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# WATER QUALITY FOR IRRIGATED-RICE-BASED CROPPING SYSTEM IN THE ODA RIVER VALLEY BOTTOM AT BESEASE, GHANA

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**Abstract**

The Valley Bottom Rice Development Project was started in Ghana in 1990 under the Agricultural Sector Rehabilitation Programme of the Ministry of Food and Agriculture. To assess the quality of river and shallow groundwater for irrigation at the Besease project site, physico-chemical analysis were carried out from 1994 to 1997 and the results were evaluated. The total dissolved solids (TDS) of river water ranged from 60.00 to 260.00 mg $l^{-1}$, with a mean of 117.99 mg $l^{-1}$, and that of groundwater ranged from 95.00 to 482.00 mg $l^{-1}$ with a mean of 297.8 mg mg $l^{-1}$. The adjusted sodium absorption ratio (ASAR) of river water ranged from 0.08 to 0.28 with a mean of 0.12, and that of groundwater ranged from 0.24 to 2.62 with a mean of 1.72. Based on these and other measurements, both river and shallow groundwater are suitable for irrigated rice farming in the Oda river valley bottom at Besease. However, the study indicated excess bicarbonate ($HCO_3^-$) content of groundwater (mean: 16.24 meg $l^{-1}$), capable of reducing the yield and quality of rice.

## Introduction

Under the Ghana Agricultural Sector Rehabilitation Programme (ASRP) of the Ministry of Food and Agriculture (MOFA), a collaborative research project, Valley Bottom Rice Development, was initiated by the MOFA in 1990. The collaborators were the Water Research Institute (CSIR), Crops Research Institute (CSIR), Soil Research Institute (CSIR), Savanna Agricultural Research Institute (CSIR), University of Science and Technology (UST), University of Ghana (UG), University of Cape Coast (UCC), University of Development Studies (UDS) and Irrigation Development Authority (IDA). The Water Research Institute (CSIR) was mandated to liaise with other national research institutions and university faculties to carry out field research activities relating to hydrology and water resources component.

The authors intend to present a series of papers to discuss the qualitative and quantitative aspects of the water resources component for rice-based cropping system in the valley bottoms of Ghana. The current paper assesses the quality of the surface and ground water resources in relation to project objectives at one of the sites at Besease in the Ashanti Region of Ghana.

*The study area*

Besease is a farming community in the Ashanti Region of Ghana with a rural population of about 1,750. The study area covers about 107 ha of valley bottom lands (Fig.1).

The climate is tropical with typical bi-modal rainfall peaks. The mean annual rainfall is 1420 mm. The major season occurs from April to July and the minor season from September of October. The relative humidity ranges from 64 per cent in January to 84 per cent in August. Though the project area falls within the semi-deciduous forest zone of Ghana no natural vegetation currently exists in the area, due largely to unrestricted human interference. The present vegetation include tickets, swamps, secondary forests, cultivated and grass fallow lands.

The soils of the Oda inland valley range from deep imperfectly drained loamy sands in the lower slopes to sandy clay and poorly drained alluvial deposits in the valley bottoms (Kankam-Yeboah & Mensah, 1997). Rice cultivation is undertaken by mainly settler farmers on plot units of about

