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Assessment of the ecological impacts of floriculture industries using benthic macroinvertebretes metric index along Wedecha River, Debrezeit, Ethiopia

Sisay Misganaw Tamiru
Department of Development and Environmental Management Studies, University of Gondar, PoBox 196, Gondar, Ethiopia
sisymis@yahoo.com

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Abstract

Wedecha River was loaded with floriculture industries effluent in Debrezeit; which is very important for agriculture and domestic activities of the surrounding people. It was exposed to waste water discharge from floriculture industries. Biological information was used to assess the quality of water and anthropogenic impacts on aquatic ecosystem. A total of 6 sites, one reference site less impaired to represent natural conditions from upstream, and 5 impaired sites in the downstream were sampled for macroinvertebrates parameters in the Wedecha River to assess the quality of water, ecology of the river and impact on aquatic life. Impaired sites data were compared to reference conditions. 18 metrics representing richness, composition and tolerance/intolerance measures were considered for the index development. Of these, 7 metrics were found to be useful because they give unique information in the reference site with impaired sites. The metrics used for the development of index were total number of taxa, number of Mollusca, percent Hemiptera, percent Chironomidae, percent Coleoptera, percent Mollusca and percent dominant taxon. The metrics were scored on a continuous scale from 0 (poor) to 10 (good) using the upper and lower threshold of their distribution in the reference and impaired sites. For the development of Wedecha river index, scales were added to produce a score from 0-100. The index was divided into four classes; greater than 75 was very good (S0=100), 50-74.9 was good (no metric in this division), 25-49.9 was poor (S5=44) and less than 24.9 was very poor (S1, S2, S3 and S4 with a MI score of 13.4, 5.4, 3.6, and 9.3, respectively). The MI was effective for distinguishing impacted sites. Therefore, floriculture industries wastewater discharged to the nearby rivers has enormous effect on the degradation of the ecosystem. To sustain the ecological conditions of the nearby rivers, wastewater treatment and environmental audit are suggested. Environmental assessment and environmental auditing enables the floriculturist to keep humans and the environment safe. Taking care of workers, soil, water and the environment has to be seen with great care and caution because it is difficult to maintain a healthy community and carry out development in a degraded environment.

Keywords: Water quality, Macroinvertabrate, Pollution, Metrics, Biodiversity, Abundance.

Introduction

Floriculture industry is one of the booming sectors in Ethiopia. Due to the growth of the industry, environmental concerns are growing. Environmentalists are raising many concerns in relation to the expansion of floriculture industries in Ethiopia such as the use of pesticides and chemical fertilizers, disposal of waste and the protection of water bodies. The industry uses too much pesticides and chemical fertilizers which damage the environment. According to the Ministry of Agriculture and Rural Development, Crop Protection Department's Quarantine Office; Ethiopian Floriculture industries uses more than 300 chemicals as pesticides and growth regulators. Thus, its discharge found to kill useful organisms and disturb biodiversity. It is believed that too much pesticide is getting into water bodies damaging the biodiversity and excessive chemicals killing useful organisms in the soil[1,2].

Ecological integrity is the summation of chemical, physical and biological integrity[3]. So that degradation of water resources with floriculture effluent occurs by altering attributes that influence and determines the integrity of surface water resources, such as water quality, habitat structure, flow regime, energy source and biotic interactions that influence the ecological integrity of the whole system[4,5].

Benthic macroinvertebrates have proven to be a very useful tool for testing aquatic ecological paradigms. Ecologists recommend the use of resident organisms as bioassessment tool, such as insects, arachnids, aligochaets, molluscs that are sensitive indicators of disturbances[6]. Biological assessments are used to evaluate impacts on aquatic ecosystems[7]. Biological monitoring and assessment of aquatic systems is widely accepted as complementing more traditional methods of evaluating human impact based on physical and chemical variables. Biological assessments are often used to indicate the water quality and changes on the aquatic community[8,9].

Biological parameters, called metrics represent elements of the structure and function of the bottom dwelling macroinvertebrate assemblage. Metrics change with increased human influence[10]. Metrics include specific measures of diversity, composition, and functional feeding group and include ecological information on tolerance to pollution[11].

Bioassessment is a monitoring technique to characterize the health of a water body. A water body's health can be determined by gathering multiple measures of biological data, converting the data into a single numeric index, and then comparing the index with an index developed for a reference condition/ minimally impacted[12].

This study was designed along Wedecha River near Debrezeit. There are many floriculture industries established along Wedecha River. These industries discharge their effluent wastewater to the nearby water bodies including Wedecha River. The industries are known to use different toxic chemicals, and the effluent water may pollute the surrounding water bodies. The study was designed to assess the effect of these floriculture industries on the surrounding rivers using bioindicators.

It was hypothesized that Floriculture industries wastewater affects the diversity and abundance of macroinvertebrates in rivers. The major objective of the study was to assess the ecological impacts of floriculture industries on surrounding river ecosystem, using bentic macroinvertebrate assemblages as bioindicators. But specifically it was based on the objectives: 1. Assess the effects of floriculture industries wastewater on macroinverteberates biodiversity (stream biota) using metrics such as richness measures (eg. Total taxa), composition measures (eg. percent chironomidea) and tolerance measures (eg. percent dominant taxa). And Select macroinvertebrates metrics and develop BMI (Biotic Metric Index) for Wedecha River.

Materials and methods

The study area: This study was conducted near floriculture projects, at Debrezeit along Wedecha River. Debrezeit is found in Oromiya administrative region, East Shewa Zone, Adaa Chukala Wereda, 50 kms west of the zonal capital, Nazaret and 45 kms east of Addis Ababa. Its central coordinates are 038o05'53" East, 08o44'52" North at an Altitude of 1925ms (Figure-1). It is characterized with a humid tropical climate and intense precipitations from June to August. The air temperature varies around the year from a minimum of 06°C to a maximum of 36°C (Ethiopian National Metrological Services Agency, personal communication).

Wedecha River is found about seven kms north of Debrezeit town. It originates in the central highlands of Ethiopia and flows through populated area, the central rift valley and discharges to the Awash River in the southeast. Streams throughout the area generally have moderate to high flows and narrow floodplains including Wedecha River. There is intensive agricultural activity including cattle grazing and establishment of floriculture industries in the surrounding of Wedecha River. There are more than 15 floriculture industries. The effluent of floriculture industries is directly discharged to the river (Appendix-1).

