Effects of agrochemicals on surface waters and groundwaters in the Tunga-Kawo (Nigeria) irrigation scheme

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Abstract The Tunga-Kawo Dam has a reservoir capacity of 22 Mm^3, and was designed to irrigate 900 ha of land in the Midland region of Nigeria. This paper examines the quality of surface water and groundwater within the scheme. In particular, the seasonal variation of the concentrations of nitrate, phosphate, dissolved oxygen and hydrazine during the year 2000 is discussed. Three sample points: SF1, SF2 and SF3, were selected for monitoring the surface water quality at the upstream, impounded water and downstream sections, respectively. The quality of groundwater was monitored using samples from a well near the dam (GW2) and the downstream section (GW3). Water samples were taken on a weekly basis from the sample points during the year 2000. It was found that the concentrations in the surface water were higher than the WHO standards for drinking water. For example, the nitrate level in SF3 increased from 0.0 mg l^{-1} before application of fertilizer to 74.1 mg l^{-1} after fertilizer was applied, while the phosphate level rose from 1.2 mg l^{-1} to 19.2 mg l^{-1} during the same period. Similarly, the level of hydrazine increased from 62 μg l^{-1} to 102 μg l^{-1}. In particular, the concentrations of the determinants in the samples from the downstream section exceeded those in the impounded water and water from the upstream section. In addition, the level of DO at the downstream section SF3 was lower than that of the upstream section. The level was lower than the minimum level required to support a balanced population of desirable flora and fauna. This difference was attributed to the agrochemicals used by the farmers. Although the quantity of fertilizer applied by the farmers is below the quantity required for optimum yields, the excess chemicals in surface and groundwater could be attributed to the techniques and timing of application. The magnitude of these impacts can be reduced by efficient methods of source control of the pollutants.

Key words irrigation, fertilizer, pesticide, water quality, field data

Effets d'intrants agrochimiques sur les eaux de surface et souterraines du périmètre irrigué du Tunga-Kawo (Nigeria)

Résumé Le barrage de Tunga-Kawo a un réservoir de 22 Mm^3 et a été construit pour irriguer 900 ha de terre dans la région centrale du Nigeria. Cet article examine la qualité de l'eau de surface et de l'eau souterraine dans le périmètre irrigué. En particulier, nous discutons la variation saisonnière des concentrations en nitrate, phosphate, oxygène dissous et hydrazine au cours de l'année 2000. Trois points d'échantillonnage (SF1, SF2 et SF3) ont été sélectionnés pour surveiller la qualité de l'eau de surface respectivement en amont, au barrage et à l'aval. La qualité de l'eau souterraine a été surveillée grâce à des échantillons provenant d'un puits (GW2) proche du barrage et d'un point (GW3) à l'aval. Les échantillons d'eau ont été prélevés chaque semaine au cours de l'année 2000. Les résultats ont montré que les concentrations dans l'eau surface sont plus élevées que les valeurs recommandées par l'OMS pour l'eau potable. Par exemple, la concentration en nitrate au point SF3 a

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augmenté de 0 mg l^{-1} avant l'application de fertilisants à 74.1 mg l^{-1} après, tandis que, pendant la même période, la concentration en phosphate au point SF3 a augmenté de 1.2 mg l^{-1} à 19.2 mg l^{-1}. De même, la concentration en hydrazine a augmenté de 62 µg l^{-1} à 102 µg l^{-1} au point SF3. En particulier, les concentrations des éléments déterminants dans les échantillons prélevés à l'aval sont supérieures aux concentrations observées au niveau du barrage et à l'amont. La concentration en oxygène dissous au point aval SF3 est quant à elle inférieure à celle observée à l'amont. Le niveau est au dessous du niveau nécessaire pour maintenir une population équilibrée en faune et en flore désirables. Cette différence a été attribuée aux intrants agrochimiques utilisés par les agriculteurs. Bien que la quantité de fertilisants appliquée par les agriculteurs soit au dessous de la quantité nécessaire pour obtenir le meilleur rendement, l'excès d'éléments chimiques constaté dans les eaux de surface et souterraines peut être attribué aux techniques et à la période d'application. L'ampleur de ces impacts peut être réduite par une méthode de contrôle à la source des polluants.