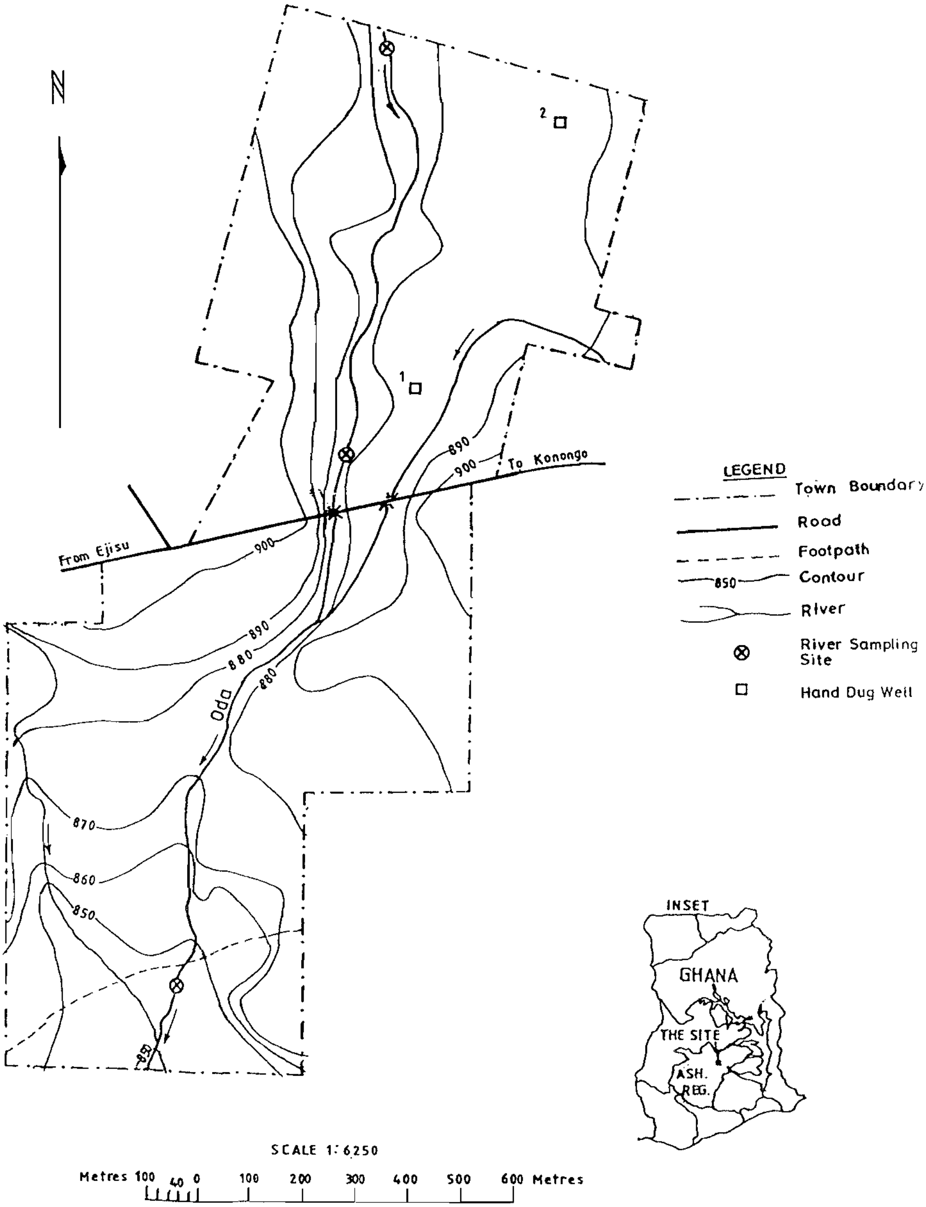


Fig. 1. Map of the Besease project site showing water sampling points

0.25 ha per farmer under rain-fed and flood conditions. Agricultural water management by the farmers is very low.

The area is drained by the Oda river (Fig. 2), which is seasonal and whose basin is about 143 $km^3$ (Kankam-Yeboah & Mensah, 1997). Table 1 shows some flow statistics of the Oda river from 1990 to 1995. Kankam-Yeboah, Duah & Mensah (1997) have studied two hand-dug wells at the project site with depths of 4.7 m. The static water level and yield of the wells range from 0.41 to 0.98 m and 3.0 to 4.3 $m^3/h$, respectively.

This is because the salinity of the soil water is related to, and often determined by, the salinity of the irrigation water. Rice growth, yield and quality of grains are all affected by the total dissolved salts in the irrigation water. According to Pescod (1992), dissolved salts increase the osmotic potential and pressure of soil solution, thereby increasing substantially the amount of energy that crops should expend to take up water. As a result of this, respiration is increased and the growth and yield of most crops (including rice) decline progressively as osmotic pressure increases.