Sampling sites S0 to S5 are upstream to the downstream are in the region bounded by latitudes 08°46'21" to 08°47'49" and by longitudes 039°00'53" to 039°01'02", and ranging in altitude from 1,872 to 1,885 ms. This was measured using Global Positioning System (GPS). The upstream site was considered a reference site (S0). Sites were chosen near the relevant discharge point along 100 meters (S1, S2 and S3) and S5 on the downstream near the newly established floriculture industries. But site S4 is about one km away from the discharge points in the downstream between S3 and S5 (Figure-1).

The water quality of Wedecha River was studied on the basis of its agricultural and domestic activities (drinking, washing etc.); as floriculture industries are discharging the wastewater in to the river.

Reference conditions: To address levels of impact to any given river, understanding of the inherent biological variabilities and natural potentials of streams is necessary. This is accomplished using a reference approach[13], which is based on minimal human impact. The objectives of the reference are to collect and summarize data from least disturbed site using as a framework in order to develop appropriate criteria for bioassessment interpretation[14].

Selection of reference area: Reference sites for each location must meet 11 criteria[15]: i. pH > 6 if black water stream, then pH<6 and DOC>8 mg/l, ii. DO > 4ppm, iii. Nitrate < 300 mg/l, iv. Urban land use < 20% catchment area, v. Forest land use > 25% catchment area, vi. Remoteness rating: optimal or suboptimal, vii. Aesthetics rating: optimal or suboptimal, viii. Instream habitat rating: optimal or suboptimal, ix. Riparian buffer width >15m, x. No channelization, xi. No point source discharge.

However, as there was a problem getting a reference site that fulfills all the above criteria; it was identified based on the following criteria as indicated[16]: i. Same water body type, size, and chemical characteristics as treated site, ii. Within same watershed as treated site, iii. Minimal application of aquatic pesticides within the last few years, and iv. Limited anthropogonical inputs.

A reference site, S_0, was selected to compare against the contaminated sites in all impacted sites. Biological measures taken in impacted sites were compared to this reference site. S_0 was chosen because it is found in the upper stream of the river with no floriculture impact and has some of the lowest levels of the contaminants from agricultural activities and grazing animals and it fulfill some of the above criteria.

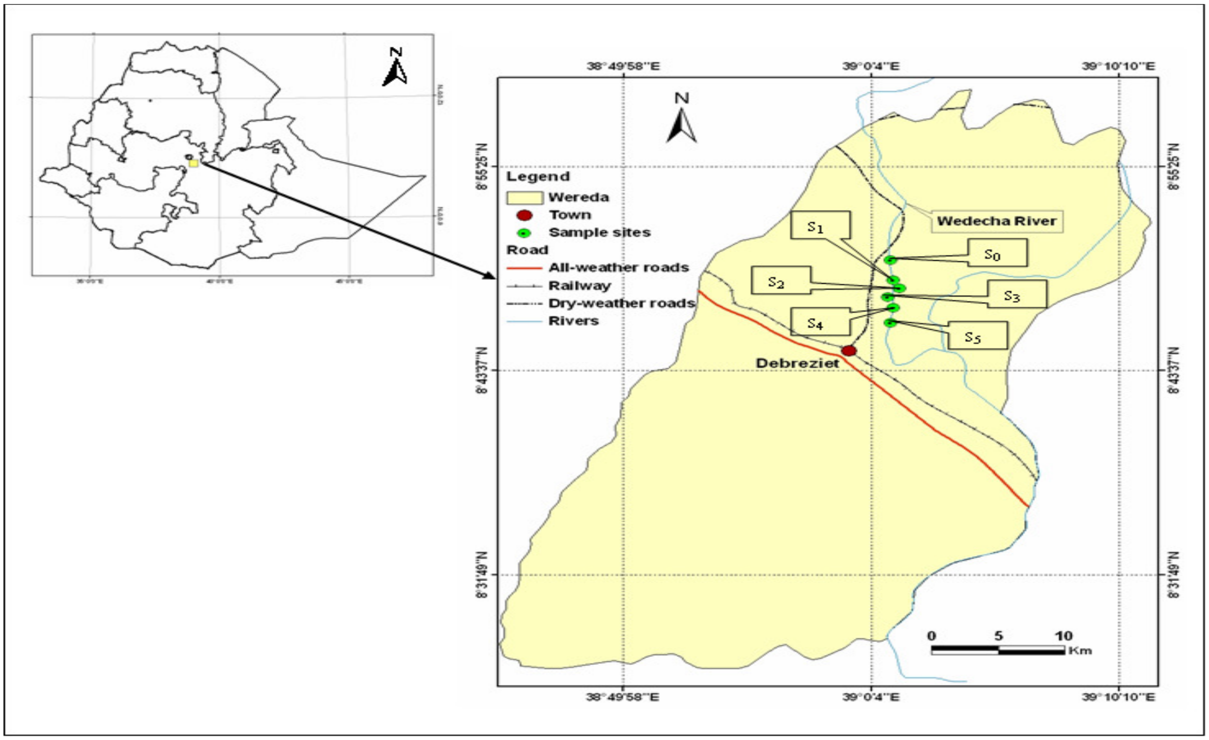


Figure-1: Map of Wedecha River showing study sites, S0 to S5 from upstream to downstream (The researcher).

Sampling: Samples were collected at approximate monthly interval following the protocols used for wadable rivers[17].

Sampling sites covered 100 meters stretch (for impacted sites starting from point sources of discharge) to the macroivertabrates sampling.

Benthic macroinvertebrate samplings were conducted in the dry season, when the benthoses are thought to be reliable indicators of environmental stress; there is no rain dilution factor.

Macroinvertebrate sampling and identification: Benthic macroinvertebrates were collected to provide a qualitative description of the community composition at each sampling site. Samples were collected at each of the six sites by disturbing the substrate within a distance of about 0.5m above the mouth of a net. The kick (disturbed) samples were collected in a standard Scoop net and Surbur sampler (mesh size = 500 µm, sampling area = 0.9 m^2). Sampling was continued for 30 minutes for a distance of 100 meters following the wadeble rivers protocols for streams[17,18]. The kick samples of all members of a group in one site were collected in a single bottle and preserved with 96% ethanol with a label identifying the location, date and time.

