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The Influence of Point Source and Non-Point Source of Pollution in the Runde River, Zimbabwe

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Abstract

Oceans are sinks of freshwater inflows and watershed runoffs. The river water qualities determine ocean waters at certain periods and for this reason are closely monitored. The Runde River is a large freshwater system that discharges into the Indian Ocean. This study aims to analyze the influence of agricultural runoff on river water quality from the dry season August 2004 and end of wet season April 2005. There was no significant difference in dissolved oxygen concentrations between the control and test sites and it is difficult to infer any evidence of pollution from the data. The same pattern applies to the other variables that include total nitrogen, nitrate-nitrogen, ammonical nitrogen and total phosphates. There is no clear pattern in the average values of the water quality variables between the control sites and test sites. This research showed that the Runde River is not significantly polluted, and the experimental hypothesis that agricultural developments in the surrounding area are altering the Runde River is false. Significant differences in nutrient accumulation in stream bottom sediments were recorded in sodium, potassium and total phosphates in the water column but this is in flowing water. Significant differences in nutrient accumulation in stream bottom sediments were recorded in sodium, potassium and total phosphates in the water column but this is in flowing water. Significant differences in nutrient accumulation in stream bottom sediments were recorded in sodium, potassium and total phosphates in the water column but this is in flowing water.

Introduction

De Laessoe [1,2] on foot exploration of the Runde River reported on the wilderness nature of the catchment, the variable aquatic habitats, the wide spectrum of aquatic fauna and the water quality. In more recent times the Runde River catchment in Zimbabwe (Figure 1) has come under intense agricultural development with uncertain consequences' on the biotic integrity and water quality of the drainage systems. The influence of agricultural activities on the freshwater river system is of concern to the availability of drinking water [3]. The Runde River serves as important sources of water for humans, animals and crops.

Figure 1: Map showing the situation of the study area in South east Zimbabwe.

The agricultural estates (Figure 2) in the Runde catchment generate sewage that is provisionally treated and then directed to the main watercourses. Water flowing flowing from sewage works or diffuse areas can almost always become biologically more pure, if time is allowed for microbial action to go to completion. This requires a large volume of water so that the concentration of pollutants remains low, a relatively neutral pH, low levels of nutrients, and abundance of dissolved oxygen. In practice, the minimal diluent flow is five times the flow of effluent, if regeneration within a reasonable distance downstream in drainage channels and streams is to be achieved [4]. In practice dilution of flowing water may be difficult to achieve given high ambient temperatures and evaporation rates. Of all the requirements for aquatic organisms, the need for oxygen is the greatest. The best modern sewage works may reduce the nitrogen output of their effluent by as much as 40% by using denitrifying bacteria to convert nitrates to nitrogen [4]. It becomes inevitable for the mineral content in the downstream sections to be higher in concentrations than in the upstream sections. Sodium, potassium, phosphate and inorganic nitrogen compounds are all nutrients, which may cause eutrophication in rivers.

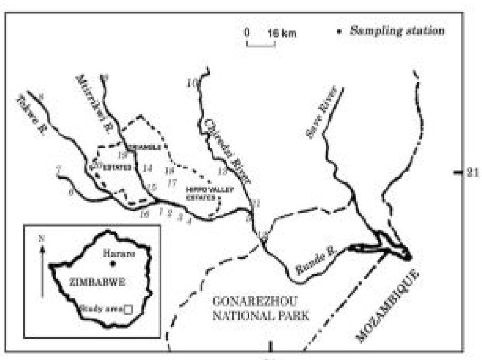

Figure 2: Simplified map of the southeast lowveld river system showing location of the different sampling stations along the studied watercourses.

Even the inflow of completely treated sewage into river water places a biological problem in the environment. If the river becomes anaerobic anywhere in its subsequent course, nitrate will be partially reduced to nitrite in the stream. Nitrite itself is potentially dangerous to babies because their intestinal flora can reduce it to nitrite. High concentrations are more likely to occur in the summer months, when diluents inflow is low [5]. The nitrate often comes from excessive use of fertilizer. Nutrients in particular nitrates and phosphates cause eutrophication problems associated with algal blooms. The Runde River and its tributaries are sinks of human generated catchment activities. Consequently, benthic macro invertebrates may be to varying degrees under stress. It is critical to understand whether nutrients among stream sites become more similar or different after exposure to a common stressor. The nutrients in the water column and stream bottom sediments of the intensive agricultural zone and reference sites in the peasant agricultural zone were investigated over time. This, in turn, should help predict how the ecosystem responds when 'stressed' by human activities, such as by runoff from the land.

Organic material enters waterways in many different forms as sewage, as leaves and grass clippings, or as runoff from livestock feedlots and pastures. When organic matter is added to a stream, a process of decay by bacterial oxidation begins. Natural bacteria and protozoan in water break down organic material begin to use up the oxygen dissolved in the water [6,7]. The decomposing animals then occur in very large numbers probably due to lack of competition or predation and abundant food supply. As a result, many types of fish and bottom-dwelling animals fail to survive when levels of dissolved oxygen drop below two to five parts per million. When this occurs, it kills aquatic organisms in large numbers and leads to disruptions in the food chain. Typically, organic pollution leads to a decrease in species, but an increase in individuals, unless conditions become so bad that no animals can survive.

The monitoring of human impacts on aquatic ecosystems is important to secure species diversity in the long-term [8,9]. Within the southeast lowveld, the major threat to the quality of water in the Runde River is as a result of point and nonpoint sources of agricultural activity. Sewage treatment plants may increase nutrient levels in the water, such as nitrogen nitrates, phosphorous, seriously affecting distribution of benthic macro invertebrates. A study of the physico-chemical aspects of the Runde River followed observations that the river is surrounded by intensive agricultural activities and anthropogenic activities which may be radically altering its physico-chemical composition. The hypothesis that agricultural development degrades water quality in the Runde River by increasing levels of runoff and treated sewage was investigated. The physico-chemical compositions of the Runde river water column and sediment bottoms were investigated.

Study Area

NOAA Earth Observation Satellite gives the location or station ID OF Chiredzi Latitude 20°00'S and Longitude 32°00'E, approximately 400 km south east of Harare (Figure1). Altitude is about 500 m a.s.l. in the southern highveld of Zimbabwe and includes the area drained by the Chiredzi, Mtirikwi, Tokwe and Runde Rivers (Figure 2) about 350 km south east of Harare. The three tributaries, the Chiredzi, Mtirikwi and Tokwe Rivers pass through low input peasant agricultural areas before entering the Runde River in the study area (Figures 1 and 2). Annual runoff from the Runde/Save hydrological zone is estimated at 5900 x 10^6 m^3 per year [10] making this hydrological zone the second most important in terms of runoff yield in Zimbabwe. Not only does the annual runoff vary with mean annual rainfall, but it also varies from year to year in a particular year.

