th>SSP</th>
<th>MAR</th>
<th>KR</th>
<th>Na (%)</th>
<th>TH (mg L⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI4</td>
<td>0.99 ± 0.29</td>
<td>56.08 ± 6.39</td>
<td>30.44 ± 9.43</td>
<td>1.08 ± 0.41</td>
<td>47.59 ± 10.20</td>
<td>369.00 ± 78.46</td>
</tr>
<tr>
<td>DM1</td>
<td>0.50 ± 0.15</td>
<td>36.87 ± 4.50</td>
<td>44.44 ± 7.93</td>
<td>0.42 ± 0.07</td>
<td>26.67 ± 3.52</td>
<td>582.50 ± 249.51</td>
</tr>
<tr>
<td>DM2</td>
<td>0.67 ± 0.53</td>
<td>20.74 ± 10.14</td>
<td>51.20 ± 19.25</td>
<td>0.25 ± 0.24</td>
<td>19.43 ± 501.38</td>
<td>2,986.80 ± 10.20</td>
</tr>
<tr>
<td>ZN1</td>
<td>0.67 ± 0.39</td>
<td>27.51 ± 9.27</td>
<td>44.15 ± 5.86</td>
<td>0.34 ± 0.20</td>
<td>24.43 ± 182.70</td>
<td>1,627.00 ± 10.70</td>
</tr>
<tr>
<td>ZN2</td>
<td>0.49 ± 0.11</td>
<td>16.30 ± 3.47</td>
<td>34.30 ± 8.68</td>
<td>0.19 ± 0.05</td>
<td>15.56 ± 517.59</td>
<td>3,012.54 ± 3.70</td>
</tr>
<tr>
<td>NY2</td>
<td>1.91 ± 1.19</td>
<td>48.74 ± 14.98</td>
<td>29.25 ± 8.90</td>
<td>0.89 ± 0.89</td>
<td>45.56 ± 828.00</td>
<td>2,053.86 ± 15.25</td>
</tr>
<tr>
<td>NY1</td>
<td>0.82 ± 0.35</td>
<td>53.07 ± 7.90</td>
<td>40.65 ± 10.89</td>
<td>0.76 ± 0.27</td>
<td>35.55 ± 171.85</td>
<td>495.63 ± 5.69</td>
</tr>
<tr>
<td>DK2</td>
<td>0.62 ± 0.14</td>
<td>46.02 ± 6.64</td>
<td>47.86 ± 19.63</td>
<td>0.70 ± 0.17</td>
<td>37.77 ± 157.73</td>
<td>324.00 ± 5.05</td>
</tr>
<tr>
<td>TN3</td>
<td>0.97 ± 0.12</td>
<td>57.87 ± 3.16</td>
<td>15.64 ± 0.34</td>
<td>1.04 ± 0.13</td>
<td>43.98 ± 23.00</td>
<td>404.09 ± 2.52</td>
</tr>
</tbody>
</table>

**Table 4** | Classification of water samples based on soluble sodium percentage (SSP) values

<table>
<thead>
<tr>
<th>Water source</th>
<th>Water classes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good (&lt;50)</td>
</tr>
<tr>
<td>LI4</td>
<td>20%</td>
</tr>
<tr>
<td>DM1</td>
<td>100%</td>
</tr>
<tr>
<td>DM2</td>
<td>95%</td>
</tr>
<tr>
<td>ZN1</td>
<td>100%</td>
</tr>
<tr>
<td>ZN2</td>
<td>100%</td>
</tr>
<tr>
<td>NY2</td>
<td>60%</td>
</tr>
<tr>
<td>NY1</td>
<td>100%</td>
</tr>
<tr>
<td>DK2</td>
<td>100%</td>
</tr>
<tr>
<td>TN3</td>
<td>100%</td>
</tr>
</tbody>
</table>

groundwater samples in Duko and Zanlerigu was below 1 and therefore good for irrigation purposes. Ninety percent of groundwater samples in Dimbasinia were of good quality for irrigation according to the Kelley’s ratio index (Table 5). The Kelley’s ratio of the groundwater samples in Nyangua ranges between 0.19 and 3.51. While 70% of the water samples from Nyangua have good water quality for irrigation according to the Kelley’s ratio index, the remaining 30% is unsuitable for irrigation. On the average, dry season samples had a higher Kelley’s ratio than wet season samples. All the samples with a Kelley’s ratio >1 were collected in the dry season in Dimbasinia and Nyangua.

**CONCLUSION**

The current study was conducted in northern Ghana to establish the suitability of water for small-scale irrigation. While we found most of the water sources, including small reservoirs, dams, wells and rivers, were suitable, pockets of unsuitable water for irrigation were found, largely due to upstream use such as fertilizer application in upland areas, which might have affected water quality in the water sources in question. The higher recorded *E. coli* and fecal coliform counts found in some sources should be addressed with urgency, since they could cause serious threat to irrigation and human health. Overall, this study found that opportunities for scaling small-scale irrigation exist in all the sites but two. The sites in Duko and Bihinaayilli require installation of deep wells due to lack of groundwater in the shallow aquifers.

**ACKNOWLEDGEMENTS**

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**REFERENCES**


<table>
<thead>
<tr>
<th>Water source</th>
<th>Samples good (&lt;1)</th>
<th>Samples unsuitable (&gt;1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM2</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>ZN2</td>
<td>100%</td>
<td>Nil</td>
</tr>
<tr>
<td>NY2</td>
<td>70%</td>
<td>30%</td>
</tr>
<tr>
<td>DK2</td>
<td>100%</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Water source: DM2 = Dimbasinia shallow wells, ZN2 = Zanlerigu shallow wells, NY2 = Nyangua deep wells, DK2 = Duko shallow wells.

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*Table 5 | Classification of well water samples based on Kelley’s ratio (KR) values*


Millennium Ecosystem Assessment 2005 Ecosystems and Human Well-Being. World Resources Institute, Washington, DC.


Warrence, N. J., Bauder, J. & Pearson, K. E. 2002 Basics of salinity and sodicity effects on soil physical properties. Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana, USA.


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