ASSESSMENT OF WATER QUALITY FOR IRRIGATED RICE PRODUCTION AS AFFECTED BY A CLUSTER OF AUTO MECHANIC WORKSHOPS UPSTREAM

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Abstract
In the rice irrigated field, located at the Central Agricultural Station of Kwadaso in Kumasi in the Ashanti region of Ghana, the main sources of water for the crop are rain and stream water for irrigation which takes it source from clusters of auto mechanic workshops and car washing bays. Due to possible contamination of the stream water it was necessary to assess the levels of some selected contaminants. A total of fifteen water samples were collected from the stream and the irrigated field (three from each location) and analyzed for pH ranging from 5.61-6.25, Electrical Conductivity of irrigation water (EC_{iw}*) 0.06-0.25ds* m^{-1}*, Total dissolved Salts (TDS) 68.9-143.1mg* l^{-1}*,* HCO_3^- *99.34-140.00)mg* l^{-1}*, Sodium Adsorption Ratio (SAR) 0.38-0.49, Soluble Sodium Percentage (SSP) 26-40, Residual Sodium Concentration (RSC) 2.19-3.09, Kelly Ratio (KR) 0.30-0.55, in addition, some selected heavy metals which are normally concentrated in such areas. The analyzed chemical constituents and its corresponding values were compared with international standards. The upper course of the study area had the highest levels of the chemical constituents in water. Salinity and other chemical constituents showed a decreasing trend towards the lower course of the study area. The presence of the auto mechanic workshops and car washing bays influence the quality of the stream. The Water from the stream was identified to be suitable for irrigation. Further studies on the seasonal variations of the water quality parameters are highly recommended in the study area.*

Keywords: irrigation water quality, sodium adsorption ratio, contamination, auto mechanic workshop and SAWAH

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1.INTRODUCTION

Irrigation waters whether derived from springs, diverted from streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. In addition to the dissolve salts, which has been a major constraint for centuries (Ayers and Westcot 1985), irrigation water always carry substances derived from its natural environment or from the waste products of man's activities (domestic and industrial effluents). These substances may vary in a wide range, but mainly consist of dirt and suspended solids (SS). Thus resulting into the emitters' blockages in micro-irrigation systems, bacteria populations and coliform which are harmful to the humans and animals.

Irrigation water quality is related to its effects on soils, crops and its management. High quality crops can be produced only by using high-quality irrigation water keeping other inputs optimal (Ayers and Westcot 1985). Characteristics of irrigation water that define its quality vary with the source of the water. The chemical constituents of irrigation water can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot 1985; Rowe et al. 1995). The chemical constituents may take their source from industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues, spillage of petrochemicals, and atmospheric deposition (Wuana and Okieimen 2011). Thus the accumulation of heavy metals and metalloids in the irrigated soil. Heavy metal is a general term used to describe a group of metals and metalloids with an atomic density greater than 5.0 g cm^3 (Duffus 2002). These elements occur naturally in soils and rocks at various ranges of concentrations; they are also found in ground and surface water bodies and sediments (Hutton and Symon 1986). Unchecked industrial and human activities have contributed significantly to elevated (pollution) levels of these metals, in surface and subsurface soils when compared to those contributed from geogenic or natural processes (Dasaram et al. 2011). Their pollution of the environment even at low levels and the resulting long-term cumulative health effects are among the leading health concerns all over the word (Huton and Symon 1986). The concern is heightened by their persistence in the soil and their tendency to bio-accumulate, move along the food chain and also poison soil microorganisms (Udousoro et al. 2010).

The heavy metals most frequently encountered in this waste include copper, lead, cadmium, zinc, manganese and nickel, all of which pose risks to the environment. At the Soil Research Institute's research station at Kwadaso, irrigation water for the rice fields has not been assessed for heavy metal concentration even though a cluster of auto mechanic workshops are located upstream of the river source. It has therefore become imperative to monitor the levels of these heavy metals in the stream used for irrigation in the vicinity of automobile mechanic clusters and car washing bays in the study area, with the view to assessing the pollution risk they pose on the environment.

