P-ISSN 2382-4583 E-ISSN 2964-3648

International Journal of Agricultural Research and Educational Management
Vol. 8 No. 2 (June, 2025) | pp 11-21
Available online at https://iigdpublishers.com/journals/27

Open Access | **Original Article**

Assessment of Surface Water Quality for Irrigation from Six Different Districts in Bhutan

[1]Jamyang Khyentse

[1]National Soil Services Centre, Department of Agriculture, Simtokha, Thimphu, Bhutan.

Keywords
Irrigation Water, Electrical Conductivity, Surface Water Quality, Salinity, Sodium Adsorption Ratio, Magnesium Adsorption Ratio.

Volume 8 | Issue 2
June, 2025

P-ISSN 2382-4583
E-ISSN 2964-3648

Abstract
Irrigation water plays a vital role in increasing crop productivity. But due to the scarcity of water large areas of farmlands were left fellow in Bhutan. Hence, the government initiated numerous irrigation projects making surface water available for cultivation. However, it was also felt important to analyse these waters for their concentration of dissolved salts. Hence, this study was conducted to assess the quality of the waters used in different regions of the country. Thus, water samples were collected from 11 sampling sites in April 2021 to August 2023. A total of 99 water samples were analysed to estimate the levels of salinity, SAR, %N, Kelly's ratio and MAR. The results were compared for their suitability with the USSL guideline for classification. It was found that the salinity results ranged from 20 – 110 micromhos/cm corresponding to the salinity Class C1. Similarly, the range of water results for SAR displayed 0.01 – 1.14 corresponding to Class S1 in the USSL diagram. Both the salinity and SAR values demonstrated all the water sources are within the Class C1-S1 indicating their suitability. However, some MAR values were very high exceeding the permissible limit of 50% demanding further investigation.

INTRODUCTION

Agricultural farming requires numerous resources as inputs to achieve a profitable crop yield. Among them, irrigation water plays a critical role in crop production as well as to diversify variety of crops (Ammar T., et al, (2019). As stated by Ayers & Westcot (1994) information on both quality and quantity are important but quality requirement has often been neglected. However, now with increasing population and rapid developmental activities water is becoming scarce which is further aggravated by unprecedented climate change. Thus, in many regions of Bhutan farmers are facing severe irrigation water shortages for cultivation affecting their livelihood. It is because water not only supports the sustainability of the land for crop production it also plays integral part to sustain the overall soil health. Further, it enhances the overall farming ecosystem services (Drechsel et al (eds). 2023).

As a consequence of irrigation water scarcity large areas of cultivable lands in the Country were left fellow. It was also reported by the RNR Census of Bhutan (2019) that of: "The 66587 agricultural holdings calculate 189,465 acres, leaving 66120 fallows of which 8,957.87 acres are wetland (Chuzhing)." However, while such large-scale irrigation projects can provide immediate water scarcity solution, in long run they may also pose unexpected risk due to their poor quality through dissolved salts content. Because on irrigated fields irrigation waters are known to be the primary source of salts accumulation (Hoffman, Glenn J.,1997). As stated by Richards. L. A (1954) that quality of water is important consideration in any evaluation of salinity or alkali in the irrigated fields. In general, as described by Ayers & Westcot (1994) and Sultan and Billah

(2019) water quality can be categorized depending on certain physical, chemical and biological characteristics.

However, this study was focused only on the chemical characteristics that influence the irrigation water quality through high dissolved salts content that may cause salinity and sodium hazard. It is because irrigation water can contain numerous ions which may influence the water quality making it unsuitable for farming (Meena, A.L., & Bisht, P. 2020). It is now widely recognized that soil salinity has increased over time and soil salinity is a major global issue owing to its adverse impact on agricultural productivity and sustainability (Zaman et al., 2018)

Hence, the aim of this research was to assess the quality of waters supplied through the irrigation projects. It is because poor irrigation water quality not only reduces the crop production, they can also cause degradation of soil physical properties (Banderi et al 2012). Therefore, the first objective was to estimate the quality of the waters by analysing pH, electrical conductivity (EC), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) concentrations. Accordingly, using these parameters irrigation water fitness was assessed for salinity, sodium adsorption ratio (SAR) using USSL (1954) as reference for their sodium hazard, that may affect infiltration rates, percent sodium (%Na), Kelly's ratio (Kelly WP, 1963), and magnesium adsorption ratio (MAR) proposed by Raghunath IIM (1987), as described in the subsequent sections in the results and discussion section.