Mots clefs irrigation; fertilisant; pesticide; qualité d'eau; données de terrain

INTRODUCTION

Farmers apply fertilizer to boost crop yields, while herbicides are applied to control weed growth. Not all of the fertilizer applied is utilized by plants as fertilization rates exceed crop requirements, and inappropriate application techniques are used. Some of the excess chemicals are washed to irrigation canals during irrigation or rainfall, and conveyed downstream, while some remain in the soil, infiltrate and pollute the aquifers. In addition, pesticides that are neither adsorbed nor rapidly lost by volatilization, are likely to be available for leaching, thereby contributing to pollution of groundwater (Briggs & Coortney, 1989). Zeid & Biswas (1990) reported that in the mid-1970s, the overall concern with fertilizer and pesticide pollution of waters was limited, even in developed countries. Although understanding of the contamination of water bodies in developed countries has considerably increased, the overall picture of fertilizer and pesticide contamination in developing countries is still limited today. This could be attributed to a number of reasons such as: (a) instrumentation problems in detecting low concentrations (in lower microgram range) of residual fertilizer and pesticide, (b) lack of historical records on past pesticide and fertilizer use, (c) economic and manpower constraints, and (d) non-involvement of industries in research activities in developing countries. Despite these constraints, the use of agrochemicals is increasing, and their presence in drinking water continues to constitute a health hazard. For example, the presence of nitrate (from fertilizer) in drinking water at concentrations greater than 50 mg l^{-1} could cause methaemoglobinaemia in babies aged less than 6 months (WHO, 1998). In addition, nitrate in the alimentary canals of humans may react with amines to form carcinogenic nitrosamines, which could contribute to the development of gastric cancer.

In a survey of 131 out of 320 coastal counties in the USA (Wolfe, 1999), it was found that 80% of coastal pollution originates from land-based non-point sources such as runoff from city streets, agricultural fields, leaky septic tanks, motor vehicles and animal feed operations. But the pollution from heavy industrial facilities and sewage treatment plants, which used to be the major sources of water pollution, was reported to be under control in the country (Wolfe, 1999). Jimoh (2003) discussed the seasonal variation in the levels of nitrate, phosphate and dissolved oxygen in the surface water of the Tunga-Kawo irrigation scheme. It was reported that the concentration of nitrate and phosphate in water samples from the drainage channel exceeded the level of the respective ions in the water from the reservoir. In particular, the concentration of

