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Influence of agricultural runoff on the spatial distribution and abundance of benthic macro invertebrates in the Runde River, Zimbabwe

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The water quality of the Runde River in southeast Zimbabwe was studied using physico-chemico-characteristics and biological monitoring parameters. Water and sampling points were obtained from 20 sampling stations to establish the variation in the physico-chemico characteristics and the integrity of the benthic macro invertebrates. The study recorded variations in the physico-chemical characteristics. A total of 12 orders, 26 families and 33 genera of macro invertebrates were observed. No significant (p>0.05) differences were found in Shannon index for benthic macro invertebrates between control and test sites. The Margalef index for benthic macro invertebrates for the control sites was lower than the test sites suggesting differences in nutrient levels and sources. Using Multiple Correspondence Analysis, Principle Component Analysis, Factor Analysis, majority of the sites were centrally clustered suggesting a failure in diagnostic characteristics to distinguish impaired sites from unimpaired sites and indication that the Runde River water quality was not different in the upstream and downstream of commercial agriculture. The hypothesis was that agricultural development is a key determinant of variability in benthic macro invertebrate distribution and abundance may not hold. The findings in the study are surprising considering the known impacts of commercial agriculture on river water quality thus, the need for a long time study on the same river. Physico-chemical and biodiversity of a river fluctuate seasonally.

Keywords: Agricultural runoff, benthic macro invertebrates, Runde River, spatial distribution.

INTRODUCTION

Invertebrates in the Runde catchment are a critical component of the aquatic food web in it. The insects and crustaceans that live in streams are indicators of water quality because all organisms require specific conditions to live. If the water quality is poor, or if a polluting event occurred within the past few months, it will be reflected in the macro invertebrate population.

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Invertebrates provide valuable food resources for other invertebrates (Wallace and Webster, 1996), fish (Makoni and Mangwaya, 1997). A change in invertebrate assemblages can directly and indirectly affect the rest of the food web, causing ecological and economic change (Moyo, 1997). Aquatic invertebrates are primarily affected by the structure of the macrophyte community (Talling and Lemoalle, 2006), turbulence, light intensity, temperature, food availability (Thomson and Downes, 2003), and dissolved oxygen (Marshall, 1997). Changes in vegetation composition can alter the density and composition of predator and prey communities, thus having an indirect effect on invertebrates (Samways and Steytler, 1996).

Benthic fauna are characterized by high taxonomic diversity, and rapid response of most of its constituent members to environmental cues such as dissolved oxygen, quantity and quality of food, current, light, substrate quality and predation. Water quality ratings of excellent, good, fair and poor are based on the tolerance levels of the organisms found and the diversity of organisms in the sample. A stream with excellent water quality should support organisms from all three pollution tolerance groups. Few species attain great population densities, perhaps because of pollution and the lack of interspecific competition (Santhi et al., 2001). Waters enriched with organic matter, sewage have highly restricted fauna (Marshall, 1997). Little information is available on the abundance, diversity and host relationships of benthic fauna, hence the need to continue with macro invertebrate inventories that can lead to the indirect identification of the many phyla. Some of the benthic macro invertebrates are of human health importance. Out of 13,789 snails collected 916 (6.6%) harboured patent trematode infections e.g. *Bulinus tropicus B. globosus, B. forskalii and Biomphalaria pfeifferi* (Chingwena, 2002).

Chambari and Ndlela (2001), undertook measures to reduce prevalence of schistosomiasis and snail population densities at Hippo Valley sugarcane estates. Prevalence of *Schistosoma haematobium* was reduced from over 50% in 1980 to below 10% in 2000 (Chambari and Ndlela, 2001). Similarly, prevalence of *S. mansoni was* reduced from 25% in 1980 to below 10% in 2000 (Chambari and Ndlela, 2001). Snail numbers in water bodies in the sugarcane estates fluctuated over the years, dropping from over 100,000 snails in 1986 to about 10,000 snails in 1998. The amount of niclosamid used to control snails varied over the years with less than 10 kg per year being used between 1995 and 1998 (Chambari and Ndlela, 2001). A marked improvement in safe water and sanitation facilities was noted. The relative importance of macro invertebrates to fish is important in understanding fish feeding behaviour and ecology of streams. Chakona et al. (2007), investigated fish predation on benthic macro invertebrates in a seasonal stream in north-western Zimbabwe. The cumulative impact of the entire fish assemblage on benthic macro invertebrate assemblages was investigated over four months in a removal experiment in isolated pools that persist through the dry season, in an intermittent stream in north-western Zimbabwe.

In one study, fish removal had no effect on the zoo benthos taxa richness but led instead to large increases in the densities of certain macro invertebrates. There was a progressive increase in the body size of Odonata in pools without water over 34 and 55 days after treatment and, by 78 days post-treatment, the proportion of large-sized odonates was significantly higher in fishless than in control pools. Peak densities of predaceous invertebrates coincided with a sharp decline in macro invertebrate densities in the pools without water about three months after fish removal. Although fish may be important benthic predators, they are not keystone predators because the macro invertebrate community structure may be influenced by the assemblages of both vertebrate and invertebrate predators, rather than by a single keystone predator. Invertebrates are an important fraction of the diet of many fishes and birds (Wallace and Webster, 1996, Makoni and Mangwaya, 1997, Madanire-Moyo and Barson, 2009). Within a single pool the vegetated sites often support a greater diversity of macro-invertebrates than do the open water sites (Chakona et al., 2008, Nhiwatiwa, 2009).

However, non-native species such as the water hyacinth *Eichhornia crassipes* may seriously alter the ecosystem functions that macrophytes provide (Marshall, 1997, Brendonck et al., 2003). Little is known about the relationship between macro invertebrates, fish and macrophytes in southeast lowveld rivers.

Despite detailed recommendations for curbing the entry of alien organisms into South Africa, freshwater snails continue to be introduced (Appleton, 1996). Whereas the earliest introduced species originated in the Americas, the three most recent have been Asian and probably came via the aquarium trade which gets its supplies from Hong Kong. Currently four of the 12 alien species recorded in South Africa have become invasive, two over the past 50-70 years, one within the last 15 years and one within the last 10 years. Water quality influences the abundance, species composition, stability, productivity, and physiological condition of indigenous populations of aquatic organisms (Dallas, 2002, Madanire-Moyo and Barson, 2009). Moyo and Phiri (2002), noted a decrease in the occurrence of molluscs along the Mukuvisi River, at a site with heavy metals associated with industrial pollution. Madanire-Moyo and Barson (2009), observed a decrease in parasitic diversity of African catfish *Clarias gariepinus* that was related to increased organic pollution in the upper Manyame catchment, Zimbabwe.

The number of taxa can be considered as a measure of ecosystem degradation and is a more responsive measure than ecological measures such as the number of organisms. A sharp decrease in the number of taxa along the Mukuvisi River was explained by a decline in water quality (Moyo and Worcester, 1997). In contrast to the previous author the macro invertebrate communities at sites with a burden of heavy metals are dominated by midge (Chironomidae) larvae. Moyo and Phiri (2002) found a high number of oligochaetes among the macro invertebrate community collected from Mukuvisi River and associated this with evidence of organic pollution. The decline in macro invertebrate diversity on the Mukuvisi River is largely a result of the decline in water quality along the course of the river (Moyo and Phiri, 2002). Much of the work on aquatic pollution in the Upper Manyame catchment has focused on the analysis of physicochemical conditions of water (Mathuthu et al., 1993, 1997, Jarawaza, 1997, Magadza, 1997, 2003, Zaranyika, 1997).