The second objective of the study was that these results are aimed to serve as a baseline for the future irrigation water quality monitoring activities, because so far no such study has ever been conducted in the Country. This was felt necessary as water quality may not always remain the same. It could be polluted through anthropogenic interferences due to numerous developmental activities, influence of climate changes and alterations in the geochemical processes (Drechsel et al (eds). 2023). Such adverse changes in the quality of irrigation water in future can have direct or indirect impact on plant growth, soil health and on water management practices. Therefore, this baseline is expected to guide whether the crop failures are caused by deteriorated irrigation water quality, or due to the effect of soil degradation, or as a result of increased fertilizers use rampantly (National Water Quality Handbook 2003). Once there is a baseline, any impacting factors that may occur in farming system can be traced back and it may help sustaining economic growth.So, a lack of irrigation facilities has impacted the farming community's income which in turn is affecting the national food security. Therefore, the government has launched numerous irrigation projects to construct irrigation facilities in various districts conveying water from far away streams and rivers to farmers' fields as shown in the map in Figure 1.

MATERIALS AND METHODS

This section presents the three subsections such as water sampling sites, field water sampling procedures, and the laboratory analysis of samples.

Water Sampling Sites

In total eleven sampling sites were selected from six different dzongkhags, synonymous to districts in English, in the first Column of Table 1, followed by gewog, a sub-district. The third Column represents the names of the sampling sites with their corresponding GSP coordinates based on which a map displaying all three information are shown in Figure 1.

Table 1: Information of locations from where the water samples were collected

Dzongkhag	Gewog	Sampling site	GSP Coordinates	
Zhemgang	Bardo	Khomshar	E- 0900 58' 28.6''	N- 270 08' 00.01''
Trongsar	Drakteng	Samcholing	E- 0900 32' 02.9''	N- 270 24' 05.8''
Punakha	Shenga…	Jimthang Yuwa	E- 0890 54' 32.9''	N- 270 35' 50.7''
Wangdue	Athang	Rukha	E- 0900 13' 23.3''	N- 270 12' 00.2''

[1]Jamyang Khyentse

Wangdue	Nyisho	Pangkabji	E- 0900 02' 31.9''	N- 270 32' 53.2''
Wangdue	Thedtso	Rinchengang	E- 0890 52' 16.8''	N- 270 27' 19.5''
Wangdue	Dangchu	Lanchu Yuwa	E- 0900 10' 34.8''	N- 270 32' 63.0''
Wangdue	Gangtey	Mangchu Kha	E- 0900 08' 27.2''	N- 270 29' 36.2''
Wangdue	Phangyul	Demcheythang	E- 0900 02' 59.0"	N- 270 34' 41.0"
Tsirang	Kilkhorthang	Dungkarcholing	E- 0900 08' 33.4''	N- 260 59' 36.4''
Dagana	Lhamoizingkha	Changi Khola	E- 0890 44' 76.3''	N- 260 45' 54.0''