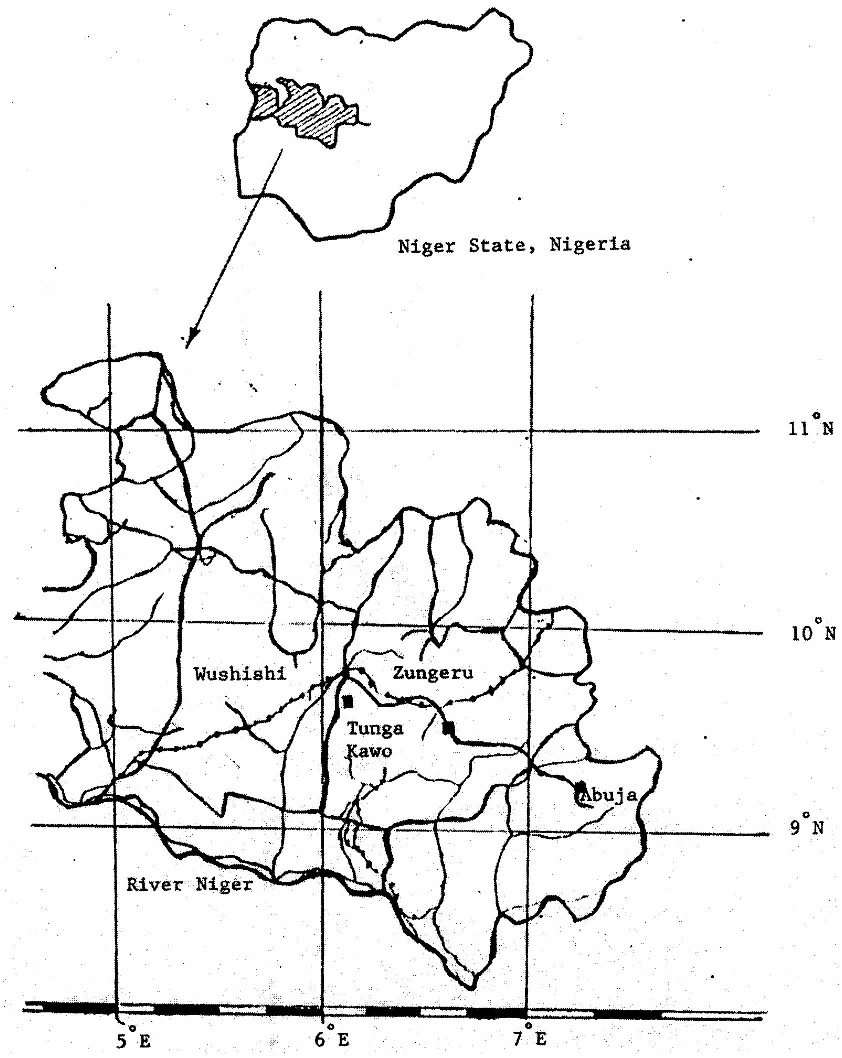

Fig. 1 Map of Niger State showing the location of Tunga-Kawo Irrigation Project.

nitrate in the water from the drainage channel exceeded the safe limit of 50 mg l^{-1} (WHO, 1998) after the dry season farming. The implication of the study is that the water from the streams is unsuitable for drinking. This paper reports seasonal variations in the concentrations of nitrate, phosphate, dissolved oxygen, and hydrazine in both surface water and groundwater from February to October. It also discusses factors controlling the variation, and steps that could be used to reduce residual fertilizer or herbicide in the waters.

DESCRIPTION OF PROJECT SITE

The Tunga-Kawo irrigation project is located at latitude 9.5°N and longitude 6.25°E (Fig. 1). The Tunga-Kawo Dam is built across the flood plain of the Ubandawaki and Bankogi. The project was conceived in 1955 as a way of reducing flooding of valuable agricultural land along rivers Ubandawaki and Bankogi. The reservoir was therefore, intended to provide control facilities for downstream irrigation of an area of 900 ha.

The dam and irrigation network were constructed with a 250 ha irrigable area. A number of communities are located downstream of the scheme and these communities depend on water from the drainage channels in the scheme for their domestic needs.

The seasonal movement of the Intertropical Convergence Zone (ITCZ), resulting in wet and dry seasons influences the climate of the region. Rainfall is strongly seasonal, and occurs between May and October, with the peak rainfall occurring in September. The annual rainfall ranged between 1200 and 1300 mm. The dry season lasts between November and March. The mean monthly maximum and minimum temperature are 37.3°C and 19.7°C, respectively, and the hottest months are February, March and April. The vegetation lies within the Guinea savannah. The River Ubandawaki on which the dam is located has a catchment area of 166 km^2. The river with its tributaries eventually discharges into the River Kaduna at the downstream end of the irrigation area.

The Tunga-Kawo project is situated on the Bida sandstone formation which consists of fine sandstones sometimes overlain by plinthite (ironstone or laterite). The principal elements contributed by the formation are Al, Fe, K and Na (Bowden *et al.*, 1998). The soil is predominantly sandy clay loam (SCL) and sandy loam (SL). The soil is low in organic matter content (about 2.2%) and total nitrogen (about 0.13%), while the available phosphorus is high (7.9 mg kg^{-1}).

METHOD OF INVESTIGATION

The irrigable area selected for study is 49 ha, i.e. 22% of the developed area. Preliminary investigation shows that NPK and urea fertilizers are the commonest type of fertilizer used by the farmers, while gramozone (dichloride or dipyridillum derivative) is commonly used as a pesticide. Other types of pesticide applied by the farmers include atrazine, gammalin 20 (organochloride) as well as aldrex T. It was found that herbicides are seldom used due to their high cost. Thus, the determinants of interest are nitrate, phosphate and dissolved oxygen. Hydrazine, a man-made chemical, not found in natural water but used in the synthesis of biologically active compounds like pesticides and insecticide, was also adopted as indicator for the presence of pesticide in water. Sampling points were selected to cover both surface and groundwater. Figure 2 shows the location of the points selected for monitoring surface water as well as the location of water wells that were dug for taking groundwater samples. Water samples were taken from the selected points on weekly basis and the concentration of each determinant was determined using a C100 multi-parameter bench spectrophotometer. The operation of the photometer is based on the principle of colorimetric analysis (Jeffery *et al.*, 1989). Specific compounds will react with others to form a colour, the intensity of which is proportional to the concentration of the substance to be measured. The concentration of the specific compound is based on the following principle (Hanna Instrument Manual, 1996):

(a) The measurement of pH level in the sample is based on the phenol red method.
(b) Nitrate-nitrogen is determined based on the cadmium reduction method. The reaction between nitrate-nitrogen and the reagent causes an amber tint in the sample.
(c) The concentration of phosphate is based on the amino acid method. The reaction between phosphate and the reagent causes a blue tint in the sample.

