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Assessment of agricultural practices on water quality of the Tono Dam in the Upper East Region of Ghana

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Population growth has resulted in drastic increase in demand for agricultural products for consumption and also as raw materials for agro-based industries. Associated with this increased demand is the application of agrochemicals to increase yields. This study assessed the impact of agricultural practices employed by farmers in the Tono catchment in the Upper East Region of Ghana on water quality. The study involved a combination of surveys and laboratory analyses. Structured questionnaires were administered to farmers to determine the various agricultural practices employed towards increasing crop yields as well as their knowledge on the environmental effects of these practices among others. Laboratory analysis was performed to determine the levels of physicochemical parameters of the reservoir water so as to ascertain its pollution level. The study showed that farmers in the catchment used mechanized ploughs to till their lands and applied fertilizer and other agrochemicals to increase yield. These practices potentially can pose serious threats on water quality of the reservoir. Although the levels of all the parameters analyzed were within the WHO guideline values, it is recommended that farmers within the area should be educated on proper application of agrochemicals and farming practices in order to ensure that the quality of the water is maintained. In particular, farming around the intake areas of the dam should be prohibited as this constitutes a major source of sediment into the reservoir.

Key words: Agricultural practices, agrochemical usage, surface water quality.

INTRODUCTION

Agriculture comprises mainly farm lands of large and small sizes where crops and animals are produced individually or simultaneously. Even though farm sizes in Ghana are small, the traditional method of farming has also changed over time. These days, the time frame of rotations has been reduced and farming has been targeted on commercially productive crops. In addition, agriculture has become more intensive with the requirement for the use of heavy machinery, agricultural inputs such as fertilizers, agrochemicals, and large irrigation schemes. These practices that are carried out to increase crop production can impact on water quality

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through the introduction of nutrients as a result of soil tillage and application of fertilizer, and other agrochemicals such as pesticides into the aquatic ecosystems. Also, contamination from pathogenic organisms in manure adhered to soil carried in run-offs (FAO, 1995). In the literature, a range of pollutants from non-point sources have increased to include visible matter, suspended solids, oxygen-demanding materials, nutrients, pathogenic microorganisms, heavy metals, pesticides, and hydrocarbons (Adams et al., 2006). The Eriksson et al. (2007)'s priority pollutant list includes the most common water quality parameters such as organic and suspended matter, nutrients, pH and heavy metals such as, copper, cadmium ,nickel, lead, platinum , chromium and zinc, and polycyclic aromatic hydrocarbons (PAHs). A major source of these in surface water is from agricultural inputs such as chemical fertilizers (Robinson et al., 2007).

The impacts of agriculture on water quality depend on both large and small scale factors. Large scale factors such as landscape, topography, climate and parent material have large impacts on farming areas. These factors characterize the ecosystems and determine the type of farming practices that are possible in the area. Small scale factors such as land use change, pollution and degradation can also impede on the quality of water in a particular area. Tillage is mainly of three types- the conventional tillage, conservation tillage and No-till. Tillage of farmlands in all its types including digging, stirring, and turning over is to make the soil loosed. Tilling can be man-powered, draft animal-powered or mechanized. Generally, fertilizer refers to any substance, organic or inorganic, added to the soil or applied on the leaves of plants to help increase the rate of growth. Nitrogen, phosphorous and potassium are the main elements required by plants for growth. Any substance that supplies just one of the three principal macronutrients is a straight fertilizer while mixed fertilizers are those materials that supply more than one principal nutrient. The elevated rate of fertilizers application as in quantity and frequency usually overtakes the natural ability of the soil to retain and change the nutrients and harmonizing their availability with crop demands

After continuous tillage, the soil becomes hard just below the depth of the tillage. This greatly affects soil water drainage as soil compaction increases surface runoff since less rainwater is permitted to percolate. This can increase the risk of erosion, and in return leading to loss of the surface soil and nutrients, and non-point source pollution of aquatic ecosystems. Sediments from surface and bank side erosion enter streams and rivers and it is considered to be a major surface water pollutant (Tebrügge and Düring, 1999; FAO, 1996). Precipitation events in particular contribute to increased concentrations of suspended matter in water bodies. Sediment deposition also contributes to changes in channel formation and flow characteristics. Also, suspended matter reduces the amount of light that is able to penetrate inside the water; turbid water may impede feeding mechanisms and respiration of large invertebrates and fish (Doeg and Koehn, 1994; Wood and Armitage, 1997; Relyea et al., 2000).

