Impacts of Agricultural Activities on Water Quality in the Dufuya Dambos, Lower Gweru, Zimbabwe

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Abstract: ***Recently, concern over agricultural diffuse pollution sources in integrated water quality management has been growing. High inorganic and organic fertilisers application rates may increase groundwater pollution and these effects were investigated in the Dufuya Wetland (19°17'S; 29°21'E) in Chief Sogwala area of Lower Gweru Communal Lands, approximately 42km west of the City of Gweru, Zimbabwe. Forty-two (42) water samples were collected for analysis of pH, conductivity, calcium, nitrates, and phosphates during the months of September, October, and November 2008. A questionnaire procedure was used for collection of manure application rate, wetland and crop management data in the studied area. The results demonstrated that cattle manure in the Dufuya wetland is applied at the rate of 30t/ha- 60t/ha per year. Groundwater and surface runoff water samples have pH, conductivity, calcium, phosphates and nitrates levels within the WHO permissible guideline of 6.5-8.5, 1500μScm^{-1}, 200mg/l, 0.09mg/l and 10mg/l respectively. The mean nitrate and phosphate concentrations in surface run-off water in the garden and the sponge are 0.00275mg/l, 0.0117mg/l and 0.00377mg/l, 0.00077mg/l respectively. Groundwater concentrations are 0.026mg/l, 0.0167mg/l and 0.0021mg/l, 0.00228mg/l for nitrates and phosphates respectively. There was no significant difference in the mean concentrations of nitrates and phosphates in water (ground/surface) in the sponge and the garden (P < 0.005). Fertiliser applications have no negative effects on dambo water quality.***

Keywords*:* Dambos, Agriculture, Water quality, Nitrates, Phosphates

1. Introduction

A small fraction (about 2.5%) of earth's water is fresh and suitable for human consumption [33]. The rest (more than 97%) is in oceans and seas. Of the less than 2.5% of fresh water approximately 13% is groundwater; an important source of drinking water for many people worldwide [3]. More than 50% of the world's population depends on groundwater for drinking water. For many rural and small communities, groundwater is the only source of drinking water [5].

However, in Zimbabwe, the recurrence of droughts have made people realise the need to intensify use of major groundwater supply sources, wetlands resources, in the dry areas of Zimbabwe, which cover the southern, central and western parts with natural Regions III, IV and V as a way of supplementing the unreliable rain fed cropping [6]. About 74% of the smallholder areas are located in these fragile agro-ecological environments [33]. [26] reported that "..... *rice has for a century formed the staple food for Mashona, the swampy areas in eastern Rhodesia being pitted with old rice fields which are now abandoned in favour of recently introduced maize crop....*".

However, sustainable agriculture has been one of the greatest challenges [9]. Sustainability according to [13] implies that agriculture not only secure a sustained food supply, but that its environmental, socio-economic and human impacts are recognised and accounted for within national development plans. Consequently, concerted agricultural research and extension efforts have focused on intensive utilisation of wetlands under cropping with a view to improving food output from them [19]. However, the leaking N and P on both surface and groundwater from intensive agriculture have raised concern over possible contamination of drinking water supplies [16] exposure to high levels of nitrate poses a potential risk to those with an undeveloped or impaired ability to enzymatically protect haemoglobin: infants and persons with specific gastro-intestinal disorders. [12] postulated that high nitrates levels in water and forage can be fatal to ruminant animals through the same mechanism [15]. There is also some evidence to suggest a relationship between cancer and nitrosamines, which may form in the human gut from nitrates [34].

The impacts of leaking N and P on both surface and groundwater are well documented. Groundwater nitrate levels measured in Alberta are higher in areas of high rates of N-fertilization [15]. Observed migration of soluble nitrogen through soil profiles is consistent with application rates [29]. A Manitoba study of nitrate in the top twelve feet of cropped fields reported nitrate concentrations greater than 150 Ibs/ac in the top four feet of 65-85% of vegetable-growing fields [28]. A study of 27 Alberta streams showed a direct correlation between water quality and levels of agriculture inputs in the catchment basins [23].