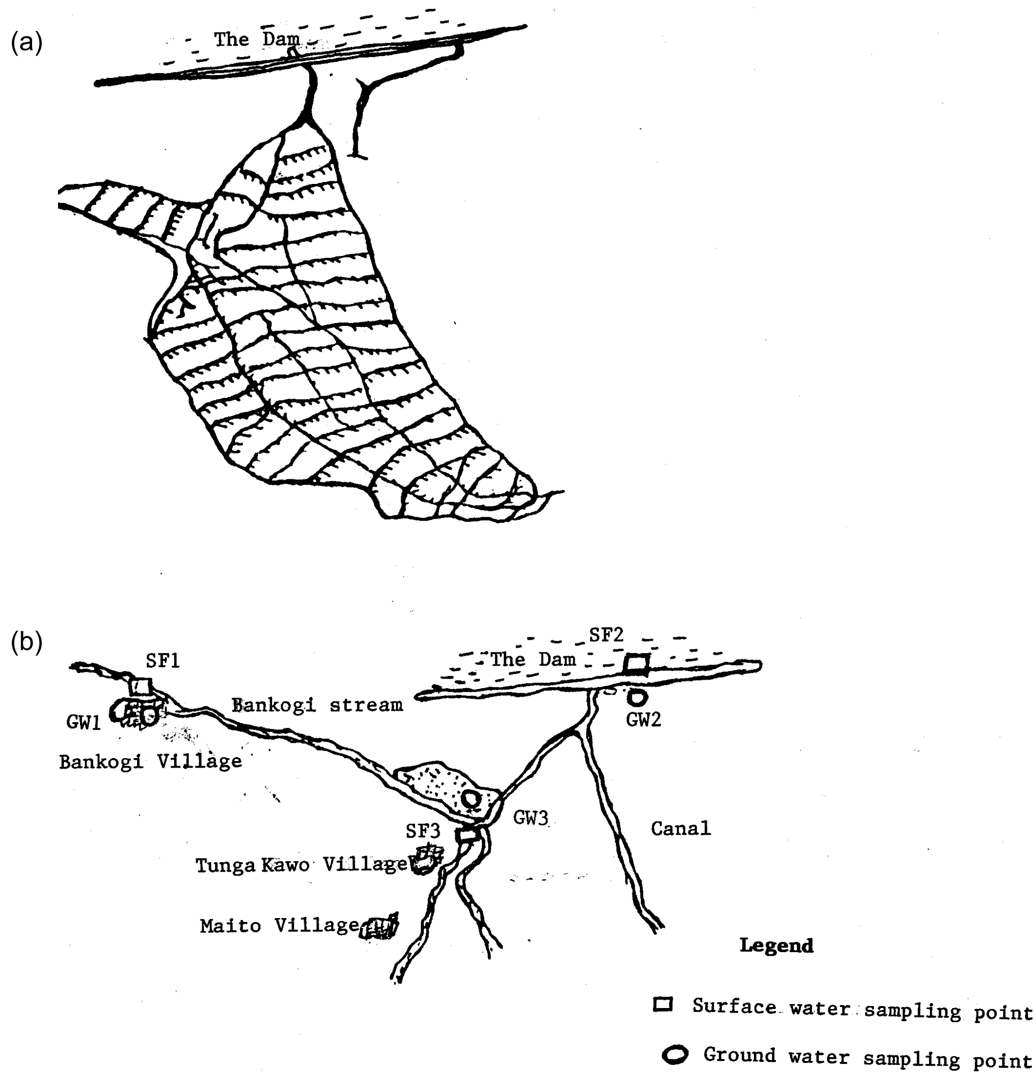

Fig. 2 Tunga-Kawo Irrigation Scheme and sampling points. (a) Irrigation scheme layout showing the main canal and field channels. (b) Sampling point within and around the irrigation area.

(d) The determination of the level of dissolved oxygen is based on the azide modified Winkler method.