In addition, the oversaturation of soil with nutrients allows precipitation to carry the extra nutrients into water systems through runoff, and erosion. The eroding and transport of soil particles and fine silt from farmlands into aquatic ecosystems is a major cause of introduction of nutrients from fertilizers applied on farm lands. Excessive supply of inorganic nitrogen and phosphorus compounds leads to elevated nitrification, high oxygen demand and production of toxic un-ionized ammonia. The impact of these nutrients on ponds, lakes, seas and oceans includes enrichment of water courses, increased nitrification, increased oxygen demand. Studies by the UK government showed that pesticides concentrations exceeded those allowable for drinking water in some samples of river water and groundwater (White and Hammond, 2009). Fish and other aquatic biota may be harmed by pesticide contaminated water. Surface runoff into rivers and streams can be highly lethal to aquatic life, sometimes killing all the fish in a particular stream.

The Tono dam promotes dry season production of food crops (vegetables and cereals) and as a source of water for livestock, and as such is very important to the people of the Upper East region and the country as a whole. This research sought to determine the various agricultural practices carried out in the catchment area of the dam, and to also assess the levels of physicochemical parameters in the reservoir. The outcome of this project will be useful to all stakeholders and also inform policy making with regards to regulating agricultural activities around the dam in order to ensure its sustainability.

MATERIALS AND METHODS

Study area

The study area (Tono watershed) lies in the Kassena-Nankana District within the Guinea Savannah woodlands. The district falls approximately between latitude 11° 10‟ and 10° 3‟ North and longitude 1° West in the Upper East region of Ghana (Figure 1). The climate of the Tono watershed is mainly characterized by the dry and wet seasons, which are influenced by two air masses namely the North-East trade winds and the South-Weterly (tropical maritime). Day temperatures are as high as 42°C in March while night temperatures reach a low of 18°C around December. The Municipality observes the tropical maritime air mass between May and October. The average annual rainfall is 950 mm (GSS, 2014).

The catchment is mainly covered by the Sahel and Sudan Savannah types of vegetation consisting of open savannah with fire-swept grassland interspersed with deciduous trees. However, due to anthropogenic activities the woodland savannah has been reduced to open lands with economic trees such as baobab, acacia, sheanut and dawadawa which have been retained over time. There are two main types of soil found within the watershed namely groundwater laterite and savannah ochrosols. The drainage system of the catchment area is constituted mainly around the tributaries of the Sissili River, Asibelika, Afumbeli, Bukpegi and Beeyi. A tributary of the Asibelika River (Tono River) is the one

