Research Note: Evaluation of Irrigation Water Quality for Paddy Production at Bumbwisudi Rice Irrigation Scheme, Zanzibar

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Introduction

Water quality plays a crucial role in successful production of crops. Overtime the quality of groundwater is constantly changing in response to daily, seasonal and climatic factors (Ackah *et al.,* 2011). A thorough water analysis and evaluation is therefore important for any successful crop production operation. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long term productivity. The crop performance is influenced by fertility status of the soil and quality of water used to irrigate the crop (SDWAF, 1996; Majumdar, 2001). Analysis of water quality for irrigation is Zanzibar is especially important because the declining water resources, increased population, low rice yields and water competition with other development activities including domestic uses, necessitates the need to understand the quality and quantity of water needed for adopting good crop production systems that minimize environmental pollution, favor water saving, while improving yield in irrigated rice.

Conceptually, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user and is defined by certain physical, chemical and biological characteristics (FAO, 1985).

According to the South African water quality guidelines (SAWQG, 1996), the term water quality describes the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of aquatic ecosystems. It means water quality for irrigation is described by properties that judge its fitness for irrigation purposes.

The suitability of water for irrigation depends on a variety of factors, most relevant and important are; (salinity) concentration of Total Dissolved Solids (TDS), expressed in ECw unit, which mainly affects crop yields, (element toxicity) concentration of certain ions, which may be toxic to plants or have unfavorable effects on crops, soils and public health and (sodicity) concentration of cations, which may cause de-flocculation of clays in soils resulting damage to soil structure and permeability (Bauder *et al.,* 2007).

Ayers and Westcot, (1985) classified irrigation water into three groups based on salinity, sodicity, toxicity and miscellaneous hazards. These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources.

In 1985 Food and Agriculture Organization of the United Nations (FAO) produced guidelines for evaluation of water quality for irrigation. The key parameters include pH, electrical conductivity (EC), Sodium content (Na) measured in (SAR) and bicarbonate (HCO3-). These parameters are discussed in the following sections.

Water pH

The pH is an indicator of the acidity or basicity of water, but is seldom a problem by itself. The main use of pH in a water analysis is for detecting abnormal water. The normal pH range for irrigation water is from 6.5 to 8.4. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain toxic ions (FAO, 1985). An abnormal value is a warning that the water needs further evaluation. Water with a pH below 7 is acid and water with a pH above 7 is alkaline (Brunton and Ourimbah, 2011). Most natural waters have pH of between 5 and 8. High values of pH above 8.5 are often caused by high carbonate (CO_3^{2-}) and bicarbonate ($HCO3^-$) concentrations (Ayers and Westcot, 1985).

Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current, which is carried by various ions in solution such as chloride, sodium, sulphate, nitrate, carbonate, bicarbonate, calcium and magnesium. Electrical conductivity is commonly used as an estimate of the concentration of total dissolved salts (TDS) or total salinity in irrigation water. The instrument used to measure ECw is the EC-meter and the standard unit used to express electrical conductivity is Deci Siemens per meter (dS/m) or Micro Siemens per centimeter (μS/cm). One dS/m is equivalent to one thousand micro Siemens per centimeter μS/cm. The readings in the instrument are proportional to the concentration of dissolved salts. This implies that lower units of ECw indicate low concentration of dissolved salts and vice versa. FAO, 1985 indicated values of ECw less than 3 dS/m as free from salinity (Ayers and Westcot, 1985). Plants take up water through a process of osmo-regulation, wherein elevated salt concentration within plants causes water to move from the soil surrounding root tissue into the plant root. Saline conditions restrict or inhibit the ability of plants to take up water and nutrients, regardless of whether the salinity is caused by irrigation water or soil water which has become saline because of additions of salty water (Bauder *et al,* 2006).

Sodium content (Na)

The effect of sodium ions in irrigation water is its tendency of reducing infiltration rate and soil permeability (Ayers and Westcot, 1985). Sodium causes soils to disperse or lose soil structure (Akoto, et al., 2010). As soil structure deteriorates soil compaction or tightness will increase and water infiltration, water percolation and root growth are all decreased. Sodium adsorption ratio (SAR) is the most commonly used parameter for evaluating groundwater suitability for irrigation purposes (Ayers and Westcot, 1985). SAR is calculated using the following formula (equation 1).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \text{.................} \quad (1)$$

Where: Na, Ca and Mg are sodium, calcium, and magnesium contents in mill-equivalent per liter (meq/l) respectively. Irrigation water having SAR less than 3 meq/l, there is no restriction on use whereas irrigation water source, 3-9 meq/l have slightly to moderate restrictions on use while those having SAR greater than 9 meq/l have severe restriction on use as it destroys soil structure and reduce permeability of soil.