Few studies in isolated studies by Moyo and Worster (1997), Moyo and Phiri (2002) have given light on biota in streams away from the main watershed in Zimbabwe.

MATERIALS AND METHODS

Study area

The study area is drained by the Chiredzi, Mtirikwi, Tokwe and Runde Rivers (Figure 1) 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 (Figure 2). The Runde River catchment is approximately 41000 km^2 in area (Mugabe et al., 2007). The Runde River strongly influences the southeast lowveld and the nation's everyday life and the long term economic development and is at the core of ecosystem survival. The low veld predominant land use is the intensive production of sugarcane under irrigation. Irrigation is facilitated by the use of canals and overnight storage dams that enable flood irrigation of the sugarcane.

Chemical fertilizers, floodplain irrigation, canal irrigation and diesel-powered riverbed sand abstraction in the low veld have enabled the expansion of intensive agriculture into zones with nutrient-limited soils and severe soil moisture deficits, effectively changing the distribution of high potential agricultural lands. The access and manipulation of the region's hydrologic resources has profound environmental consequences and may lead to

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

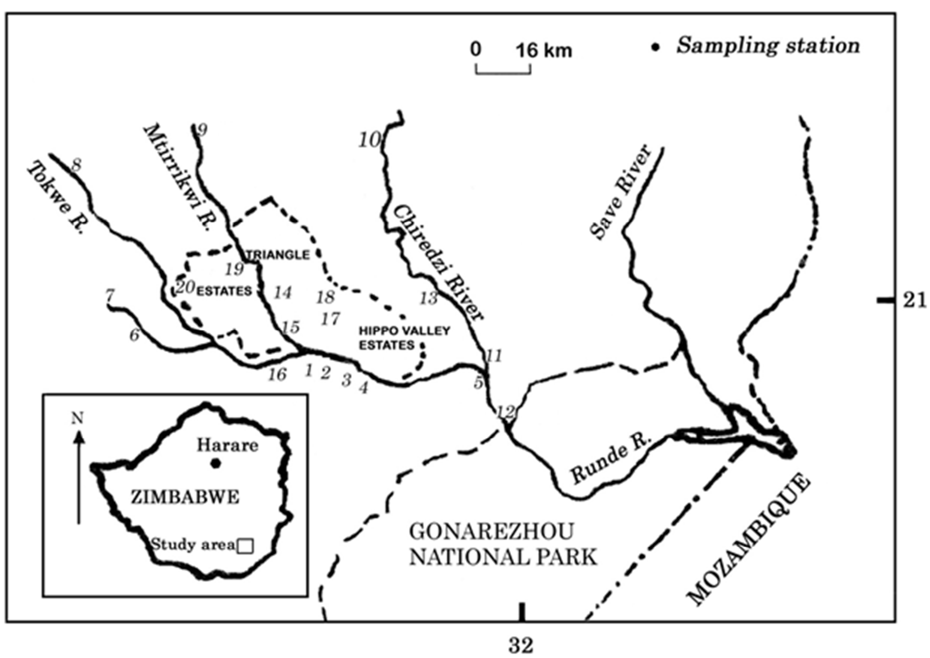

Figure 2. Simplified map of the southeast low veld river system showing location of the different sampling stations along the studied watercourses.

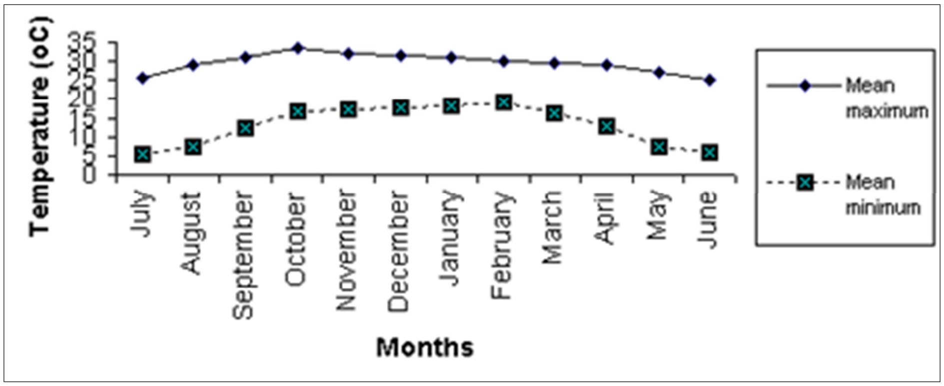

Figure 3. Mean maximum and minimum temperatures at Gonarezhou National Park (n=11).

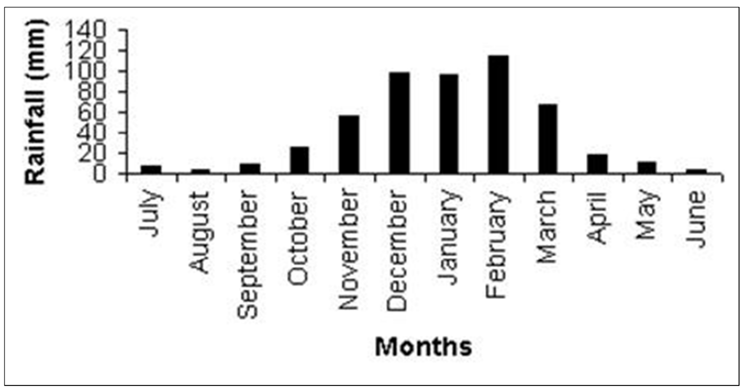

Figure 4. Mean monthly rainfall at Gonarezhou National Park based on data collected over 31 years (Source: Department of Meteorological Services).

unforeseen resource degradation. The hydrology, catchment activities and land use patterns may strongly influence benthic settlement patterns, survival, and river health and river water quality. Figures 3-7 describe the hydrological features of the study area in Figures 3-7.

Methods

Water samples were collected nonstop over a 12 month period using protocols described by Marshall (1997), Wetzel (2001). The water samples were analyzed using protocols described by Golterman et al (1978). Benthic samples were taken in the dry season August 2003 and wet season of April 2004 in the upstream of Chiredzi, Mtirikwi and Tokwe Rivers at Hippo Valley and Triangle Sugar Estates (Figure 2), using a SASS4 protocol for water quality described by Gratwicke (1998), Dallas (2002, 2004) and Vos et al. (2002). Samples of macro invertebrates were collected from a stream, identified and a water quality rating of stream was established. Collections of the invertebrates were made using a standardized net.

The collector moves upstream pushing and rubbing stones with his feet, attempting to disturb the substrate to a depth of about 10 cm,

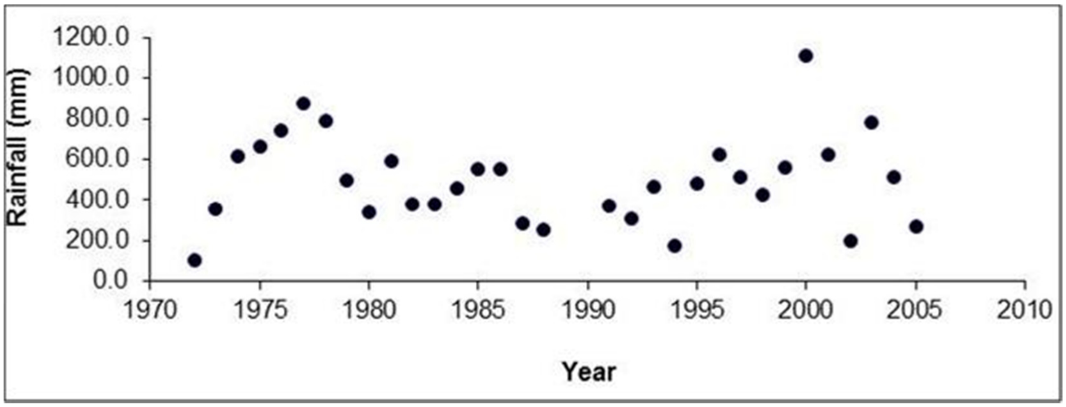

Figure 5. Long-term annual rainfall record for the Gonarezhou National Park (n=31, CV=50 %) (Source: Department of Meteorological Services, Harare).