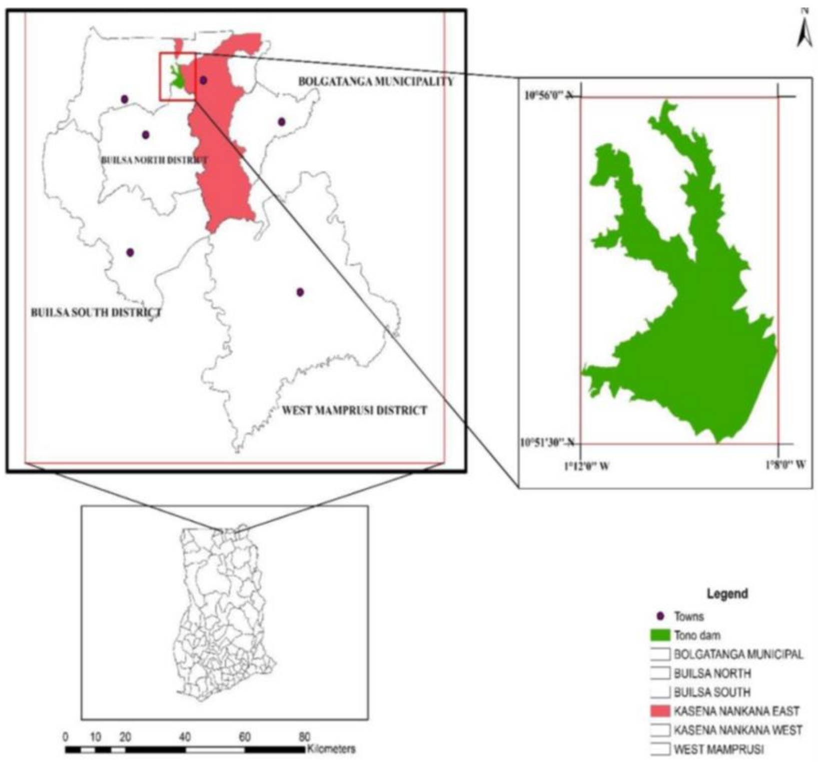

Figure 1. Map of the study area.

dammed to provide irrigation services to the municipality. The topography is low-lying and undulating and consists of elevations which range from 200 to 300 m (GSS, 2014).

Field reconnaissance survey

A preliminary field survey was conducted at the study area to gather initial information about the dam. A survey was also done to determine some of the general characteristics of the study area with respect to the location of farmlands around the dam, and also to interact with farmers in order to gather information towards the questionnaire design. The research was conducted from Janaury, 2018 to May, 2018.

Survey

Structured questionnaires were administered to 193 farmers within the catchment area of the Tono Dam in order to obtain information on the various agricultural practices carried out on the farms in the catchment area. The questionnaires helped to know some of the economic and social factors that drive farmers to employ the various agricultural practices. Additionally, the survey helped to assess the knowledge of the farmers with regards to the following: usage of agrochemicals, reading of labels on agrochemicals before purchase and application, safe disposal of containers and residues of agrochemicals, and general agricultural practices in the catchment area of the dam. In determining the sample size, the following mathematical formula was used: $n = \frac{N}{1+N(\propto)^2}$ (Puopiel, 2010) where n is the sample size, N is the population and α is the margin of error which in this study was chosen as 0.1 with confidence interval of 90%.

Water sampling procedure

The dam was divided into 3 sections; A, B, C (Figure 2). Section A represents the upstream portion of the dam where water enters from the tributaries; Section B represents the midstream; and Section C represents the area closer to the embankment wall. Three samples were taken in duplicates from each section across the length at approximately 100m apart as shown in Figure 2. In all, 18 samples were collected for analysis. This was to compare the levels of the various parameters with distance from shore in order to ascertain the impacts of anthropogenic activities on the quality of water in the dam. Plastic bottles, each of 1.5 litre volume were used as sample containers. Sample containers were thoroughly washed with distilled water and then rinsed with water from the sampling area before collecting the samples. The samples were taken at a depth of not more than 1m from the surface of the water and stored in an ice chest and transported to the laboratory for analysis.

Analytical methods

The samples were analyzed for the following physicochemical parameters using standard methods (APHA, 1998): pH, electrical conductivity, turbidity, total dissolved solids (TDS), ammonia (NH_4-N), nitrate (NO_3-N) and phosphate (PO_4-P). Measured values were then compared with WHO (2017) water quality standards in order to ascertain the level of pollution of the dam. A brief description of the various methods is given as follows. Turbidity was determined with DR LANGE LPG325 turbidity meter. Standard solution was used to