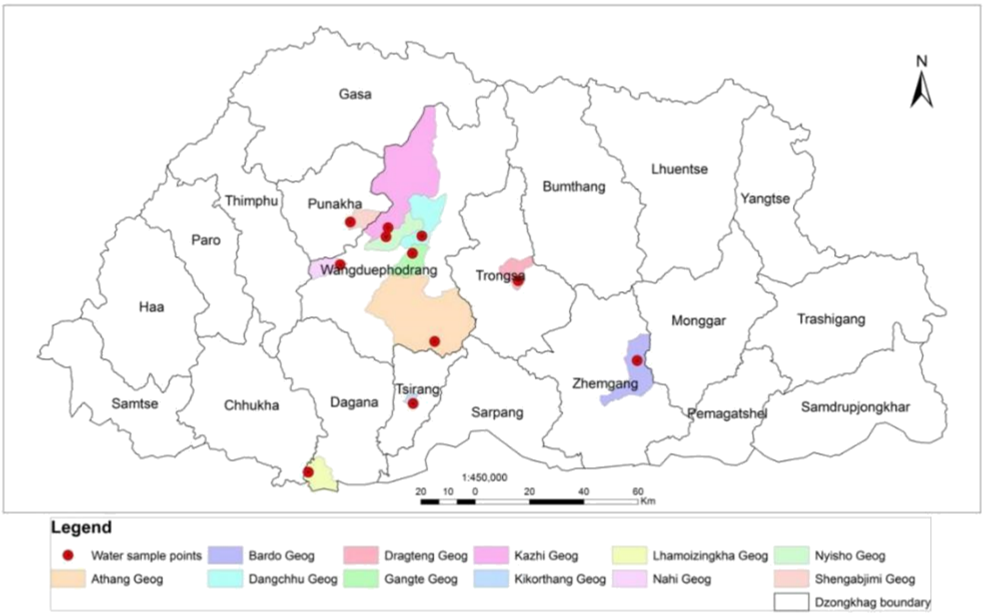

Figure 1: Map showing the dzongkhags, gewogs and the water sampling sites.

Field Water Sampling Procedure

Irrigation water samples were collected from eleven sampling sites in three successive years (2021, 2022, and 2023). Regarding the timing of sampling in 2021 and 2022 the samples were collected in the month of mid to end of the April. From these samples it was also expected to study the sediment load in irrigation water. Since no sediment was detected in the samples of 2021 and 2022 timing for 2023 was scheduled in the month of August, which is a peak monsoon season. However, even in the samples of 2023 no sediments were detected.

The samples were collected in HDP bottles of 1 L capacity and the collection method used was a grab samples method carried out in accordance with the American Association of Public Health's standard methods (APHA, 1998), as the source is expected to be relatively constant in chemical composition in order to avoid contamination the bottles were through washed first with distilled water and then washed by the source water prior to collecting the samples from it. Also, every possible precaution was taken to obtain a representative sample for which three replicates were collected from each site every year. The sample bottles were then carefully labeled with their respective replicates and transported to the laboratory for chemical analysis. No pre-treatment was done. Thus, in the period of three years' a total of nine samples were collected from each site which made the overall total of 99 water samples from 11 sites.

Laboratory Analysis

The chemical parameters analysed in water samples were pH, Electrical Conductivity (EC), calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) as displayed in the Table 2 under the Section 3 for results and discussion. The unit for ECw is µS/cm, and the soluble cations such as Ca2+, Mg2+, Ka+ and Na+ are expressed in milliequivalents per litre (meq L-1). Using these analytical parameters four chemical indices were derived as presented in the equation 1 to 4 where all the ions were expressed as meq L-1.

The pH was measured by using PHM83 Autocal pH Meter with most common ion-selective electrode incorporating both glass and the reference (Harris Daniel C., 2007). The EC was determined using CDM83 Conductivity Meter. For determination of Ca2+ and Mg2+ PU 9100X Atomic Absorption Spectrometer was used. For the analyses of Ka+ and Na + Segmented Flow Analyzer model 5000 along with the Model 420 Flame Photometer were used. For the descriptive statistical analysis SPSS software version 27 was used.

RESULTS AND DISSCUSSIONS

The chemical parameters analysed in the water samples are presented in Table 2 along with the corresponding village names in the second Column to identify the sampling sites.

Table 2: Parameters tested in water samples and their respective concentrations

Sl.No.	Sampling site	pH	ECw	Ca2+	Mg2+	K+	Na+
			µS/cm		meq L-1		
1	Khomshar	6.56	20.0	0.21	0.33	0.007	0.078
2	Samcholing	6.89	30.0	0.17	0.35	0.014	0.080
3	Jimthang Yuwa	7.74	70.0	9.38	0.98	0.009	0.074
4	Rukha	7.62	50.0	5.48	0.58	0.019	0.049
5	Pangkabji	7.67	40.0	5.59	1.10	0.005	0.082
6	Rinchengang	7.16	30.0	0.99	0.84	0.008	0.077
7	Lanchu Yuwa	7.88	90.0	30.75	0.77	0.007	0.026
8	Mangchu Kha	7.01	20.0	0.15	0.19	0.007	0.073
9	Demcheythang	7.78	110.0	18.04	7.40	0.010	0.006
10	Dungkarcholing	6.66	20.0	0.09	0.29	0.008	0.081
11	Changi Khola	7.90	80.0	4.61	41.47	0.011	0.042

The resulted presented in Table 2 reflects the overall mean of three years' data. In each year three replicates were collected and by the third year 9 replicates from each site were tested. The data in Table 2 is further summarized using SPSS software version 27 as maximum (Max), minimum (Min), mean, standard deviation (SD) and coefficient of variance (CV) in Table 3 to better understand the range of concentrations among the parameters.