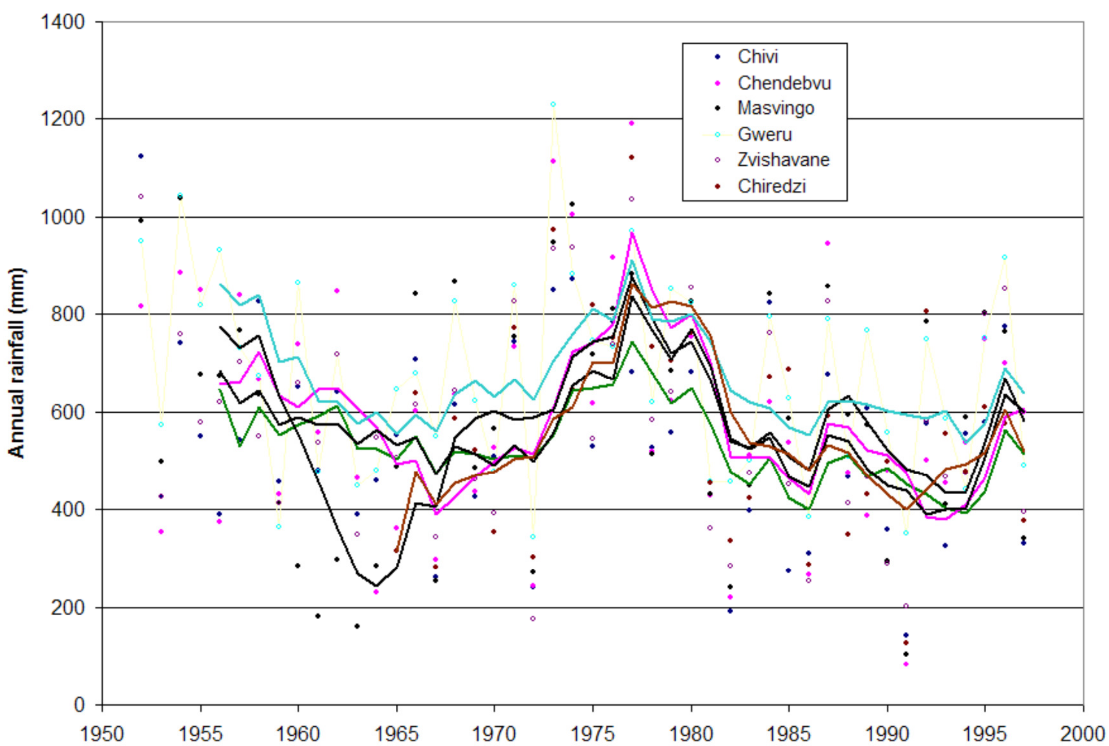

Figure 6. 5-year running averages of annual rainfall totals in the Runde catchment at Chendebvu, Chiredzi, Chivi, Gweru, Masvingo and Zvishavane (after Mugabe *et al*., 2007).

the net being held just downstream, to catch animals carried away by the current (Gratwicke, 1998, Vos et al., 2002). Sampling usually took about three minutes, and this is in a series of short, thirty second bursts. The invertebrates were then tipped into a shallow tray where they are separated from debris and identified down to family level. The presence or absence of a family is noted on the SASS sheet which has sensitivity ratings on it (Thirion et al., 1995).

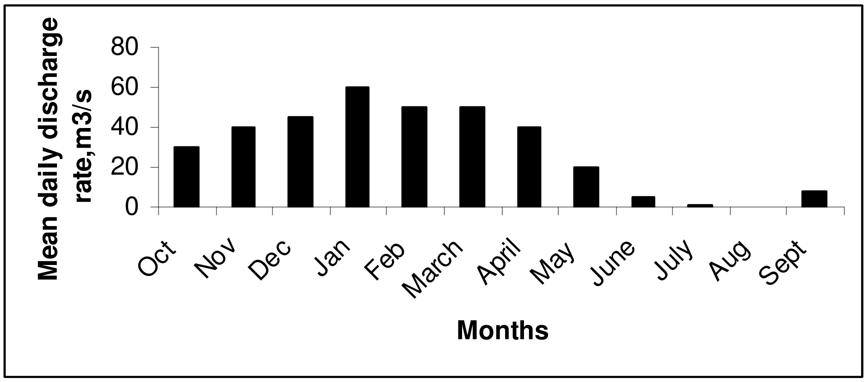

Figure 7. Annual discharge at the Runde discharge gauge station, Masvingo. The change in mean daily discharge rate, m3/s in the Runde River (Source: Department of Water and hydrology, 2010).

When the score of each family present is added up, it gives a total which is called the sample score (Chutter, 1998). When this is divided by the number of families present, an average score per taxon (ASPT) is given (Chutter, 1998). The ASPT is, therefore, a measure of the average sensitivity of all the organisms present to organic pollution (Gratwicke, 1998, Vos et al., 2002, Dallas, 2002). The limitations and the problems involved in using a grab of this type have been noted by Karr (1981). Upon retrieval all accumulated material from the samplers were collected and preserved. The collected organisms were identified at the family level and genus. List of families collected from the rivers was compiled. Live sorting and preliminary counting of readily identified taxa were carried out in the field, before preserving the sorted invertebrates in 70 % isopropryl alcohol for laboratory identifications and checks using keys of Thirion et al (1995), Appleton (1996), Braack (2000) and Picker et al (2003).

All benthic specimens were examined with an Olympus binocular microscope, using an objective lens with a zoom magnification from 0.7 to 4.0 and eye-pieces of 15x magnification. When necessary an adapter lens fitted to the objective doubled the magnification. All measurements were done using a calibrated 1 mm eye-piece Scale. Illustrations or sketches in guide books (Thirion et al., 1995, Appleton, 1996, Braack, 2000 and Picker et al., 2003) were used as a guide to nomenclature of specimens. Illustrations were schematic and were intended to show pattern characteristics rather than precise anatomical detail. In those groups where mesonotal and abdominal markings, as well as wing patterns, provide taxonomic characters, dorsal views of the whole insect was also used. In other groups, where body markings provide few or no usable taxonomic characters, wings were also considered.

Identification of the insect specimen was done at the family and genus level. Data analyses were also done using Excel. Inter-site differences in concentrations of nutrients were analysed using ANOVA. The following references were used for the taxonomical determination of species: Parish (1975), Braack, 2000, Thirion et al., (1995), Picker et al., (2003) and Appleton (1996). In order to determine the changes in species composition in relation to different treatments in relation to water quality, the Shannon Index (H') was calculated. The Shannon Index for each treatment was calculated using the formula (Ludwig and Reynolds 1988):

$H' = -\sum (p_i \times \ln(p_i))$, where p_i is the fraction of the entire population made up of species i, and ln is the natural logarithm.