In light of these potential health risks and the fact that nitrate levels in groundwater and surface waters seem to be increasing globally [30], a study seeking to assess the effects of agricultural activities in the Dufuya wetland on water quality with particular emphasis on nitrates and phosphates was conducted.

2. Methodology

2.1 Description of the Study Site

The study was conducted on Dufuya (19°17'S; 29°21'E) wetlands in Chief Sogwala area of Lower Gweru Communal Lands, ca. 42 km west of Gweru, Zimbabwe. The area has an elevation of 1274 m above sea level, a watershed area of 724 ha, wetland area of 63.3 ha, and a cropped area of 28.2 garden units and a mean garden area of 0.127 ha [1]. The wetland drains into the Somkamba stream, a tributary of the Vungu River. Water drains into the dambo from a large spring (locally known as a sponge), which is covered by a dense growth of vegetation. An intermittent stream meanders southwards from the spring creating a perennially damp marshy strip that bisects the system with two similar sets of gardens flanking either side of the open marshy strip.

The soils are deep Kalahari sand showing weakly developed AC profiles with silt plus clay content of less than 15% in all horizons above 2 metres and no marked or sudden changes in clay content in any horizon within this depth and lying at a uniform slope of 4% [24]. The natural vegetation consists of *Phragmites australis, Thelypterris confluens and Typha Capensis.*

The area lies in Natural Region III receiving rainfall ranging from 650 to 800 mm per annum (average 752mm per annum) with a co-variation of 19%. The mean annual temperature is 21^{o}C with insignificant frost occurrence in the months of June and July [31]. The rainfall occurs during a single rainy season extending from November to April. Infrequent showers followed by high temperatures and hot dry desiccating south-easterly winds, which significantly reduce rainfall effectiveness, characterise the rainy seasons. This makes rain-fed cropping highly unreliable. As a result, smallholder farmers in the Dufuya area have resorted to intensive utilisation of wetlands where availability of water is assured.

The wetland gardens forms long narrow fields (typically 300 m X 40 m) and are usually placed immediately adjacent to another often sharing common fences. Water is lifted with buckets from shallow hand dug wells and used to irritate vegetable crops using the flood system on raised beds. Leafy vegetables (especially rape and cabbage), tomato, green beans and onions are a very important component of the farming system [1]. Dufuya area is a major source of fresh vegetables for the Gweru urban market.

2.2 Experiment Design

The design of the experiment was a simple randomised design in which there were two treatments. Treatment 1 was water samples collected from wells and points outside the garden and Treatment 2, water samples collected from the garden. For surface run off analysis, two sample collection points were identified outside the garden and four in the garden. Eight wells were sunk, two outside the garden and six in the garden for groundwater samples collection.

2.3 Data Collection and Processing

Two types of manure that is used by the farmers in their crop production were analysed to establish the quality. These were; communal manure from Chief Sogwala and commercial farm manure from Vungu Small Scale Commercial Area. The manures were air dried, passed through a 2mm sieve, analysed for organic carbon [21], total N using the Kjeidahl procedure [27] and [4]. Soil and ash content was determined by ashing manure in a Muffle Furnace (450^{o}C) frorn 16 hours. The ash was dissolve din concentrated hydrochloric acid and separated from mineral by filtering. The soil was oven dried and weighed. The aerobically composted manure was analysed to determine total phosphorus and total nitrogen.

Groundwater samples were collected from (8) wells and surface run-off water samples were collected from six (6) points and in-situ measurements and laboratory analysis were carried out on the samples. Totally twenty-four (24) groundwater samples and eighteen (18) surface run-off water samples were collected during the months of September, October and November of 2007. Each well and point was sampled three times and pH, conductivity, calcium, nitrates and phosphates were analysed in these waters.