Table 3: Shows the overall range of the parameters with their concentrations

Parameters tested	Unit	Max	Min	Mean	SD	CV
pH		7.90	6.56	7.35	0.51	6.88
EC	µS/cm	110	20	50.9	31.77	62.40
Ca2+	mEqL-1	30.75	0.09	6.86	0.62	140.20
Mg2+	mEqL-1	41.47	0.19	4.94	12.29	248.98
K+	mEqL-1	0.019	0.005	0.010	0.004	41.47
Na+	mEqL-1	0.082	0.006	0.061	0.026	42.99

When assessed for the dominance cations order based on the average concentrations it was found in the order of Ca2+ (6.86) > Mg2+ (4.94) > Na+ (0.061) > K+ (0.010)

pH value

Although the main focus of the study was to assess the EC and principal cation ions. However, pH values were also determined so that in future any changes that may occur, if necessary, can be traced back to this baseline report. Moreover, it was recommended that irrigation water has to be tested for both pH and alkalinity (Cox, D. 1995; Tom Fernandez, 2018). To measure the pH the most widely employed ion-selective electrode was used because the electrode responds selectively to H+ only. It then builds up a potential difference of 0.059 16 v for every factor of 10 difference in [H+] ions across the electrode membrane thus enabling to measure the pH (Harris, Daniel C., 1997). The highest pH value was 7.9 at the sampling site Changi Khola in Dagana dzongkhag, and the lowest pH was at 6.56 at Khomshar in Zhemgang dzongkhag. On an average the pH value of waters in 11 sites was found to be 7.35 as shown in the Table 3.

EC for Salinity Hazard

The measurement of ionic concentration of soluble salts in water samples indicates the salinity of irrigation water. In the Soil and Plant Analytical Laboratory (SPAL), it is measured as the electrical conductivity (EC) of water in milli Siemens per centimetre (mS/cm). The periodic testing of salinity in the irrigation waters is crucial because high level of soluble salts can increase the osmotic pressure of the soil solution. This will severally affect plant roots' efficiency for the uptake of nutrients and water. Such situation can cause a physiological drought which eventually reduces the plant vigor and crop yields.

To address these problems the concentration of soluble salts in irrigation water was classified into four classes of salinity by USSL (1954) namely, C1, C2, C3 and C4 as presented in Table 4. This classification system is used here as the standard criteria to evaluate the fitness of our waters for irrigation.

Table 4: Guideline for interpretation of salinity hazard in irrigation water

Water classes	EC (dSm-1)	Remark
C1 – Low salinity	0 – 0.25	Very good and can be used for irrigation safely
C2 – Medium salinity	0.25 – 0.75	Can be used with moderate leaching
C3 – High salinity	0.75 – 2.25	Can be used for irrigation with some management practices
C4 – Very salinity	2.25 – 5.00	Cannot be used for irrigation purposes.

The EC results of 11 sites are presented in the Figure 1. The X-axis represents the names of the water sampling sites, and the Y-axis displays the concentration of EC expressed as dSm-1 to be comparable with the unit in the guideline Table 4.