Table 1. Summary of benthic macro invertebrates identified in all sample stations.

Order	Family	Genera
Acari	Hydrachnidae	Hydrachna
Anisoptera	Gomphidae	Ictinogomphus
Coleoptera	Dysticidae	Cybister
	Gyrinidae	Aulogyrus
	Hydrophilidae	Hydrophillus
	Psephenidae	Cybister
Collembola	Sminthuridae	Sminthurus
Crustacea	Arrenuridae	Arrenura
Diptera	Chironomidae	Chironomus
Ephemeroptera	Heptageniidae	Afronurus
	Baetidae	Baetis
Hemiptera	Belostamitadae	Belostoma
	Gerridae	Gerris
	Vellidae	Velia
Megaloptera	Corydalidae	Taeniochauloides
Mollusca	Corbiculidae	Corbicula
	Limnaediae	Limnaea
		Planorbis
	Planorbidae	Helisoma
		Gyraulus
		Promenetus
		Physa
		Sphaerium
	Physidae	Pisidium
	Sphaeriidae	Eupera
		Quadrula
	Unionidae	Coelatura
Odonata	Aeshnidae	Aeshna
		Anax
	Chlorocyphidae	Platycypha
	Libellulidae	Libellula
	Coengriidae	Agrion
Trichoptera	Hydropsychidae	Hydropsyche

The value of the Shannon-Wiener Index usually lies between 1.5 and 3.5 for ecological data and rarely exceeds 4.0.

The Margalef diversity index is calculated as the species number (S) minus 1 divided by the logarithm of the total number of individuals (N). The calculation uses the natural logarithm:

$$D = \frac{(S-1)}{\ln N}$$

Multiple Correspondence Analysis (MCA) (Dillion and Goldstein, 1984) examined the direct and indirect effects of a gradient in nutrient concentration and hydrologic disturbance on benthic community structure in the study area. 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 Correspondence procedure was used in SPSS (SPSS, 1996) to identify the two strongest underlying factors in the relationships between the water quality variables. By assigning each variable a specific number within each dimension, the information was displayed in an easily understood chart, commonly called a perceptual map.

RESULTS

Physical and chemical properties

The river water quality in the study area fluctuates within the 12 month period and depends much on effluent discharged at point source and non-point source discharge outfalls. Surface water temperature was narrow (21.8-26.5 ^{o}C) with a mean of 24.3 ^{o}C, conductivity values were between 170.2 μScm^{-1} and 567.4 μScm^{-1} (April and May) with a mean of 305.5 μScm^{-1}.

Major animal taxa

No macro invertebrates were found in April when the rivers were in flood. The animal taxa encountered in the sampling sites are shown in Table 1. The percentage composition of the taxa caught for the month of May is shown in Figure 3, Tables 2-3. For the month of May site 4, a discharge point recorded the highest

Table 2. Average benthic macro invertebrate indices and diversity indices and t test results.

Method		**May**	**Sig.**		**August**	**Sig.**
	Control site	Test site		Control site	Test site	
Shannon index	-0.996	-0.4117	NS	-0.885	-0.4746	NS

Table 3. Relative abundances (%) of different benthic macro invertebrates taxa colonizing nine sampling sites in May.

	Sites									
Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
Aeshnidae								4		4
Arrenuridae				1						1
Baetidae								1		1
Belostamitadae	1				15	3	7		1	27
Chironomidae							1			1
Coengriidae	1								1	2
Corbiculidae			1							1
Gerridae	1									1
Heptageniidae							1			1
Hydrachinidae				1		1				2
Hydrophilidae		1								1
Libellulidae					3		1			4
Limnaedae			8	26	1					35
Physidae								1		1
Planorbidae	1		4	1	2			11	1	20
Sphaeriidae	2									2
Unionidae	2							3		5
Veliidae	1									1
Total	9	1	13	29	21	4	10	20	3	110
Relative abundance (%)	8.18	0.91	11.82	26.36	19.09	3.64	9.09	18.18	2.73	100

percentage (26.4%) of different benthic macro invertebrates but this was followed by site 5 (19.1%), a mixing zone of Runde River water and feeder stream. In August site 13 recorded the highest percentage (33.1%) of different benthic macro invertebrates and this was followed by site 4 (13.8%) a discharge point (Table 4). Table 4 shows percentage contribution of the taxa caught in the study area in August. The seasonal distribution of phyla (Figure 8) shows a community dominated by mollusks (gastropods and bivalves), which contributed between 50.7% (August) and 52.8% (May) of total fauna collected. There is a higher density of gastropods than bivalves. The phylum Acari contributed between 1.8% (May) and 4.4% (August) of fauna collected (Tables 3-4, Figures 10-11). Anisoptera were present and contributed 1% (August) of fauna collected (Figure 11). Coleoptera contributed between 0.9% (May) and 7.2% (August) (Figures 10-11). Collembola contributed 5.9% (August) of fauna collected (Figure 6). Phylum Crustacea contributed 0.9% of the sample collected May

Table 4. Relative abundances (%) of different benthic macro invertebrates taxa colonizing 20 sampling sites in August.

	Sites									
Family	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aeshnidae			3	12	4	3	8		2	
Baetidae					1	1				
Chlorocyphidae										
Coengriidae	1									
Corbiculidae			12	30			2			
Corydalidae						3				
Dysticidae						1				
Gerridae					3					
Gomphidae						1		2		
Gyrinidae										
Hydrachnidae				9	1					1
Hydropsychidae								1	1	
Limnaedae										
Physidae										
Planorbidae		2		2					10	
Psephenidae			7							
Sminthuridae			17							
Sphaeriidae			4			1	2			
Vellidae										
Total	1	2	43	53	9	10	12	3	13	1
Relative abundance (%)	0.26	0.52	11.17	13.77	2.34	2.6	3.12	0.78	3.78	0.26

Table 4. (Continued). Relative abundances (%) of different benthic macro invertebrates colonizing 20 sampling sites in August.

	Sites										
Family	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Total**
Aeshnidae		4							18		54
Baetidae											1
Chlorocyphidae			1								2
Coengriidae											1
Corbiculidae		3					7				54
Corydalidae			1								4
Dysticidae											1
Gerridae										4	7
Gomphidae			1								4
Gyrinidae				10							10
Hydrachnidae		6									17
Hydropsychidae											2
Limnaedae		1									1
Physidae											3
Planorbidae		9	125				37				185

Table 4. (Continued). Relative abundances (%) of different benthic macro invertebrates colonizing 20 sampling sites in August.