The procedures recommended by [2] were followed during the field and laboratory work. Water samples were collected at 20cm depth below the surface water level in the 8 wells (groundwater samples) and 6 selected point (surface run-off samples) during the sampling period. Each sample was poured into 2 litre polythene bottles after rinsing twice with the sample water covered with lids and transported in icebox for chemical analysis at the Midlands State University's Chemistry Laboratory. As soon as the samples reached the laboratory, water was filtered and the filtrate was used for analysis. In case of the water samples needing to be stored for a week period, a few drops of chloroform were added to prevent any algal growth and the stored in the refrigerator.

Water pH was determined using a Philips digital pH meter. Conductivity was measured by a conductivity metre (Hanna Instrument code HI-8633). Nitrate and phosphates content were analysed using ultraviolet spectrophotometric screening method at wavelength of 640nm and 830nm respectively as these samples had low organic matter content.

2.4 Data Analysis

At test for the difference in pH, conductivity, nitrate, phosphates and calcium in surface run-off water and groundwater was computered using SPSS version 7.5 for Windows. PROC GLM Procedures was used to calculate the mean levels and standard error nitrates, phosphates, pH, calcium and conductivity in surface run-off water and groundwater.

3. Results

3.1 Wetland and Crop Management

A 100% irrigated crop rotation system that includes tomato, maize (September to February), rape and wheat (March to August) on raised beds is the most common farming practice in the Dufuya Wetland. Raised beds allow for the free movement and excess water is carried away in furrows that separate the beds. No cultivation is allowed within 3 days of broadcasting. The community has employed the following agricultural best management practices as a way of curbing wetland degradation; no burning of grassed waterways, vegetated buffers adjacent ton water bodies and vegetated field-filter strips. Fields are bordered with small shrubs and are occasionally dotted with trees. Some of the fields remain uncultivated and covered with indigenous vegetation. There are contour ridges between the fields and no evidence of significant runoff problems.

3.2 Quality of Fertilizer Used

The survey carried revealed that the smallholder farmer in the Dufuya area usually rely on cattle manures and mineral fertilisers applied in combination or separately to increase crop productivity from the wetland.97% of the soil fertility enhancement is by cattle manure and 3% by mineral fertiliser. Two types of cattle manures from the local community and adjacent commercial farms. Cattle manure analysis indicated that for a given amount applied into the soil, manure from the commercial area and manure from communal area constitute 22.82% and 9.13% of organic carbon respectively. Commercial manures have a higher percentage of nitrogen (1.36%) as compared to communal manures (0.51%). Percentage level of phosphorous for the two manures was insignificant. Table 1 below summarises the quality of the two types of manure in terms of organic carbon, total nitrogen, C: N ratio, phosphorous, soil and ash content.

Table 1: Quality of manures from Communal area (Chief Sogwala) and Commercial area (Vungu Small Scale Farming Area)

	Communal Manure (%)	*Commercial Manure (%)*
Organic Carbon	9.13	22.82
Total Nitrogen	0.51	1.36
C: N Ratio	17.9	16.8
Phosphorous	8.4154×10^{-2}	5.0288×10^{-2}
Soil and ash	90.87	77.18

3.3 Manure Application Rates

Manure is used in basal application at planting. The wetland is cropped twice each year, winter season (March to August) and summer season (September to February). The manures are applied at a rate of 15-30t/ha per planting, (30-60t/ha per year). At this rate, the cultivated 28.2ha receives between 846t and 1692t of manure each year. The average amount of organic carbon, total nitrogen, phosphorous, soil and ash applied to the wetland can be summarised as indicated in Table 2 below.

Table 2: Average amount of organic carbon, total nitrogen, phosphorous (P), soil and ash applied to the Dufuya wetland each year.