[1]Jamyang Khyentse

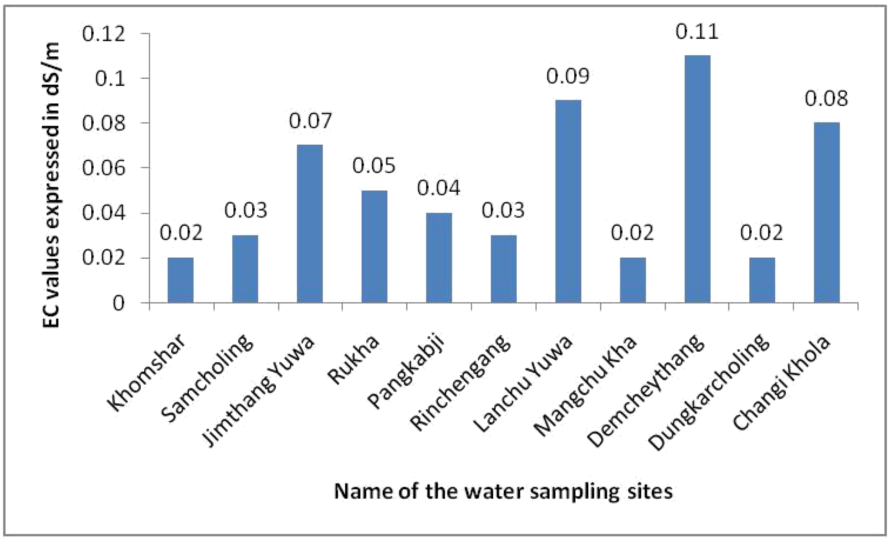

Figure 2: EC results from 11 water sampling sites expressed as dSm-1.

When the EC values are compared with the reference values in Table 4, all the results from 11 sampling sites are found below the 0.25 dSm-1. Thus, all our results fall within the range of 0-0.25 dSm-1. The highest EC value is 0.11 dSm-1 as shown in Figue 1; from Demcheythang village, of Phangyul gewog in Wangdue dzongkhag, while the lowest values of 0.02 dSm-1 are from Khomshar village in Bardo gewog in Zhemgang dzongkhag; Mangchukha village of Gangtey gewog in Wnagdue dzongkhag, and Dungkarcholing of Kilkhorthang gewog in Wangdue. All EC results fall within the Class C1 indicating that the waters contain very low salinity. Hence, they are very good and can be used for irrigation safely.

The results observed in the test water samples were also compared using Wilcox and USSL (1954) diagram shown in Figure 2. Wilcox plots have a total of two required parameters, X and Y-Axis. This single chart system has a combination of salinity, and sodium hazard which is discussed in the Section 3.3. X-Axis represents the electrical conductivity expressed in micromhos/cm (µmhos/cm), and Y-Axis represents the calculated sodium adsorption ratio (SAR). SPAL's unit µS/cm in the Table 2 is standardized to the same unit as µmhos/cm. Thus, the maximum EC value equals to 110 µmhos/cm and minimum of 20 µmhos/cm with a mean of 50.9 µmhos/cm to be more comprehensive as shown in Table 3 above.

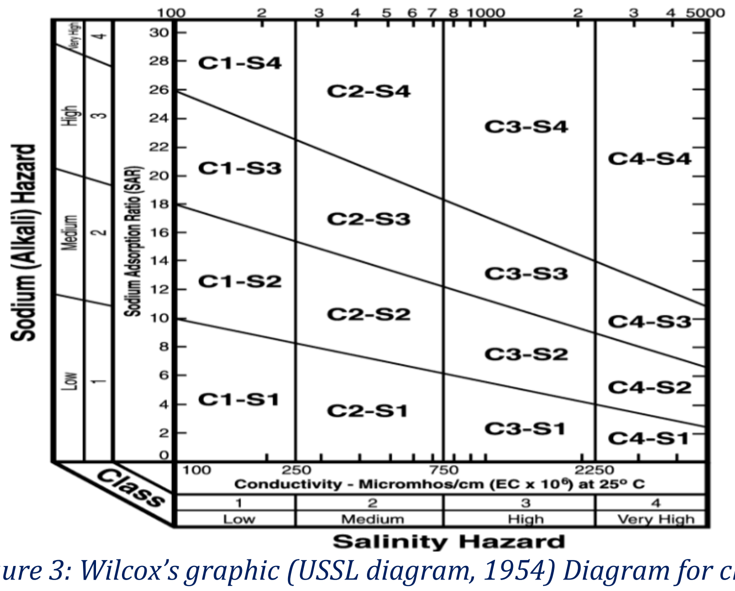

Figure 3: Wilcox's graphic (USSL diagram, 1954) Diagram for classification of irrigation waters

So the salinity hazard coded as C1- C4 along the X-Axis in Figure 2 represented with EC they are classified as C1-Low, C2-medium, C3-high, and C4-very high salinity hazard. When the results of waters from 11 sampling sites ranging from 20 – 110 micromhos/cm were compared with the classification limits all water sample values were less than 250 micromhos/cm representing the class C1 – S1. Therefore, the results demonstrated that EC results from all water sources are very good and they can be safely used for irrigation purposes.

