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The Impact of Impoundment on Downstream Macro invertebrate Communities at Koga Irrigation Dam, West Gojam, Ethiopia

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Abstract: ***Despite its vital importance, river regulation affects downstream lotic environment and aquatic fauna. In this study, downstream effects of reservoir were evaluated using macro invertebrate bio-assessment techniques. Macro invertebrates community structure and physicochemical parameters were assessed at upstream and downstream sites relating to dam impact. Samples from four sites were collected using standard dip-net (500-µm mesh size) and identified to family level. Rapid Bio-assessment Protocol-II metrics and scoring criteria was used to quantify changes in macro invertebrate community structure and water quality. Downstream of reservoir; total abundance, Chironomidae abundance and Hilsenhoff Biotic Index values increased. However, richness, Ephemeroptera Plecoptera and Trichoptera taxa and Ephemeroptera abundance decreased. Trichoptera were absent from reservoir and downstream sites, but the number of gatherers and filter-feeder individuals were higher than reaches above the reservoir. Physicochemical parameters were significantly different ($p < 0.05$) among sites except temperature. A post-hoc test for Shannon Diversity Index indicated a significant difference ($p < 0.05$) between Site 1 and Site 4. Habitat and water quality changes have disrupted downstream continuum of macro-invertebrate communities. Generally, impoundments have profound impacts on macro invertebrates within reservoir and below it as indicated by this study; therefore, needs an appropriate conservation measures.***

Keywords: Downstream, Impoundment, Irrigation, Koga Dam, Macro invertebrates

1. Introduction

Mankind has modified lotic environments by reservoir construction for many centuries (Brandimarte *et al.* , 2005). In most countries worldwide the rapidly growing populations have placed demands on the water supplies to the extent that few of any large or medium sized rivers remain undisrupted by impoundments (Dickens *et al.* , 2008). Despite their vital importance and our total dependence in the natural systems, indeed river continuum is profoundly affected when subjected to alteration, which may be natural or human generated (denHeyer, 2007).

Although Africa is, after Oceania, the driest continent in the world, it uses few of its renewable water resources. Hence, potential for increasing irrigation still exists especially in sub-Saharan Africa in order to meet a significant contribution to food security and economic growth (FAO, 2007).

In Ethiopia, nearly 80% of the population is engaged in subsistence agriculture, which is largely rain-fed. There is a high year-to-year variability in the amount and timing of rainfall, and data suggest that there are recurrent periods of drought every 6-8 years in the country. The limited and unreliable availability of water has led to several dramatic episodes of famine in the past three decades (Tadesse, 2008). The urgent need for water security has led to the construction of dozens of small man-made reservoirs in the country. These structures, however, create problems such as changes in water quality, alteration of the aquatic ecosystems, and disruption of production systems. The biota within the impounded water and downstream of the dam are modified in response to these physicochemical changes (Palmer and O'Keeffe, 1990).

Aquatic organisms integrate the effects of a variety of pollutants and even reflect short-term, critical fluctuations in water quality (Hoang, 2009). Therefore, biological monitoring is essential to evaluate the environmental health of aquatic ecosystems. US EPA (1987) recommended a focus on biological assessment of water quality. This recommendation was based on evidence that measurement of the biotic component of aquatic ecosystem provides information about environmental stress that is missed by periodic or continuous monitoring of physical and chemical factors. Amongst aquatic organisms that can be used for bio-assessment, macro invertebrates have proved to be excellent indicators for the quality of freshwater stream habitats (Mandavillae, 2002; Rosenberg and Resh, 1993).

Most of the studies conducted in Ethiopian rivers (Baye Sitotaw, 2006; Solomon Akalu, 2006; Admasu Tassew, 2007; Birenesh Abay, 2007; Habiba Gashaw, 2010 and others), showed the relation between physicochemical change and the status of biological communities along the lake shores and rivers. However, these studies were focused on factors such as industrial waste discharges and tannery effluent that can influence the structure of benthic macro invertebrates. Hence, the particular impacts of river impoundments on downstream benthic fauna were not assessed. Thus, it is of great importance to evaluate the impact of river impoundments particularly on water bodies using benthic macro invertebrates as indicators. Therefore, in this study downstream effects of impoundments were examined using macro invertebrate monitoring to provide basic information about dam-related benthic macro invertebrate communities and to evaluate potential effects of dams on benthic resources.