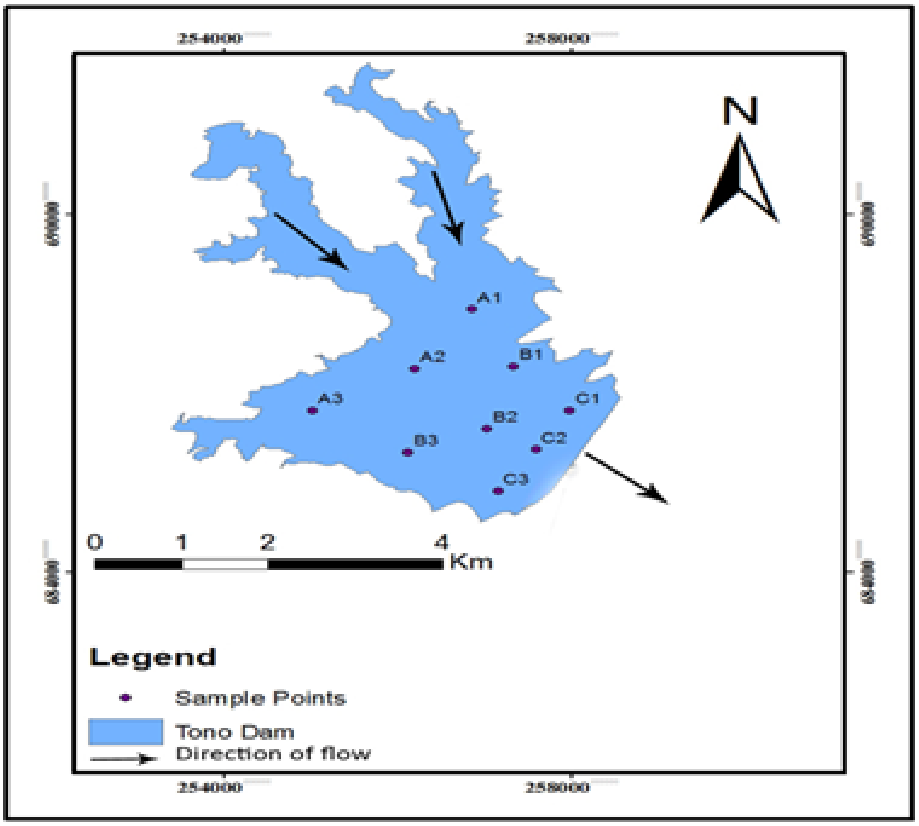

Figure 2. Map of the Tono Dam showing the location of the sampling points.

calibrate the meter after which the probe was dipped into the sample and the readings recorded. pH was measured using a pH meter (WTW pH325). Standard solutions were prepared by dissolving the standard pH buffer tablets in distilled water. An indicator electrode (pH Electrode) in conjunction with a reference electrode was first dipped in the standard solutions to confirm their pH. The electrode was then rinsed with distilled water and dipped in the sample to measure the pH value. Turbidity and pH measurements were done on-site. Gravimetric method was applied in the determination of Total Dissolved Solids, while electrical conductivity was determined using the EC meter. This meter measures the resistance offered by the aquatic system in between two platinized electrodes. The instrument was standardized with known values of conductance compared with a standard solution of KCl. Nitrate determination was based on the principle of formation of 5-nitrosalicylic acid complex under highly acidic conditions as described by Adonadaga (2014). Determination of ammonium was based on the formation of potassium iodide-amalgam. Five ml of appropriately diluted sample was mixed with 200 µl of potassium sodium tartrate solution and 200 µl Nessler's reagents and thoroughly stirred. Samples were allowed to stand for five to eight minutes leaving a golden yellow coloration, and then measured photometrically at 425 nm with a UV/VIS spectrophotometer (SHIMADZU UV-2459). Phosphorus was determined based on the ascorbic acid method. This method relies on the fact that orthophosphate reacts, in acid medium, with ammonium molybdate and potassium antimonyl tartrate to form phosphomolybdic acid. This is reduced by ascorbic acid to form highly coloured molybdenum blue which can be measured in a spectrophotometer at 880 nm wavelength.