Addis Ababa University, Limnology laboratory on the day following the collections, benthic macroinvertebrate samples were cleaned and the samples were transferred to white enamel or plastic tray and a small amount of the sample was randomly placed in a Petri dish to be identified. Using a dissecting microscope and identification keys aquatic insects were identified to family level and placed in vials containing 70% ethyl alcohol.

Only the organisms from the sweep were used to estimate the index based on relative abundances of macroinveratbrates. All sweeps were used to calculate the index based on taxon richness.

Metrics were reviewed based on description in the Hilsenhoff from the data[19]. Then Wedecha River index was calculated from the metrics from the data to produce an estimate of aquatic community health at each site.

Macroinvertabrate Metric Selection: Metrics: A metric is a characteristic of the biota that changes in some predictable way with increased human influence[20]. Various attributes of the benthic macroinvertebrate community have been characterized in the form of quantitative measures called metrics. For example, metrics dealing with species richness or diversity, such as total taxa, can be used as indicators of community health because an ecologically healthy system is generally expected to support a more diverse community of fauna that can be supported in an ecologically impaired area. The identifications and counts of organisms collected at each site provide the information used to calculate a suite of metrics for each benthic sample[20,21].

Metrics evaluated for use with benthic macroinvertebrate data in a typical Macroinvertebrate Index of Biotic Integrity (MIBI) are represented in four categories[19].

Metric categories: i. Richness measures (such as total taxa), ii. Tolerance measures (such as percent tolerant taxa), iii. Composition measures (such as percent dominant taxa), and iv. Trophic structure measure (such as percent shredders)[19,21].

Index: An IBI (Index of Biological Integrity) is made of combining several biological indicators, called metrics into a summary index. The summary can be used to measure the condition of a water body as well as diagnose the type of stressors damaging the organisms living in the water. Measuring the biota within a water body provides a good assessment of resource condition because the characteristics of the biota reflect the degree of human influence in the surrounding water bodies. This information can then be used to minimize the negative impacts and improve the health of the water and the surrounding habitat[22]. IBI metrics evaluate species richness; indicator taxa (stress intolerant and tolerant); relative abundances of trophic guilds and other species groups; the incidence of hybridization, disease, and anomalies such as lesions, tumors, or fin erosion (fish) and head capsule abnormality (stream insects)[23].

For index development, a set of metrics or community attributes; only those metrics that are known to be responsive to river degradation are used. Each of the metrics index is calculated from the sample data[20].

Seventeen metrics representing richness, composition and tolerance/intolerance measures were considered for the index development (Table-2). During development of index, a metric has to: i. be able to differentiate between reference and impaired sites (show habitat degradation), ii. represent at least some different aspects of the community (species composition, richness, tolerance, feeding groups, and the like), and i. minimize redundancy among individual component metrics or provide unique information i.e. not be linearly correlated with another metric or no overlap of information[11,20].

Table-1: Candidate metrics and expected direction of metric response to increasing perturbation[15].

Category	Metrics	Description (Definition)	Expected response to Increasing impact
Taxonomic Richness	No. taxa	Measures the overall variety of the macroinvertebrate assemblages	Decrease
	No. Odonata taxa	Number of dragonflies and damselflies taxa	Decrease
	No. Hemiptera taxa	Number of water or true bugs taxa	Decrease
	No. Diptera taxa	Number of "true" fly taxa, which includes midges	Decrease
	No. Chironomidae taxa	Number of taxa of chironomid (midge) larvae	Decrease
	No. Coleoptera taxa	Number of beetle taxa (adult or larva)	Decrease
	No. Mollusca	Number of taxa of Mollusca	Increase
	No. Physidae taxa	Number of taxa of Physidae	Increase
	No. Planorbidae taxa	Number of taxa of Planorbidae	Decrease
Taxonomic composition	% Odonata	Percent of mayfly nymphs	Decrease
	% Hemiptera	Percent of caddisfly larvae	Decrease
	% Diptera	Percent of dipterans	Decrease
	% Chironomidae	Percent of midge larvae	Decrease
	% Coleoptera	Percent of beetle larvae and aquatic adults	Decrease
	% Mollusca	Percent of Mollusca	Increase
	% Physidae	Percent of aquatic Mollusca	Increase
Tolerance/ Intolerance	% Dominant taxon	Percent of the most abundant taxon	Increase

Statistical analyses: Bivariate statistics, boxplot and scaterplot graphs were used to evaluate biological parameters among the reference and impacted sites. Pearson bivariate correlation analysis was used to relate benthic macroinvertebrate metrics to each other. All statistical analysis was performed using the SPSS statistical software[24] and Excel spreadsheet.

Results and discussion

Along Wedecha River, a total of 6 sites, one reference site and five impaired sites were surveyed during the study periods (Figure-1). From samples collected for analyses of benthic macroinvertabrates and summary of the macroinvertebrates collected from each sites are given in Table-1 and Appendix-1, respectively.

Benthic Macroinvertebrates: A total of 17,373 macroinvertebrate individuals of 34 families were collected from all 6 sites of the study area (Appendix-1). Macroinvertebrate sample sizes ranged from 77(S5) to 6,309 (S4) individuals per site and taxa richness ranged from 7 (S1 and S5) to 30 families (S0). Physidae (Mollusca) was the most abundant family collected (5992 individuals), followed by Hydrobiidae (Mollusca, 715 individuals), Coenogrionidae (Odonata, 467 individuals), Viviparidae (Mollusca, 354 individuals), Gerridae (Hemiptera, 308 individuals), Chironomidae (Diptera, 128 individuals), Notonectidae (Hemiptera, 126 individuals), others are below 100 individuals. Among the 34 families collected (Appendix 1), 15 were found only in the reference site, 4 were commonly found in impaired sites, and 2 were common in impaired and the reference site. The abundance of organisms is given in Table 2(A-C).

Coleoptera and Hemiptera were abundant in the reference and impaired sites almost in the same proportion. Most larval and adult aquatic Coleoptera (Beetles) are tolerant of wide changes in pH and dissolved oxygen concentration. Many adults cannot use dissolved oxygen and must rise to the surface to respire atmospheric oxygen. Few beetles are recognized as indicator organisms of environmental health[25,26]. Most hemipterans are either lentic or slow water lotic forms. They are all air breathers and are more tolerant of environmental extremes than most other insects. The water boatman, the water strider, Gerridae, are among the few insects that can tolerate pH values less than 4.5 and are among the last to disappear when lakes and streams acidify[27].