Sodium Adsorption Ratio (SAR) or Sodium Hazard

SAR is defined as a measure of the amount of sodium relative to the amount of calcium and magnesium in a water sample. Irrigation waters containing high concentration of sodium are undesirable because sodium gets adsorbed on the soil cation exchange sites causing soil aggregates to break down and deflocculated. As a result the pores of the soil will be sealed and make it impermeable to water flow reducing rate of infiltration and crops will be deprived of adequate water.

For estimated SAR value the calculation was done using the method proposed by the USSL (Agricultural Handbook No.60) as shown in the Equation 1.

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad 1$$

The results of SAR displayed that highest value was 1.14 from Dungkarcholing in Tsirang dzongkhag and lowest was 0.01 from Lanchu Yuwa and Demcheythang site as represented in Table 5.

Table 5: Shows calculated values of SAR, %Na, Kelley's Ratio (KR) and Magnesium Adsorption ratio (MAR) of water samples.

Sampling site	SAR	% Na	Kelly's ratio	MAR
Khomshar	0.89	12.48	0.14	61.11
Samcholing	0.94	13.03	0.15	67.31
Jimthang Yuwa	0.17	0.71	0.01	9.46
Rukha	0.15	0.80	0.01	9.57
Pangkabji	0.24	1.21	0.01	16.44
Rinchengang	0.46	4.92	0.04	45.90
Lanchu Yuwa	0.01	0.08	0.00	2.44
Mangchu Kha	0.98	17.38	0.21	55.88
Demcheythang	0.01	0.02	0.00	29.09
Dungkarcholing	1.14	17.27	0.21	76.32
Changi Khola	0.06	0.09	0.00	90.00

When the results were compared with the reference values for Sodium hazard classified as S1, S2, S3, and S4 in Table 6 all the values fall within the range of 0-10 for SAR. The guideline shows that our results are within the Class S1, interpreting it as low sodium hazard. Hence, the irrigation water results indicated they have little to no hazard for almost all crop cultivation. However, sodium-sensitive crops like stone-fruits and avocados may be injured due to build-up of sodium concentrations (Richards. L.A., 1954).

Table 6: Guideline for interpretation of SAR in irrigation water

Class	Water class interpretation	SAR	Remarks

S1	Low sodium hazard	0-10	Little to no hazard
S2	Medium sodium hazard	10-18	Appreciable hazard but can be used with appropriate management
S3,	High sodium hazard	18-26	Unsatisfactory for most of the crops
S4	Very high sodium hazard	>26	Unsatisfactory for most of the crops

Furthermore, as the permeability hazard of irrigation water samples are related to both the SAR and EC values, the system in Figure 2 combines salinity and sodium hazard of the irrigation water for a better understanding of their interactive effect. Thus, the results were compared with the values in Figure 2 which displays X-Axis with salinity hazard and Y–Axis representing sodium hazard. The comparative results illustrated that all water values fall within the salinity (C1) and sodicity hazard (S1). Hence, it was observed that all water samples from 11 sites demonstrated class C1-S1 indicating as a very good quality.

The observed water results were further compared with the stated reference values by the National Environment Commission (NEC) of Bhutan. It proposed suitability level for irrigation water of EC value of 2000 µS/cm and SAR of 26. This classification refers as Class C (Moderate) in the Water quality standards (2018). Hence, this guideline contradicts with the values stated in Table 6 for SAR class S3 (18-26) which contains high sodium hazard and thus unsuitable for most of the crops.

Percent sodium (%Na) was calculated using the equation 2 as shown below:

$$\% \, Na = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}} \, x \, 100 \qquad 2$$

In the study it was found that percentage sodium ranged from 0.02 to 17.38% with an average value of 6.10% for 11 sampling sites, as illustrated in Table 5 in third Column titled %Na. The lowest value was reported from Demcheythang, and highest value of 17.38% from Mangchu Kha followed by 17.247 from Dunkarcholing. According to the suitability rating quoted by Meena, Arjun Lal & Bisht, Priyanka. (2020) from Wilcox, USDA, (1955) value less than 20 is considered as excellent, and 20-40 as good. Since the tested water results ranged within 0.02 to 17.38% it was concluded that all water quality fall within the class – Excellent.