The objectives of this study were therefore to:

- Determine the physicochemical parameters, composition and abundance of macro invertebrates in the upstream and downstream sites along the river
- Identify the habitat and water quality factors that have affected species distribution and macro invertebrate community structure and
- Assess the correlations between physicochemical and macro invertebrate metrics in order to relate them with downstream impacts of Koga river

2. Materials and Methods

2. 1 Description of Study Area

The study was carried out at Koga dam, West Gojjam Amhara Administrative Region. The catchment is situated between 11^{o} 11' to 11^{o}32' N and 37^{o} 04' to 37^{o}17' E with an altitude of 1803 m (at dam site) to 3200 m (at source of the river) above sea level. The plan of the project is to develop an irrigation scheme utilizing water stored in the reservoir. The study area was mapped with geographic information system (GIS) using information obtained by Global Positioning System (GPS: Magellan 315).

2. 2 Sampling

Prior to sampling reconnaissance was carried out and four sampling sites were established including the upstream reference sites. Reference site selection was based on the criteria for the reference site selection stated in David *et al.* (1998). Two reference sites on the upstream of reservoir, one site on the impoundment and one at the downstream were selected. The sites from S_1 to S_4 were used to study the degree of downstream habitat alteration and the impacts of impoundment on benthic macro invertebrates. The sampling sites were designated as S_1 to S_4.

3. Data Collection

3. 1 Physicochemical Data Collection

The physicochemical parameters measured in this study include pH, Temperature (T), Total Dissolved Solids (TDS), Conductivity and Dissolved Oxygen (DO). These parameters were selected because they were assumed to give immediate impact on the habitat and therefore measured in-situ using pH/T/TDS/Conductivity meter except Dissolved Oxygen which was measured in-situ using DO meter (970 DO2 meter, UK).

3. 2 Macro Invertebrate Data Collection

Samples of macro invertebrates were collected from October 2010 to March 2011 at the four sampling sites. All the sites had more or less of similar microhabitats which were situated at about 100m reach length. The samples from each microhabitat were pooled in order to represent more individual microhabitat patches and generate data sets with a larger amount of taxonomic information. Equal sampling effort was made at each sampling time in order to minimize bias that would result from inappropriate sampling technique. The visible macro invertebrates were removed using forceps and handpicking. The remaining debris was sieved with water through a 500 µm and put into the specimen bottle. Samples were preserved with 70% ethanol and 10% formalin in the field and identified in the laboratory using dissecting microscope and standard identification keys (Bouchard, 2004; Ehrlich and Steele, 2003; Gooderham and Tsyrlin, 2002).

Samples were taken according to the USEPA's Rapid Bio-assessment protocol II (Family Level) using standard dip net (500 µm mesh size) (Barbour *et al.* , 1999). Bioassessment of river water was done on the basis of the protocols and techniques given by Plafkin et *al.* (1989). Bio-classification of different sites of River were calculated in terms of total taxa richness, Family Biotic Index (FBI modified), ratio of scrapers/filterers and collectors, ratio of EPT (Ephemeroptera, Plecoptera and Trichoptera) and Chironomidae abundances, percent contribution of dominant-family, EPT index, and community loss index. Scoring method developed by Plafkin et *al.* (1989) was used separately to calculate family biotic index (FBI) which was then converted into the percent comparison and bioassessment scores. Total scores obtained were then used to categorize different sites. Finally, the percent comparability of total metric scores for each study site to those for a selected 'least impaired' reference stations yields an impairment score for each site.

4. Data Analysis

Data collected for the physicochemical parameters and benthic macro invertebrates were analyzed using Analysis of variance (ANOVA) and Pearson correlation. One way ANOVA was conducted on the data from upstream and downstream areas for temperature, conductivity, dissolved oxygen, TDS, pH and number of individuals for each sampling station. Pearson correlation analysis was used to determine the relationship between the number of macro invertebrate taxa, functional feeding groups and each of the variables: temperature, conductivity, dissolved oxygen and pH. All calculations, statistical analyses and graphs were calculated and drawn up by using Microsoft Excel spread sheet and SPSS statistical software Version 16. 00.