Psephenidae											7
Sminthuridae									4		23
Sphaeriidae											7
Vellidae	4					3					4
Total	4	23	128	10	0	3	44	0	22	4	387
Relative abundance (%)	1.03	5.94	33.08	2.58	0	0.78	11.37	0	5.69	1.03	100

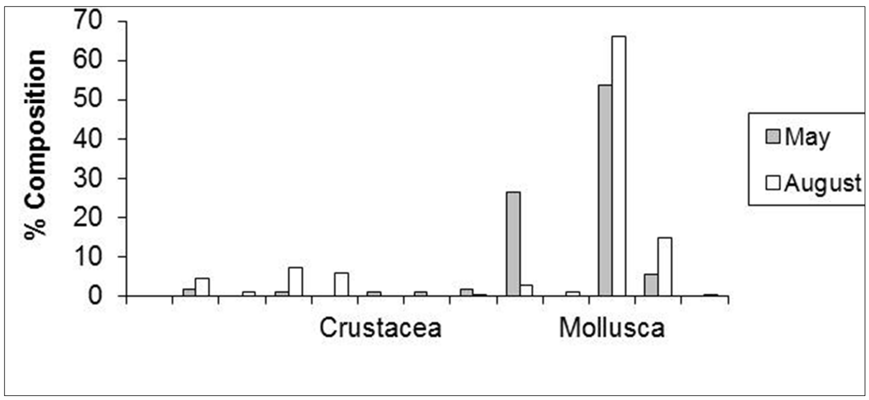

Figure 8. Seasonal distribution of phyla.

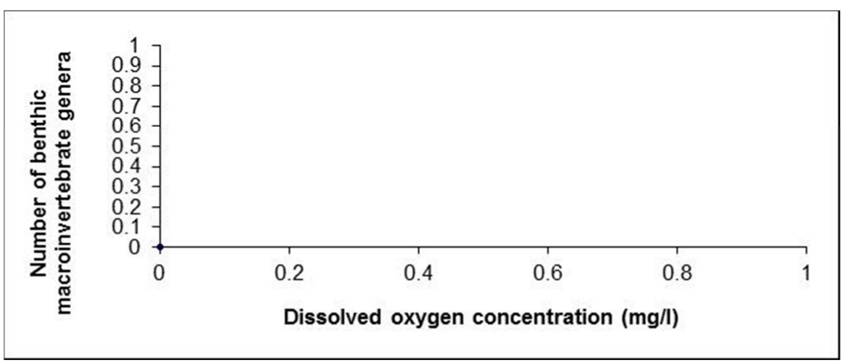

Figure 9. Relationship between numbers of benthic macro invertebrate and dissolved oxygen concentration.

2005 (Figure 10). The phylum Diptera was present and contributed 0.9% (May) of fauna collected (Figure 10). Phylum Ephemeroptera contributed between 1.8% (May) and 0.3% (August) of fauna collected (Tables 3-4, Figures 10-11). Hemiptera contributed between 26.4% (May) and 2.8% (August) of the sample collected. Phylum Megaloptera contributed 1% of the sample collected August. Mollusca contributed between 53.6% (May) and 65.9%

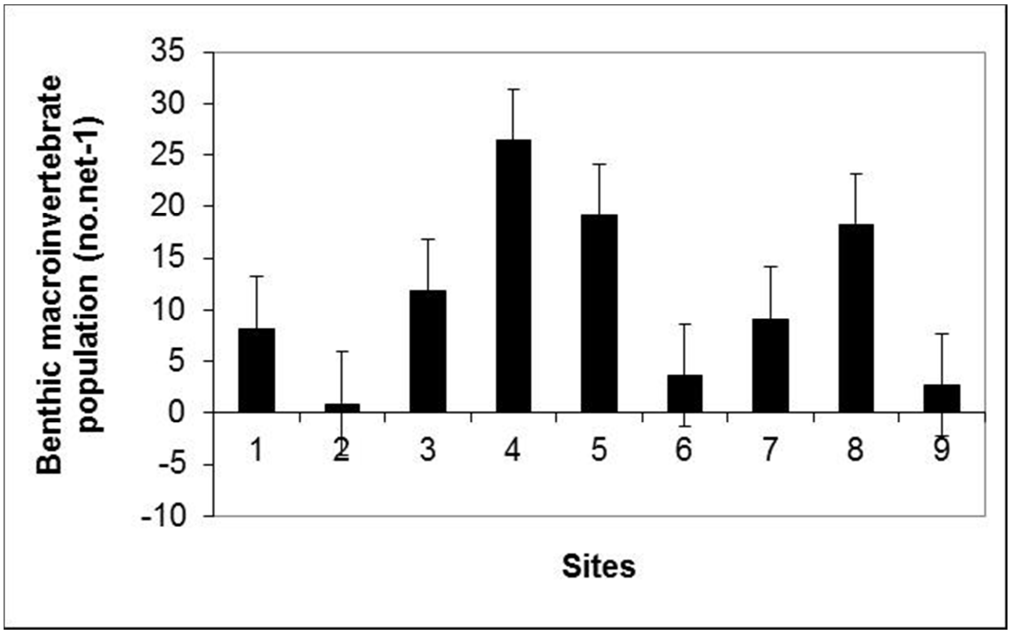

Figure 10. Benthic macro invertebrate relative abundance at different sites in May.

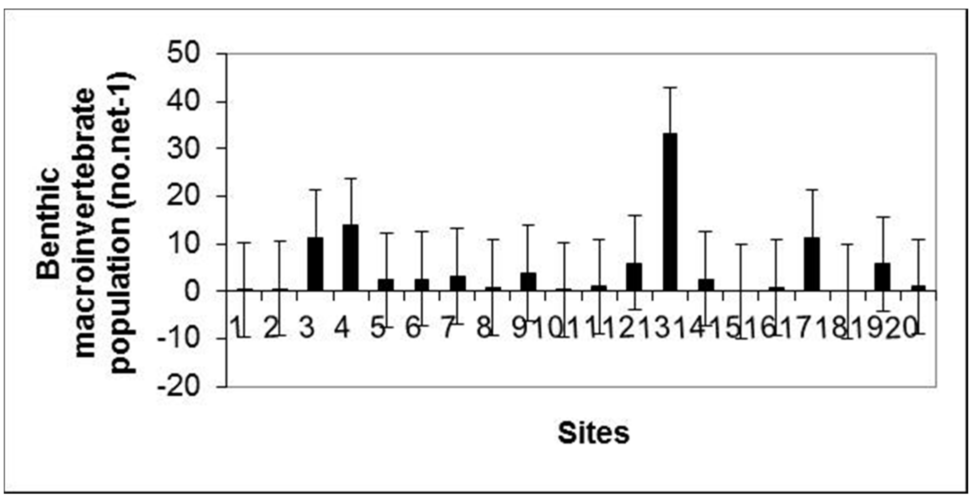

Figure 11. Benthic macro invertebrate relative abundance at different sites in August.

(August) of the fauna collected. Phylum Odonata was present and contributed 5.4% (May) and 14.7% (August) of the samples collected. The phylum Trichoptera contributed 0.5% (August) of the fauna collected (Figure 11). Figure 9 shows a strong relationship (r^2=0.62) between benthic macro invertebrates and dissolved oxygen.

Species richness and abundance

The benthic population (no.net-1) caught in May showed that site 4 had the highest numbers (25.2 animals/net-1) and sites 5 and 9 also recorded very high densities (Figure 10). Figure 10 shows that sites 3, 4, 14 and 17 had very high populations with the highest being

Table 5. Mean density (no.m^2) invertebrates from river bottom sediments (The significance of differences between test and control sites by t-test is shown as: NS=not significant).

Variable	Control sites	Test sites	Sig.
Mean density (May)	11.0	12.05	NS
Mean density (August)	5.3	25.2	NS
Mean density (May+August)	5.8	8.1	NS

recorded at site 14. In May very high relative abundances were recorded at site 4 (26%), site 4 (19.1%), site 8 (18.2%) and site 3 (11.8% (Table 3)). Very low relative abundances were recorded in May at site 2 (0.9%). In August (Table 4) very high relative abundances were recorded at site 3 (11.2%), site 4 (13.8%), site 13 (33.1%) and site 17 (11.4%). Very low relative abundance was recorded at site 1 (0.3%), site 2 (0.5%) and site 16 (0.8%). No macro invertebrates were collected in lined water supply canals (sites 15 and 18). The gastropod mollusc was the most abundant, Limnaedae and Planorbidae, were the most abundant families present throughout the sampling period (Tables 3-4). Densities ranged between 50/m^2 in May and 48/m^2 in August.