The objective of the study was, to assess the qualitative of the stream water for irrigated rice.

2. MATERIAL AND METHODS

2.1 Study area description

The study was carried out on the paddy rice research plot in the premises of CSIR-Soil Research Institute which is located at the Central Agricultural Station, Kwadaso Ghana. The geographical location of Kwadaso lies in Latitude 6.42^{o}N and Longitude 1.34^{o}W with an altitude of 284m above mean sea level.

Previously, the study area was cultivated with paddy rice under the initiative of SAWAH rice project. Under this project, rainfall and stream water was the main source of water for irrigation. However, the stream water takes its source from an area with clusters of auto mechanic workshops and car washing bays, and stretches from the southern part of the area (upper course) to the northern part (lower course). The study area is within the tropical climatic zone with a bi-modal rainfall peaks (i.e. major and minor seasons). The major season normally begins in March; reaches a peak in July and drops sharply in August whilst the minor season starts in September with the lowest occurring in late November. Thereafter, there is a long dry period from December to February during which negligible amounts of rain normally (below 10mm) are received.

Mean monthly temperatures remain high throughout the year only falling around 24^{o} C in August. February and March are the hottest (nearly 28^{o}C) recorded months. Absolute minimum temperatures of around 20^{o}C are usually recorded in December and January with absolute maximum temperature of about 33^{o}C occurring in February and March.

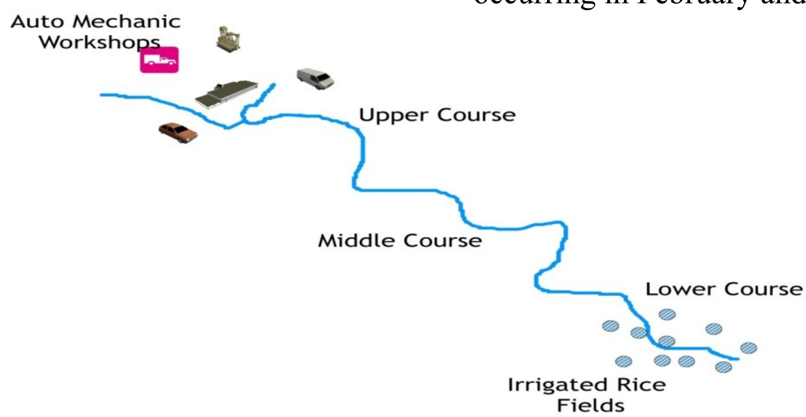

Figure 1: Schematic diagram showing relative positions of the course of the stream

2.2 Water Sampling and chemical analysis

Three (3) locations on the stream (upper, middle and lower course) and the irrigated field were selected as sampling sites. From each sampling location, three sets of samples were collected. This was done during the month of July, 2014. The bottles used for sampling were cleaned with dilute hydrochloric acid (0.1MHCl) and rinsed thrice with deionized water as suggested by De (1989). The bottles were kept air tight and labelled properly for identification. Stoppering of the bottles was done quickly to avoid aeration during sampling. Electrical conductivity (EC_{iw}) and pH of the samples were measured on-farm using portable EC-meter and pH-meter respectively.

The samples collected from the study area were carefully transported in an opaque bag to CSIR-Soil Research Institute's laboratory, Ghana and kept in a refrigerator for analysis. Sodium (Na^+) and Potassium (K^+) were determined by a flame photometry (Jackson, 1967); Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Copper (Cu), Zinc (Zn), Manganese (Mn), Lead (Pb) and Iron (Fe) by Atomic Absorption Spectrophotometer (AAS) (Jackson, 1967; Page *et al.,* 1982); Chloride (Cl^-), Bicarbonate (HCO_3^-), Carbonate (CO_3^{2-}), Sulphate (SO_4^{2-}) and Nitrate (NO_3^-) by titration method (Jackson, 1967).