(e) Hydrazine is based on the ASTM (American Society for Testing and Materials) manual of water and environmental technology method D1385-88 for natural and treated water. The reaction between hydrazine and the liquid reagent causes a yellow tint colour in the sample.

Samples were taken on a weekly basis between February and October 2000 from the following points:

- SF1: surface water sampling point 1, which is upstream of the irrigation scheme;
- SF2: surface water sampling point 2 on the reservoir;
- SF3: surface water sampling point 3 on the drainage channel;
- GW2: groundwater sampling point at the upstream end of the irrigation scheme. The well was located 20 m away from the embankment, and the water depth was 3 m from the surface.

– GW3: groundwater sampling point at the downstream section. The water depth was 3 m from surface.

RESULTS AND DISCUSSION

Nitrate

The variation in the concentration of nitrate in the waters are shown in Fig. 3. The figure shows a marked rise in nitrate levels in the surface water downstream of the irrigable area (SF3) with the commencement of fertilizer application. This level increased to a peak concentration of 74.1 mg l^{-1}. In particular, the recommended WHO safe maximum limit of 50 mg l^{-1} was exceeded between Julian days 190 and 220 (that is, within the month of July). The farmers applied fertilizer between Julian days 77 and 84 (i.e. in March) in the year 2000. The rise in nitrate level at the downstream section after fertilizer application suggests that chemical residues on the land surface were washed by rain to the drainage channels. The nitrate level exceeded the safe limit between August and October, the period after irrigation. The pattern of variation is consistent with the pattern observed in 1999 (Jimoh, 2003). The nitrate levels in SF1 as well as SF2, were consistently lower than the nitrate level in SF3. Thus, the rise in nitrate levels in surface water downstream of the irrigable area (SF3) could be attributed to fertilizer application.

In GW2, nitrate concentrations are slightly higher than that of GW3. However, the level of nitrate in both wells is lower than the safe limit. This suggests that the application of fertilizer at the irrigation scheme does not have a negative impact on the nitrate level in the groundwater. Thus, the community living around the project area could be encouraged to use groundwater for their domestic activities; however, the use of surface water should be discouraged.

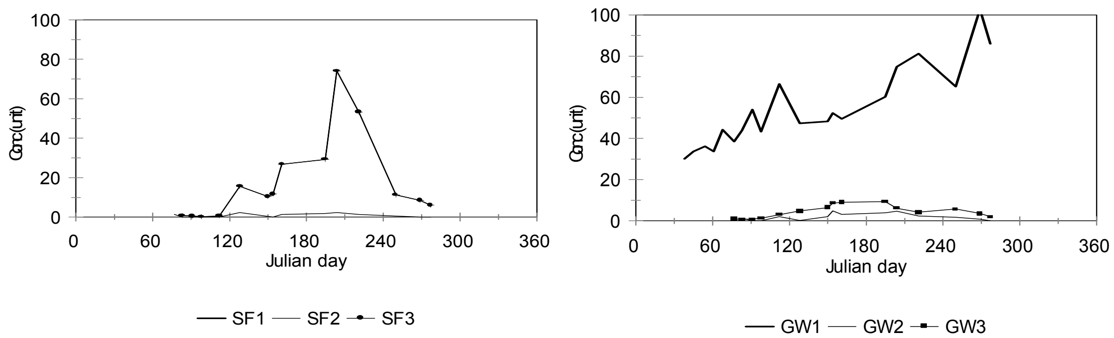

Fig. 3 Seasonal variation in nitrate concentration.

Phosphate

Figure 4 shows the fluctuations in phosphate levels in the waters. There was a considerable increase in phosphate concentration to above the maximum allowable