The Runde River captures agricultural runoff from the intensive agricultural areas and is thought to be influenced by fertilizers and sewage. This study area was selected because it covers a wide range of typical Zimbabwean land uses, including sugarcane production at Triangle Sugar Estates and Hippo Valley Estates, and sugarcane processing mills at Hippo Valley and Triangle (Figure 2). The flow regime is characteristic of semiarid watercourses; extremes of discharge occur with low winter base flows of 1 or 2 cumecs and occasional high summer flood flows exceeding 100 cumecs. Climatic variability has been identified for the lowveld [11]. Dube [11] and Dube and Jury [12] have reported on the impacts of drought, drought forming processes and atmospheric circulation systems that affect the southeastern African region precipitation events.

The study area lies below 600 m contour and is hot and semi-arid. The climate of the lowveld is hot and wet from mid-November to April, cool and dry from May to August, and hot and dry from September to mid November. The temperatures range from 8.1^{o}C in July to 50^{o}C in January, with a mean of 24^{o}C to 36^{o}C. A significant feature of the rainfall is its unreliability, both in terms of quantity and duration. The variation from year to year is so great that the annual rainfall can range from 20% to 200% of normal. The rainfall varies considerably from a low of 108.0 mm in 1972 to a high of 1114.6 mm in 2000 [13]. The water quality assessments were conducted 2004 and 2005 dry seasons, when the perennial streams consisted of pools a few metres wide and up to 2 m deep connected by shallower stretches of flowing water.

The Runde watershed is situated within an area of intensive commercial farming area characterized by the Hippo Valley and Triangle Sugar Estates. Site 4 (Figure 2) is situated on a discharge point. Site 2 receives domestic and agricultural effluent discharged into the lower section of the Mtirkwi River. Site 5 receives agricultural runoff from the small-scale intensive farms in the proximity of lower Chiredzi River. Other sampling sites along the Runde River receive inflow from surrounding areas. All sampling stations are ecologically similar with respect to bottom substrate i.e. sand, gravel, rock, or mud, depth, stream width and banks.

Methods

Stratified random sampling in which the rivers were subdivided according to land use zones was undertaken. Sampling positions were randomly selected within stratified zones thus ensuring that chances of missing any general biotic associations are extremely small. Sample stations were to be readily accessible. The sampling stations represent a wide range of water quality conditions in the study area (Figure 2). Site 4 is a discharge point of pre-treated sewage. Site 17 is characterized by both pre-treated sewage and runoff from the fertilized fields. Effluent from agricultural processing factories was investigated at sites 12 and 16. Field runoff was investigated at site 14. Sample sites 6, 7, 8, 9 and 10 were selected on the reference streams and are situated in peasant agricultural areas. Samples taken from upstream of pollution of Chiredzi, Mtirikwi and Tokwe establish expected biological conditions in the absence of the persistent point nutrient discharges. Benthic samples were taken in the dry season August 2004 and end of wet season April 2005 at Hippo Valley and Triangle sugar estates, using a 0.1m^2 Van-Veen grab. Upon retrieval all accumulated material from the samples were collected and preserved. The collected organisms were identified at the family level and genus. List of families collected from the rivers was compiled.

The temperature of the water and the concentration of dissolved oxygen were measured with YSI dissolved oxygen meter. Water was collected in thoroughly rinsed bottle containers and immediately stored in a freezer for later analysis. Measurements of water temperature, pH, dissolved oxygen, light penetration, and conductivity were undertaken in August during the dry season and April during the end of the wet season. Conductivity, pH, oxygen and temperature were measured with portable measuring devices (WTW). Light penetration was measured using a Secchi disc. Other data collected include substrate composition (such as sand, gravel, stones, etc) and description of surrounding area (amount of tree cover and land use, etc). In the laboratory, the samples were filtered through Whatman GF/C fibre glass filters. The concentrations of total phosphorous were then determined by the reactive molybdate method, ammonia by the indophenol method, and nitrate and total nitrogen by the sulphanilamide method, using a cadmium reduction column and a Hitachi 100-40 spectrophotometer [14]. The concentrations of inorganic cations (lead, magnesium, cadmium, copper, zinc and calcium) were determined by atomic absorption spectrophotometry. The accuracy of atomic absorption analysis to problems of inorganic pollution has been a matter of debate with recorded deviations of from correct analysis of 1-2 per cent [15] Potassium was determined by flame photometry. Physical analyses of water were carried out in the field. Water and sediment were analyzed for physical and chemical water parameters.

The saturation concentration (C_s) of dissolved oxygen at the temperature at which the sample was taken may be found from Table [16] by interpolation. Then if the actual concentration of oxygen in the sample is found by analysis to be C, the percentage saturation is given by 100 x C/C_s. Because the value of Cs varies with pressure, the value of C_s was corrected for altitude by division by the appropriate correction factor extracted from Mackereth et al. [16].

The sampling stations were put into two groups. The first includes the five that were located upstream of the effluent sources and are meant to be control stations indicating the unpolluted state of the rivers. The second includes the remaining five that are located downstream of the effluent sources and are presumably meant to indicate the effect of agriculture on the Runde River. The data are organized into groups by putting the ten stations into two groups so that this can be interpreted more accurately. The first includes the five that were located upstream of the effluent sources and are meant to be control stations indicating the unpolluted state of the rivers. The second includes the remaining five that are located downstream of the effluent sources and are presumably meant to indicate the effect of agriculture on the Runde River. Sediment samples were limited to nine sites due to instructions received from sugarcane policing authorities to halt dredging for minerals (Gold and Diamonds).

A T-test was used to test the hypothesis that the means of nutrient concentrations between the Runde persistent point nutrient discharge and the furthest downstream Runde sampling station are significantly different. A T-test was also used to test the means of the nutrient concentrations between the upstream and downstream sites. The assumption in the T-test is that any difference in response is due to the treatment or lack of treatment and not to other factors. The Pearson correlation coefficient analysis was carried out using SPSS version 10 software. Relationships among water quality variables were computed across locations as a combined analysis.