Invertebrates used to evaluate water quality are often given a number to represent their tolerance or intolerance to pollution; higher numbers represents increased tolerance while lower numbers represent intolerance[28,26].

Values of 0 through 3 are considered indicative of a low tolerance to stress, values of 4 through 6 a moderate tolerance, and values of 7 through 10 a high tolerance. The pollution tolerance values are based on one or a few types of impacts[19]. Pollution tolerance values are mainly given for organic pollution and may not accurately reflect an organism's tolerance to heavy metals or toxic chemicals (pesticides)[28,29]. Tolerance values of the macroinvertabrates of the study area from appendix1 are shown in Table-3. So that we can evaluate the water quality of the study area on tolerance values of the organisms.

Table-2(A-C): Common macroinvertebrate families at reference and impaired sites.

(A) Taxa very common at the reference site.

Taxa		Abundance	% *
Order	Family		
Ephemeroptera	Baetidae	13	100
Odonata	Aeshinidae	33	94.3
	Calopterygidae	13	100
	Coenogrionidae	442	94.6
Diptera	Chironomidae	116	90.6
	Psychodidae	26	100
	Simuliidae(black flies)	13	100
Hemiptera	Belostomatidae	46	75.4
	Corixidae	31	91.2
	Gerridae	298	96.8
	Notonectidae	103	81.7
	Velidae	49	100
Mollusca	Planorbidae	57	95

*Percent of the total family.

(B) Taxa common in impaired sites.

Taxa		Abundance	% *
Order	Family		
Coleoptera	Hydrophilidae	65	92.9
Mollusca	Hydrobiidae	715	100
	Physidae	14622	98.8
	Viviparidae	354	100

*Percent of the total family.

(C) Taxa common to reference and impaired sites.

Taxa		Abundance		% *
Order	Family	Reference	Impaired	
Coleoptera	Gyrinidae	10	11	47.6, 52.4
Hemiptera	Naucoridae	14	13	51.9 ,48.1

*Percent of the total family.

Table-3: Tolerance values of macroinvertabrate families collected at all sites.

Taxa	Family	Tolerance	Reference
Mollusca	Hydrobiidae	7	15
	Physidae	8	15
	Planorbidae	7	15
	Viviparidae	6	15
Ephemeroptera (mayflies)	Baetidae	4	30
	Caenidae	7	28
	Heptageniidae	4	30
Hemiptera (water or true bugs)	Belostomatidae	10	31
	Corixidae	5	15
	Gerridae	Undetermined	15
	Hydrometridae	Undetermined	15
	Naucoridae	5	15
	Nepidae	8	15
	Notonectidae	Undetermined	15
	Pleidae	Undetermined	15
	Velidae	6	15
Coleoptera (beetles)	Dytiscidae	5	31
	Elmidae	4	30
	Gyrinidae	4	31
	Haliplidae	5	31
	Hydrophilidae	5	31
	Elimidae	5	28
Diptera (Two-winged or “true flies”)	Ceratopogonidae	6	28
	Psychodidae (moth flies)	10	30
	Simuliidae (black flies)	6	30
	Tabanidae (horse and deer flies)	6	30
	Chironomidae (non-biting or true midges)	6,1,2,4	31
Odonata (dragonflies and damselflies)	Aeshnidae	3	30
	Calopterygidae	5	30
	Coenagrionidae	9	30
	Cordulegastridae	3	28
	Gomphidae	1	30
	Lestidae	9	28

The complete absence of EPT taxa (Ephemeroptera, Plecopetra and Trichoptera) in impaired sites showed that there is indication of water and habitat quality impairment[32]. The total absence of Plecopetra and Trichoptera in the reference site showed the presence of human impact. However, in these study taxa richness was observed in the reference site while in the impaired sites, lower taxa were observed.

Macroinvertebrate metrics and metric index were developed from the biological data in Appendix 1 from the 6 sampling sites to evaluate the status of floriculture industries influence on the study area.

Index development for the study area: A total of 17 metrics that have good values in the reference sites thought to be applicable to the Wedecha River were used (Table-4). A correlation analysis was performed on the candidate metrics (Table-5) to discriminate metrics for index development. Bivariate scatterplot was examined to reject metrics that showed a strong correlation (r> 0.9) (Table-6).

Table-4: Observed values of metrics thought to be applicable to the Wedecha River.

Metric	Site					
	S0	S1	S2	S3	S4	S5
Total No. taxa	30	7	10	10	14	7
No. Odonata	501	20	3	4	0	0
No. Hemiptera	547	10	11	6	35	2
No. Diptera	157	10	1	1	1	2
No.Chironomidae	116	10	0	0	0	2
No.Coleoptera	24	26	12	5	42	3
No.Mollusca	238	2536	2974	3883	6231	70
No.Physidae	180	2536	2974	3420	5656	36
No.Planorbidae	57	0	0	1	1	1
% Odonata	33.7	0.8	0.1	0.1	0	0
% Hemiptera	36.8	0.4	0.4	0.2	0.6	2.6
% Diptera	10.6	0.4	0	0	0	2.6
% Chironomidae	7.8	0.4	0	0	0	2.6
% Coleoptera	1.6	1	0.4	0.1	0.7	3.9
% Mollusca	16	97.5	99.1	99.6	98.8	90.9
% Physidae	12.1	97.5	99.1	87.7	89.6	46.8
% Dominant taxon	12.1	97.5	99.1	87.7	89.6	46.8

Table-5: Pearson correlation matrix of all metrics data.

	No. taxa	No. Odon	No. Hemi	No. Dipt	No. Chiro	No. Coleo	No. Mollu	No. Phys	No. Planor	% Odon	% Hemi	% Dipt	% Chiro	% Coleo	% Mollu	% Phys	% Dom taxon
No. taxa																	
No. Odon	.949																
No. Hemi	.968	.998															
No. Dipt	.944	1.000	.997														
No. Chiro	.937	.999	.994	1.000													
No. Coleo	.347	.182	.223	.189	.191												
No. Mollu	-.256	-.514	-.471	-.521	-.531	.529											
No. Phys	-.280	-.531	-.489	-.537	-.546	.536	.997										
No. Planor	.957	.999	.999	.998	.995	.174	-.507	-.527									
% Odon	.952	1.000	.998	.999	.998	.181	-.513	-.530	.999								
% Hemi	.946	.997	.996	.996	.994	.153	-.546	-.565	.998	.997							
% Dipt	.885	.968	.963	.969	.969	.060	-.664	-.685	.972	.969	.983						
% Chiro	.846	.942	.936	.944	.945	.016	-.710	-.732	.948	.944	.963	.996					
% Coleo	-.050	.104	.092	.114	.122	-.321	-.706	-.719	.119	.108	.171	.346	.426				
% Mollu	-.934	-.994	-.992	-.994	-.993	-.138	.574	.593	-.996	-.995	-.999	-.989	-.972	-.207			
% Phys	-.739	-.828	-.825	-.829	-.828	.107	.731	.765	-.844	-.832	-.868	-.937	-.960	-.597	.882		
% Dom taxon	-.599	-.697	-.694	-.699	-.698	.202	.753	.791	-.719	-.703	-.749	-.849	-.888	-.729	.769	.979	

Table-6: Highly correlated metrics.