2.3 Irrigation water quality

For current irrigation water quality assessment, sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium concentration (RSC) and Kelly ratio (KR) were monitored. According to Richards (1954), sodium adsorption ratio (SAR) is expressed as:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + mg^{2+})}{2}}} \quad (1)$$

Todd (1980) defined soluble sodium percentage (SSP) as:

$$SSP = \frac{Na^+ + K^+}{Ca^{2+} + mg^{2+} + Na^+ + K^+} \times 100 \quad (2)$$

Eaton (1950) also defined residual sodium concentration as:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + mg^{2+}) \quad (3)$$

Kelly's ratio (KR) (Kelly, 1963) described as:

$$KR = \frac{Na^+}{Ca^{2+} + mg^{2+}} \quad (4)$$

All ionic concentrations are in milli equivalent per liter (meq l^{-1}).

3. RESULTS AND DISCUSSION

General physico-chemical parameters

Water quality standards for suitable irrigation (DOE 1997; WHO 2004) are indicated in Tables 1. Also Tables (2-6) represents the physio-chemical results of the analysis of water samples at the study area.

From the analyzed results, the spatial distribution of water quality parameters of the stream water indicated a general trend. Thus, decrease from the upper course (area near the auto mechanic workshop) to the lower course (area closed the irrigated rice field).

Stream water quality for irrigation purpose

The pH of the study area was generally acidic ranging from 5.61 to 6.41 which below the acceptable range (Table 1). Generally the pH of the stream showed a decreasing trend from the upper course towards the lower course. Application of fertilizers, especially Ammonium Sulphate and other agrochemicals during the cultivation may largely explain the more acidic nature of the water samples in the lower course.

The EC_{iw} of the study area ranged from 60 to 250µs/cm (Table 3) which is excellent for irrigation (Table 2). Within the study area the EC_{iw} values decreased significantly from the upper course to the lower course which gave the lower value of 60µs/cm. The low EC_{iw} level in the lower course was probably due to dilution from ground water and lateral flow. EC_{iw} values in the fields were significantly higher than that of the lower course. Agronomic practices including application of agro-chemicals properly increased the EC_{iw} values. Generally the stream is lower in salinity except the upper course which is moderate. The higher the EC_{iw}, the less water is available to the plants, even though the soil may appear wet, leading to low productivity (Adams et al. 2014). Total dissolved salts are also important to be considered in the assessment of irrigation water quality, because many of the toxic solid materials may be imbedded in the water, which may cause harm to the plants (Matthess 1982).

Table 1: Water quality standards for irrigation water quality

Parameters	DoE	WHO
	(1997)	(2004)
pH	6.5-8.5	6.5-8.5
EC_{iw}(ds/m)	2.25	
TDS(mg/l)	1000	1000
Na^{+}(mg/l)	200	200
K^{+}(mg/l)	12	
Ca^{2+}(mg/l)	75	
mg^{2+}(mg/l)	30-35	50
Cl^{-}(mg/l)	150-600	250
SO_4^{2-}(mg/l)	400	250
NO_3^{-}(mg/l)	10	50
CO_3^{2-}		
HCO_3^{-}(mg/l)		91

Table 2:Limits of some important parameter indices for rating water quality and its suitability in irrigation use

Category	Water quality indices*			Suitable for irrigation
	EC_{iw} (µs/cm	SAR	SSP	
I	< 700	<10	<20	Excellent
II	700-3000	10-18	20-40	Good
III	>3000	18-26	40-80	Fair
IV	-	>26	>80	Poor

According to Ayers and Westcot (1985), Todd (1980) and Wilcox (1955) respectively