Multivariate Statistics

Understanding how river water responds to combinations and gradients of physical disturbance and nutrient inputs is important for the practical management of stream ecosystems, and to add to our knowledge of stream ecology. Multiple Correspondence Analysis (MCA) was used to examine the direct and indirect effects of a gradient in nutrient concentration and hydrologic disturbance on benthic community structure at 20 sites in the study area. The MCA models produced perceptual maps that facilitated pattern recognition and diagnostic characteristics. Model results should indicate the relationship between nutrient concentration, physico-chemical characteristics, and benthic fauna. The results should imply the direction of the response of stream benthic communities to nutrient stimulation.

The particular problem in the case of water quality monitoring is the complexity associated with analyzing the large number of measured variables [17]. The data set on water quality contain rich information about the behavior of the water resources. The classification, modeling and interpretation of monitoring data are the most important steps in the assessment of water quality. Multivariate statistical methods including factor analysis have been used successfully in hydrochemistry for many years. Multivariate statistical approaches allow deriving hidden information from the data set about possible influences of the environment on water quality [18]. Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable [19]. A factor is a qualitative dimension, a coordinate axis. Both structure and pattern are needed for a complete solution. The original variables are typically standardized so that the basic input to a common factor analysis is the correlation matrix. There are three stages in factor analysis [19]:

- For all the variables a correlation matrix is generated
- Factors are extracted from the correlation matrix based on the correlation coefficients of the variables
- To maximize the relationship between some of the factors and variables, the factors are rotated.

Common factor analytic model expresses each observable variable in terms of unobservable common factors and a unique factor, commonly expressed as:

$$X1={}_{v1\,(1})CF_{(1)}+V_{1(2)}CF_{(2)}+\text{-----}+{}_{v1(m)}CF_{(m)}+e1$$

$$X2={}_{v2(1)}CF_{(1)}+V_{2(2)}CF_{(2)}+\text{----}+{}_{v2(m)}CF_{(m)}+e2$$

$$Xp={}_{vp(1)}CF_{(1)}+V_{2(2)}CF_{(2)}+\text{-----}{}_{vp(m)}CF_{(m)}+ep$$

Variables with higher loadings are to be considered as having a greater influence. With sample size less than 100 the smallest loading would have to be greater than 0.30 in order to be considered significant. Eigenvalues generated in Factor Analysis correspond to an eigen factor which identifies the groups of variables that are highly correlated among them. Lower eigen values may contribute little to the explanatory ability of the data. Only the first few factors are needed to account for much of the parameter variability. The limitation in Factor Analysis is that factor scores cannot be calculated directly but instead must be estimated [19].

SPSS Categories' ability to perform correspondence and multiple correspondence analyses helps numerically evaluate similarities between two or more nominal variables in the data. With its principal components analysis procedure, data can be summarized according to important components. Variables of different measurement levels can be analyzed using nonlinear canonical correlation analysis. Multiple correspondences allow more than two variables to be used in analysis. With this procedure, all the variables are analyzed at the nominal level (Unordered Categories).

Descriptive Statistics, Multiple Correspondence Analysis (MCA), and Two step cluster analysis were used to analyze the data. The MCA was used as it organizes variables into a table (may also be described as a weighted principle component analysis). The table organizes similarities between individuals and creates links between variables, into geometrical distances that are displayed in a graphic format. A two-step cluster analysis categorizes individuals into groups according to the most salient characteristics. As a result homogenous categories of ordination were identified. The study evaluated the possibility that a smaller group of water quality parameters/locations might provide sufficient information for water quality assessment. Factor Analysis was applied to a surface water quality data set collected from the Runde River and feeder streams using 'the Statistical Package for the Social Sciences Software SPSS 15.0 for Windows'.

The following references were used for the taxonomical determination of species: Parish [20], Pennak [21], Thirion et al., [22], Needham [23] and Appleton [24]. Factor Analysis was applied to a surface water quality data set collected from the Runde River and feeder tributaries using 'the Statistical Package for the Social Sciences Software SPSS 15.0 for Windows.

Results

(Tables1-2) show water quality values collected from sample sites chosen in the study area. The water quality values indicated great variability at all sampling sites. The water quality values (temperature, Ph, DO, electrical conductivity, TDS, Secchi) changed with the seasons (Tables 1-2) at the control and test sites. Mean water temperature values ranged 22.5°C to 28.7°C at the control and 26.2°C to 28.3°C at the test sites in the hot wet season. A mean of 5.4 mg/l was recorded at the test sites with ranges 4.6 mg/l to 6.3 mg/l, respectively. Electrical conductivity ranged 106 uScm-1 to 293.3 uScm-1 at the control sites and 98.6 uScm-1 to 241 uScm-1 at the control sites and 98.6 uScm-1 at the test sites. Secchi light penetration measured an average of 390.0 cm on the control sites and 315.9 at the test sites (Table 1).

Mean water temperature was 23.4°C at the control site and 24.2°C at the test sites sites in the cool dry season. An average Ph 6.4 was recorded on control sites and 7.2 on test sites. A mean DO ranged from 0.9 mg/l to 7.8 mg/l on control sites and 1.3 mg/l to 5.4 mg/l on test sites in the cool dry season (Table 2). Secchi light penetration ranged from 27.5 cm to 81.3 cm on control sites and 14.1 cm to 71 cm on test sites. A mean of 40.8 cm and 47.3 cm Secchi light penetration was measured on the control and test sites respectively.

Dissolved oxygen concentration ranged from 0.9 mg/l to 7.7 mg/l, the lowest being measured in May at control site 7 (Table 1). (Figure 3) shows that average dissolved oxygen was slightly more than 4 mg/l whereas it ranged from 1.3 mg/l to 6.6 mg/l. Average dissolved oxygen greatly varied among the control and test sites (Figure 4) in all the 20 study sites. Average dissolved oxygen is not significantly different (t test, $p>0.05$) between the control sites and test sites although the control sites have slightly greater levels of dissolved oxygen (Figure 3). There is no clear pattern in the average values of the water quality in sites above the effluent outfall and below the effluent outfall. These data show that there was no significant difference in dissolved oxygen concentrations above and below the effluent outfall in August, April and May, and it is difficult to infer any evidence of pollution from these data. Dissolved oxygen is a key indicator of organic enrichment.