Bicarbonate (HCO3-)

Bicarbonates (HCO3--) concentration in irrigation waters is primarily important in its relation to calcium (Ca^{2+}) and Magnesium (Mg^{2+}). There is a tendency for both calcium and magnesium to react with bicarbonate in the water and /or soil precipitating as either calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$). Magnesium carbonate is more soluble, and therefore has a less tendency to precipitate. The precipitation of either calcium or magnesium from water as carbonate salts increases and raises the relative proportion of sodium which directly raises the sodium hazard rating. The acceptable range of HCO3-- content in irrigation water is from 1.5 to 8.5 meq/l. Values greater than 8.5 meq/l can severely affect irrigation equipment (Ayers and Westcot, 1985). Considering Zanzibar as an island with limited land and water resources with respect to its population and food demand, especially rice, there was therefore a need to characterize the water quality and determine its suitability for paddy rice production.

Materials and Methods

Descriptions of the study area

The research was conducted at Bumbwisudi rice irrigation scheme in Zanzibar Island. The site is situated at 06° 03′ 32″S and 39° 15′ 37″E and 40 m above mean sea level, about 13 km North East of Zanzibar town. The soil texture is sandy clay loam (54% sand, 13% silt and 33% clay).

Climate

The average maximum and temperature is fairly constant however, maximum temperature fluctuates between 32.8°C and 29.2°C while the minimum temperature ranges from 21.2°C to 24.6°C. The scheme depends solely on ground water and rainfall as water sources.

Rainfall in Zanzibar is bimodal; there is a long rain season from March to June and a short rain season from October to December. The bimodal distribution of rainfall determines two growing seasons. Mean annual rainfall is 1517 mm. Mean daily sunshine hours ranges from 6.6 hrs to 8.8 hrs during the cloudy and the clear months respectively. Mean monthly solar radiation ranges from 16.2 MJm-2day-1 in July (the coldest month) to18.8 MJm-2day-1 in January (the hottest month), respectively. Evaporation ranges from 119.8 mm in April to 174.7 mm. Wind run ranges from 2.3 m s-1 to 3.6 m s-1 in the calm and the windy months respectively (Climatic parameters from Kisauni meteorological station-Zanzibar (1987-2012).

Water quality analysis

Irrigation water quality was therefore assessed in terms of its quality parameters by laboratory determination of most important water quality parameters; the pH, total dissolved solids measured in electrical conductivity (EC), sodium content measured in sodium adsorption ratio (SAR) and bicarbonate. Sampling points were selected such that the samples taken are representative of the different sources from which water is obtained for irrigation. The sampling points were uniformly distributed throughout the sources within the irrigation scheme, and yielded samples that are representative of the system (Kenkel, 2013; Li and Migliaccio 2010). The water samples were being taken to the national water laboratory in Saateni Zanzibar within two hours of being taken. The sampling protocol adopted was as described by Nielsen and Nielsen (2006).

Results were compared with the ones in the guidelines produced by FAO (1985) (Table 1). Water quality analysis was conducted in the laboratory using standard procedures as described by Kenkel (2013). The laboratory analysis includes pH, electrical conductivity (EC), sodium (Na) and bicarbonate (HCO3-). The pH was measured potentiometrically using glass electrode pH meter as described by Maclean (1982) and Kenkel (2013); Ammonium acetate extract was used to determine (Ca) and (Mg). The water electrical conductivity (ECw) was measured using EC meter as per methods described by Li and Migliaccio (2010). The above mentioned chemical characteristics are the most commonly used parameter for evaluating groundwater suitability for irrigation purposes according to (FAO, 1985).

Results and Discussion

Monitoring water quality by regular testing is an important part of maintaining a safe and reliable water sources, and for ensuring ecological balance to better protect human health and the environment (Ahuja, 2013). The water quality was assessed in terms of its quality parameters; the pH, dissolved solids measured in electrical conductivity (EC), sodium content measured in (SAR) and bicarbonate being the most important ones. Results were as follows.

Water pH

The pH of irrigation water at Bumbwisudi irrigation scheme was 8.26 (Table 1). According to the guidelines, accepted pH range for irrigation water is from 6.5 to 8.4 (Ayers and Westcott, 1985). Since the pH value is within the standard range for irrigation, the Bumbwisudi water source could be judged as good for irrigation purposes. The value is close to the maximum limit of accepted pH, care must be taken in ensuring that the pH does not shift outside the normal range through regular seasonal monitoring to check if there are additional basic cations in the irrigation water that would slightly elevate the pH.