5. Results and Discussions

5. 1 Physicochemical Parameters

The mean and standard deviation values for the physicochemical parameters examined in the upstream and downstream sites during the sampling are given in Table 1. The mean pH concentration along the Koga Riverine system ranged from 7. 06 ± 0. 07-7. 15 ± 0. 02 (Table 1). This study revealed that pH was significantly higher ($p < 0.05$) at downstream site. However, there is no significant difference between upstream site 2 (S_2), downstream and reservoir. The increase in pH from upstream to downstream is likely to be the result of general increase in plankton productivity which effectively decreases CO_2 concentrations and boosts pH. Similar finding (an increase in pH at impacted sites) was recorded in the study conducted by Baye, (2006).

Temperature changes downstream of reservoir are considered a key factor contributing to changes in stream ecosystem integrity (denHeyer, 2007). This study showed an increase in temperature from upstream to reservoir but a decreasing trend at downstream. However, one way ANOVA test showed insignificant ($p > 0.05$) difference in temperature between the sampling areas of the upstream and downstream for all sampling periods. This might be due to differences in the sampling time of the day.

Conductivity between upstream (S_1), reservoir and downstream showed a significant difference with ($p < 0.05$). The highest conductivity values were recorded at downstream site, which is 165. 8µs/cm on average, and the minimum value recorded at sampling site1 with average conductivity value of 76. 95µs/cm. The mean concentration of total dissolved solid (TDS) ranged from 38. 58 ± 13. 84 - 82. 8 ± 7. 66. Reference sites (site1 and site2) averaged 38. 58 mg/l and 58. 85 mg/l respectively. However, impaired sites averaged 66. 25 mg/l and 82. 8 mg/l for site 3 and site 4 respectively. Downstream site (S_4) showed about two fold increment compared to reference site (S_1) indicating an increasing impact of impoundment on the downstream water bodies. There were significant differences in TDS ($p < 0.05$) between upstream (S_1), reservoir and downstream sites. These suspended solids are provided primarily by surface run-off from agricultural lands, river bank erosion caused by cattle grazing and watering along the river. Several studies (Dow and Zampella, 2000; Hoang, 2009) showed that watershed disturbance (and associated erosion) and organic loading from intensive agricultural activities and domestic wastewater discharges increase stream water ionic concentrations and subsequently conductivity. Therefore, the reasons for elevated TDS and Conductivity might be associated with watershed disturbance and run-off of organic wastes, fertilizers and pesticides from agricultural lands.

The mean dissolved oxygen concentration during the sampling period ranged from 8. 48 ± 0. 38- 8. 76 ± 0. 49 mg/l. There was no significant difference in dissolved oxygen between reference and impaired sites ($p > 0.05$). However, clearly the mean DO concentration was higher in the upstream sites. This might be as a result of anoxic water being discharged for irrigation that releases water from hypolimnetic part of the reservoir. This result is consistent with that of IEA (2000) which stated that low levels of DO in the reservoir and downstream sites might be due to the decomposition of organic matter from soil and vegetation inundated during reservoir impoundment.

Table 1: Physicochemical parameters of the study area with Mean (± SD) at each sampling time. (Conductivity in µs/cm, pH in pH scale, Dissolved oxygen in mg/l, TDS in mg/l and Temperature in °C)

Factors	Site 1	Site 2	Site 3	Site 4
pH in pH scale	7. 06 ± 0. 07	7. 1 ± 0. 03	7. 14 ± 0. 02	7. 15 ± 0. 02
Temperature (° C)	21. 65 ± 2. 55	22. 03 ± 2. 69	25. 25 ± 3. 66	23. 2 ± 2. 24
Total dissolved solids (mg/l)	38. 58 ± 13. 84	58. 85 ± 9. 79	66. 25 ± 14. 16	82. 8 ± 7. 66
Conductivity (µs/cm)	76. 95 ± 27. 65	117. 78 ±19. 16	133 ± 27. 99	165. 8 ± 15. 53
Dissolved oxygen (mg/l)	8. 76 ± 0. 49	8. 76 ± 0. 49	8. 16 ± 0. 62	8. 48 ± 0. 38

6. Biological Parameters

6. 1 Macro Invertebrate Assemblage

A total of 9032 macro invertebrates representing 10 orders and 37 families were recorded. Insects were the dominant group with 29 out of the 37 identified taxa. The Hemiptera were the most diverse order with 10 families, followed by Coleopteran and Ephemeroptera each with 5 families, Diptera with 4 families, Odonata with 3 families. Lepidoptera and Trichoptera were only represented by Pyralidae and Philopotamidae families respectively. Non-insect taxa include 3 families of Arachnida, 4 families of Gastropod mollusks and only one family of Hirudinea (Table 2). Of the total collected macro invertebrates, insects comprised more than 95% of total count (richness). Among insect orders, Diptera had the highest richness (38. 57%) caused by the high richness of chironomidae (19. 63%), followed by coleopteran (18. 59%), hemiptera (15. 98%), ephemeroptera (8. 83%) and lepidoptera and trichoptera (0. 06% each).