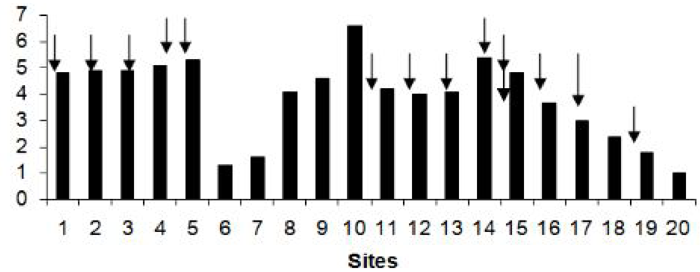

Figure 3: The variation of the concentration of dissolved oxygen in river water among the 20 different sampling sites. The arrows indicate stations located below the effluent outfall points, i.e. test sites.

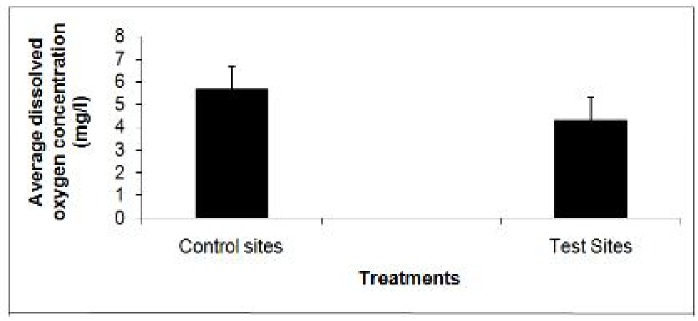

Figure 4: Average dissolved oxygen concentration recorded in the water column in both the control sites and test sites during the whole study period. There are no significant differences between the control sites and test sites (t test, $p>0.05$).

Mean conductivity ranged from 98.6 μS^{-1} to 1600 μS^{-1}, the lowest being recorded in April at polluted site 2, the highest being measured in May at site 7 (Table1). Mean Secchi transparency ranged from 10.7 cm to 915 cm, the lowest being measured in August at polluted site 6, the highest being measured in May at unpolluted site 18 (Table1). Mean TDS ranged from 57.6 mg/l to 841 mg/l, the lowest being measured in May at unpolluted site 9, and the highest being measured in May at polluted site 17 (Table 1).

Average concentrations of nutrients were significantly different in calcium and potassium in the water column above and below the water column in May (Tables 1,2). No significant differences in nutrient concentrations were recorded in the river bottom sediments between sites above the outfall and below the outfall in May (Table 2). No significant differences were found in physical variable in the water column (Table 3). (Table 4) shows that total phosphates were significantly different in the water column between sites above the outfall and below the outfall in August.

When all the study sites are considered for the month of May the significant differences in the water column were recorded in calcium and potassium (Table 5) but this is in flowing water where the nutrients are being exported. Calcium and orthophosphates were significantly different in river bottom sediments in all sites in May (Table 6). Calcium showed significant differences at all sites in the water column during the study period (Table 7). These data show that there were no significant differences between the mean values at stations located above the effluent outfalls and those located below them. These data certainly do not support the notion that the Runde River is severely polluted by the upstream agricultural activities.

Variables		Control Sites	Test sites
Temperature (°C)	Mean	25.9	27.1
	S. Dev	2.644	1.012
	Median	25.3	26.5
	Variances	6.99	1.012
	Minimum	22.5	26.2
	Maximum	28.7	28.3
pH	Mean	6.9	7.5
	S. Dev	0.438	0.303
	Median	6.8	7.4
	Variances	0.192	0.092
	Minimum	6.4	7.2
	Maximum	7.6	7.8
Dissolved oxygen (mg/l)	Mean	5.4	2.6
	S. Dev	0.713	1.331
	Median	5.5	5.3
	Variances	0.508	1.772
	Minimum	4.6	2.6
	Maximum	6.3	5.9
Conductivity (µScm-1)	Mean	178.6	161.9
	S. Dev	75.028	61.749
	Median	175.7	172.7
	Variances	5629.14	3812.968
	Minimum	106	98.6
	Maximum	293.3	241
Total dissolved solids (mg/l)	Mean		304.9
	S. Dev		216.669
	Median		205.3
	Variances		46945.43
	Minimum		85.7
	Maximum		841
Secchi disc (cm)	Mean	455	315.9
	S. Dev	269.389	170.889
	Median	390	327.5
	Variances	72570.63	29203.04
	Minimum	136.7	120
	Maximum	915	755.3

Table 1: Summary of descriptive statistics characterizing water quality in the hot wet season (n=20).

Variables		Control Sites	Test Sites
Temperature (°C)	Mean	23.4	24.2
	S. Dev	3.352	3.084
	Median	22.7	23.9
	Variances	11.234	9.509
	Minimum	22.5	26.2
	Maximum	28.7	28.3
pH	Mean	6.4	7.2
	S. Dev	7.6	7.8
	Median	6.8	7.4
	Variances	0.192	0.092
	Minimum	6.4	6.5
	Maximum	8.5	8.7
Dissolved oxygen (mg/l)	Mean	2.7	3.3
	S. Dev	2.421	1.144
	Median	1.6	3.2
	Variances	5.86	1.309
	Minimum	0.9	1.3
	Maximum	7.8	5.4
Conductivity (µScm-1)	Mean	552.8	339
	S. Dev	544.426	378.114
	Median	296.3	339
	Variances	296400	142969.9
	Minimum	107	95
	Maximum	1606	1376

Total dissolved solids (mg/l)	Mean		681.69
	S. Dev		751.355
	Median		511
	Vari-ances		564534.9
	Mini-mum		57.6
	Maxi-mum		2263
Secchi disc (cm)	Mean	40.8	47.3
	S. Dev	22.877	24.328
	Median	32.3	58.3
	Vari-ances	523.372	591.865
	Mini-mum	27.5	14.1
	Maxi-mum	81.3	71

Table 2: Summary of descriptive statistics characterizing water quality in the cool dry season (n=20)

Variable	Control sites	Test sites	Sign.
Dissolved oxygen (August)	6.6	6.2	NS
(April)	5.3	5.6	NS
(May)	3.4	3.2	NS
pH (August)	7.4	7.3	NS
(April)	7	7.4	NS
(May)	8	8.3	NS
\Conductivity (August)	200.1	168.3	NS
(April)	101.4	186.1	*
(May)	875.5	535.3	NS
Secchi transparency (August)	76.1	54.8	NS
(April)	30.1	50	NS
(May)	583.3	254.2	NS
TDS (May)	441.7	274.9	NS
Temperature (August)	20.5	22.5	*
April	24.1	27.5	*
May	23	25.5	NS

Table 4: Summary of t test for physical variables in the water quality data collected for analysis. The significance of differences between stations located above and below effluent outfalls by t-test is shown as: NS, not significant; *P<0.05; n=20.