RESULTS AND DISCUSSION

Survey

Of the total number of farmers interviewed, 43% of them had some form of education, with the highest level being Senior High School. In terms of farm size, the highest was four acres representing 10%, an indication that most of the farming activities were done on subsistence basis. With regard to the number of visits per day, the highest response (34.7%) was for three visits, and although others visited more than three times a day, the explanation was that the number of visits generally depends on the stage of the crops and vegetables planted. So at the early stages, the visits are more frequent compared to when the plants have survived and are now at the growing stage. The survey results also showed that about 96% of the farmers apply agrochemicals especially chemical fertilizers on their farms. When asked why the preference for chemical fertilizers instead of organic fertilizers, they responded that the chemical fertilizers were readily available and easy to apply. When asked the specific names of agrochemicals they apply, most of them (78.2%) were unable to mention any names. They explained that the agrochemical dealers provided them with the specific

Table 1. Levels of physicochemical parameters at the sampling points.

Parameter/Sample	A1	A2	A3	B1	B2	B3	C1	C2	C3	WHO (2017) gudelines
pH	8.54	8.14	8.04	8.23	8.46	8.23	8.53	8.18	8.27	6.5-8.5
TURBIDITY(NTU)	4.6	4.1	4.8	3.0	2.3	2.1	1.1	1.6	1.9	5
E.C (µS/cm)	88.9	79.8	79.7	80.1	79.5	79.5	79.4	81.7	79.5	1000
TDS (mg/L)	59.4	53.3	53.3	53.5	53.1	53.1	53.1	54.8	53.1	500
AMMONIA(mg/L)	0.875	0.846	0.898	1.046	2.373	1.070	0.865	0.979	0.927	1.5
NITRATE(mg/L)	1.135	1.485	1.609	1.451	0.955	1.428	1.225	1.564	1.00	10
PHOSPHATE(mg/L)	0.045	0.038	0.043	0.041	0.043	0.041	0.046	0.075	0.094	-

Table 2. Values of turbidity (NTU).

	Upstream			Midstream			Downstream		
Sample ID	AI	A2	A3	B1	B2	B3	C1	C2	C3
Reading (NTU)	4.6	4.1	4.8	3.0	2.3	2.1	1.1	1.6	1.9

chemicals based on the description of the problem on their farms. In other words, the farmer needs to only tell the agrochemical dealer that he has weeds on his maize farm and the agrochemical dealer provides him with the chemical for that purpose. When asked if they wear protective gear during chemical application, 92.2% of them responded in the affirmative, an indication of their awareness of the potential health hazards associated with the usage of these chemicals. However, an inspection of the protective gears showed that nose mask was the one mostly used.

Physicochemical analysis

Levels of all the measured physicochemical parameters are shown in Table 1. Two measurements were made for each parmeter and an average was calculated.

pH

The pH values ranged from 8.04 to 8.54, with sampling point A1 exceeding the WHO guideline upper limit of 8.5 (Table 1; Figure 3). Several factors, both natural and anthropogenic, could account for these levels of pH in the water samples. The process of photosynthesis by algae and plants use of hydrogen, which could have also contributed to this increased pH level (Lachhab et al., 2014). All the samples collected at each point are alkaline in nature. The observed changes may be due to excessive fertilizer application in the farms in the catchment area of the dam.

Turbidity

The turbidity values of the water samples ranged from 1.1 NTU to 4.6 NTU, with the highest turbidity value occurring at sampling point A1 (Table 2). However from the results obtained, none of the water samples exceeded the WHO recommended acceptable limit of 5.00 NTU. Results obtained from the analyses show that turbidity decreases as you move from the source (A) to the embankment wall (C). The amount and size of suspended sediment is dependent on water flow (Murphy, 2007). As the flow rate decreases towards the embankment, there is more sedimentation and hence less turbidity. Higher turbidity values in samples closer to the source can be attributed to the fact that runoff water coming with high flow rates from farms contains much sediment, inorganic and organic matter. It is thought that 75% of sediments polluting water bodies are derived from farming (Collins and Anthony, 2008). The sediments from farms may contain clay, silt, organic and inorganic matter, plankton, bacteria etc. (APHA, 1998). The dam also becomes deeper as you move towards the embankment wall (C). Most primary producers (plankton and bacteria) dwell in the shallow parts of the ecosystem where nutrients are abundant, hence making the deeper parts much clearer than the shallow parts. High flow rates keep particles suspended instead of settling to the bottom. In aquatic ecosystems with naturally-occurring high flows, turbidity can be high (Perlman, 2014). Anthropogenic activities are also higher at the shallow parts contributing to high turbidity.