	No. taxa	No. Odon	No. Hemi	No. Dipt	No. Chiro	No. Mollu	No. Planor	% Odon	% Hemi	% Dipt	% Phys
No. Odon	.949										
No. Hemi	.968	.998									
No. Dipt	.944	1.000	.997								
No. Chiro	.937	.999	.994	1.000							
No. Phys						.997					
No. Planor	.957	.999	.999	.998	.995						
% Odon	.952	1.000	.998	.999	.998		.999				
% Hemi	.946	.997	.996	.996	.994		.998	.997			
% Dipt		.968	.963	.969	.969		.972	.969	.983		
% Chiro		.942	.936	.944	.945		.948	.944	.963	.996	
% Domin taxon											.979

Metrics in Table-7 showed linear relationships.

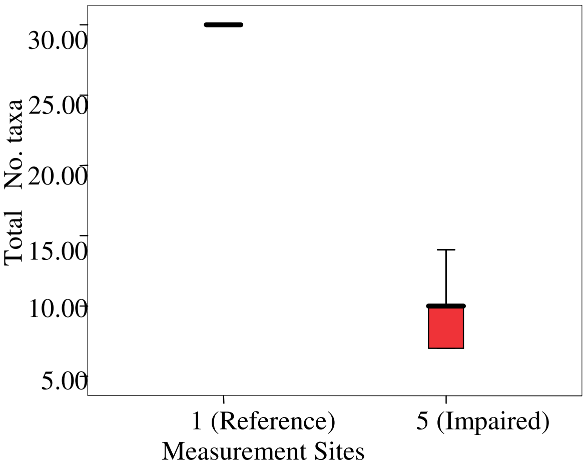
Number of Coleoptera, Percent Coleoptera and Percent Mollusca had no strong correlation and total number of taxa had non-linear relationship. Based on the results of the Pearson correlation matrix and the bivariate scatterplot, number of Odonata, number of Hemiptera, number of Diptera, number of Chironomidae, number of Planorobidae, percent of Odonata and percent of Diptera were rejected. As Number of Odonata, Number of Hemiptera, Number of Diptera, Number of Chironomidae, Number of Planrobidae, percent of Diptera and percent of Odonata were rejected percent of Hemiptera were retained; in the same way as Number of Hemiptera and Percent of Diptera were, rejected percent of Chironomidae was retained.

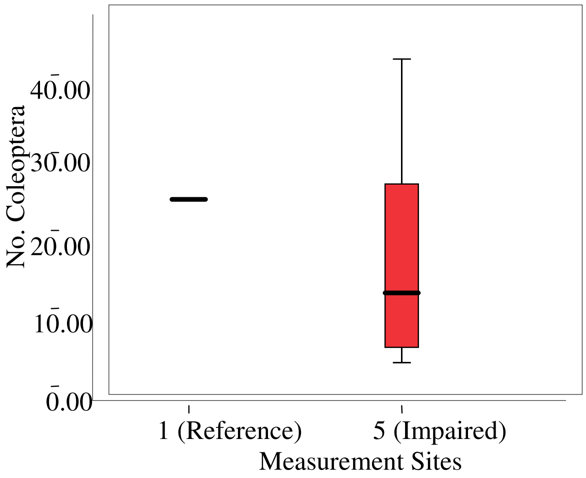
Number of Mollusca and number of Physidae and percent of Physidae and percent Dominant taxa had strong correlation and linear relationship; percent Dominant taxa and Numbers of Mollusca were retained because orders thought to provide better information than the individual families[33].

The remaining eight metrics, which showed no strong correlation and non-linear relationship, were evaluated for their discriminatory power using box plots (Figure-2). The seven metrics: number of taxa, number of Mollusca, percent Hemiptera, percent Chironomidae, percent Coleoptera, percent Mollusca and percent dominant taxon had good discriminatory power between the reference and impaired sites; so that they were considered for the final index development. Number of Coleoptera was rejected because it shows overlap in the Box and whisker plots of the candidate metrics in the reference and impaired sites.

Table-7: Linearly correlated metrics.

	No. Odon	No. Hemi	No. Dipt	No. Chiro	No. Mollu	No. Planor	% Odon	% Hemi	% Dipt	% Phys
No. Hemi	✓									
No. Dipt	✓	✓								
No.Chiro	✓	✓	✓							
No. Phys					✓					
No. Planor	✓	✓	✓	✓						
% Odon	✓	✓	✓	✓		✓				
% Hemi	✓	✓	✓	✓		✓	✓			
% Dipt								✓		
% Chiro		✓							✓	
% Domin taxon										✓