Electrical conductivity (ECw)

Electrical conductivity (ECw) of water was 0.53 dS/m. According to water quality standards it is within the range of none restrictions, i.e. less than 0.7 dS/m. According to guideline for evaluation of water quality for irrigation (Ayers and Westcott, 1985), water with ECw values less than 0.7 dS/m and TDS values less than 450 mg/l has low salinity level and non-restrictions on use (Table 2). The irrigation water in Bumbwisudi can therefore be classified as having low salinity hazards and can be used as source of irrigation water without restrictions and may not pose any injury to the crops. ECw plays a vital role in suitability of water for irrigation. Higher EC in water creates a saline soil (Ackah *et al.,* 2011).

Sodium content (Na) and Sodium adsorption ratio (SAR)

The sodium content of Bumbwisudi water source measured in SAR was 3.3 meq/l (Table 1). According to the guidelines (Table 2) amount of sodium present is within the accepted range and can be judged as free from sodium hazards. Irrigation water containing large amounts of sodium is of special concern due to its effect on the soil properties and poses a sodium hazard. High sodium content (SAR) leads to development of an alkaline soil (Khodapanah *et al.,* 2009). SAR is the most commonly used for evaluating groundwater suitability for irrigation purposes (Ayers and Westcot, 1985).

Excess sodium in irrigation water produces undesirable effects of changing soil properties and reducing soil permeability. Hence assessment of sodium concentration is necessary while considering the suitability of water for irrigation (Nishanthiny *et al.,* 2010). Continued use of water having a high concentration of sodium leads to a break down in the physical structure of the soil. Sodium is adsorbed and become attached to the soil particles. The soil then becomes hard and compact when dry and increasingly impervious to water penetration. Sodium replacing calcium and magnesium is a hazard as it causes damage to soil particles (Hamza, 2012).

Bicarbonate (HCO3-)

Bicarbonate (HCO3-) content in irrigation water was 4.3 meq/l. This value falls in slightly to moderate in the guideline. Since the (HCO3-) value is within the standard range for irrigation, the Bumbwisudi water source could be judged as good for irrigation purposes (Bauder *et al.,* 2007; FAO, 1985). Referring to Table 2, water can be used for irrigation but with slight to moderate restrictions on use. The presence of high levels of bicarbonates will precipitate with calcium when the soils dry and produce calcium carbonate ($CaCO_3$). Production of calcium carbonate will cause concentration of Ca and Mg decrease relative to sodium and the SAR index will be bigger. This will cause an alkalizing effect and hence increase the level of pH. Therefore we can say high pH levels in water are an indication

Table 1: Chemical properties of Bumbwisudi irrigation water source

Chemical property	Quantity	Normal range
pH	8.26	6.5 – 8.4
Electrical conductivity (ECw) (dS/m)	0.53	< 3.0
Total Dissolved Solids (TDS) mg/L	339	< 1920
Sodium (N) (meq/l)	6.5	0 - 40
Calcium (Ca) meq/l	4.8	0 - 20
Magnesium (Mg) meq/l	2.9	0 - 5
Bicarbonate (HCO3-) (meq/l)	4.3	< 8.5
Sodium adsorption ratio (SAR) (meq/l)	3.3	< 9.0

Source: FAO (1985)

Table 2: Guidelines for evaluation of water quality for irrigation

Potential irrigation problem	Units	Degree of restriction on use		
		None	**Slight to moderate**	**Severe**
Ecw	dS/m	< 0.7	0.7 - 3.0	> 3.0
Total Dissolved Solids (TDS)	Mg/L	< 450	450 – 1920	> 1920
Sodium (N)				
Surface irrigation	SAR	< 3	3 - 9	> 9
Bicarbonate (HCO3-)	me/I	< 1.5	1.5 - 8.5	> 8.5
pH	Normal range 6.5-8.4			

Source: FAO (1985)

of high content of carbonate and bicarbonates ions (Abrol *et al.,* 1988; Majumdar, 2001). Bicarbonate is also toxic to roots and reduces shoot growth, reduces uptake of phosphorus and many of the micronutrients (Hajiboland *et al.,* 2003). Bicarbonate reacts with calcium to form calcium carbonate and render the calcium unavailable in high pH soils. As a result the reduced amount of free calcium and magnesium in soil allows sodium to compete for and occupy the negatively-charged exchange sites on clay particles. Excess sodium in clay destroys the soil structure and reduces percolation of water though the soil profile (Abrol *et al.,* 1088; Majumdar, 2001; Marchuk 2013).