TABLE 1
*Discharge data of Oda river at Besease (1990/91 - 1994/95)*

| *Year* | *Mean ($m^3/s$)* | *Maximum ($m^3/s$)* | *Minimum ($m^3/s$)* | *Total run-off ($\times 10^6$ $m^3$)* |
|---|---|---|---|---|
| 1990/91 | 0.153 | 2.478 | 0 | 4.86 |
| 1991/92 | 0.473 | 4.035 | 0 | 14.95 |
| 1992/93 | 0.190 | 3.418 | 0 | 5.98 |
| 1993/94 | * | 1.438 | 0 | * |
| 1994/95 | 0.172 | 2.233 | 0 | 5.43 |

* Insufficient data for meaningful analysis

*Irrigation water quality*

For most agricultural water quality studies, major physico-chemical parameters that can be measured have been provided in detail by Kandiah (1990). However, this paper focuses only on a few of the most important parameters which are likely to influence soil salinity, permeability and specific ion toxicity problems in the Oda river valley bottom at Besease. The parameters include total dissolved solids (TDS), sodium ($Na^+$), calcium ($Ca^{2+}$), potassium ($K^+$) and magnesium ($Mg^{2+}$). Other parameters include chloride ($Cl^-$), bicarbonate ($HCO_3^-$), nitrate ($NO_3^-$), hydrogen ion concentration (*p*H) and electrical conductivity ($EC_w$).

Total salt concentration (for all practical purposes, total dissolved solids) is one of the most important agricultural water quality parameters. Pescod (1992) has noted that the rate of accumulation of salts in the soil (soil salinization) is directly affected by the salinity of the irrigation water. Aside this, irrigation water that contains ions of boron, chloride and sodium above recommended values (Table 2) can cause rice toxicity damage, depending on the stage of crop growth, climate and soil conditions.

Sodium is a unique cation because of its effect on soil. When present in the soil in exchangeable form, it causes adverse physico-chemical changes in the soil, particularly to soil structure. It has the ability to disperse soil, when present above a certain threshold value, relative to the concentration of total dissolved salts. Soil dispersion results in reduced infiltration rates of water and air into the soil. When dried, dispersed soil forms crusts that are hard to till and interfere with seed germination