	Communal Manure	*Commercial Manure*
Organic Carbon	65.554 - 131.31	28.959-57.91
Total Nitrogen	3.667 – 7.3348	1.726 – 3.452
Phosphorous	0.605 – 1.210	0.0638 – 0.1276
Soil and ash	653.45 – 1306.9	97.94 – 195.88

The total nitrogen and phosphorous applied to the wetland per year ranges between 5.393 - 10 786 and 0.669 – 1.338 respectively.

3.4 Water Quality

In the study area, the pH of the water samples ranged from 6.51-8.41. There was a significant difference in the pH levels in groundwater and surface runoff water ($P<0.005$). The pH for surface water in the sponge and the garden was not significantly different ($P>0.05$). Groundwater in the sponge and surface water in the garden had no-significant difference in the pH level ($P>0.05$) (Table 3).

Conductivity of the water in the Dufuya wetland ranges from 85.9 μScm^{-1} in surface water in the sponge to 2019.4 μScm^{-1} in ground water in the garden. Other sampled water sources showed significant differences except for groundwater and surface water in the sponge ($P>0.05$).

Mean nitrate concentration levels were far below the WHO permissible limits of 10mg/l and were not significantly different in the groundwater and surface water in the study area ($P<0.05$). Generally, higher nitrates levels were recorded in the garden than the sponge (0.018mg/l and 0.023mg/l against 0.12mg/l and 0.017mg/l). However, the nitrate concentration levels range from 0.01mg/l in surface water in the sponge to 0.047mg/l in groundwater in the garden.

Values for phosphates were very low ranging from 0mg/l (both groundwater and surface water) to 0.0097mg/l in groundwater in the garden. Phosphates concentration levels in surface water in the sponge and the garden had a significant difference ($P>0.05$) while there was no significant differences in the groundwater ($P<0.0005$). Table 3 summarizes the findings.

A significant difference in the calcium concentration levels was recorded in surface and ground water in the sponge and the garden ($P>0.05$) values.

Table 3: Mean and standard (error values) of pH, conductivity, nitrates phosphates and calcium of surface run-off water and groundwater in the sponge and garden

	Surface Water		*Groundwater*	
	Sponge	Garden	Sponge	Garden
pH	6.99^{a}	7.13^{ab}	7.30^{b}	7.75^{c}
	-0.089	-0.104	-0.0827	-0.0711
Conductivity	106.3^{a}	264.2^{b}	105.7^{a}	1008.3^{c}
	-6.98	-30.06	-8.63	-152.72
Nitrates (Mg/l)	0.012^{a}	0.018^{a}	0.017^{a}	0.023^{a}
	-0.0007	-0.0031	-0.0067	-0.0019
Phosphates (Mg/l)	7.76E-04^{a}	4.04E-3^{b}	2.28E-03^{c}	1.95E-03^{c}
	-0.0003	-0.001	-0.0014	-0.0007
Calcium (Mg/l)	1.598^{a}	2.891^{b}	1.931^{c}	6.105^{a}
	-0.043	-0.318	-0.432	-1.193

NB* Values with the same superscript in a row are not significantly different
*Standard errors

4. Discussion and Recommendations

Wetlands are natural filter that improve the quality of the water that flows through them [14]. The presence of a dense growth of vegetation and high plant productivity, together with considerable contact between water and sediments through sheet-flow promotes anaerobic and aerobic processes that can remove pollutants and enable organic matter to accumulate in the soil [14]; [10] and [20]. Nitrogen is removed by vascular plants and microorganisms, denitrification and ammonia volatization ([8] and [11]. Phosphorous is removed from wetlands mainly through adsorption onto mineral sediments [25] and [7] but is also removed through uptake by plants and by precipitation as insoluble phosphates of iron, aluminium or calcium [[22].