Table 2: Macro invertebrate Compositions Collected at Different Sites of Koga Riverine System

Taxa list	*Sites*					
	Reference Site 1 (S1)	Reference Site 2(S2)	Impoundment (Reservoir) Site 3 (S3)	Down stream Site 4 (S4)	TV	FFG
ARACHNIDA						
Pisauridae	3	0	10	3	8	Prd
Tetragnathidae	3	5	2	0	4	prd
Water mite	0	4	0	1	6	prd
COLEOPTERA						
Dytiscidae	10	36	0	8	5	prd
Elmidae	86	90	9	24	4	scr
Gyrinidae	120	13	0	0	4	prd
Haliplidae	115	624	22	31	5	shr
Hydrophilidae	24	76	79	312	5	c-g
DIPTERA						
Ceratopogonidae	28	24	50	38	6	prd
Chironomidae	233	418	899	1773	6	c-g
Culicidae	0	0	8	9	8	c-f
Tabanidae	0	0	0	4	5	prd
EPHEMEROPTERA						
Baetidae	164	129	25	34	5	c-g
Caenidae	85	48	135	167	7	c-g
Ephemeridae	1	1	0	0	3	c-g
Heptagenidae	1	4	0	0	3	scr
Trichorythidae	2	2	0	0	4	c-g
HEMIPTERA						
Belostomatidae	37	47	109	173	10	prd
Corixidae	3	4	159	24	9	prd
Gerridae	16	6	29	0	9	prd
Hydrometridae	3	1	0	0	9	prd
Mesoveliidae	5	6	0	0	9	prd
Naucoridae	14	31	0	0	5	prd
Nepidae	5	3	12	53	8	prd
Notonectidae	46	20	272	210	8	prd
Pleidae	9	9	43	47	8	prd
Veliidae	20	28	0	0	6	prd
HIRUDINEA						
Leech	0	0	22	105	10	prd
LEPIDOPTERA						
Pyralidae	1	4	0	0	5	shr
MOLLUSCA						
Lymnaeidae	0	0	12	90	6	c-g
Physidae	5	10	21	31	8	c-g
Planorbidae	0	0	10	26	7	scr
Sphaeridae	0	0	5	3	6	c-f
TRICHOPTERA						
Philopotamidae	3	2	0	0	3	c-f
ODONATA						
Aeshnidae	21	4	3	0	3	prd
Coenagrionidae	102	184	218	356	8	prd
Libellulidae	56	48	137	117	7	prd
TOTAL	1221	1881	2291	3639		
NO. OF TAXA	30	30	24	24		

Note: TV = Tolerance Value, FFG = Functional Feeding Groups, c-f = Collector feeders, c-g =collector gatherers, prd =predators, shr =shredders, scr =scrapers

As indicated in figure 1, the collected macro invertebrate were more abundant in the downstream and reservoir. Still the difference is statistically not significant (p = 0. 135). The results of this study showed that the impacted sites (reservoir and downstream) were dominated by the Dipterans, whereas the non-impacted reference sites were relatively dominated by Mayflies. The mean abundance of benthic community was also higher at downstream site. This suggests that reservoir discharge imposed downstream impacts on invertebrate abundance.

Taxa richness was generally higher in the upstream sites than the impacted sites (Figure 1). However, the difference was not significant. This might have come from the condition in which more tolerant taxa added while at the same time some of the more sensitive taxa are still able to survive. Such a situation will boost the overall number of taxa.

A post-hoc test for Shannon Diversity Index indicated a significant difference ($p < 0.05$) between upstream (S_1) and downstream site (S_4). This indicated that diversity was also impacted by the impoundment. Several studies have shown that the low taxa richness downstream of reservoir related to the physical, chemical and biological alterations (denHeyer, 2007; Munn and Brusven, 1991).

EPT taxa were higher in the upstream stations (6 taxa each) than reservoir and downstream sites where only two EPT taxa were recorded (Figure1). Pearson correlation analysis revealed that EPT index was highly correlated with all of the recorded physicochemical parameters. The high correlation ($p < 0.01$) of the EPT index with environmental variables indicated the potential of using this index as bio-indicators in the study area.