Table 3: Physical parameters of the water sample

Sample	pH	$EC_{(IW)}$	TDS
		µs/cm	mg/l
UC*	6.25	250.00	143.1
MC	6.13	170.00	105.9
LC	5.61	60.00	29.4
RF 1	5.97	150.00	88.5
RF 2	6.41	120.00	68.9
Mean	6.07	150.00	87.16
SE	0.14	16.71	18.91

UC: Upper Course, MC: Middle Course, LC: Lower Course, RF: Rice Field, SE: Standard Error

Table 4: Acidic ions of the water sample

Sample	NO_3^-	NH_4^+	SO_4^{2-}	Cl^-	CO_3^{2-}	HCO_3^-
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
UC*	2.07	1.01	38.00	113.82	112.00	140.00
MC	1.66	0.35	33.00	121.54	100.00	140.00
LC	2.22	0.30	46.00	84.88	56.00	99.34
RF 1	2.48	0.65	40.00	131.19	104.00	118.34
RF 2	4.11	0.05	29.00	135.04	92.00	110.55
Mean	2.51	0.47	37.20	117.29	92.80	121.65
SE	0.42	0.17	2.92	8.91	9.75	8.08

UC: Upper Course, MC: Middle Course, LC: Lower Course, RF: Rice Field, SE: Standard Error

Values of TDS for the study area clearly indicated that the stream water is good for irrigation (Table 1-3). Within the study area TDS showed similar trend as EC_{iw}

Electrical conductivity of irrigation water (EC_{iw}) and Na^+ play a very important role in suitability of water for irrigation (Rao 2005). Soil containing large contents of Na^+ with HCO_3^- or Cl^-/SO_4^{2-} turns a soil alkaline or saline respectively (Todd 1980).

Higher Na^+ content in irrigation water causes an increase in soil solution osmotic pressure (Rahman et al. 2012). Since plant roots extract water through osmosis, the water uptake of plants decreases. The osmotic pressure is proportional to the salt content or salinity hazard (Rahman et al. 2012). The salt, besides affecting the growth of plants directly, also affects the soil structure, permeability and aeration, which indirectly affect plant growth. Furthermore, high Na^+ and elevated carbonate content also cause displacement of exchangeable Ca^{2+} and Mg^{2+} from the clay mineral of the soil (Matthess 1982). Thus, an increase of soil pH, nutrient availability and hindered microorganism activity in the soil.

$$Na-clay + H_2O \rightarrow H-clay + Na^+ + OH^- \quad (5)$$

$$CO_3^{2-} + H_2O \rightarrow HCO_3^- + OH^- \quad (6)$$

Moreover, the total concentrations of soluble salt in the irrigation water was also classified as indicated by Richards (1954) as low (C_1), medium (C_2), high (C_3) and very high (C_4) salinity based on electrical conductivity zones. From Figure 2, these zones (C_1-C_4) had EC_{iw} of <250 µS cm^{-1}, 250 to 750 µS cm^{-1}, 750 to 2,250 µS cm^{-1} and >2,250 µS cm^{-1}, respectively (Rao 2005). According to this classification all samples from the study area were classified as low saline water except samples from the upper course of the study area which was classified as medium saline water (Table 3).

Another significant chemical parameter identified for assessing the degree of suitability of water for irrigation was sodium content or alkali hazard, which is expressed as the sodium adsorption ratio (SAR). Sodium adsorption ratio measures the potential dangers posed by excessive sodium in irrigation water (Alagbe 2006).

The sodium hazard or SAR is expressed in terms of classification of irrigation water as low (S_1: <10), medium (S_2: 10 to 18), high (S_3: 18 to 26) and very high (S_4: > 26). A high SAR value implies a hazard of sodium (alkali) replacing Ca^{2+} and Mg^{2+} in the soil through a cation exchange process that damages soil structure, mainly permeability, and which ultimately affects the fertility status of the soil and reduces crop yield (Gupta 2005).