These findings reported by the above-mentioned authors were reflected by the insignificant difference in the nitrates and phosphates concentration in the sponge and the garden in both surface water and groundwater in the Dufuya wetland. Scientists have estimated that wetlands remove between 70% and 90% of entering nitrogen [15]. The estimated mean retention of phosphates by wetland is 45% [17]. The establishment of vegetated buffer zones of 30m from the streams and vegetated field-edge strips allowed for the flourishing of vegetation in the studied area which in turn functions in sediment trapping and pollutant removal. In a similar study carried out by [18], it was noted that much wider buffers were needed to remove significant amounts of clay-sized particles. [17] observed phosphorous deposition in the riparian wetlands is cumulative [7]. The scenario might be similar to the one at the studied area where measurements in the wetland might not reflect the possibilities of pollution whilst the opposite might be true downstream where fine clay particles are deposited.

Low C:N ratio mixtures in manure can generate nitrate levels above the groundwater standard [32]. A majority of investigators believe that for C: N ratios above 30 there will be little loss of nitrogen. In the Dufuya wetland, the quality of measures used have C: N ratios below 30, thus indicating that there is loss of nitrogen from the manure into the groundwater which is subsequently removed by the wetland vegetation which is on support of the findings reported by [14].

The high conductivity in the Dufuya (105.7- 1008.3 μScm^{-1}) is explained by nutrient loading of over 1000 tonnes of soil and ash applied yearly. The salts in the ashes are not required by plants in large quantities and as a result they accumulate in water bodies hence an increase in pH and conductivity. Leaching of calcium ions and other cations tend to increase the conductivity of water. A long term monitoring of the physical and chemical variables is needed so as to assess the extent of the impact of agriculture.

References

[1] Adreini, M.S., Steenhuis, T.S. and Makombe, G. (1995). Water Management and Dambo irrigation systems in Zimbabwe. In: Owen, R., Verbbek K., Jackson, J. and Steenhuis, T. (eds) Dambos Farming in Zimbabwe: Water Cropping and Soil Potentials for Smallholder Farming in the Wetlands, pp. 117-126. Conference Proceedings, CIIFAD, Cornell University, New York.

[2] APHA, AWWA AND WPCF. (1998). Standard methods for examination of water and waste water. 20 (edition). N.W. Washington D.C

[3] Bachmat, J.W.S. (1994). Groundwater contamination and Control, Marcel Deckker, Inc, New York.

[4] Bremner, J.M and Mulvaney, C.S. (1982). In: A.L. Page (ed.) Methods of Soil Analysis pp 595-622. Agronomy Series No. (Part @, American Society of Agronomy, Madison, M.I).

[5] Canter, L.W. (1987). Groundwater Quality Protection. Lewis Publications, Inc, Chelsea, MI.

[6] Chenje, M., Sola, L AND Paleczny, D. (eds). (1998). The State of Zimbabwe's Environment 1998. Government of the Republic if Zimbabwe, Ministry of Mines, Environment and tourism, Harare, Zimbabwe.

[7] Cooper, J.R. and Gilliam, J.W. (1987). Phosphorus Redistribution fro cultivated fields into riparian areas. Soil Science Society American Journal 51: 1600-1604.

[8] DeLaune, R.D., Smith, C.J. and Sarafyal, M.N. (1986). Nitrogen cycling in a freshwater marsh of Panicum Hemitomon on the deltaic plain of the Mississippi River. Journal of ecology 74: 249-256.

[9] Edwin, D. O. (1996) Control of water pollution from agriculture. FAO Irrigation and drainage paper SJ. GEMS/water collaborating Centre, Burlugton, Canada.

[10] Hummer, D.A. (1992). Creating Freshwater Wetlands. Lewis Publisher. Boca Raton.

[11] Howard-Williams, C. (2004) Cycling and retention of nitrogen and phosphorus in wetlands: a theoretical and applied perspective. Freshwater Biology 15:391-431.

[12] Hudak, P.F. (1999) Regional trends in nitrate content of Texas groundwater. Journal of hydrology, Amsterdam, 228: 37-47.