Total dissolved solids

The Total Dissolved Solids (TDS) of the analyzed samples ranged from 53.1 to 59.5 mg/L. TDS decreased downstream from A1 (Upstream) to C1 (Downstream). The same also occurs on the other side, thus from A3 (Upstream) to C3 (Downstream) (Table 3). This can be

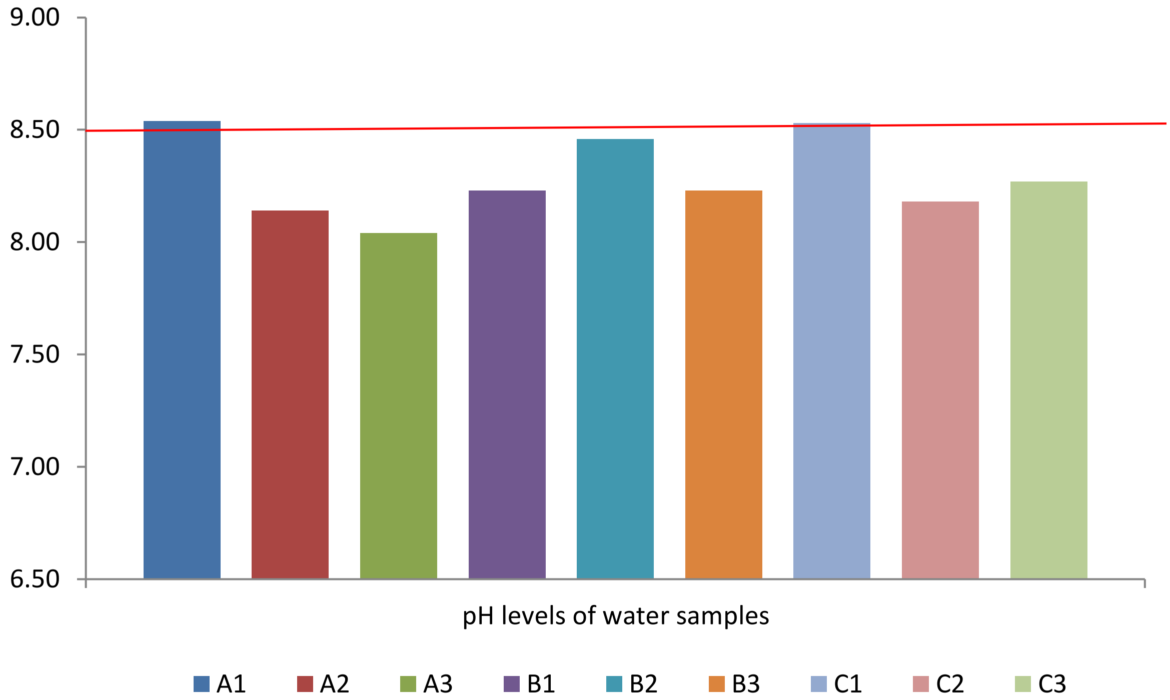

Figure 3. pH values of the water samples.

Table 3. Values of TDS of the samples (mg/L).

	UPSTREAM			MIDSTREAM			DOWNSTREAM		
Sample ID	AI	A2	A3	B1	B2	B3	C1	C2	C3
Reading (mg/L)	59.4	53.3	53.3	53.5	53.1	53.1	53.1	54.8	53.1

attributed to the agricultural runoffs generated on both shores finding its way to the dam carrying sediments, nutrients and organic matter.