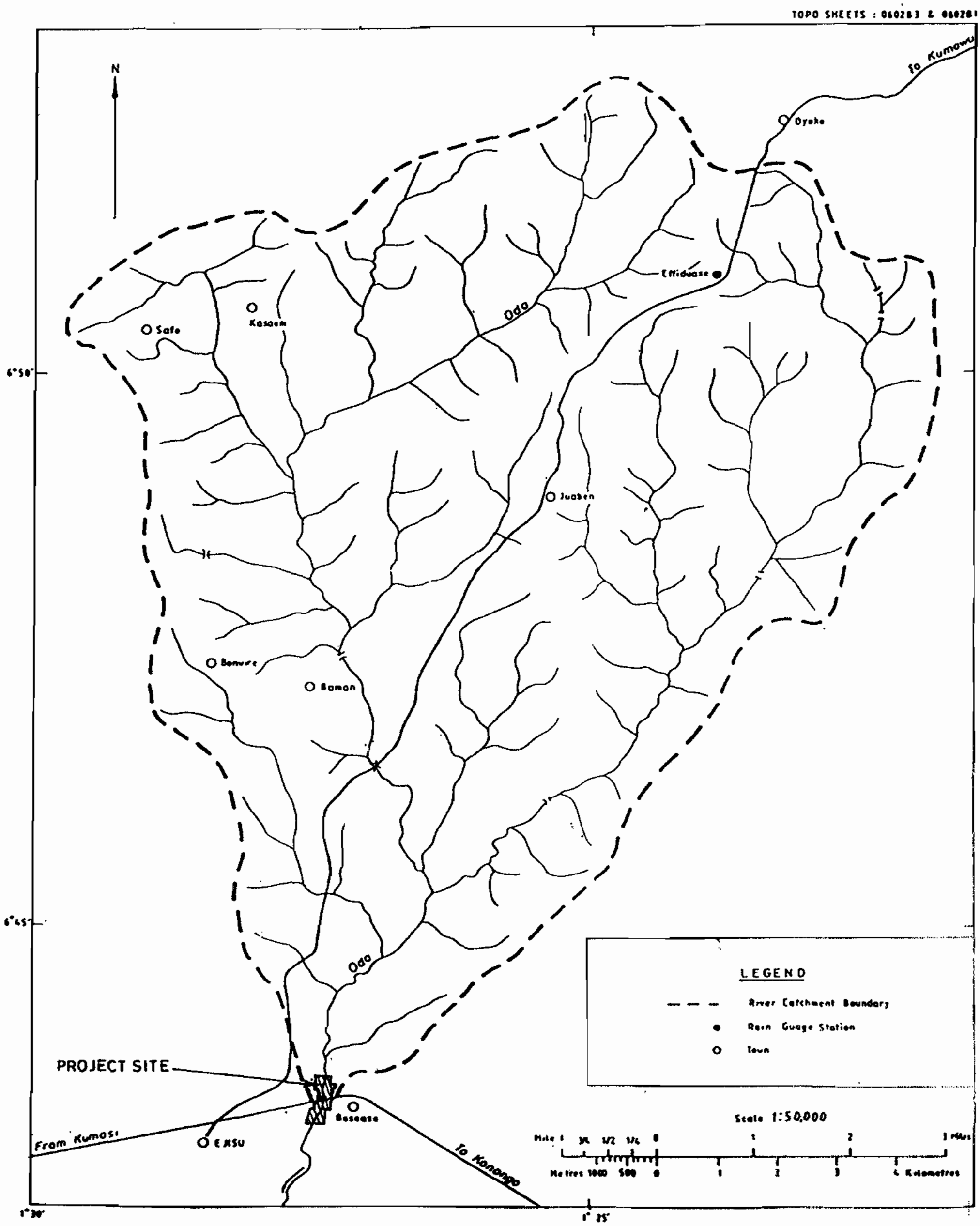


Fig. 2. Drainage basin of Oda river showing the project site at Besease

TABLE 2
*Guidelines for interpretation of water quality for irrigation*

| *Potential irrigation problem* | *Units* | *Degree of minimum use* | | |
|---|---|---|---|---|
| | | *None* | *Slight to moderate* | *Severe* |
| *Salinity* | | | | |
| Electrical conductivity | dS $cm^{-1}$ | <7.0 | 7.3-30.0 | >30.0 |
| TDS | mg$l^{-1}$ | <450 | 450-2000 | >2000 |
| *Infiltration* | | | | |
| ASAR = 0 - 3 | | >0.7 | 0.7-0.2 | <0.2 |
| = 3 - 6 | | >1.2 | 1.2- 0.3 | <0.3 |
| = 6 - 12 | | >1.9 | 1.9-0.5 | <0.5 |
| = 12 - 20 | | >2.9 | 2.9-1.3 | <1.3 |
| = 20 - 40 | | >5.0 | 5.0-2.9 | >2.9 |
| Electrical conductivity | dS $cm^{-1}$ | >5.0 | 5.0-2.0 | <2.0 |
| *Specific ion toxicity* | | | | |
| Sodium (Na) | ASAR | | | |
| Surface irrigation | | <3.0 | 3.0-9.0 | 9.0 |
| Sprinkler irrigation | | <3.0 | >3.0 | |
| Chloride (Cl) | | | | |
| Suface irrigation | meq $l^{-1}$ | <4.0 | 4.0-10.0 | >10 |
| Sprinkler irrigation | meq $l^{-1}$ | <3.0 | >3.0 | |
| Boron (B) | mg $l^{-1}$ | <0.7 | 0.7-3.0 | >3.0 |
| *Miscellaneous effects* | | | | |
| Nitrogen ($N-NO_3$) | mg $l^{-1}$ | <5.0 | 5.0-30.0 | >30.0 |
| Bicarbonate ($HCO_3$) | meq $l^{-1}$ | <1.5 | 1.5-8.5 | >8.5 |
| *p*H (Normal = 6.4-8.4) | | | | |