Limnaedae ranked first in density among all species collected on all sampling dates. Belostamitadae ranked second to Limnaedae (Table 6). Other high ranking fauna were Planorbidae, Unionidae, Hydrachnidae, Sphaeriidae and Gyrinidae (Table 6). But there is no evidence that dominance change with time. The benthic dominance ranks shifted with changes in month (Table 6).

Figures 12-13 show that the benthic macro invertebrate Margalef index for the control sites was lower than that of the test sites suggesting differences in nutrient levels and sources. The Margalef index measures species richness and it tries to compensate for sampling effects (Magurran, 2004). For other commonly used diversity indices such as Shannon index (Shannon and Weaver, 1963) the proportions and not absolute numbers are considered. No significant differences were found in the Shannon index for benthic macro invertebrates between the control and test sites in all the study periods (Table 2).

Figures 14-15 show ordination diagrams which are based on Factor Analysis and Canonical Correspondence Analysis (CCA) of the associated water quality with benthic macro invertebrate organisms. The diagram of ordination displays the basic clusters (Figure 16) obtained by the classification technique. The benthic macro invertebrate families and individuals are located in the top plane of the right side between axis I and II. These organisms are followed by the cations Calcium, Magnesium and DO. TotN (Total nitrogen), NO3N, NH4N and TotPO4 (Total phosphate) show a special pattern and are separated in one group in negative side between axis I and II.

Table 5 shows the mean density (no. m^{-2}) of benthic invertebrates collected from the river bottom sediments for analysis. No significant relationships ($p>0.5$) in mean density of benthic macro invertebrates were found between the control and test sites (Table 5). The component loadings in Figure 14 suggest that Factors 2-3 have dominating influence in the Runde River. MCA were applied for the evaluation of temporal/spatial variations and the interpretation of a large complex water quality dataset of the Runde River. The results of Principal Component Analysis (PCA) and Factor Analysis (FA) revealed that most of the variations are explained by dissolved mineral salts along the whole Runde River and in individual stations. Cluster Analysis in Discriminant analysis showed the best results

Table 6. Ranking of benthic macro invertebrates at sample sites between May and August.

Species	May 2005	August 2004
Aeshnidae	8	2
Baetidae	6	10
**Belostamitadae*	2	
Chironomidae	6	
Chlorocyphidae		9
Coengriidae	5	10
Corbiculidae	6	2
Corydalidae		7
Dysticidae		10
Gerridae	6	6*
Gomphidae		7
Gyrinidae		5
Heptagenidae		6*
Hydrachnidae	5	4
Hydrophilidae	6	
Libellulidae	8	
Limnaedae	1	10
Physidae	6	8
Planorbidae	3	1
Psephenidae		6*
Sminthuridae		3
Sphaeriidae	5	6*
Unionidae		4
Vellidae	7	7

* same ranking

for data reduction and pattern recognition during both spatial and temporal analysis. Spatial DA revealed total suspended solids, calcium, sodium, alkalinity, nitrate nitrogen, total phosphorus, ammonical nitrogen, orthophosphates, calcium, magnesium, sodium, potassium, benthic families, conductivity, temperature, benthic individuals, dissolved oxygen in upstream and lower stream. FA clears the numerical fog in the analysis and interpretation of complex datasets in water quality assessment, identification of pollution sources/factors, and understanding of temporal and spatial variations of water quality for effective river water quality management. The factors outlined below show the important variables in each component loading.

Factor 1: pH, DO, Conductivity, TDS, Families, Individuals, TotN, NO3N, NH4N, TOTPO4, P2O5, Ca and Mg,

The variables Ph, Conductivity, TDS, Families, Individuals and P2O5 have high negative loadings on Component 1.

Factor 2: Temperature, Ph, Families, NH4N, TotPo4, Ca, Mg and K

Temperature, pH, TotN, Nh4N and P2O5 have high negative loadings on Component 2.

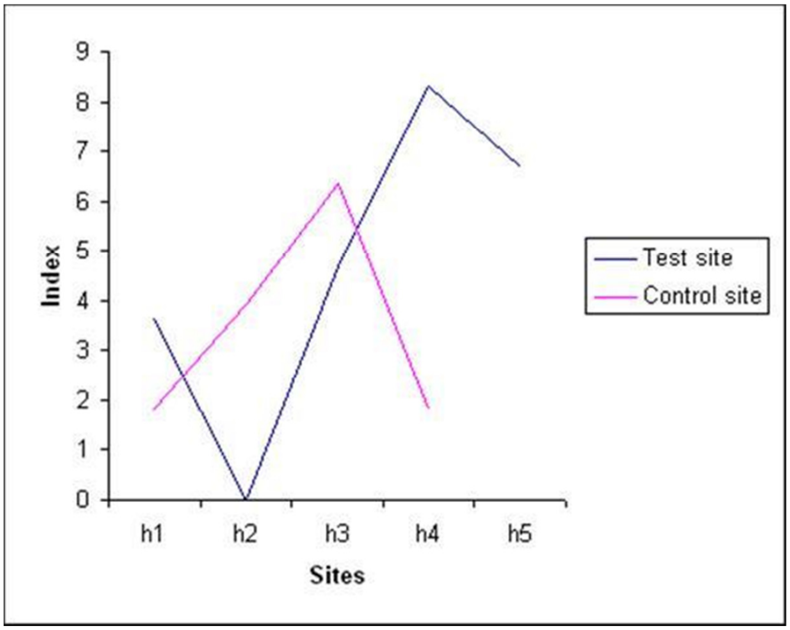

Figure 12. Benthic macroinvertebrate Margalef diversity index in May.

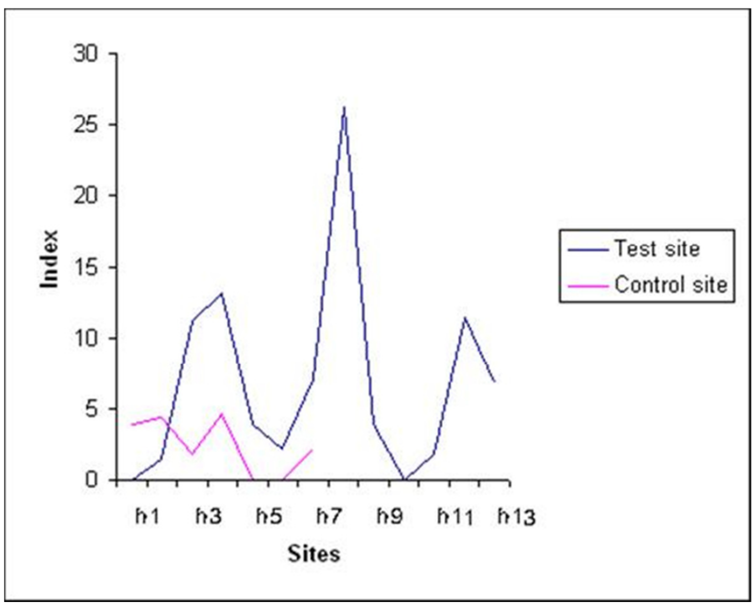

Figure 13. Benthic macroinvertebrate Margalef diversity index in August.