Variables	Control sites	Test sites	t-value
TotN	7.3	5.6	NS
NO_3N	4	4	NS
NH_4N	5.7	5	NS
$TotPO_4$	2.8	4	NS
P_2O_5	32.4	8	NS
Ca	6.5	10.7	*
Mg	n.d	n.d	
K	0.8	1.3	*
Na	10.3	41.4	NS
n.d=not determined			

Table 5: Average concentration of nutrients in water in nine control sites and nine test sites in May. The differences were tested using T-test for unequal variances in May. The differences were tested using T-test for unequal variances (*=<0.05;NS=P>0.05, n=9).

Variables	Control sites	Test sites	t-value
TotN	43.8	49.5	NS
NO_3N			
NH_4N	5.7	5	NS
$TotPO_4$	n.d	n.d	
P_2O_5	32.4	8	NS
Ca	1.7	20.4	NS
Mg	1.4	4.2	NS
K	0.2	0.1	NS
Na	n.d	n.d	
n.d=not determined			

Table 6: Average concentration of nutrients in sediment in nine control sites and nine test sites in May. The differences were tested using T-test for unequal variances (NS=P>0.05).

Variables	Control sites	Test sites	t-value
TotN	6.3	8.7	NS
NO_3N	1.7	5.7	NS
NH_4N	4	3	NS
$TotPO_4$	2.8	29.9	*
Ca	14.1	11.1	NS
Mg	29.4	29.7	NS
K	0.9	1.3	NS
Na	n.d	n.d	
n.d=not determined			

Table 7: Average concentration of nutrients in water in nine control sites and nine test sites in August. The differences were tested using T-test for unequal variances in August. The differences were tested using T-test for unequal variances (*=P<0.05; NS=P>0.05).

Interrelationships among water quality variables that include dissolved oxygen, pH, conductivity, Secchi transparency and total dissolved solids across locations were examined using Pearson's correlation coefficient (Table 8). A significant and negative correlation was found between pH and dissolved oxygen, dissolved oxygen and conductivity, dissolved oxygen and Secchi transparency, dissolved oxygen and total dissolved solids. A significant and positive correlation was found between total dissolved solids and dissolved oxygen, although this did not seem to make much sense. A significant and positive correlation was found between conductivity and total dissolved solids, Secchi transparency and conductivity. The Spearman's rank correlation was used to examine interrelationships among nutrients in sediments (Table 9). A significant positive correlation was found between total nitrogen and ammonium nitrogen (Table 10-12).

Ammonium nitrogen showed no significant differences between the control and test sites in the wet season only (Figure 5). No significant differences were noted in total phosphates between the control and test sites in the wet and dry season (Figures 6-12). Total phosphate was significantly different by season.

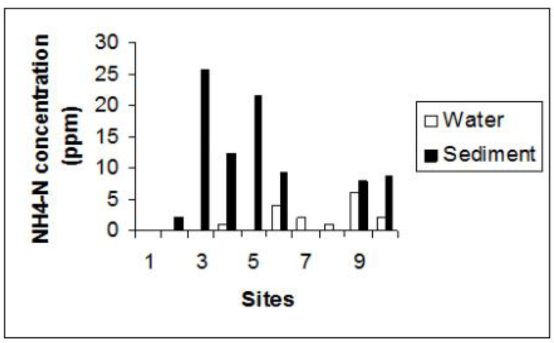

Figure 5: The variation of concentrations of ammonical nitrogen in ppm in the water column and sediments at different sites in August.

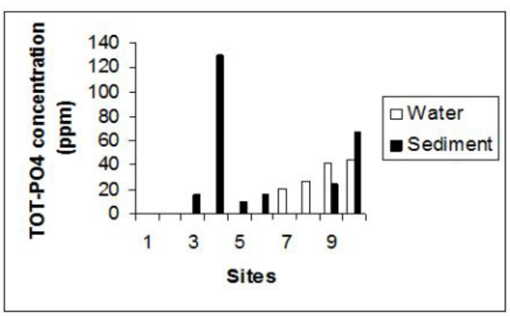

Figure 6: The variation of concentrations of total phosphates in ppm in the water column and sediments at different sites in August.

Variables	Control sites	Test sites	t-value
TotN	19.9	10.7	NS
NO_3N	4.6	5.17	NS
NH_4N	12.4	5.6	NS
$TotPO_4$	53.6	11.6	NS
Ca	5.9	17.3	NS
Mg	n.d	n.d	
K	1	1.3	NS
Na	n.d	n.d	
n.d=not determined			

Table 8: Average concentration of nutrients in sediment in nine control sites and nine test sites in August. The differences were tested using T-test for unequal variances (NS=P>0.05).

Variables	Control sites	Test sites	t-value
TotN	49.5	40.5	NS
NO_3N			
NH_4N			
$TotPO_4$			
P_2O_5	8	36.9	*
Ca	1.7	15.5	*
Mg	1.4	2.8	NS
K	0.2	0.1	NS
Na	n.d	n.d	
n.d=not determined			

Table 9: Average concentration of nutrients in sediment in control sites and test sites in May. The differences were tested using T-test for unequal variances (*=p<0.05; NS=P>0.05, n=13).

Variables	Control sites	Test sites	t-value
TotN	21.5	23.1	NS
NO_3N	9.2	5.2	NS
NH_4N	3.6	6.7	NS
$TotPO_4$	12.6	26.8	NS
P_2O_5	1.2	11.4	NS
Ca	0.9	7.7	*
Mg	0.7	1.5	NS
K	0.1	0.2	NS
Na	n.d	n.d	NS
n.d=not determined			

Table 10: Average concentration of nutrients in sediments during study period. The differences were tested using T-test for unequal variances (*=P<0.05; NS=P>0.05).

	Variable	1	2	3	4	5	6
1	Temperature	1	-0.088	0.2	-1.141	-0.168	-0.066
2	pH	-0.083	1	-0.547*	0.215	0.422	-0.216
3	Dissolved oxygen	-0.2	-0.547*	1	-0.675**	-0.644**	-0.456*
4	Conductivity	-0.141	0.215	-0.675*	1	0.744**	0.812**
5	Secchi transparency	-0.168	0.422	-0.744**	0.744**	1	0.415
6	Total dissolved solids	-0.066	-0.216	0.812**	0.812**	0.415	1
* Significant at 5% level ** Significant at 1% level							

Table 11: Pearson correlation coefficients among water quality variables (n=20).