If the catchment is altered by agricultural activities such as preparation of farmlands or other soil-disturbing use, it can accelerate erosion and runoff, thereby increasing TDS. Research has proven that during precipitation, 60-96% of the suspended solids are from surface sources rather than bank-side erosion and that sediments from agricultural areas are ten times greater than forested areas (Allan et al., 1997; Walling, 2005). None of the TDS values recorded exceeded the WHO recommended limit of 1000 mg/L .

Electrical conductivity

Electrical conductivity gives an account of all dissolved ions in a solution. A sudden increase or decrease in conductivity in a body of water can indicate pollution. The mean conductivity of all the analyzed water samples ranged from a low of 79.4 µS/cm to a high of 88.9 µS/cm (Table 4). Agricultural runoff will increase conductivity due to the additional chloride, phosphate and nitrate ions (EPA, 2012). The WHO maximum permissible level for electrical conductivity is 1000 µS/cm. For all the samples, EC reduced from sampling point A1 to sampling point C1; from area of low agricultural activities to area of high anthropogenic activities and intense agricultural activities. A similar trend was observed as one moved from A3 to C3 (area of lesser anthropogenic activities and intense agricultural activities). Conductivity is dependent on water temperature and TDS (Talley, 2000). There was a different situation from A2 to C2 where EC values decreased from A2 to B2 but increased at C2. In general, TDS is the sum of the cations and anions in water and because EC depends on the overall ionic concentration in water, it is often used as an index of the total dissolved solids (TDS) carried by a stream.

Ammonia

The mean value of ammonia for the eighteen analyzed

Table 4. Levels of electrical conductivity of the samples (µS/cm).

	Upstream			Midstream			Downstream		
Sample ID	AI	A2	A3	B1	B2	B3	C1	C2	C3
Reading (µS/cm)	88.9	79.8	79.7	80.1	79.5	79.5	79.4	81.7	79.5

Table 5. Ammonia concentration in the samples (mg/L).

	Upstream			Midstream			Downstream		
Sample ID	AI	A2	A3	B1	B2	B3	C1	C2	C3
Reading (mg/l)	0.875	0.846	0.898	1.046	2.373	1.070	0.865	0.979	0.927

Table 6. Nitrate concentration in the samples (mg/L).

	Upstream			Midstream			Downstream		
Sample ID	AI	A2	A3	B1	B2	B3	C1	C2	C3
Reading (mg/l)	1.135	1.485	1.609	1.451	0.955	1.428	1.225	1.103	1.00

samples ranged from 0.846 to 2.373 mg/L (Table 5).

Lower values (less than 1 mg/L) were recorded for samples collected a few meters away from the shores (A1to A3) and the embankment wall (C1 to C3). The opposite happened at B which represents midstream where the dam is much deeper. Unlike groundwater, surface water nutrients concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, (WHO, 2017). The sample B2 recorded the highest ammonia value in the midstream section. However, ammonia becomes more toxic with just a little increase in pH. All samples were alkaline in nature, meaning they have increased pH (7.19 to 8.76) and ammonia becomes more toxic as the pH increases. In aquatic ecosystems, ammonia exist in two forms, called total ammonia nitrogen. These two forms are represented chemically as NH_4^+ and NH_3. NH_4^+ is ionized ammonia as it has a positive electrical charge; while NH_3 is termed un-ionized ammonia as it has no charge. This difference is very important because NH_3 is more toxic to aquatic organism. The odour threshold concentration level of ammonia in water is approximately1.5 mg/L and a taste threshold of 35 mg/litre has been proposed for the ammonium cation (WHO, 2017). With regards to odour B2 exceeds the threshold but none of the samples exceeds the taste threshold.

Nitrate

The main source of nitrate is inorganic fertilizers. The mean values of nitrate for the analyzed samples ranged from 0.955 mg/L (B2) to 1.609 mg/L (A3) (Table 6). The acceptable level of nitrate in water recommended by the WHO is 10.0 mg/L. In surface water, nitrification and denitrification may occur, depending on the temperature and the pH. Nitrate values decreases as you move from A1 to A3 indicating concentration of nitrate in runoffs from farms in A3 is higher than in A1.