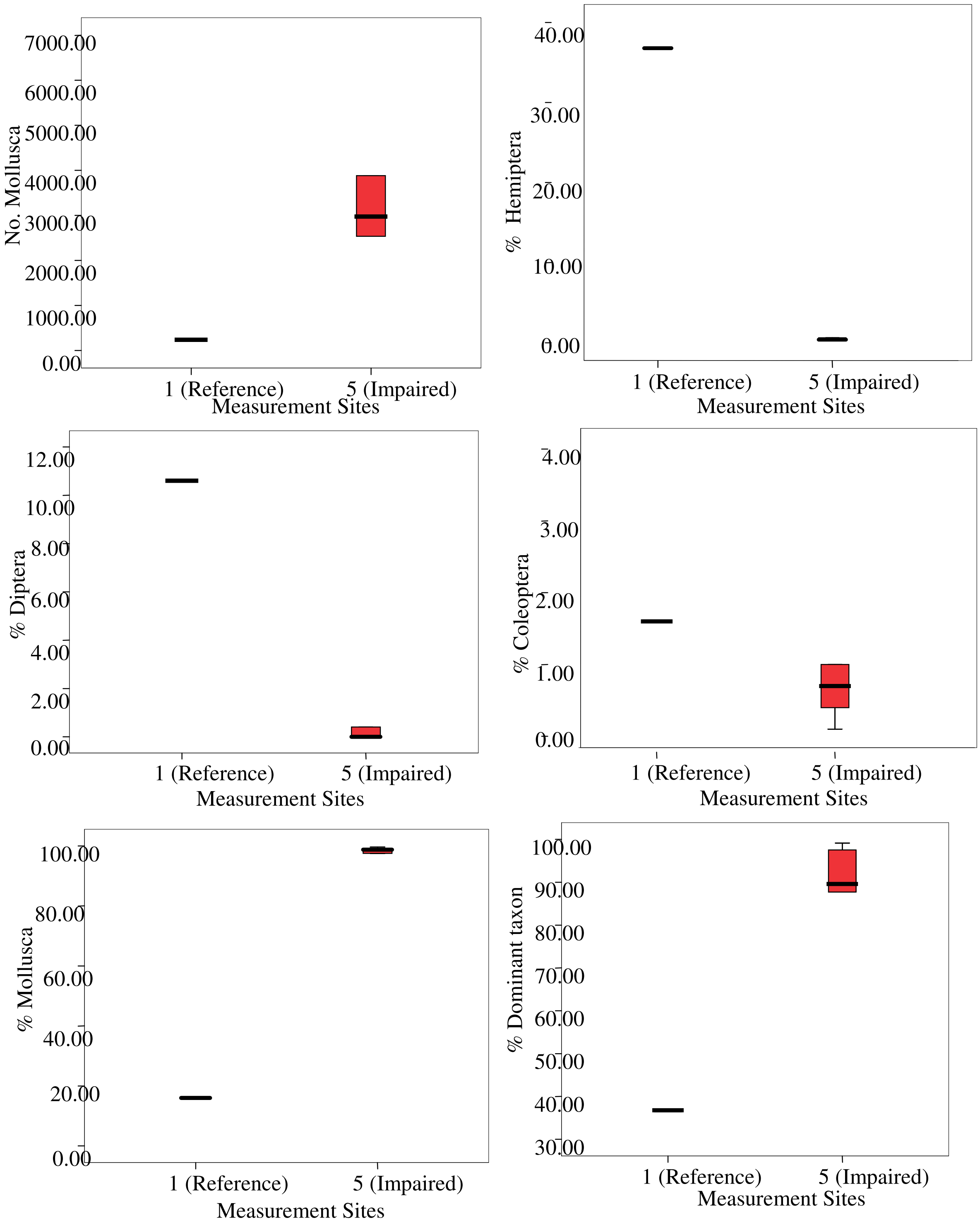


Figure-2: Box and whisker plots of the candidate metrics in the reference and impaired sites.

NB: The centre horizontal line represents the median value, the outer horizontal lines are the interquartile values, and the range bars show maximum and minimum of non-outliers. Sample sites are 1 and 5 for the reference and impaired sites, respectively.

The observed values of the seven metrics for each measurement site are given in Table-8. The observed values for all the metrics initially thought to be applicable to the Wedecha River were already given in Table-4. From these values, the percentiles (upper and lower threshold values) of each metric in the reference and impaired sites were calculated (Table-9).

Table-8: Observed metric values of the seven selected metrics for each site.

Metric	Site					
	S0	S1	S2	S3	S4	S5
Total No. taxa	30	7	10	10	14	7
No. Mollusca	238	2536	2974	3883	6231	70
% Hemiptera	36.8	0.4	0.4	0.2	0.6	2.6
% Chironomidae	7.8	0.4	0	0	0	2.6
% Coleoptera	1.6	1	0.4	0.1	0.7	3.9
% Mollusca	16	97.5	99.1	99.6	98.8	90.9
% Dominant taxon	12.1	97.5	99.1	87.7	89.6	46.8

The Seven metrics were scored on a continuous measurement scale from 0 (poor) to 10 (good) based on the upper and lower threshold value of the metrics in the reference and impaired sites (Table-10) using the formula to calculate metric scores as indicated below.

Metric scores were calculated using the following formula:

$$Metric\ score = \frac{(observed - lower\ threshold^{a}}{Upper^{b} - lower\ threshold^{a}} x10$$

[a]Lower treshold for metrics that decrease (increase) with perturbation is 25th (75th) percentile of impaired. [b]upper threshold for metrics that decrease (increase) with perturbation is 75th (25th) percentile of the reference 33.

For positive metrics (i.e., those that increased with improving conditions), the upper expectation (ceiling) was the 75th percentile of the distribution of reference reaches, while the lower expectation (floor) was the 25th percentile of the distribution of impaired reaches[33].

Metrics with a value above the ceiling receive a score of 10, while those below the floor scored 0. All other values were linearly scaled along the range between the high and the low[33].

For negative metrics that decreased with improving condition, the ceiling was the 75th percentile of the distribution of impaired reaches and the floor was the 25th percentile of the distribution of reference reaches. Negative metrics with a value above the ceiling scored 0, while those below the floor scored 10. All other values were linearly scaled along the range between the low and high as for positive metric. To calculate, the Wedecha Macroinvertebrate Index, metric scores were added together, multiplied by 10 and divided by the number of metrics scored to produce a range of 0-10033.

WMI Wedecha Metric Index) was developed based on the seven metrics. These are total number of taxa, number of Mollusca, percent Hemiptera, percent Chironomidae, percent Coleoptera, percent Mollusca and percent dominant taxon.

Table-9: Percentile of the candidate metrics in the reference and impaired sites

Metrics	Measurement site	Percentiles		
		25	50	75
No. taxa	reference site	30	30	30
	impaired site	7	10	10
No. Mollusca	reference site	238	238	238
	impaired site	2536	2974	3883
% Hemiptera	reference site	36.8	36.8	36.8
	impaired site	0.4	0.4	0.6
% Chironomidae	reference site	7.8	7.8	7.8
	impaired site	0	0	0.4
% Coleoptera	reference site	1.6	1.6	1.6
	impaired site	0.4	0.7	1
% Mollusca	reference site	16	16	16
	impaired site	97.5	98.8	99.1
% dominant taxon	reference site	12.1	12.1	12.1
	impaired site	87.7	89.6	97.5

The score for each core metric and the final index score for each site is presented in Table-10. The WMI ranges from 3.6 at S3 to 100 at S0. A boxplot of WMI (Figure-3) depicted the discriminatory power of the index to distinguish between differentially impacted sites and the reference site.