[13] Jolankai, G. (1986). Non-point source pollution modeling results for an agricultural watershed in Hungary, In: Land Use Impacts on Aquatic Ecosystems. J. Lauga, Decamps and M.M. Holland. Proceedings of the Toulouse Workshop, MAB-UNESCO &VPIREN-CNRS, France, pp 165-189.

[14] Kadlec, R.H. and Kadlec J.A. (2005). Wetlands and water quality. In: Greeson, P.E., Clark, J.R and Clark, (eds) Wetland functions and values: The state of our understanding 436-456. American Water Resources Association, Minneapolis.

[15] Keeney, D.R. (1982). Nitrogen management for maximum efficiency and minimum pollution. Chapter 16, Agronomy Monograph 22, F.J Stevenson, Ed., American Society of Agronomy, Madison.

[16] Keeney, D.R. and R.F. Follet. (1991). Managing nitrogen for groundwater quality and farm profitability. Soil Science Society of America, Inc. Madison, WI.

[17] Logan, T.J., (1990). Agricultural best management practices and groundwater quality. Journal of Soil and Water Conservation 45: 201-206.

[18] Logan, T.J., (1993).Agricultural best management practices and groundwater quality: Current Issues. Agriculture Ecosystem Environment 46:223-231.

[19] Mharapara, I.M. (1995). A fundamental approach to dambo utilization. In: R. Owen, K. Verbeek, J. Jackson and T. Steenhuis (Edns). Dambo farming Zimbabwe. pp 1-8, University of Zimbabwe Publications, Harare, Zimbabwe.

[20] Mitsch, W.J. and Gosslink J.G. (2000) Wetlands. 2nd edn. Van Nostrand Reinhold, New York.

[21] Nelson, D.W. and Sommers, E.M. (1998). Total C, organic C and organic matter. In: A.L. Page (ed). Methods of soil analysis, pp 59-579. Agronomy series No. 9, Part 2.

[22] Nicholus, D.S. (1997).Capacity of natural wetlands to remove nutrients from waste water. Journal of Water Pollution Control. 55: 495-505.

[23] Postma, D., C Boesen, H. Kristiansen and F. Larsen. (1991). Nitrate reduction in an unconfined sandy aquifer: Water chemistry, reduction processes, and geochemical modeling. Water Resources Research. 27: 2027-2045.
[24] Provisional Soil Map of Zimbabwe, Rhodesia, 1979.1:1 000 000 Map Second edition.
[25] Richardson, C.J. (1985). Mechanisms controlling phosphorus retention capacity in freshwater wetlands. Science 228: 1424-1427.
[26] Sawer, E.R. (1909). Cedara Memoirs in South African Agriculture, pp 190-193.
[27] Steveson, F.J. (ed). (1982). Nitrogen in Agricultural Soils, Agronomy Series No. 22 (Madison, Wis. American Society in Agronomy, Crop Science Society of America, Soil Science Society of America).
[28] Trudell, M.R., R.W. Gillham and J.A. Cherry, (1986). An in-situ study of the occurrence and rate of denitrification in a shallow unconfined sand aquifer. J. Hydro., Amsterdam, 83:251-268.
[29] U.S. EPA, (1992). National water quality inventory-1990 report to congress, EPA 502/9-92/006, Office of Water, Washington D.C.
[30] U.S. EPA, (1994). National water quality inventory-1992 report to congress, EPA -841-R-94-001. Office of Water, Washington D.C.
[31] Vincent and Thomas, (1960). An Agricultural Survey of Southern Rhodesia, Part 1 Agro-Ecological Survey, Government Printers, Salisbury.
[32] White, R.E. (1999). Principles and practice of soil science. The soils as a natural resource. Third Edition. Blackwell Science Ltd. Oxford.
[33] Whitlow, J.R. (1988). Degradation of wetlands. Influence of human factors on erosion. Inland degradation in Zimbabwe. Report prepared for the Department of Natural Resources, Harare, Zimbabwe.
[34] WHO (World Health Organization), (1995). Guidelines for drinking water quality, 2nd .Ed.

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