*Source:* Modified from FAO (1985)

and emergence of rice seedlings. Irrigation water could be a source of excess sodium in the soil solution and it should be evaluated for this hazard. The most reliable index of soium hazard of irrigation water is the sodium adsorption ratio (SAR) defined by the following equation:

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

where the ionic concentrations are expressed in meq $l^{-1}$

It should be noted that equation 1 does not take into account changes in calcium concentration in soil water due to changes in the solubility of calcium. Since rainfall in the study area is considerably high and affinity between $Ca^{2+}$ and both $CO_2$ and $HCO_3$ is chemically high, the use of equation 1 has been extended to take account of this by calculting the Adjusted Sodium Adsorption Ratio (ASAR) as outlined by Ayers & Westcot (1976, 1985) and Tchobanoblous & Burton (1991). ASAR is defined by the following equation:

$$ASAR = SAR * \{ 1 + (8.4 - pHc) \} \quad (2)$$

where $pHc$ is a variable derived factor from Ayers & Westcot (1985), in reference to the alkalinity and concentrations of sodium, potassium, calcium and magnesium ions of irrigation water.

Electrical conductivity is widely used to indicate the total ionized constituents of water. It is directly related to the sum of the cations (or anions) as determined chemically and is closely correlated, in general, with the total salt concentration. Electrical conductivity is a rapid and reasonably-precise determination and values are always expressed at a standard temperature of 25 °C to enable comparison of readings taken under varying climatic conditions. It should be noted that electrical conductivity of solutions increases with approximately 2 per cent per °C increase in temperature. Electrical conductivity has been expressed as dS/cm.

Hydrogen ion concentration (*p*H) is an indicator of the acidity or alkalinity of water but it is seldom a problem by itself. The normal range for irrigation water is from 6.5 to 8.4 (Ayers & Westcot, 1997; 1985). The *p*H values outside this range are a good warning that water may have unsatisfactory quality.

## Experimental

Forty-eight samples of water from the Oda river and two hand-dug wells at the project site (*see* Fig. 1) were collected monthly (1994 - 1997) in 1-litre plastic bottles after rinsing with water. Physico-chemical parameters such as total dissolved solids (TDS), sodium ($Na^+$), calcium ($Ca^{2+}$), potassium ($K^+$), magnesium ($Mg^{2+}$), chloride ($Cl^-$), bicarbonate ($HCO_3^-$), nitrate ($NO_3^-$), hydrogen ion concentration (*p*H) and electrical conductivity ($EC_w$) were analyzed in the Environmental Chemistry laboratory of the Water Research Institute.

The APHA (1985) standard methods were used to carry out the laboratory analyses. The Ayers & Westcot's (1985) irrigation water quality guidelines were used to carry out the evaluation for suitability of the water for irrigation.

## Results and discussion

*River water quality for irrigation*

It should be emphasized that the water quality has been assessed with reference to only the major FAO irrigation quality standards (Table 2). The statistical summary of the physico-chemical analysis of the Oda river water at Besease is presented in Table 3.

The mean TDS of river water was determined as 118 mg $l^{-1}$, much below the FAO value of 2000 mg $l^{-1}$ which is considered as an unsuitable level for irrigation water. TDS values as high as 1170 mg $l^{-1}$ have been recorded by Al- Salem (1987) for untreated river water in Amman, Jordan. The mean sodium and chloride concentrations (0.55 and 0.32 meq $l^{-1}$) fell below the minimum guideline value of 10.0 meg $l^{-1}$ likely to cause soil salinity problems or crop toxicity. The above results indicated virtually no salt pollution compared with, for example, results documented by Abdel-Ghaffar, El-Attar & Elsokkary (1988) and Al-Salem (1987).