Conclusion and Recommendations

This research was conducted to evaluate the performance of paddy rice cultivation in Zanzibar in terms of yield, quality of water for irrigation, and water productivity in Zanzibar. This paper reports the water quality component of the study whereby the water quality was evaluated to determine its suitability for irrigated paddy rice production.

Irrigation water analysis in the study area revealed no restriction in its use for rice cultivation. All parameters analyzed for quality evaluation water source in Bumbwisudi irrigation scheme are within the FAO acceptable range for irrigation purposes and farmers can continue using it as irrigation water because it is free from salinity and sodium hazards.

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References

Abrol, I.P., Yadav, J.S.P., and Massoud, F. I. (1988). Salt-affected Soils and Their Management, FAO Soils Bulletin Issue 39. Soil Resources, Management and Conservation Service. FAO, Rome, Italy.

Ackah, M., Agyemang, O., Anim, A.K., Osei, J., Bentil, N.O., Kpattah, L., Gyamfi, E.T. and. Hanson, J.E.K. (2011). Assessment of groundwater quality for drinking and irrigation: The case study of Teiman-Oyarifa community, Ga East Municipality, Ghana. In: Proceedings of the International Academy of Ecology and Environmental Sciences 1(3-4):186-194.

Ahuja, S. 2013. Monitoring Water Quality: Pollution Assessment, Analysis, and Remediation. Elsevier, Waltham, MA, USA. 400pp.

Akoto, O., Wi-Afedzi, T., Aidoo, G. and Apau, J. (2010). Evaluation of water from Bokro stream for irrigation and its effect on soil. Journal of Science and Technology 30(2) 135.-141.

Ayers, R.S. and Westcot, D.W. (1985).Water Quality for Agriculture, Irrigation and Drainage Paper No. 29, FAO, Rome.179pp.

Bauder, T.A., Waskom, R.M. and Davis, J.G. (2007). Irrigation Water Quality Criteria. Extension Fact Sheet no. 0.506, Colorado State University. pp 1-5.

Brunton, V. and Ourimbah, D.P.I. (2011). Irrigation water quality fact sheet. Department of Primary Industries, a part of the Department of Trade and Investment, Regional Infrastructure and Services 3pp.

FAO (1985). Water quality for agriculture. FAO Irrigation and drainage paper No. 29, Rome 174pp.

Hajiboland, R., Yang, X.E. and Romheld, V. (2003). Effect of bicarbonate on root growth and accumulation of organic acids in Zn-inefficient and Zn-efficient rice cultivars (*Oryza sativa* L.). Plant and soil (250):349-357.

Hamza, N.H. (2012). Evaluation of Water quality of Diyala River for irrigation purposes. Diyala Journal of Engineering Science 5(2): 82-98.

Kenkel, J. (2013). Analytical Chemistry for Technicians, Fourth Edition. CRC Press, 537pp

Khodapanah, L., Sulaiman, W.N. and Khodapanah, N. (2009). Groundwater quality assessment for different purposes in Eshtehard district, Tehran, Iran. European Journal of Scientific Research 36(4): 543-553.

Li, Y. and Migliaccio, K. (2010). Water Quality Concepts, Sampling, and Analyses. CRC Press. Taylor & Francis Group, Boca Raton, FL, USA. 344pp.

MacLean, E.O. (1982). Soil pH and lime requirement. In: Methods of Soil Analysis Part 2 (Edited by Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy. Madison Wisconsin pp. 199-224.

Majumdar, D.K. (2001). Irrigation Water Management: Principles and Practice. PHI Learning Pvt. Ltd., New Delhi, India. 500pp.

Marchuk, A. (2013). Effect of cations on structural stability of salt-affected soils. PhD Thesis. School of Agriculture, Food and Wine, University of Adelaide. March 2013. 153pp.

Nielsen, D.M. and Nielsen, N. (2006). The Essential Handbook of Ground-Water Sampling. CRC Press, Taylor & Francis Group, Boca Raton, FL, USA 328pp

Nishanthiny, C.S., Thushyanthy, M., Barathithasan, T. and Saravanan, S. (2010). Irrigation water quality based on hydrochemical analysis, Jaffna, Sri Lanka. American-Eurasian Journal of Agriculture and Environmental. Science.7 (1):100-102.

Rayment, G.E. and Lyons, D.J. 2011. Soil Chemical Methods – Australasia. CSIRO Publishing, Australia.

SDWAF (1996) South African Water Quality Guidelines. Volume 4 Agricultural Use: Irrigation second edition 180pp.

Welz, B. and Sperling, M. 2008. Atomic Absorption Spectrometry. John Wiley & Sons, Science – 965pp.