	Variable	1	2	3	4	5
1	TOTN	1	0.405	0.766**	0	0.208
2	NO_3N	0.405	1	0.201	0.451	-0.399
3	NH_4N	0.766**	0.2	1	0.008	0.37
4	$TOTPO_4$	0	0.451	0.008	1	-0.316
5	Benthic density	0.208	-0.399	0.37	-0.316	1
**Significant at the .01 level						

Table 12: Spearman rank correlation coefficients among nutrient variables (n=20).

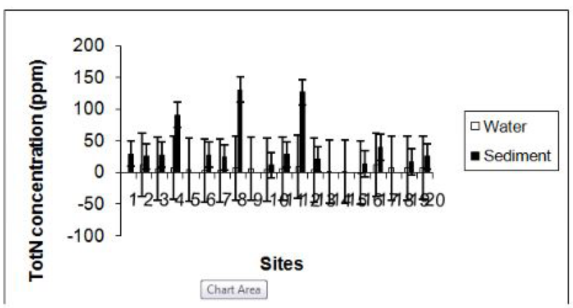

Figure 7: The variation of concentration of total nitrogen in ppm in the water column and sediment at different sites in May.

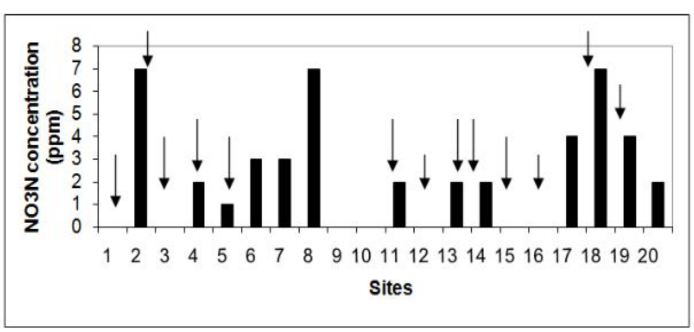

Figure 8: The variation of concentrations of nitrate nitrogen in ppm in the water column at different sites in May. The arrows indicate stations located below the effluent outfall points, i.e. test sites.

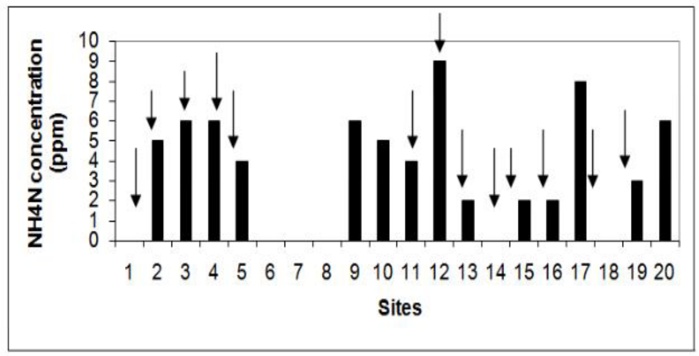

Figure 9: The variation of concentrations of ammonical nitrogen in ppm in the water column at different sites in May. The arrows indicate stations located below the effluent outfall points, i.e. test sites.

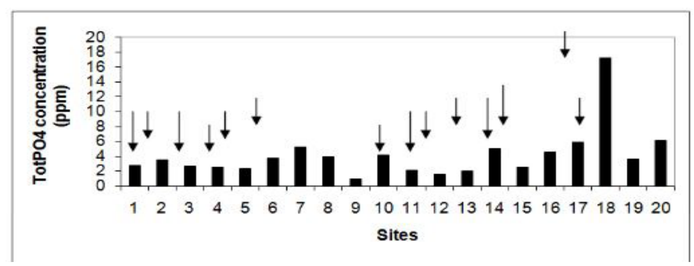

Figure 10: The variation of concentrations of total phosphates in ppm in the water column at different sites in May. The arrows indicate stations located below the effluent outfall points, i.e. test sites.

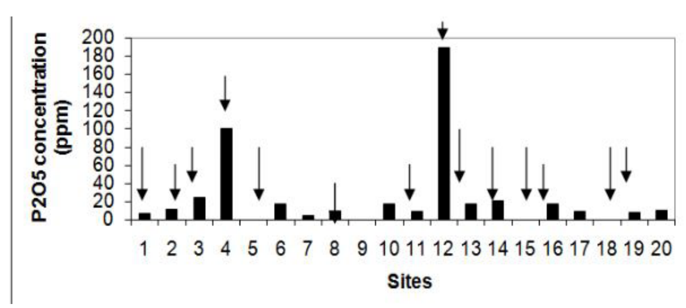

Figure 11: The variation of concentrations of orthophosphates in sediments in ppm at different sites in May. The arrows indicate stations located below the effluent outfall points, i.e. test sites.

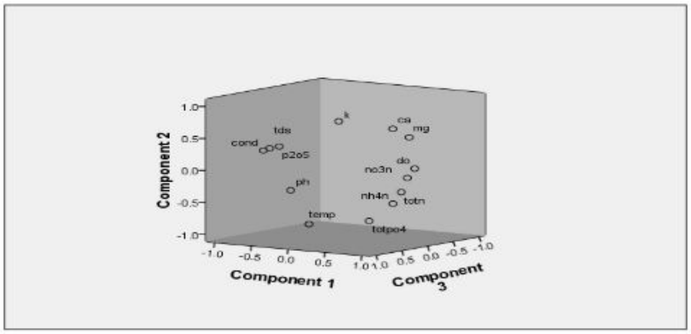

Figure 12: PCA output of investigated sample plots in physico-chemical data. Notes: PC1 explained 53.9%, PC2 explained 80.0% and PC3 explained 92.2% of the variance in the data.

Multivariate analysis

Variables with higher loadings are to be considered as having a greater influence. With sample size less than 100 the smallest loading would have to be greater than 0.30 in order to be considered significant. Eigenvalues generated in Factor Analysis correspond to an eigen factor which identifies the groups of variables that are highly correlated among them. Lower eigenvalues may contribute little to the explanatory ability of the data. Only the first few factors are needed to account for much of the parameter variability. The limitation in Factor Analysis is that factor scores cannot be calculated directly but instead must be estimated [19].

Water quality data are summarized in visual perceptual charts in (Figures 12-15). Five clusters were recognized. Each cluster comprises a set of sites with greater homogeneity of water quality than when compared with other sample cluster. Four clusters can be seen in the ordination diagram (Figure 12). The first cluster recognized Mg, pH, DO, Temperature and Families as a group. The second cluster recognized NO_3N, $TotPO_4$ and individuals. Third cluster shows TDS and Conductivity as a group. The fourth cluster recognized TotN, NH_4N, P_2O_5 and K as a group.