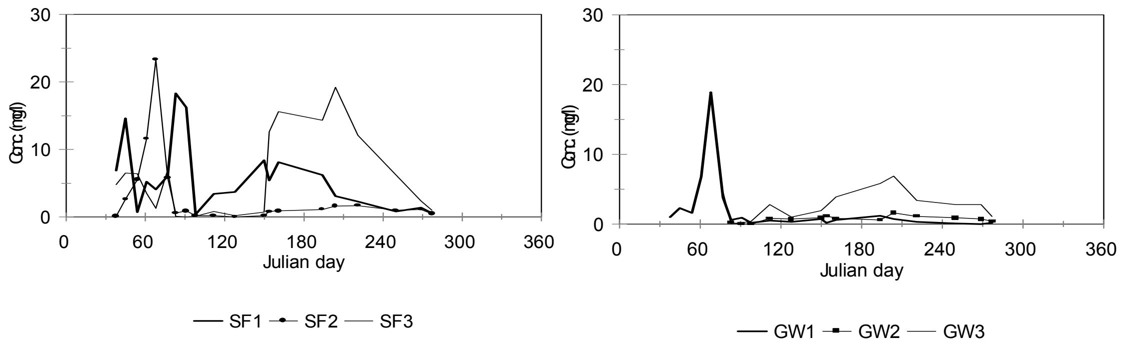

Fig. 4 Seasonal variation in phosphate concentration.

limit of 5 mg l^{-1} (The International Joint Commission, 1986) in both the surface water SF3 and groundwater GW3. The values were consistently higher than those values in SF2 and GW2. This observation is attributed to the increased use of inorganic fertilizer in the area since the soil has low levels of phosphorus (7.97 mg kg^{-1}). At this level of phosphate in SF3 and GW3, the organoleptic properties of drinking water are affected. The excess amount of phosphate leads to eutrophication of the water bodies, causing algal blooms and rapid growth of certain aquatic plants. This phenomenon is causing great concern because the villagers around the irrigable area depend on both the surface water and groundwater for drinking. Natural water normally contains minor concentrations of phosphorous compounds, unless it is polluted with agricultural, industrial and sewage effluents (Nikoladze *et al.*, 1989). Water containing high phosphate concentration produces eutrophication of the receiving water, especially if large amounts of nitrate are present (Hach Reagents and Procedures, 1987). The result is the rapid growth of aquatic vegetation in nuisance quantities and an eventual lowering of the dissolved oxygen content of the surface water due to the death and decay of the aquatic vegetation.

However, the phosphate level in SF2 was higher than that of SF3 between Julian days 55 and 75 (i.e. in March). In particular, the phosphate level was as high as 25 mg l^{-1} during this period. The presence of high phosphate levels in the sample could be attributed to either the presence of phosphorus in the soil, biological waste or residues from trees in the area.

pH levels

Figure 5 shows the seasonal variation in pH levels. The pH values for SF2, SF3, GW2 and GW3 fell within the range 6.5–8.0, the WHO (1998) acceptable standard for drinking water. The pH values for SF1 are lower than pH values of SF2 or SF3. That is the pH of samples from SF1 is slightly acidic.

Dissolved oxygen level

The seasonal variation in dissolved oxygen in surface water and groundwater is shown in Fig. 6. The DO level at SF2 (upstream section) ranged between 4 and 6 mg l^{-1},

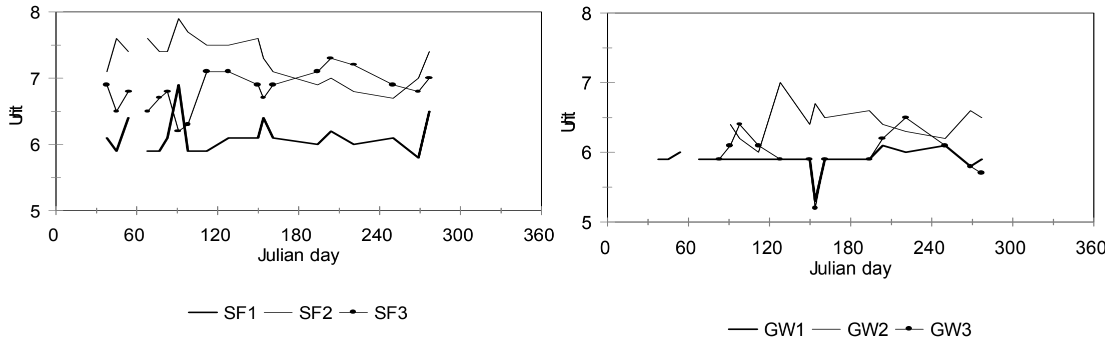

Fig. 5 Seasonal variation in pH level.