Kelly's Ratio (KR) or Kelly's Index (KI)

KR was calculated using Na+, Mg2+ and Ca2+ in the equation adopted by Kelly WP (1963) as presented in the Equation 3.

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad 3$$

From Table 5 in the fourth Column, it was found that the highest value for KR was 0.21 and lowest 0.0. Thus, the results indicated all 11 samples are suitable for irrigation because KR reports that <1.0 is safe to use and >1.0 not suitable for irrigation.

Magnesium Hazard (MH) or Magnesium Adsorption Ratio (MAR)

MAR was calculated by using the equation proposed by Raghunath (1987) in Equation 4.

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} x\, 100 \qquad 4$$

The water samples results in Table 5 demonstrated that lowest MAR value of 2.44 % from Lanchu Yuwa, and highest value of 90.0 % from Changi Khola, with an average of 42.14 %.

The MAR ratio emphasizes the importance of magnesium for soil and plant health because a MAR values < 50 % is specified as suitable, while the values >50 % as not suitable for use. It is because values greater than >50 % are assumed harmful to soil and plant growth. It was detected that MAR values from five waters are extremely higher than the permissible limit. The results of MAR values exceeding the permissible limits are arranged in the increasing order as shown here: Mangchu Kha (55.88) <Khomshar value (61.11) <Samcholing (67.31) <Dungkarcholing (76.32) <Changi Khola (90.00).

The possible justification for their high concentration of magnesium hazard could be due to the prevalent dolomitic limestone sites in water catchments which are sporadically common in Bhutanese landscapes. Qadir et al (2018) quoted Vyshpolsky et al (2008) who reported that in their recent water quality assessment results revealed more and more high concentrations of magnesium than calcium in surface water. Hence, Qadir et al (2018) stated that high concentration of magnesium in water can build-up salt level in irrigated soils which will result in soil degradation and impact crop yield negatively. Thus, the five water sources with extreme results needs to be further investigated for their causes so that necessary treatment could be planned to avoid the deterioration of soil health and crop productivity.

CONCLUSION

The main analyses performed on the quality of the waters were salinity, SAR, %Na, kelley's ration and MAR. The results for salinity, SAR, %N, and Kelly's ratio indicated they are an ll suitable for irrigation purposes. The results for salinity and SAR demonstrated that all 11 waters fit within the USSL classification of Class C1-S1 confirming they are safe for use.

However, while six results for magnesium hazard were within the permissible limit five results demonstrated extremely high values ranging from 55.88 – 90.00 %. Such high concentrations could adversely affect the soil condition and crop yields. Hence, further study needs to be conducted on these waters so that the treatment required can be carefully planned.

Although this water quality evaluation is the first of its kind ever conducted, the overall findings provided a better insight for new possibilities for the effective management of surface waters application in Bhutan. This research finding will also impact especially in the field of hydroponic and drip irrigation systems which are now becoming more and more common entities where water quality is of great concern.

Thus, to have comprehensive data parameters such as bicarbonate, carbonate, boron and chloride ions should be considered in future research. Such research findings will provide an effective irrigation water use and soil fertility management plans to farmers, extension officials and the agriculture researchers ensuring national food security.

RECOMMENDATIONS

[1]Jamyang Khyentse

In the current study the focus was only on the salinity and SAR where bicarbonate and carbonate were not considered. Therefore, it is highly recommended that in future bicarbonate and carbonate should be studied to obtain a comprehensive data to evaluate residual sodium carbonate (RSC). This will enable to study all the principal cations and anions in irrigation waters, and their influences on soil pH, soil quality and other plant nutrients uptake.

Specific ion effects of boron and chloride also needs to be taken into consideration in future study. It is because although they are essential plant nutrients but high concentrations could cause toxicity to plants, and hence they are required to be assessed. In the current scenario toxic effect caused by specific elements like boron and chloride are not well understood by the farming community.

The other most important investigation needed to be conducted is to study the cause for the five extreme values for MAR detected in this study, and provide a comprehensive report. Accordingly, the report should advise whether the waters and the soils to be treated or appropriate crop selections to be the better option in the field affected by high concentration of magnesium.