In the UK, around 60% of nitrates in water bodies are estimated to have farming origins (White and Hammond, 2009). Concentration levels of nitrate increase as you move downstream from A1 to B1where runoff is generated directly from farmlands in Gia, a very active farming community. Hence B1 recorded the highest concentration of nitrate at the midstream (Table 6). The uptake of nitrate by plants is accountable for most of the nitrate reduction in surface water and the concentration of nitrate may increase as the water moves towards the extremities of the dam (AWWARF, 1995). From the results, almost all the sample points closer the shores recorded quiet significant figures. They receive runoff first from farmlands because nitrogen levels increase with increased use of nitrogen fertilizers (Stalnacke et al., 2003). Samples collected at section A recorded quiet high levels because they are closer to the shores where runoff is high. When you move midstream B2 recorded the highest value of nitrate than B1 and B3, as sample point B1 is located right on the runoff generated from Gia and moves towards the direction of B2. In some occasions, an increase in rainfall is matched with an increase in total nitrogen concentrations. Under UK climatic conditions, peaks in nutrient flows and erosion events can be observed during winter and early spring when precipitation is high and there is little crop cover to

Table 7. Levels of phosphate in the samples (mg/L).

	Upstream			Midstream			Downstream		
Sample ID	A1	A2	A3	B1	B2	B3	C1	C2	C3
Reading (mg/l)	0.045	0.038	0.043	0.041	0.043	0.041	0.046	0.075	0.094

take up mobilized nutrients. This is particularly evident in the wet season. Reduction in precipitation is only partially linked with a reduction in total nitrogen concentrations. The samples recorded lower values as rainfall was not at its peak.

Phosphate

The value of phosphate levels for the analyzed samples ranged from 0.038 to 0.094 mg/L (Table 7). From Table 7, phosphate levels are higher at A1 and A3 compared to A2 while for midstream they are higher at the center (B2) compared to B1 and B3. Higher concentration levels were recorded downstream where water exits the reservoir through the spillway to the canals and eventually to the farm. Flow paths differ between nutrient species. Phosphates may enter aquatic ecosystems from a range of sources, however with regards to the analyzed samples runoff containing fertilizer and agrochemicals from farmlands in the catchment and also washing of clothes and auto-mobiles are major contributors to the existence of phosphate in the dam. For example, phosphorus transport occurs mainly adhered to soil particles as overland flow (Defra, 2004; Hart et al., 2004). Surface runoff carrying nutrients and sediments vary seasonally and peaks are closely linked to precipitation. Under UK climatic conditions, peaks in nutrient flows and erosion events can be observed during winter and early spring when precipitation is high and there is little vegetative cover to take up dissolved nutrients. A possible attribute for the low phosphate levels recorded in the samples is the fact that rainfall was not at its peak in the area during sample collection.

Conclusion

The effects of agricultural activities on the quality of surface water in the Tono Dam was assessed in this research. The survey results revealed that majority of the farmers have not received any formal education and cannot read safety guidelines on how to safely apply agrochemicals. Results from the administered questionnaires revealed that although majority of the farmers did not read application guidelines of the agrochemicals. Additionally, laboratory analysis of samples from upstream, midstream and downstream indicated parameters such as turbidity, TDS and nutrient levels have been impacted by these agricultural activities, thereby deteriorating the general quality of the water. In particular, upstream areas recorded very high levels of TDS and conductivity while nutrients were high in the downstream areas, although none of the areas exceeded the WHO permissible guideline values. In order to safeguard the quality of the dam, it is recommended that farming activities should not be carried out at the intake areas of the dam as this introduces a lot of sediment into the reservoir. Also, at areas where farming activities are permissible, such activities should be done a distance of at least 50 meters away from the banks. Finally, farmers within the catchment of the dam should have access to agricultural extension farmers who will provide them with knowledge on the proper application of agrochemicals.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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