Site below reservoir, with decreased and altered flow patterns, supported more percent Chironomidae and percent dominant taxa and fewer percent Ephemeroptera than reference sites above the reservoir. Pollution sensitive Caddisfly families were completely absent from downstream site. The reduction in EPT taxa and percent Ephemeroptera indicates habitat alteration. Lenat (1988) explained that invertebrate taxa in the three EPT orders tend to be sensitive towards habitat disturbances and changes in water quality. Researchers (Lehmkuhl, 1972; Munn and Brusven, 1991) have linked downstream decline of EPT taxa to changes in habitat diversity, fluctuating water levels, altered thermal regimes and altered food supplies.

Analysis of variance for H-FBI scores showed significant difference among the four sites ($F_{3, 12} = 3.843$; $p = 0.039$). The H-FBI values in the present study showed an increase from upstream to downstream site. The HBI score increased as water quality decreased downstream indicating that benthic community is influenced by organic enrichment.

A reach in good condition will have high total richness and EPT richness, but low H-FBI score. In comparison to all other sites, site 1 and 2 had the lowest HBI which are 5. 04

and 5. 14 respectively (Figure 1). This indicated that the resident benthic community was populated with the most sensitive fauna of all sites examined. Therefore, the relatively low HBI, high EPT index, and high taxa richness at upstream stations and an increase in abundance and percent dominant taxa at reservoir and downstream sites supports site 1 and 2 designations as a reference sites.

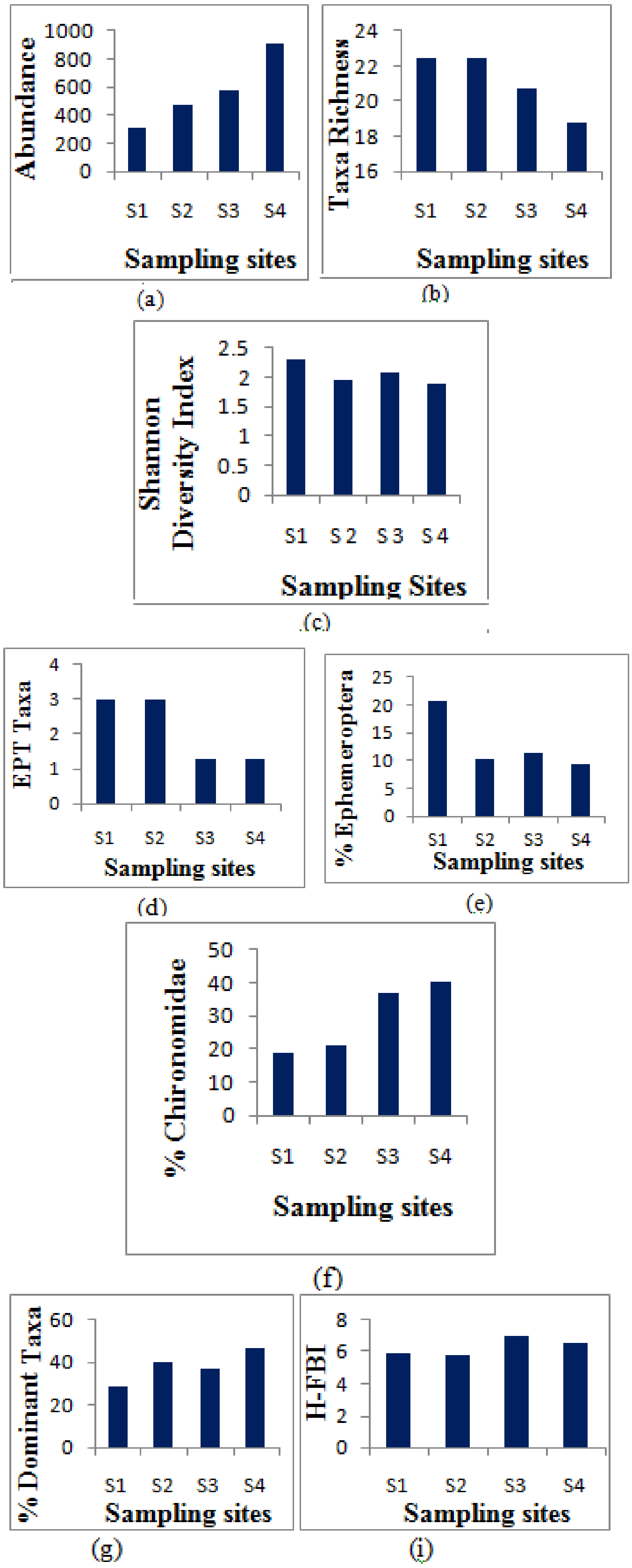

Figure1. Differences in Mean abundance (a), Taxa Richness (b), Shannon diversity index (c), EPT Richness (d), % Ephemeroptera (e), % Chironomidae (f), % Dominant Taxa (g) and HFBI (i) between upstream and downstream sites.