From Table 7 all the water samples from the study area were in the “excellent” range and hence very suitable for crop irrigation. The samples also had soluble sodium percentage (SSP) in a class range of “excellent” except samples from the lower course which was close to the irrigated field has “good” range; this may partly be due to low value of potassium (K^+) in the lower course of the study area.

Table 5: Basic ions of the water sample

Sample	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}
	mg/l	mg/l	mg/l	mg/l
UC*	16.03	8.75	8.50	7.50
MC	14.43	5.83	7.60	7.00
LC	8.02	1.94	5.00	5.50
RF 1	14.43	3.89	9.30	8.00
RF 2	14.43	5.83	8.80	7.50
Mean	13.39	5.25	7.84	7.10
SE	1.39	1.13	0.76	0.43

UC: Upper Course, MC: Middle Course, LC: Lower Course, RF: Rice Field, SE: Standard Error

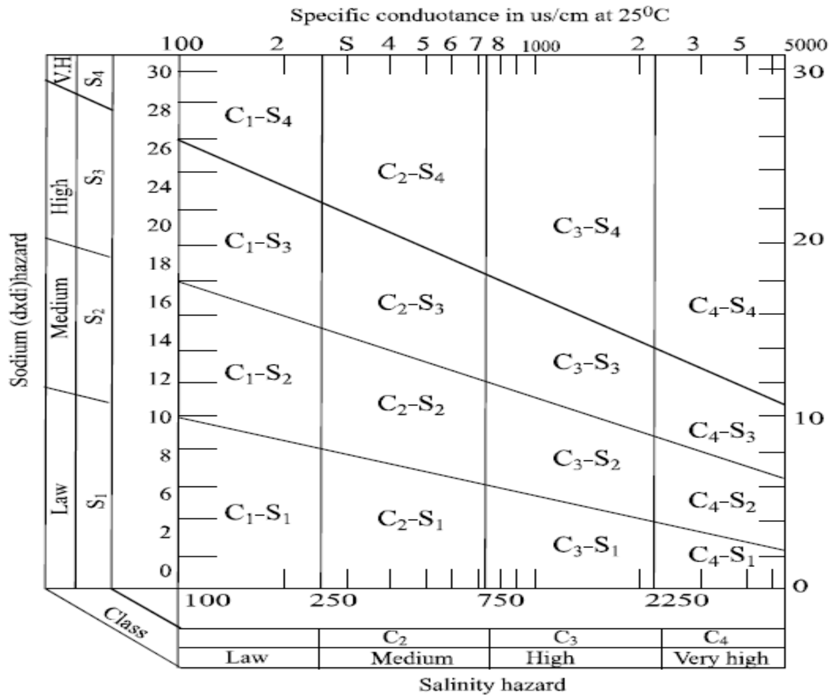

Figure 2. Salinity classification of irrigation water samples (Richards, 1954)

Average RSC of the study area varied from 2.19 to 3.09 mg l^{-1} with the highest occurring at the middle course. A positive RSC value indicated that the contents of dissolved Ca^{2+} and Mg^{2+} ions is less that of CO_3^{2-} and HCO_3^- (Raihan and Alam 2008). RSC values were satisfied in the study area. According to Gupta and Gupta (1987), satisfactory RSC should be less than 5mg l^{-1}.

In the study area HCO_3^- ranged from 99.34 to 140.00mg l^{-1} with an average value of 121.65mg l^{-1}. Irrigation water rich in HCO_3^- content tend to precipitate insoluble Ca^{2+} and Mg^{2+} in the soil which ultimately leaves higher proportion of Na and increases the SAR value (Michael, 1992) as:

$$2HCO_3^- + Ca^{2+} \rightarrow CaCO_3 + H_2O + CO_2 \uparrow \quad (7)$$

It has also been reported that, although ordinary HCO_3 - is not toxic, it can cause zinc deficiency in rice and this is severe when zinc levels exceeded 2meq/l in water used for flooding growing paddy rice (Ayers and Westcot 1985). From the study area the irrigated rice field has zinc levels less than 2meq l^{-1}, hence such problem does not exist in the SAWAH irrigated rice field in the study area. However, Kelly (1963) suggested that KR for irrigation water should not exceed 1.0. All values satisfy such a restriction; hence a good balance of Na^+, Ca^{2+} and Mg^{2+} is present in the of study area. This also indicated a good tilth condition of the soil of the study area with no permeability problem.