Table-10: Final index score for each selected metrics in each measurement sites.

Metric	Site					
	S0	S1	S2	S3	S4	S5
Total No. taxa	10	0	1.3	1.3	3	0
No. Mollusca	10	3.7	2.5	0	0	10
% Hemiptera	10	0	0	0	0.1	0.6
% Chironomidae	10	0.5	0	0	0	3.3
% Coleoptera	10	5	0	0	2.5	10
% Mollusca	10	0.2	0	0	0	1
% Dominant taxon	10	0	0	1.2	0.9	5.9
Total	70	9.4	3.8	2.5	6.5	30.8
WMI Score	100	13.4	5.4	3.6	9.3	44

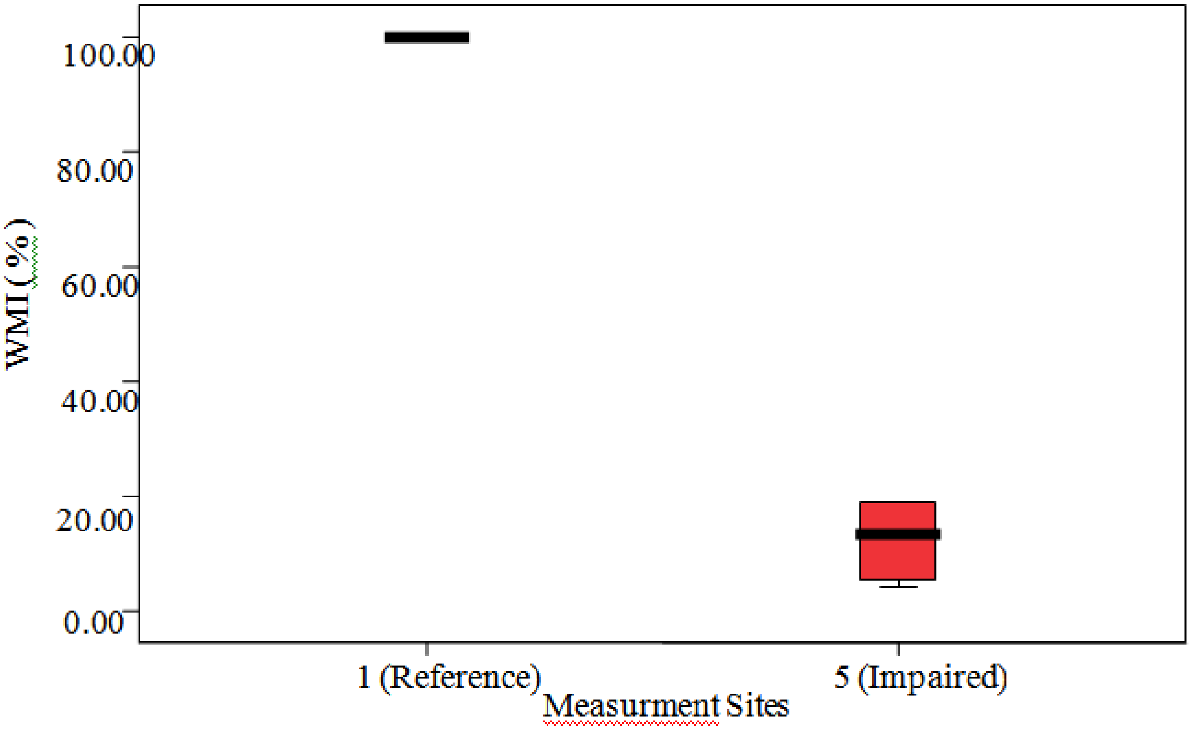


Figure-3: Box plot comparing the WMI score between reference and impaired sites.

Division of the WMI resulted in seven metrics which were 50% of the maximum value observed and was taken to be the mark between good and poor sites. In this study, 100 was the maximum observed value. The range above the 50% mark was subdivided into two with a range between 50% and 75% classified as good and above 75% as very good. The range below 50% was also subdivided into two with a score between 50% and 25% classified as poor and below 25% as very poor. For the WMI score that ranges from 0 to 100, greater than 75 was very good (S0=100), 50-74.9 was good (no metric with this division), 25-49.9 was poor (S5=44) and less than 24.9 was very poor (S1, S2, S3 and S4 with a MI score of 13.4, 5.4, 3.6, and 9.3, respectively).

The Seven metrics used in the development of WMI were found to be useful for assessing biological impairment (Table-8). They measure different aspects of the macroinvertebrate assemblage. The metric index result in Table-10 and the boxplot (Figure-3) showed the impairment levels of the study sites, as five of the sites were highly disturbed and one was relatively less disturbed. This is justified as noted by Merritt and Cummins that high richness, the higher the number of different kinds of macroinvertabrates and the higher the index, the better the stream condition and the better water quality[34]. That is, number of taxa decreases with decreasing water quality. In Wedecha River, the number of taxa is relatively high in the reference site, S0. This showed diversity increased where human influence is less but abundance of individual organisms was higher in polluted sites (Appendix-1). This was also observed in Maryland streams[11].

Increment in abundance does not show better environment because disturbance may favor some tolerant, opportunistic and less competent taxa with reduction in sensitive taxa (the community will be dominated by few taxa). When streams become excessively acidic or alkaline, the change can adversely affect the biota. As those fish and macroinvertebrates unable to tolerate the altered conditions decline, tolerant organisms increase in numbers due to lack of competition for food and habitat.

This results in an unhealthy biological community dominated by a few tolerant taxa[35,36]. So, WMI developed using the seven metrics had successfully classified the differentially impacted sites into different integrity classes and the reference site was very good (100% index). S5 was observed as poor. S1, S2, S3 and S4 sites were very poor. This can be due to the dominance of tolerant species in S1, S2 and S3 sites, which are direct point sources of floriculture industries effluent discharge where pesticides, growth regulators and fertilizers that affect the aquatic biota were released. It was noted by Roy and his collogues as; absence of intolerant taxa and moderate tolerance taxa is associated with toxicity in streams. Wedecha is loaded with floriculture industries effluent[37].