Both groups of researchers observed 20.5 and 32.0 meq $l^{-1}$, and 22.0 and 9.0 meq $l^{-1}$ for sodium and chloride concentrations in similar agricultural catchments of Giza (Egypt) and Amman, respectively. The adjusted sodium adsorption ratio (ASAR), i.e. 0.12, also fell lower than the minimum recommended guideline value of 9.00 capable of causing decreased soil permeability to crop roots. ASAR values of 9.30 and 2.80 have been recorded by Abdel-Ghaffar, El-Attar & Elsokarry (1988) in their studies in Alexandria and Giza (Egypt), respectively. It is notable that increased salinity and decreased soil permeability depend on increased electrical conductivity, which also depends on increasing levels of major cations and anions (essentially $Na^+$, $Ca^{2+}$, $Mg^{2+}$ and $Cl^-$). The low conductivity values (0.8-3.0 dS $cm^{-1}$) makes the Oda river water suitable for irrigated rice production, compared with the minimum guideline value of 30 dS $cm^{-1}$) likely to cause salinity or soil permeabil-

TABLE 3
*Summary of water quality data of Oda river at Besease*

| *Parameter* | *Mean* | *Minimum* | *Maximum* | *Standard deviation* |
|---|---|---|---|---|
| *p*H | 6.60 | 6.00 | 8.40 | 0.83 |
| Alkalinity ($CaCO_3$)* | 1.00 | 0.58 | 2.54 | 0.72 |
| Turbidity (NTU) | 51.60 | 8.50 | 198.00 | 82.09 |
| Conductivity (dS $cm^{-1}$) | 0.12 | 0.08 | 0.28 | 0.14 |
| Total dissolved solids (TDS) | 117.99 | 60.00 | 260.00 | 69.82 |
| Calcium ($Ca^{2+}$)* | 0.55 | 0.31 | 1.10 | 0.29 |
| Sodium ($Na^{+}$)* | 12.57 | 0.30 | 1.40 | 0.39 |
| Potassium ($K^{2+}$)** | 9.80 | 5.60 | 20.00 | 4.96 |
| Magnesium ($Mg^{2+}$)* | 0.31 | 0.19 | 1.80 | 1.50 |
| Iron (Fe)* | 1.03 | 0.02 | 2.20 | 0.88 |
| Chloride ($Cl^{-}$)* | 0.32 | 0.14 | 0.66 | 0.20 |
| Sulphate ($SO_4^{2-}$)* | 0.08 | 0.02 | 0.44 | 0.14 |
| Bicarbonate ($HCO_3$)* | 0.84 | 0.48 | 2.08 | 0.58 |
| Silica ($SiO_3$)* | 32.00 | 18.70 | 32.00 | - |
| Nitrate ($NO_3$-N)** | 1.49 | 0.01 | 3.50 | 1.49 |
| Phosphate ($PO_3$-P)** | 0.33 | 0.12 | 1.05 | 0.32 |
| Adjusted sodium adsorption Ratio (ASAR) | 0.12 | 0.08 | 0.28 | |

Note: Except *p*H, ASAR, conductivity and turbidity, other parameters have units in meq/l (*) or mg/l (**)
(Values were each computed from 48 parametric samples.)

ity problems (Ayers & Westcot, 1976; Roscher, 1989).

According to Roscher (1989), rice is slightly intolerant to saline water. That means beyond 6.0 dS $cm^{-1}$ of electrical conductivity, the leaves of rice plants may burn and defoliate; thus photosynthetic activity may be substantially inhibited, leading to low grain yield of rice.