Physico-chemical data

Factor analysis was applied to data sets obtained on physical factors, nutrient data and combined physical, nutrient and benthic macro invertebrate individuals and families. The correlation matrix of variables was generated and factors extracted by the Principal Component Analysis, rotated by Varimax rotation [19]. The factor analysis generated three significant factors which explained 85.9% of the variance in data sets. The following factors were indicated considering the water quality variables:

Factor 1: pH, DO, Conductivity, TDS, TotN, NO_3N, NH_4N, $TotPO_4$, P_2O_5, Ca, Mg and K.

Temperature, pH, Conductivity, TDS and P_2O_5 have high negative loadings on Component 1.

Factor 2: Temperature, pH, NH_4N, $TotPO_4$, P_2O_5, Ca, Mg and K.

Temperature, pH, TotN, NO_3N, NH_4N and $TOTPO_4$ have high negative loadings on Component 2.

Factor 3: Temperature, Conductivity, $TotPO_4$, P_2O_5 and K

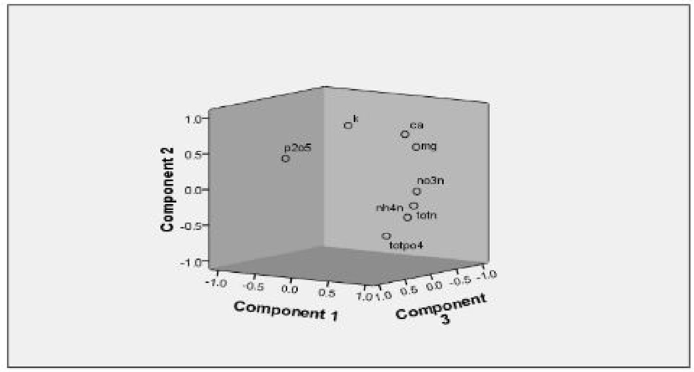

Figure 13: PCA output of investigated sample plots in nutrient data. Notes: PC1 explained 51.6%, PC2 explained 81.5% and PC3 explained 96.2% of the variance in the data.

Factor 1: TotN, NO_3N, NH_4N, $TOTPO_4$, Ca and Mg. All the variables in Factor 1 have high loadings on Component 1.

Factor 2: NH_4N, Tot PO_4, P_2O_5, Ca, Mg and Ca. NH_4N, $TotPO_4$ have high negative loadings on Component 2.

Factor 3: P_2O_5, Ca and K. Ca has a high negative loading on Component 3.

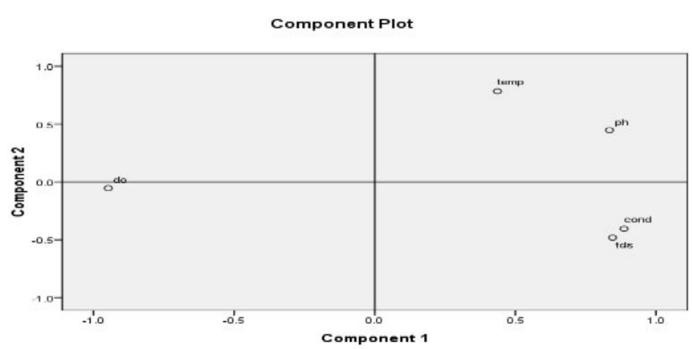

Figure 14: PCA output (PCA-biplot) of investigated sample sites in physico-chemical data. Notes: PC1 explained 65.7 % and PC2 explained 89.9% of the variance.

Factor 1: DO is nearly significant and is a key determinant factor of degradation of a water resource that is associated with a negative component 1. DO does not show clearly which sites are degraded.

Factor 2: Temperature, pH, Conductivity and TDS. Conductivity and TDS are associated with significant negative component 2.

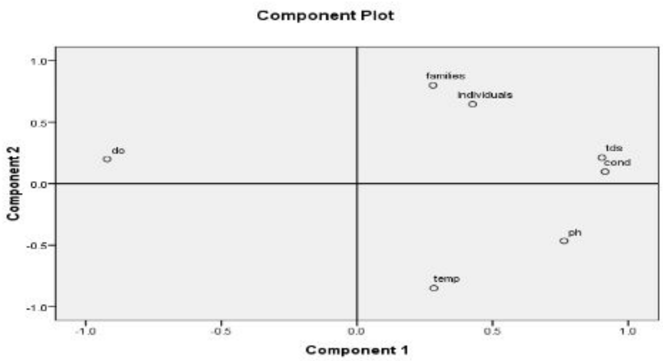

Figure 15: PCA output (PCA-biplot) of investigated sample sites in physico-chemical data. Notes: PC1 explained 48.9 % and PC2 explained 78.8 % of the variance.

Factor 1: pH, DO, Cond, TDS, Individuals. DO is associated with a negative component 1. Do does not show up clearly which sites are degraded. Factor 1 is associated with positive low loadings of families on Component 1.

Factor 2: Temperature, pH, Families and Individuals. Temperature and pH are significantly associated with negative component 2.

Discussion

The results show no significant differences between the mean values of dissolved oxygen concentrations above and below the effluent outfall in April, May and August, and it is difficult to infer any evidence of pollution from these data. Dissolved oxygen concentration is a key indicator for survival of aquatic organisms and of organic enrichment in streams. The results show significant differences in the mean values of pH and Secchi transparency in May. These data certainly do not support the notion that the Runde River is severely polluted by the upstream agricultural activities.

Mean TDS in this study ranged from 57.6 mg/l to 841 mg/l. Average TDS (mg/l) levels were higher for sites above the effluent outfall (441.7 mg/l) than sites below the effluent outfall (274.9 mg/l). Figure 4 shows that average dissolved oxygen concentration levels for both the control sites and test sites are higher than the recommended South African dissolved oxygen concentration for the warm river systems. This further confirms the evidence that the Runde River is not experiencing pronounced pollution and that the river is in a healthy state. The TDS levels measured for the south east lowveld Zimbabwe are lower than TDS levels measured in lowveld Oliphant's River in South Africa. TDS for Olifants ranges 482-1267 mg/l [25]. According to Buermann et al. [25] the limited tolerance range of aquatic organisms should be between 350-550 mg/l but for the Olifants River it is set at 800 mg/l. Tolerance to TDS is species specific. Recommended suspension concentrations for aquatic life in South Africa range between 10-25 mg/l [25]. The sites above the effluent outfalls may be carrying high suspension concentrations that are reduced in the upstream reservoir impoundments with much clearer water flowing downstream. Mean Secchi depth recordings in April varied between 14, 1 cm and 63.6 cm and in August varied between 10.7 cm and 102 cm (Table 1) indicating less frequent