ACKNOWLEDGEMENT

The author would like to thank the Project Management Unit of the Green Climate Fund Project in Bhutan for providing the funding support to conduct the fieldworks. Likewise, the author also would like to express my gratitude to the SPAL staff specially Mr. Namgay Karma Dorji and Mrs. Sangita Pradhan of GIS section for their valuable support for this study. Furthermore, the author is grateful for the anonymous reviewers for their comments which helped to improve this paper substantially.

REFERENCES

Ammar, T., Belkhiri, L., Asma, M. & Mouni, L. (2019). Suitability and Assessment of Surface Water for Irrigation Purpose. DOI: http://dx.doi.org/10.5772/intechopen.86651

Ayers, R. S., & Westcot, D. W. (1994). Water quality for agriculture. FAO Irrigation and Drainage Paper 29, Rev. 1. Rome, Italy: Food and Agricultural Organization of the United Nations.

Drechsel, P., Zadeh, M. S. & Pedrero, F. (eds). (2023). Water quality in agriculture: Risks and risk mitigation. Rome, FAO & IWMI. https://doi.org/10.4060/cc7340en

RNR Census of (2019). Rnewable Natural Resources Statistics Division, Directorate Services, Royal Government of Bhutan, Ministry of Agriculture and Forest. https://www.fao.orgess, BTH_REP_ENG_2019

Hoffman, Glenn J. "EC97-782 Water Quality Criteria for Irrigation" (1997). Historical Materials from University of Nebraska-Lincoln Extension. 1214. https://digitalcommons.unl.edu/extensionhist/1214

Richard, L.A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. US Department of Agriculture. Agricultural Handbook No. 60, Washington DC, 7 -53. http://dx.doi.org/10.1097/00010694-195408000-00012

Sultan, M. T., & Billah, S. M. (2019): Irrigation water quality of surface and ground water used for Boro rice cultivation in Khulna district in Bangladesh. https://doi.org/10.3329/bjsir.v54i3.42679

Meena, A.L., & Bisht, P. (2020). Assessment of Water Quality for Irrigation Purpose: A Case Study of Bassi and Chaksu Tehsils, Jaipur District, Rajasthan, India. http://dx.doi.org/10.7770/safer-V0N0-art1944

Water quality standards (2018). National environment commission secretariat, Bhutan.

Zaman M., Shabbir A. S,, & Heng, L. (2018). Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques. https://doi.org/10.1007/978-3-319-96190-3

Banderi,A., Sheih,M.M., Hamdi,H., Shomeli, M., Gol, A. S. D. (2012). Water Quality Assessment of Amir Kabir Sugarcane Agro-industry with Respect to Agricultural and Drinking Views. URL: http://dx.doi.org/10.5296/jee.v3i1.2353.

USSL (United States Salinity Laboratory), (1954). Diagnosis and improvement of saline and alkali soils. Agricultural Handbook No.: 60. USDA https://www.ars.usda.gov/ARSUserFiles/20361500/hb60_pdf/hb60complete.pdf

Kelley, W.P. (1963). Use of Saline Irrigation Water. Soil Science, 95, 385-391. http://dx.doi.org/10.1097/00010694-196306000-00003

Ragunath, H.M. (1987). Groundwater. Wiley Eastern Ltd., New Delhi.

Qadir, M., Schubert, S., Oster, J.D., Sposito, G., Minhus, P. S., Cheraghi, S.A.M., Murtaza, G., Mirzabaev, A., &Aaqib, M.(2018). High-magnesium water and soils: Emerging environmental and food security constraints. https://doi.org/10.1016/j.scitotenv.2018.06.090

National Water Quality Handbook, (2003). United States Department of Agriculture Natural Resource Conservation Service; Issued September 2003. https://archive.epa.gov/water/archive/web/pdf/stelprdb1044775.pdf

APHA (1998). Standard methods for the examination of water and wastewater, 20th edn, American Public Health Association, Washington DC, USA.

Harris Daniel C. (2007). Quantitative Chemical analysis. Seventh Edition. Michelson Laboratory China Lake, California, published by W. H. Freeman and Company, New York.

Cox, D. (1995). Water quality: pH and Alkalinity. UMass. Extension Greenhouse Crops and Floriculture program. University of Massachusetts Amherst.

Fernandez, T. (2018). Water alkalinity and pH: what they mean in regards to water quality. Michigan State University Extension.

Harris Denial C. (1997). Exploring Chemical Analysis published by W. H. Freeman and Company, New York.