Acidic condition in stream erodes integument of invertebrates, some metals can make toxins when more available to macroinvertabrates. Several species are very sensitive to acidic conditions in streams[34]. Therefore, runoff from floriculture industries and habitat degradation could be possible explanations for the low scores (low biological integrity) in these sites. The response of the selected metrics and the WMI scores clearly showed that the structural changes of macroinvertebrates in the Wedecha River are results of floriculture industries waste water effluent discharged to the river.

Most commonly used sensitive indicator organisms are Ephemeroptera (Mayflies), Plecoptera (Stoneflies) and Trichoptera (Caddis flies)[34]. They are often indicators of good water quality because most of them are relatively intolerant of pollution. Plecoptera are the most sensitive order of aquatic insects and many species are restricted to habitats with high levels of dissolved oxygen**.** Proportion of Ephemeropterans relative to the other taxa (percent Ephemeroptera) is expected to decrease as the water quality declines[28]**.** In Wedecha River Ephemeropterans were completely eliminated in the downstream sites. They are restricted to the reference site with very few numbers. The reference site had higher richness and this result indicate that many taxa would disappear in the presence of severe pollution from the floriculture industries.

Mollusca groups increased in the downstream with dominance; especially of Physidae. It is expected that organic matter and low dissolved oxygen favored the dominance of these tolerant species. Of the four Mollusca groups, only Planorbidae is limited to the reference site but others increase in the impaired sites showing pollution resistance or tolerance. As noted by Bouchard, snails are divided into two groups based on how they breathe[28]. One group uses gills to obtain dissolved oxygen from the water (Prosobranchia), which includes Planorbidae, while the other group breathes air using a structure that functions like a lung (pulmonata), including physidae**.** Generally, pouch snails (pulmonata) indicate nutrient enriched conditions and poor water quality[38].

The presence of gilled snails is sign of better water quality (higher dissolved oxygen). Although the presence of a few lunged snails does not necessarily indicate pollution, a large number of these snails are often indicative of impacted waters since they can survive in low dissolved oxygen conditions**[28]**. All the literature justified that sites downstream of Wedecha River are impacted with the floriculture effluent.

Conclusion

Floriculture industries have positive impacts on economic development of the country and the surrounding community on the contrary they have negative impact on the aquatic environment: macroinvertabrates depletion or degradation of biodiversity (species abundance and diversity), disappearance of sensitive taxa in the downstream stretches, food chain of aquatic organisms' and consumption of water in the surrounding communities. This is due to the disposal of wastewater to the nearby rivers. Floriculture industries use a variety of chemicals, including pesticides. These chemicals alone are dangerous enough, but when coupled with the method of usage and the conditions in which they are utilized, their danger is multiplied due to synergistic effect[39] (Synergy involves the combination of two or more substances, which produces greater effect than their sum).

The study revealed that pollution causes the structural and functional changes in macroinvertebrates. The major sources of these stressors are fertilizers, pesticides and growth regulators from the floriculture industries' waste water effluent. In Wedecha River, there is a decrease of macroinvertabrate biodiversity and disappearance of sensitive taxa at the downstream stretches.

For this study, number of taxa and number mollusca, percent hemiptera, percent chironomidae, percent coleoptera, percent mollusca and percent dominant taxon were useful to measure the biological integrity of the Wedecha River. The Macroinvertebrate index developed from these metrics successfully classified impacted sites into different integrity divisions. The index revealed that except the reference site, the other sites are degraded. This is evident from the dominance of a few tolerant taxa in the lower stream. Snails were the known dominant taxon in this river. The presences of gilled snails such as Planorobidae are sign of better water quality (higher dissolved oxygen)[28].

Hence, bioassessment can be used for rapid monitoring in the presence of resource limitations. The study showed the effectiveness of the benthic macroinvertebrate protocol in assessing river pollution condition. Therefore, environmental agencies have a good option of using macroinvertebrate with the objective in assessment and monitoring programs of rivers.

The result of the study revealed that floriculture industries are affecting Wedecha River. In this circumstance it is recommend that: i. The wastewater has to be treated before it is discharged to the nearby rivers such as ponding systems using wetlands. ii. Floriculture industries wastewater has to be recycled rather disposed to the environment. iii. Residue analysis has to be done to know the disastrous effect of floriculture industries chemicals. iv. Multimetric index has to be done as it includes several attributes of the sampled assemblage.

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Appendices

Appendix-1: Total No. of macroinvertebrate taxa collected at 6 sites on Wedecha Rive

Taxon	Site					
	S0	S1	S2	S3	S4	S5
Ephemeroptera						
Baetidae	3	0	0	0	0	0
Caenidae	2	0	0	0	0	0
Heptageniidae	3	0	0	0	0	0
Plecopetra	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0
Lepidoptera						
Pyralidae	0	0	1	0	0	0
Odonata						
Aeshinidae	33	0	0	2	0	0
Calopterygidae	13	0	0	0	0	0
Coenogrionidae	442	20	3	2	0	0
Cordulegastridae	4	0	0	0	0	0
Gomphidae	8	0	0	0	0	0
Lestidae	1	0	0	0	0	0
Coleoptera						
Dytiscidae	6	0	4	0	4	1
Elimidae	2	0	0	0	0	2
Gyrinidae	10	1	0	0	10	0
Haliplidae	1	0	0	0	1	0
Hydrophilidae	5	25	8	5	27	0
Diptera						
Ceratopogonidae	2	0	0	0	0	0
Chironomidae	116	10	0	0	0	2
Psychodidae	26	0	0	1	0	0
Simuliidae (black flies)	13	0	0	0	0	0
Tabanidae	0	0	1	0	1	0
Hemiptera						
Belostomatidae	46	4	2	2	7	0
Corixidae	31	0	0	0	1	2
Gerridae	298	0	1	0	9	0
Hydrometridae	2	0	0	0	0	0
Naucoridae	14	0	2	0	11	0
Nepidae	2	0	0	0	0	0
Notenoctidae	103	6	6	4	7	0
Pleidae	2	0	0	0	0	0
Velidae	49	0	0	0	0	0
Mollusca						
Hydrobiidae	0	0	0	343	372	0
Physidae	180	2536	2974	3420	5656	36
Planorbidae	57	0	0	1	1	1
Viviparidae	0	0	0	119	202	33
Collembola	1	0	0	0	0	0
Total number of Taxa Collected over the sample period	30	7	10	10	14	7
Total Abundance	1,485	2,602	3,002	3,899	6,309	77

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