At the same level of salinity and SAR, adsorption of Na^+ by soils and clay minerals was greater at higher Mg:Ca ratios. This was because the bonding energy of Mg^{2+} was less than that of Ca^{2+}, allowing more Na^+ adsorption. This happened when the ratio exceeded 4.0 (Michael 1992). Ayers and Westcot (1985) also reported that soil containing high levels of exchangeable Mg^{2+} caused an infiltration problem. In the study area, the ratio of Mg^{2+} and Ca^{2+} for all parameters was less than 1.0 (Table 7). Thus, it indicated a good proportion of Ca^{2+} and Mg^{2+}, which maintains a good structure and tilth condition. The presence of excessive Na^+ in irrigation water promotes soil dispersion and structure breakdown when Na^+ to Ca^{2+} ratio exceeds 3:1. Such a high Na:Ca ratio (>3:1) results in severe water infiltration problems, mainly due to lack of sufficient Ca^{2+} to oppose the dispersing effect of Na^+. Excessive Na^+ also creates problems in crop water uptake, poor seedling emergence, lack of aeration, plant and root diseases etc. (Ayers and Westcot 1985). SAWAH irrigated rice field has no such problem (Table 7).

4. CONCLUSIONS

On the basis of SAR, SSP, RSC, KR and other physical parameters of the water samples, the stream water was suitable for irrigating rice. Also, the satisfactory chemical constituent of the water sample from the study area suggested that the water could be used for irrigation. EC_{iw}, TDS and some of the ions showed higher levels in the upper course. This signifies that the presence of the auto mechanic workshops and washing bays affected the quality of the stream.

Table 6: Selected heavy metals in the water sample

Sample	Fe	Mn	Zn	Cu	Cd	Pb
	Mg l^{-1}	Mg l^{-1}	Mg l^{-1}	Mg l^{-1}	Mg l^{-1}	Mg l^{-1}
UC*	1.60	0.07	0.001	0.013	0.002	0.062
MC	1.22	0.10	0.005	0.16	0.004	0.027
LC	0.35	0.06	0.012	0.10	0.005	0.035
RF 1	1.29	0.07	0.004	0.013	0.007	0.059
RF 2	0.75	0.09	0.001	0.044	0.007	0.010
Mean	1.04	0.07	0.0046	0.07	0.005	0.0386
SE	0.22	0.02	0.002	0.03	0.00095	0.00982

*UC: Upper Course, MC: Middle Course, LC: Lower Course, RF: Rice Field, SE: Standard Error

Table 7: Selected irrigation water quality parameters

Sample	SAR**	SSP	RSC	KR	Mg:Ca	Na:Ca
		%	meq/l			
UC*	0.38	26	2.92	0.30	0.55	0.47
MC	0.39	28	3.09	0.35	0.40	0.47
LC	0.45	40	2.19	0.55	0.21	0.68
RF1	0.49	36	2.98	0.44	0.27	0.56
RF 2	0.42	32	2.44	0.37	0.40	0.52
Mean	0.43	32	2.72	0.40	0.39	0.53
SE	0.02	2.56	0.17	0.04	0.02	0.03

*UC: Upper Course, MC: Middle Course, LC: Lower Course, RF: Rice Field, SE: Standard Error
**SAR: Sodium Adsorption Ratio, SSP: Soluble Sodium Percentage, RSC: Residual Sodium Concentration, KR: Kelly Ratio

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