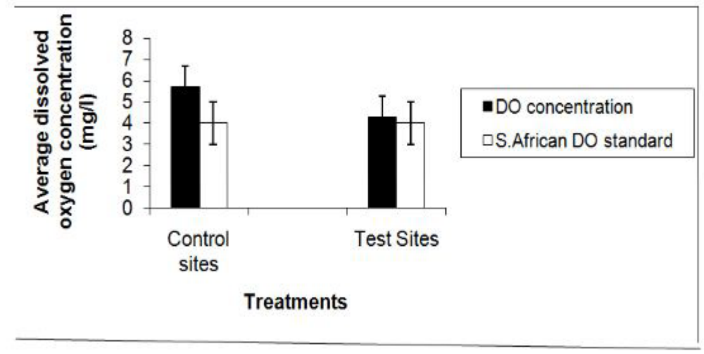

Figure 16: The average concentration of dissolved oxygen in water column in both the control and test sites in relationship to the South African standard for the whole study period.

The periodic inputs of suspended solids may decrease water clarity and light penetration. Conductivity in the river waters varied from 100 to 298 µScm^{-1} in August (Table 2). Figures 3-15 show some daily fluctuations of physico-chemical conditions that may affect the biota in the study area. The relationship between conductivity and total dissolved solids in the river systems is characterized by an r^2=0.96 suggesting a strong relationship. The level of conductivity in water gives a good indication of the amount of ionisable substances dissolved in it, such as phosphates, nitrates and nitrites which are washed into streams and ponds after fertilizer is applied surrounding fields or are present in effluent from sewage-treatment facilities.

Total phosphates showed significantly different levels in the water column among the study sites but this is in flowing water where these nutrients were being exported. No significant differences in total phosphates were recorded in river bottom sediments. Total phosphates may be nutrients associated with sewage effluent. Phosphate usually gets into water from detergents, but some phosphate is excreted in urine. Significant orthophosphates and calcium were recorded in river bottom sediments. Sediments are known to accumulate dissolved and particulate material [6,26]. There were no significant differences in nutrient accumulation (t test; p>0.05) in stream bottom sediments. No significant nitrate nitrogen concentrations were recorded in the sample sites. Nitrate usually gets into water from field drainage, usually directly into the nearest stream. Calcium, potassium and sodium were significantly different between sites above and below effluent outfall in flowing water. Levels of mean values of nutrient concentrations did not go up after the agricultural zone and sewage discharge point. The idea that agricultural development always contributes to river pollution is met with skepticism in this study.

Non-point sources have assumed greater relative importance in water quality management as point sources have come under increasingly stringent control. Unfortunately, non-point source loads are often driven by rainfall events and thus both waste load and stream flow vary significantly overtime.

Levels of total nitrogen, nitrate nitrogen and total phosphates are not significantly different between the control and test sites suggesting that the Runde River nutrient loading may not be at present a threat to the river ecology. Carmago et al. [27] observed significant increases in conductivity and nutrient (NO_3-N, NH_4-N, PO_4-P) concentrations downstream from mountain streams. Increased organic loading downstream is not apparent in the present study. Nutrients may be adsorbed and concentrated on sediments with slow processes of back-release into the water column along a river but the processes may be mediated by environmental factors and influent nutrient quantities [28]. In addition, nutrients maybe diluted as they are washed downstream by current and this tends to have a local dilution effect where additional inflows are received from surrounding areas by either ground-flow or surface-flow input. The variability in water quality data, nutrients in the river water column and nutrients in the river bottom sediments may be influenced by localized nutrient patches from agricultural runoff. The biological responses that depend on environmental conditions may include a change in density, diversity, and community structure and species composition of populations.

In the present investigation, simple correlations were studied to find the associations of water quality variables. From the simple correlation coefficients significant and negative correlation was found between pH and dissolved oxygen, dissolved oxygen and conductivity, dissolved oxygen and Secchi transparency, dissolved oxygen and total dissolved solids. The significant and positive correlations were found between conductivity and total dissolved solids, Secchi transparency and conductivity and, total dissolved solids and dissolved oxygen.

The chemical measurements support the classification of the river as an oligotrophic-mesotrophic river. The water quality variables measured are not affected by agricultural development from sites 1 to 5 in a definite way. There are several reasons why the influences may not be significant with water quality variables:

1. The nutrients are diluted by the water of the river, so that the increase in concentration is too small to be detected
2. The nutrient input is discontinuous, depending on the precipitation, i.e. can be detected only after certain incidents
3. The nutrients have been detained in the riparian buffer zone between the Runde River and the sugarcane agricultural fields so that they are not detectable in the river water column and sediments

The issue of agricultural impacts has been singled out as the most contributor of river water pollution [29,30]. The postulation that intensive agriculture may not give rise to significant river water pollution is interesting and the idea that agricultural runoff always lead to gross water pollution needs to be considered *de-novo*. The sugarcane estates employ a riparian forest buffer zone to reduce impacts on the Runde River. In principle, riparian buffer zones slow down sediment and nutrients to allow for settlement and adsorption of nutrients to sediment may take place and, uptake by plants may be another possibility [31]. The long distances to streams also allows for gentrification to take place. A mitigation of the environmental impacts of intensive agriculture has been noted in the state and transition literature by FAO [29]. It is likely that mitigated irrigation and drainage does not result in significant river water pollution.

The hypothesis that agricultural development is a key determinant of variability in nutrient concentration accumulation needs further elucidation. Nutrient patches created by influent water and rainfall could have a positive effect on benthic assemblages. Benthic fauna are an important fish food and any increase in benthic fauna assemblages could increase fish production in the streams [32-34].

Enrichment of the Runde River with nutrients needed for plant growth occurs commonly as a result of losses from agricultural fertilization and loading from sewage. Changes in the physico-chemical characteristics were viewed in the context of effluent discharge and land use. The patch concentrations of dissolved compounds in the Runde River shows that the inflowing waters from surrounding may determine the chemical composition of this river water irrigated lands. The nutrients levels recorded along the Runde River sites suggest that agricultural activities are not a key determinant of the river ecosystem. However, nutrients in influent water may have indirect beneficial impacts on the fish population through increased fish food supply. Lotic ecosystems should properly be viewed as being influenced profoundly by conservation measures of agricultural activities.

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