Factor 3: Temperature, Conductivity, Families, Individuals and K.
No3N and Mg have high negative loadings on Component 3.
Factor 4: Families, Individuals, P2O5 and Ca.
Ca and Mg have high negative loadings on Component 4.

The relationships among the plots are visualized in Figure 16. The plots have been

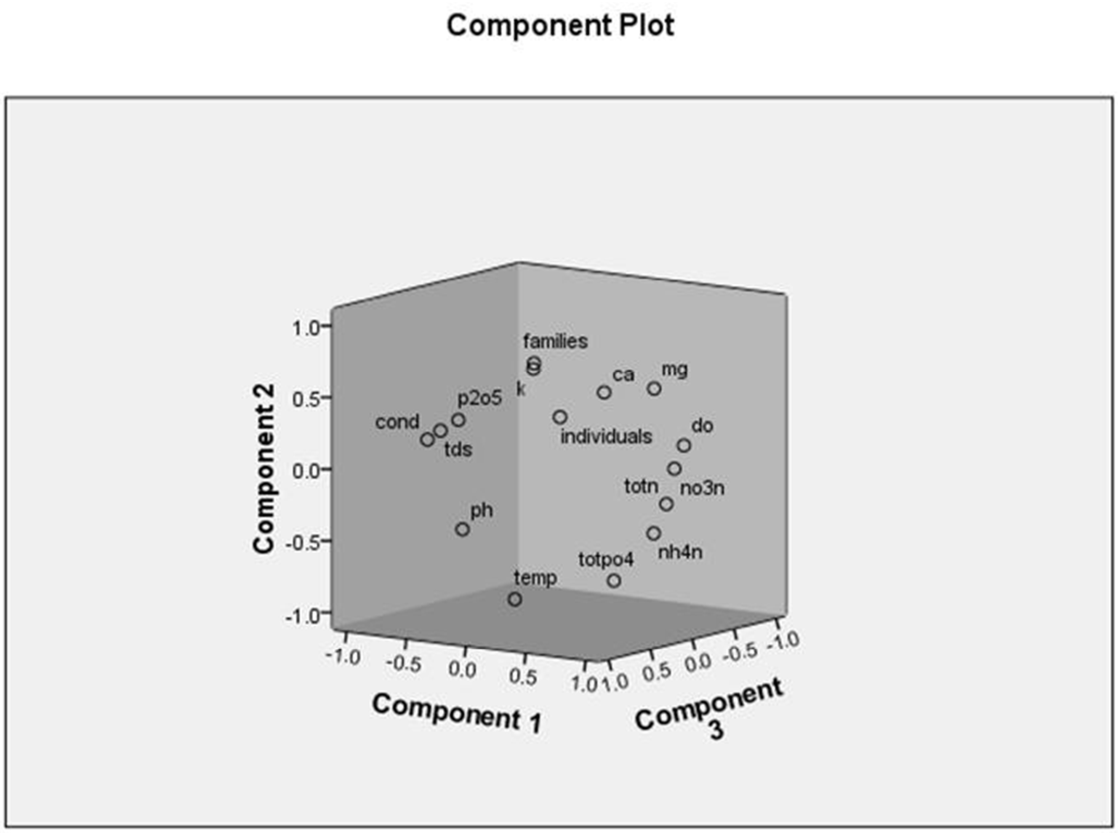

Figure 14. PCA output of investigated sample plots in water quality and benthic macro invertebrate families and individuals. Notes: PC1 explained 48.9%, PC2 explained 73.6% and PC3 explained 85.9% of the variance in the data.

grouped according to the relative influence influence of environmental variables. The pattern of the plots shows the failure of the environmental factors to discriminate the plots into degraded and undegraded water quality suggesting that the salient features of degradation of water quality play a minor role in determining the condition of the river water. Plot 4 which is a point source discharge channel is the only exception to have separated from the group of plots. The position of 4 as distinct from the rest of the plots shows the importance of point source regulation in environmental protection.

Descriptive Statistics, Multiple Correspondence Analysis (MCA), and Two step cluster analysis were used to analyse the data. The MCA was used as it organises 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 categorises individuals into groups according to the most salient characteristics. As a result homogenous categories of ordination were identified.

Water quality data were presented in five visualised clusters in Figure 16. Each cluster comprised a set of sites with greater homogeneity of water quality than when compared with other sample cluster. The relative influence of various environmental variables on macro invertebrates are expressed by arrows in the ordination plot, where the orientation of an arrow represents the direction of maximum change of a variable across the

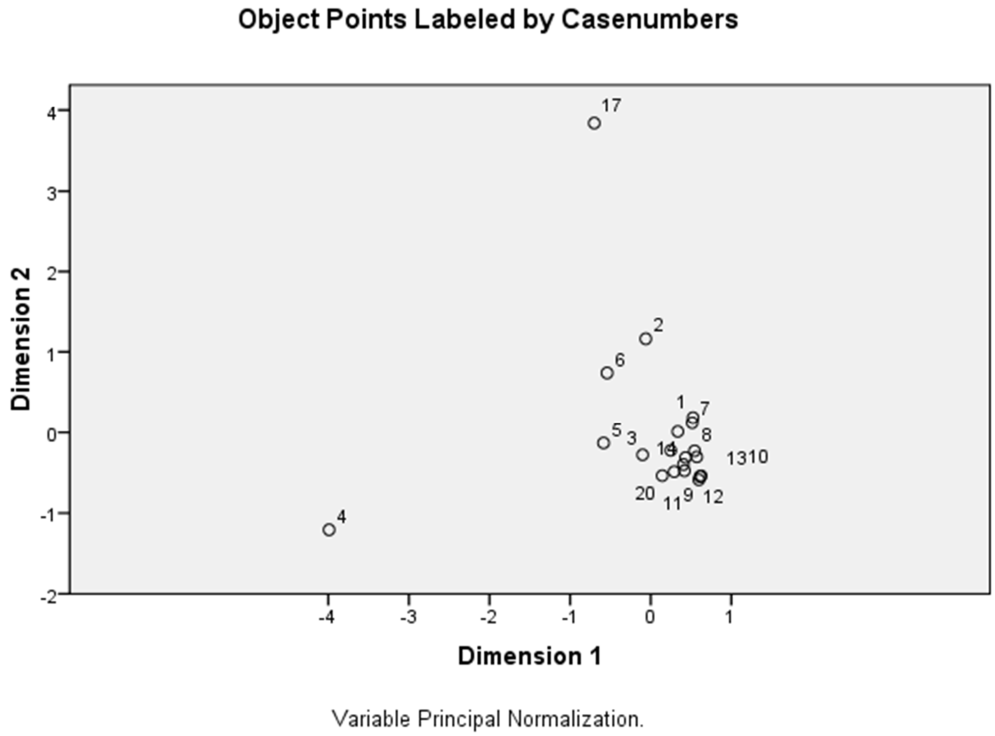

Figure 15. PCA output of investigated sample plots in water quality and benthic macro invertebrate families and individuals. Notes: PC1 explained 85.9 %, PC2 explained 48.8 %.

diagram, and the length of an arrow is proportional to the rate of change. Environmental variables with long arrows are more strongly correlated with the ordination axes than are those with short arrows, and thus more closely related with the pattern of water quality. All the variables describing the water quality are located in a distinct area along Dimension 1 and are scattered along Dimension 2. Four clusters can be seen in the ordination diagram (Figure 16). The first cluster recognized Mg, pH, DO, Temperature and Families as a group. The second cluster recognized NO3N, TotPO4 and individuals. Third cluster shows TDS and Conductivity as a group. The fourth cluster recognized TotN, NH4N, P2O5 and K as a group.