6. 2 Feeding Measures

The structure and function of macro invertebrate communities in streams with forested head water reaches follow a predictable progression, from the small, cold headwaters to the large, warm, more productive reaches near the mouth, called the River Continuum Concept (Vannote *et al.* , 1980). Small, shady headwater reaches tend to support invertebrates that consume fallen-leaf material (shredders and gatherers), whereas the larger downstream reaches, which receive more sunlight and less fallen-leaf material, support invertebrates that consume algae or decomposed leaf matter transported from upstream (filter feeders) (Ernst *et al.* , 2008). Based on the above concept, the result of the present study showed that the structure and function of macro invertebrate communities (in terms of functional feeding groups) below the reservoir is shifted, with few exceptions (see fig. 2).

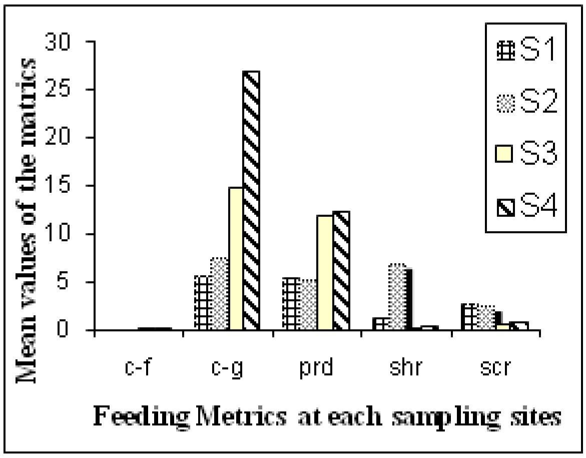

Figure 2: Mean differences of macro invertebrate feeding metrics at each sampling sites of Koga riverine watershed.

Gatherers were abundant below the dam comprising about 26. 9% of the total count and scrapers were slightly less abundant. This result is inconsistent with the study of Ernst *et al.* (2008), but supported by the idea of Serial Discontinuity Concept (Ward and Stanford, 1983) which states that the decreased ratio of coarse to fine-particulate organic matter in reaches below upper dam to reaches below middle reach dam will decrease the number of shredders. In the present study, shredders and scrapers agreed with the River Continuum Concept by increasing in the upstream sites, however, gatherers were not.

6. 3 Correlation between Physicochemical Parameters, Macro invertebrate Indices and Feeding Measure

Pearson correlation analysis between the macro invertebrate metrics and physicochemical parameters and water quality factors is indicated (Table 3). As it is shown in the table, water quality factors with exception of dissolved oxygen were negatively correlated to Ephemeroptera, Trichoptera and EPT individuals while strongly positively correlated to

Chironomidae individuals. Dissolved oxygen was positively correlated to Ephemeroptera, Trichoptera and EPT individuals and negatively to Chironomidae. This shows the reduction of these pollution sensitive taxa as human interference into system causes the increment to physicochemical parameters. The positive correlation between DO and EPT taxa indicate that EPT taxa responded parallel to DO level in the water. Pearson correlations have shown that scrapers were negatively correlated ($p < 0.01$) with all physicochemical parameters used in this study except dissolved oxygen which showed positive correlation. Predator functional feeding group showed a significant correlation ($p < 0.01$) with only temperature and dissolved oxygen concentration. The dominant functional feeding group in all the four sites was the Gathering-Collectors, which accounted for 26. 9% of the collected benthos and are about five times higher in downstream than upstream stations and two times than reservoir. However, upstream sites were dominated by shredder and scraper individuals; predators were two times more in the reservoir and downstream site. The negative correlation indicates that the increased physicochemical conditions have affected the scrapers functional feeding groups. However, DO was positively correlated ($p < 0.01$) indicating the reduction in scraper functional feeding groups with decreasing level of oxygen in the water.