The *p*H of river water (6.6) was considered normal for irrigation. Even though N-$NO_3^-$ concentration in river water was considered suitable for irrigating rice, mean $HCO_3^-$ content (0.84 meq $l^{-1}$) which has potential to cause salt deposition on plant foliage, thus likely to cause poor yield and reduced grain quality.

*Groundwater quality for irrigation*

Tables 4 and 5 present summaries of results of water quality parameters for hand-dug wells No. 1 and No. 2 of the Besease site, respectively. The mean values of TDS, $Na^+$ and $Cl^-$ of groundwater were 341.6 mg $l^{-1}$, 1.4 and 0.6 meq $l^{-1}$, respectively.

TABLE 4
*Summary of water quality data of hand-dug well No. 1 at Besease*

| *Parameter* | *Mean* | *Minimum* | *Maximum* | *Standard deviation* |
|---|---|---|---|---|
| *p*H | 6.97 | 6.18 | 7.3 | 0.46 |
| Alkalinity ($CaCO_3$)* | 3.8 | 0.42 | 5.32 | 1.42 |
| Turbidity (NTU) | 14.92 | 4.50 | 38.00 | 13.48 |
| Conductivity (dS $cm^{-1}$) | 0.44 | 0.15 | 0.67 | 0.29 |
| Total dissolved solids (TDS) | 341.60 | 95.00 | 482.00 | 152.99 |
| Calcium ($Ca^{2+}$)* | 2.75 | 0.71 | 3.89 | 1.26 |
| Sodium ($Na^{+}$)* | 1.16 | 0.44 | 1.98 | 0.54 |
| Potassium ($K^{2+}$)** | 24.24 | 7.50 | 33.60 | 11.25 |
| Magnesium ($Mg^{2+}$)* | 0.69 | 0.34 | 1.28 | 0.37 |
| Iron (Fe)* | 0.62 | 16.80 | 28.00 | 1.09 |
| Chloride ($Cl^{-}$)* | 0.62 | 0.56 | 28.00 | 0.14 |
| Sulphate ($SO_4^{2-}$)* | 0.47 | 0.02 | 1.23 | 0.49 |
| Bicarbonate ($HCO_3$)* | 3.1 | 0.34 | 4.36 | 1.16 |
| Silica ($SiO_3$)* | - | - | - | - |
| Nitrate ($NO_3$-N)** | 1.45 | 0.01 | 5.00 | 2.39 |
| Phosphate ($PO_3$-P)** | 0.49 | 0.19 | 1.00 | 0.31 |
| Adjusted sodium adsorption Ratio (ASAR) | 1.63 | 0.24 | 2.62 | - |

Note: Except *p*H, ASAR, conductivity and turbidity, other parameters have units in meq/l (*) or mg/l (**).
(-) means values not determined. (Values were each computed from 48 parametric samples.)

These values were generally more than twice the values for river water. Both ASAR (1.72) and $Cl^-$ (1.81 meq $l^{-1}$) values were below the 9.0 and 10.0 meq $l^{-1}$ threshold, respectively, likely to cause either soil salinity or specific ion toxicity to rice crop.

Conductivity values for well water ranged from 3.0 to 4.0 dS $cm^{-1}$, representing 3-4 times as high as that of river water. But by FAO irrigation water standards, the measured conductivity level was low. Nevertheless, soil permeability may be reduced with further rise in conductivity, especially if inadequate drainage facilities continue to exist at the Besease site. Ayers & Westcot (1976) and Roscher (1989) have reported that increased conductivity can more than double the rate of salinity buildup under poor drainage conditions.

For an average *p*H level of 6.8, groundwater was considered very suitable for irrigation in the Oda valley bottom. Compared to river water, however, the average N-$NO_3^-$ levels of groundwater (2.3 mg $l^{-1}$) was about twice that of river water, yet did not in anyway reach the threshold value (> 30 mg $l^{-1}$), likely to adversely affect the growth and yield of rice. Increased groundwater N-$NO_3^-$ may be attributed to vigorous stimulation of microbial activity which often promotes residual mineralization of organic matter in the long dry periods (Driessen & Dudal, 1991).