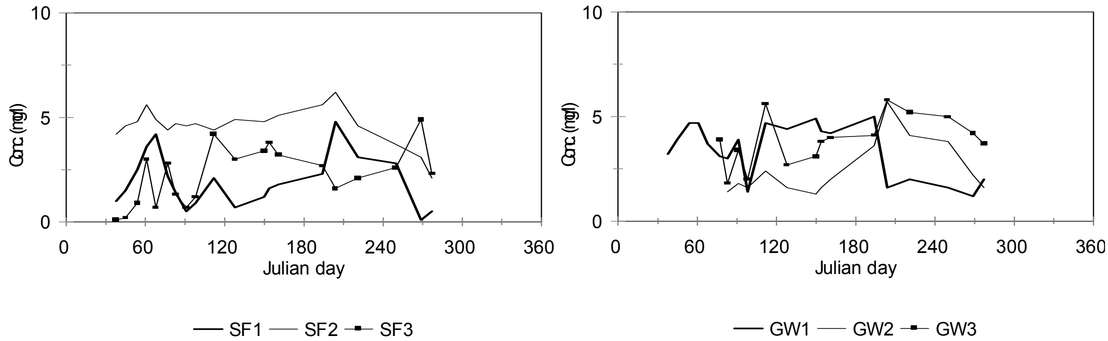

Fig. 6 Seasonal variation in dissolved oxygen level.

indicating that the water at the reservoir has the minimum DO to support a balanced population of desirable aquatic flora and fauna (Barnes *et al.*, 1984). However, the DO level at SF3 was lower than the level at the upstream section. In particular, the DO level downstream (SF3) was lower than the minimum level required to support a balanced population of desirable flora and fauna. The low level of DO in the water could be attributed to the presence of: (a) organic minerals, which cause oxygen to be used up, and (b) reducing agents, which deplete oxygen resources as they are chemically oxidized in the receiving stream

There was no significant seasonal variation in the dissolved oxygen in either GW2, or GW3. However, the dissolved oxygen level at GW2 and GW3 exceeded 4 mg l^{-1} throughout the cropping season (February to June).

Hydrazine

Table 1 shows the hydrazine concentrations in the samples. Pesticide was applied on Julian day 85, and the hydrazine levels in SF3 and GW3 show marked seasonal fluctuations after the application. The highest value of hydrazine for SF3 is >100 μg l^{-1}. However, low concentrations of hydrazine were detected in the non-irrigable areas, that is, SF1, SF2, and GW2. This confirms that the application of pesticide for agricultural purposes increases the level of hydrazine in surface and ground-waters. This finding indicates that water from SF3 or GW3 is not useful for human consumption, since it is detrimental to health.

Table 1 Concentration (µg l^{-1}) of hydrazine at the sampling points.

Julian day	GW3	SF1	SF2	SF3
205	8.0	0.0	10.0	102.0
221	13.0	2.0	5.0	87.0
250	11.0	0.0	5.0	80.0
268	12.1	2.0	0.0	62.0
277	6.2	0.0	1.0	66.0

STRATEGY FOR CONTROLLING POLLUTION FROM AGRICULTURAL FIELDS

The results of the analysis carried out on the soil samples from the study area showed that there is a general nutrients imbalance in the area. The soils are generally low in organic matter, organic carbon, total nitrogen, moderately low in phosphorus, but are moderately high in potassium. Based on the FMAWR&RD (1989) fertilizer recommendation, the rice farms will require 250 kg of NPK per hectare and 200 kg of calcium ammonium nitrate fertilizer (CAN) for optimum yields. This implies that application rates of 142 kg ha^{-1}, 75 kg ha^{-1}, and 75 kg ha^{-1}, of N, P and K fertilizer respectively, are required in the study area. However, the rates of application of fertilizer by farmers during the 2000 irrigation season were far lower: 44 kg ha^{-1}, 15 kg ha^{-1}, and 10 kg ha^{-1} of N, P and K fertilizer respectively. This is grossly inadequate for optimum grain yield. It was observed that fertilizer was applied 55 and 75 days after planting (i.e. twice during the season), by a broadcasting method. The crops were then irrigated a few days after fertilizer was applied. Previous studies (Puckridge *et al.*, 1991) have shown that the uptake rate of N fertilizer in rice field varies with time (days after planting). However, the timing and rate of application of N fertilizer in Tunga-Kawo is not consistent with the previous studies. The effect of the farming practice is high loss of fertilizer to waters. It was also found that the total amount of water applied per hectare (36 586 m^3 ha^{-1}) largely exceeded the crop water requirement (6700 m^3 ha^{-1}). This implies that much water is wasted during the farming season due to inappropriate application of water. This is consistent with Egharevba & Mohammed (2000) who stated that the water application efficiency at Tunga-Kawo irrigation scheme is as low as 20%. The excess water aids the movement of excess chemicals from the field into water bodies. The fertilizer residue detected in the waters, despite the fact that the quantity of fertilizer applied by farmers was inadequate, resulted from inappropriate application of fertilizer and wrong timing of application, as well as abundant irrigation.