Table 3: Pearson correlation (r) between environmental variables, macro invertebrate metrics and functional feeding groups

Factors	Macro invertebrate taxa					Functional feeding groups				
	Total taxa richness	Ephem-eroptera	Trich-optera	EPT-individuals	Chiron-omidae	Shredders	Scrapers	Gatherers	Filterers	Predators
PH	-0. 235	-0. 815	-0. 781**	-0. 819**	0. 816**	-0. 434	-0. 954**	0. 48	-0. 097	0. 349
	0. 381	0	0	0	0	0. 131	0	0. 06	0. 72	0. 185
Temperature	-0. 364	-0. 780**	-0. 493	-0. 780**	0. 742**	-0. 394	-0. 710**	0. 177	0. 205	0. 629**
	0. 166	0	0. 052	0	0. 001	0. 131	0	0. 512	0. 445	0. 009
TDS	-0. 244	-0. 723**	-0. 589*	-0. 725**	0. 749**	-0. 362	-0. 796**	0. 494	0. 099	0. 13
	0. 362	0. 002	0. 016	0. 001	0. 001	0. 169	0	0. 552	0. 717	0. 631
Conductivity	-0. 238	-0. 721**	-0. 590*	-0. 723**	0. 748**	0. 362	-0. 796**	0. 496	0. 102	0. 13
	0. 357	0. 002	0. 016	0. 002	0. 001	0. 169	0	0. 051	0. 706	0. 633
DO	0. 387	0. 790**	0. 506*	0. 790**	-0. 749**	0. 389	0. 725**	-0. 176	-0. 165	-0. 623**
	0. 139	0	0. 046	0	0. 001	0. 137	0. 001	0. 515	0. 541	0. 01

**. Correlation is significant at the 0. 01 level (2-tailed).
*. Correlation is significant at the 0. 05 level (2-tailed).

6. 4 Bio-classification of River Water

The biological condition of the river water was examined using a modification of Rapid Bioassessment Protocol II (RBP II) metrics and scores (Plafkin et *al.* , 1989). Metrics values for each station were scored based on comparability to the reference stations, and scores were totaled. The percent comparability of total metric scores for each study site to those for a selected 'least impaired' reference stations yields an impairment score for each site (Table 4). The analysis separates sites into four categories: non-impaired, slightly impaired, moderately impaired and severely impaired (Table 5). The biological condition scoring criteria for each benthic macro invertebrate parameter assigns numeric values of 6 for non-impaired, 4 for slightly impaired, 2 for moderately impaired and 0 for severely impaired sites (Plafkin et *al.* , 1989). Each impact category corresponds to a specific aquatic life use-support determination used in the Clean Water Act (CWA) Section 305 (b) water quality reporting process. Non-impacted and slightly impacted communities are assessed as 'support' in the 305 (b) reports; moderately impacted and severely impacted communities are assessed as 'impacted' (Table 5). According to the results obtained from the bio-classification, the sites were ranked as: station 1 and 2 > station 3 and station 4. This indicated that the reference sites were excellent in terms of biological condition and therefore were classified as non-impaired sites. However, reservoir (S_3) and downstream (S_4) sites were moderately impaired category regarding biological conditions indicating poor water quality (Table 5). This finding is supported by the finding of Sharma (2003), in which upstream sites were classified excellent in terms of biological condition while downstream sites were classified as non-impaired. Changes in water quality from upstream reservoir can alter the abundance and diversity of downstream benthic macro invertebrate communities. Moreno and Callisto (2006) determined that the poor water quality below an impoundment led to the degradation of macro invertebrate community with low values of taxa richness and diversity and high abundances of tolerant organisms. Therefore, water quality changes observed below the reservoir during the present study may have been responsible for changes observed in macro invertebrate abundance and composition. In conclusion, macro invertebrate assemblage generally showed a predictable pattern of change from upstream to downstream sites. Water quality data also indicated a decreasing trend from upstream to downstream stations. Therefore, the structure and function of macro invertebrate communities in the reservoir and downstream area were impaired. Physical habitat data indicated that the low water temperature and low flows at the site downstream of reservoir created conditions that interrupted the expected progression of stream invertebrate communities below the reservoir. The macro invertebrate communities in the site below reservoir supported fewer Ephemeroptera and none Trichoptera, and fewer scrapers and shredders than sites unaffected by the reservoir, but more Chironomidae and gatherers. Flow alterations have disrupted the expected continuum of macro invertebrate communities from headwaters to downstream reaches. Macro invertebrate abundance, total taxa richness, and EPT taxa richness were reduced at downstream reaches while HBI was increased. Bioclassification results of the Koga River showed that the water quality is excellent in terms of biological conditions in the stations upstream of the reservoir. It is likely that this stream was impacted by physical, chemical and biological changes induced by the impoundment (Table 5).