High levels of N-$NO_3^-$ in the groundwater may also be due to the mineralization of plant matter that has been buried under seasonal alluvial depositions. The advantage at the Besease site is that farmers may not immediately require nitrogen fertilizers for their crops if they should expand the use of groundwater resources. It must be pointed out that excess nitrogen is likely to lead to tiller proliferation at the expense of fruiting (Doorenbos & Pruitt, 1977; Doorenbos & Kassam, 1979; Roscher, 1989).

The averages of $HCO_3^-$ content of groundwater (3.0 meq $l^{-1}$) was considered moderately high for irrigated rice. This is unusual for paddy fields (Driessen & Dudal, 1991), but the probable explanation is that the long dry periods prevent the soil redox potential from becoming low (i.e. slightly acidic). It has been suggested by Roscher (1989)

TABLE 5
Summary of water quality data of hand-dug well No.2 at Besease

| *Parameter* | *Mean* | *Minimum* | *Maximum* | *Standard deviation* |
|---|---|---|---|---|
| *p*H | 6.71 | 5.80 | 7.26 | 0.55 |
| Alkalinity, ($CaCO_3$)* | 2.70 | 1.76 | 3.88 | 0.93 |
| Turbidity (NTU) | 210.75 | 80.00 | 570.00 | 239.69 |
| Conductivity (dS $cm^{-1}$) | 0.32 | 0.24 | 0.40 | 0.08 |
| Total dissolved solids (TDS) | 284.00 | 166.00 | 359.00 | 78.92 |
| Calcium ($Ca^{2+}$)* | 1.48 | 14.20 | 1.79 | 0.52 |
| Sodium ($Na^+$)* | 1.41 | 0.75 | 2.39 | 0.13 |
| Potassium ($K^{2+}$)** | 28.14 | 14.20 | 46.40 | 3.58 |
| Magnesium ($Mg^{2+}$)* | 0.29 | 0.13 | 0.46 | 1.57 |
| Iron (Fe)* | 2.05 | 0.20 | 5.12 | 1.85 |
| Chloride ($Cl^-$)* | 0.41 | 0.13 | 0.51 | 5.53 |
| Sulphate ($SO_4^{2-}$)* | 0.25 | 0.03 | 0.73 | 0.32 |
| Bicarbonate ($HCO_3^-$)* | 2.21 | 1.44 | 3.18 | 0.77 |
| Silica ($SiO_3$)* | - | 1.00 | - | - |
| Nitrate ($NO_3^-$-N)** | 3.08 | 0.20 | 5.60 | 2.63 |
| Phosphate ($PO_3^-$P)** | 0.40 | 1.56 | 0.70 | 0.20 |
| Adjusted sodium adsorption Ratio (ASAR) | 1.80 | | 2.14 | |

Note: Except *p*H, ASAR, conductivity and turbidity, other parameters have units in meq/l (*) or mg/l (**).
(Values were each computed from 48 parametric samples.)

that irrigating with such high carbonaceous water can lead to gaseous loss of $CO_2$, which is likely to result in deposition of $CaCO_3$ on crop leaves. This situation can lower photosynthetic activity leading to loss of grain yield, except when long earth canals are used for water delivery to rice plots. This way, much of $CO_2$ is lost to air in transit.

## Conclusion

Rice farming at the Besease project site is primarily rain-fed. The present study has shown that in terms of surface and groundwater quality, the water resources of the Oda valley bottom are very suitable for small-scale irrigation based on the Ayers & Westcot (1985) water quality guidelines. The levels of TDS, $Na^+$, $Cl^-$, *p*H and conductivity values are comparatively so low that irrigated water will not cause salinity, permeability or crop toxicity problems, except under extremely poor drainage and water management practices. Nevertheless, $HCO_3^-$ levels of the groundwater have potential to adversely affect crop photosynthetic activity leading to loss in grain yield and quality deterioration.

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