Further investigation was carried out to determine the appropriate rate of application of fertilizer or pesticide so as to reduce excess fertilizer or pesticide that will be leached to the water bodies. The vertical movement of both fertilizer (NPK) and pesticide (gramozone) solutions into a sandy clay loam soil at 5–10% moisture contents was investigated. The concentration of the fertilizer and pesticide solution adopted was 0.9 g dm^{-3} and 0.22 g dm^{-3}, respectively. The cumulative infiltration equations for water Q_w, pesticide solution Q_{pw} and fertilizer solution Q_{fw} are:

$$Q_w = 21.12(1 - e^{-2.93t}) + 3.3t$$

$$Q_{pw} = 10.8(1 - e^{-2.8t}) + 2.4t$$

$$Q_{fw} = 13.8(1 - e^{-3.1t}) + 1.8t$$

The equations show that the rate of infiltration of water is faster than that of pesticide or fertilizer. For example, the infiltration rate for water is 6 cm h^{-1}, while those of pesticide and fertilizer solution are 3.1 and 2.57 cm h^{-1} respectively. This agrees with Schwab *et al.* (1981) who stated that the physical properties of soil (including infiltration rate) can be changed by adding chemicals. The soil and subsoil act as a natural barrier to prevent pesticide or fertilizer movement from the soil surface into groundwater. Pesticide and/or fertilizer bind to the soil particles in a process called sorption and are degraded by soil micro-organisms. The chemicals lower the surface tension and cause spreading of water drops on solid surfaces resulting in wetting of that surface. If a material, which tends to be active at the surface, is present in a liquid system, a decrease in the surface tension of that liquid will occur upon movement of the solute to the surface (Weber *et al.*, 1989). That is, a solute which lowers the surface tension of a liquid in which it is dissolved, will migrate to and adsorb at the interface of that liquid with some other phase. These chemicals (fertilizer and pesticide) by acting as wetting agents, thereby alter the rate at which the solutions move through the soil. The slower rate of movement of fertilizer and pesticide solutions can be attributed to this phenomenon. The implication of this is that if fertilizer is applied by a broadcasting method, and the field is then irrigated, the excess fertilizer on the soil surface will either be washed to drainage channels or absorbed by the soil. The absorbed component will remain in the soil for some time, and move gradually to the water bodies.

Thus, the major source of water pollution in the irrigation scheme is leaching and drainage. In order to reduce the excess chemicals, farmers must apply the amount of agrochemical required by plants at each stage of growth. In addition, the required amount of water should be applied, using an appropriate irrigation technique. This implies that the use of agrochemicals depends on the crop and soil characteristics of the site.

CONCLUSION

Fertilizer and pesticides, which are continuously applied in the Tunga-Kawo irrigation scheme, have been found to affect not only the crop quality and yield, but also the quality of water downstream of the irrigation areas. Nitrate and phosphate levels in these waters exceeded levels recorded before the beginning of the irrigation season. The nitrate level exceeded the WHO standard and made surface water downstream of the irrigation area unsuitable for drinking. Phosphate in surface water exceeded 5 mg l^{-1}, the level that can support algal blooms, and adversely affects the organoleptic properties of drinking water. In groundwater the concentration of phosphate increased beyond the acceptable level for consumption. The rise in pH, which is beneficial for potability, is attributable to the impact of the embankment. Levels of pesticides also rose beyond the acceptable WHO limit. This causes a health risk because of the carcinogenic nature of the compounds.

It was found that the amount of fertilizer applied by the farmers is lower than the quantity required for optimum yields, but inappropriate techniques and timing of application resulted in the occurrence of excess chemicals in the soil. In addition, the fields were flooded resulting in the availability of water for flushing chemicals to waters. Although, water treatment techniques using granular carbon filtration (GCF) and reverse osmosis (RO) can remove these pollutants, the technique is not economical. Thus, source control is a better approach to adopt in reducing the negative impact of these agrochemicals. This will involve adopting cultivation and cultural practices that will reduce the amount of agrochemicals that can be leached to the water bodies.

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