Table 4: Metric Values, Percent Comparison, and Bioassessment Scores for Benthic Macro invertebrate Results: Family-Level Identification Data

	Metric Value				Percent Comparison				Bioassessment Scores			
Metrics	site 1 (ref)	site 2 (ref)	site 3	Site 4	site 1 (ref)	site 2 (ref)	site 3	site 4	site 1 (ref)	site 2 (ref)	Site 3	site 4
Taxa Richness	30	30	24	24	100		80	80	6		6	6
EPT index	6	6	2	2	100		33. 33	33. 33	6		0	0
Scr : c-f	84	111. 5	3. 38	7	100		4. 02	8. 33	6		0	0
EPT : Chironomidae	1. 1	0. 445	0. 178	0. 113	100		16. 18	10. 27	6		0	0
% Dominant Taxa	19. 08	33. 17	39. 24	48. 72	19. 08		205. 66	255. 35	6		0	0
Shr : Non-Shr	0. 1	0. 5	0. 01	0. 01	100		9. 62	9. 62	6		0	0
Community Loss Index	0	0	0. 46	0. 54	…	…	…	…	6		6	4
H-FBI	5. 9	5. 81	7. 04	6. 68	100		119. 24	113. 16	6		6	6
Total Score									48		18	16
									100%		37. 50%	33. 33%
Biological Condition									None		Moderately impaired	Moderately impaired

	Metric Value				Percent Comparison				Bioassessment Scores			
Metrics	site 1 (ref)	site 2 (ref)	site 3	site 4	Site1 (ref)	site 2 (ref)	site 3	site 4	Site 1 (ref)	site 2 (ref)	site 3	site 4
Taxa Richness	30	30	24	24		100	80	80		6	6	6
EPT index	6	6	2	2		100	33. 33	33. 33		6	0	0
Scr : c-f	84	111. 5	3. 38	7		100	3. 03	6. 28		6	0	0
EPT : Chironomidae	1. 1	0. 445	0. 178	0. 113		100	40	25. 39		6	2	2
% Dominant Taxa	19. 08	33. 17	39. 24	48. 72		33. 17	118. 3	146. 88		2	0	0
Shr : Non-Shr	0. 104	0. 5	0. 01	0. 01		100	2	2		6	0	0
Community Loss Index	0	0	0. 46	0. 54		…	…	…		6	6	4
H-FBI	5. 9	5. 81	7. 04	6. 68		100	121. 25	115. 07		6	6	6
Total Score										44	20	18
										100%	45. 45455	40. 90909
Biological Condition										None	Moderately impaired	Moderately impaired

Table 5: Categorization of the River Water into Impairment Level Based on Percent Comparison to Reference Station. Note: reference stations (S_1 and S_2) are considered to represent the 'best attainable' condition and to be Supportive of the Aquatic Life Use Determination

<table>
<tr><td colspan="5">Koga River Bio-assessment</td><td rowspan="6">Aquatic life use determination</td></tr>
<tr><td>Natural Or least 'impacted'</td><td>Non-impacted</td><td>Site 1 and 2</td><td>Comparable to the best situation to be expected within eco-region, watershed, etc. Balanced trophic structure. Optimum community structure (composition and dominance) for stream size and habitat.</td><td rowspan="2">Support</td></tr>
<tr><td rowspan="2">Biological Condition</td><td>Slightly impacted</td><td></td><td>Community structure less than expected. Composition (species richness) lower than expected due to the loss of some intolerant forms. Percent contribution of tolerant forms increases.</td></tr>
<tr><td>Moderately impacted</td><td>Site 3 and 4</td><td>Fewer species due to loss of most intolerant forms. Reduction in EPT index. Unbalanced trophic structure.</td><td rowspan="2">Impacted</td></tr>
<tr><td>Degraded</td><td>Severely impacted</td><td></td><td>Few species present. One or two taxa dominate.</td></tr>
<tr><td colspan="5">Low………Human Disturbance Gradient………High
(Stressor Gradient)</td></tr>
</table>

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