DISCUSSION

The results show that the low percentages of variability in the environmental factors Runde River indicate a poor effect of influence on the benthic fauna. Discharge points were found to maintain a localized influence on water quality. Discharge points influence on water quality requires regular monitoring to reduce the negative impacts at point sources. The environmental factors failed to separate in the PCA (Figure 15) into 2 main groups which include the impaired and unimpaired sites. This finding suggests that the Runde River is not significantly affected by the agricultural development in the area. Boyacioglu (2006) found broad groups that recognized pollution in the Buyuk Menderes River using PCA.

Compared to Marx and Avenant-Oldewage (1998) data, lower average dissolved oxygen concentration (6.1 mg/l) and average conductivity (305.5 μScm^{-1}) was recorded for the Runde River and tributaries. Average Secchi disc transparencies for the Runde River were higher than those recorded for the Olifants

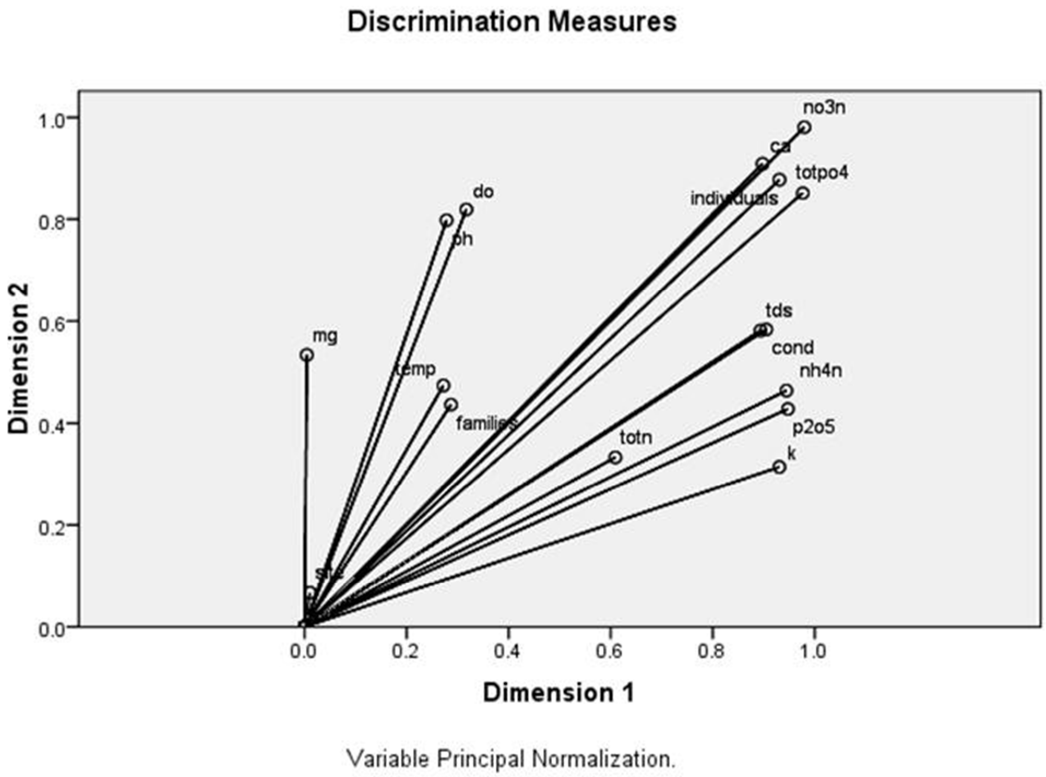

Figure 16. Redundancy Analysis biplot (D1x D2) of macro invertebrates and environmental variables (arrows). Arrows refer to the direction and relative importance of environmental variables in the ordination.

River. No macro invertebrates were found in April flood waters probably because the water became irritating to force the animals to go into drift. Macan (1963) suggests that benthic macro invertebrates may drown in wet summer floods. An increase in stream velocity can result in the disappearance of stream invertebrates due to increased drift (Wetzel, 2001). The molluscan community increased in density and diversity in test sites in August presumably as a result of changes in this habitat, which could have been brought about by influent water. The spatial variations in the water quality may have profoundly influenced dominance in key settlement areas of benthic macro invertebrates. These changes may not be independent of the physico-chemical factors.

Mean density of benthic invertebrates was 5-fold greater in sites below effluent outfall than in sites above effluent outfall in August but was almost even in May. The dominant taxa were Molluscs (gastropods+bivalves) (52%), Hemiptera (15%), Odonata (10%), Collembolla (6%), Coleoptera (4%) and Acari (3%). Spatial and temporal variations in the individual taxa may be considered in terms of intersite differences in runoff, substratum, and changing environmental factors such as water level, temperature, Ph, dissolved oxygen, light penetration, total dissolved solids and nutrients. A t test of the mean density (no.m^2), however, did not show significant differences ($p>0.05$) above and below effluent outfall suggesting that benthic macro invertebrate settlement areas may not be explained in terms of nutrient concentrations. Attempts to explain distribution of species in terms of chemical differences may not always have much success except where conditions are extreme. Benthic macro invertebrate density (no.m^{-2}) response to perturbation certainly does not support the notion that the Runde River is severely polluted by the upstream agricultural activities. Vesilind et al., (1994) suggest that benthic community responses to environmental perturbation are useful in assessing the impact of agricultural wastes. Macro invertebrates were abundant in all streams, but communities did not reflect degraded conditions; non-insect groups, mostly Mollusca, Hemiptera and Odonata dominated density and molluscs, mostly Planorbidae and Corcubilidae, dominated biomass. Of insects, mostly Odonata, dominated density and Hemipterans were important contributors to biomass.

The insect group was the most abundant animals in the sediment bottoms, and all the other non-insect groups were scarce. The greater abundance and species richness of the Runde River fauna may be attributed more to the warmer conditions in lowland areas than to the rich supply of food in the form of dissolved organic matter. It is clear from Figure 1 that the majority of sites are centrally clustered suggesting a failure in diagnostic characteristics to distinguish impaired sites from unimpaired sites. Sites 4 and 17 are outliers that are associated with discharge points. The physico-chemical and biodiversity of a river fluctuate seasonally and as a result there is need to continue further sampling campaigns on the Runde River.

CONCLUSION

The study recorded variations in the physico-chemical characteristics. A total of 12 orders, 26 families and 33 genera of macro invertebrates were discovered. No significant ($p.>0.05$) differences were found in Shannon index for benthic macro invertebrates between control and test sites. The Margalef index for benthic macro invertebrates for the control sites was lower than the test sites suggesting differences in nutrient levels and sources. The hypothesis that agricultural development is a key determinant of variability in benthic macro invertebrate distribution and abundance is rejected. Using MCA, PCA, FA the majority of sites were centrally clustered suggesting a failure in diagnostic characteristics to distinguish impaired sites from unimpaired sites an indication that the Runde River water quality is not different in the upstream and downstream of commercial agriculture. Perhaps there is need for a long time study on this river to establish the known impacts of commercial agriculture on river water quality.

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