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Bio-monitoring of water quality using benthic macro-invertebrates of river Singye Chhu in Bhutan

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Abstract

Detailed study was undertaken in 2009 and 2010 on assessment of water quality of River Singye Chhu which flows through Pasakha, the industrial hub of Bhutan. The water quality was analyzed by studying the benthic macro-invertebrates upstream of an industrial area, within the industrial area and downstream. The study revealed pollution sensitive benthic macro-invertebrates population were dominant at upstream sampling sites whereas they were completely absent in industrial area and it's immediate downstream. On the other hand pollution tolerant benthic macro-invertebrates were found abundant in industrial area and its immediate downstream. The rapid industrial development may be posing serious threats to water regime in terms of its quality. Proper treatment of effluents from industries would reduce water pollution in such affected areas to check further deterioration of water quality. This present study which is based on upstream, within industrial area and downstream of Pasakha can be considered as an eye opener.

Keywords

Water quality, Benthic macro-invertebrates, Upstream, Industrial area, Downstream, Pasakha, River Singye Chhu

Introduction

Water occupies a special place among other natural resources found on earth. It is indeed a valuable natural resource vital to the existence of all living organisms. The water bodies are closely related to human life and his livelihood. The metabolic activities essential for life take place in aqueous medium inside the living body. All enzymes, hormones and other biomolecules exist and function in the presence of water. Water dissolves nutrients and distributes them to cells, regulates body temperature, supports structures, and removes waste products. Thus, all forms of life on earth depend on water and all living things, from plants to animals, from desert dwellers to aquatic inhabitants and from microscopic bacteria to gigantic whale, need water to survive. The health and well-being of all the living beings on earth is closely tied up with the quality of water (United Nations World Water Assessment Programme (UN-WWAP) Report, 2003).

Currently, humanity is facing a serious water crisis (UN-WWAP, 2003). The United Nations World Water Assessment Programme Report (2003) states that water crises of availability, degradation, conservation and sustainability can be observed more pronouncedly in developing countries all over the world. All indicators suggest that the situation is worsening day by day and it is going to be alarming unless corrective measures are taken soon. It is estimated that at present 2.8 billion people live under conditions of water stress and by 2030 almost half the world population will live under these conditions if effective measures are not implemented (UNEP, 2009; Bates *et al*., 2008 and OECD, 2008).

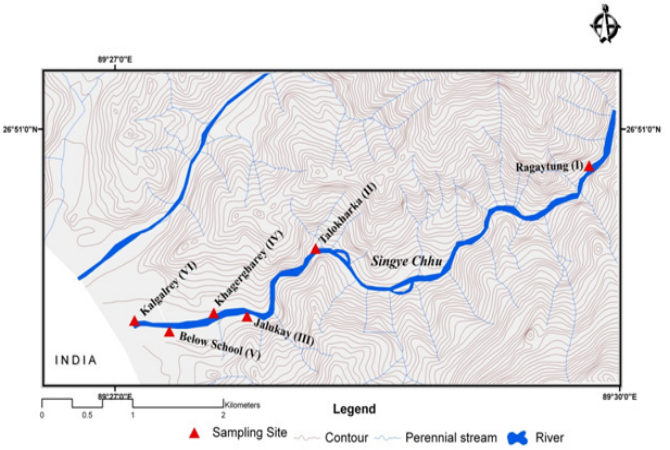
The study on benthic macro-invertebrates at upstream, within industrial area and its downstream is essential to understand the quality of water. The benthic macro-invertebrates are good indicators of water quality. The studies of their community and population in water bodies provide information on pollution status of the water they inhabit. Therefore, freshwater macro-invertebrates have been extensively used for monitoring of streams and rivers (Rosenberg and Resh, 1993a; Rosenberg and Resh, 1993b). Such studies in relation to anthropogenic land use changes and diversified human activities taking place in the catchment area are keys to understanding the causes and extent of degradation of water resources. Keeping this view in mind, a study on water quality was carried out during 2009 and 2010 in Pasakha industrial area of Bhutan.

Study Area, Materials and Methods

Pasakha, the main industrial estate of the country is located in the southern part of Bhutan at an altitude of 280 m (longitude 89Ú27'37''E; latitude 26Ú50'02''N). The industrial estate was established in 2002 by the Ministry of Economic Affairs, Bhutan. The industrial estate has an area of 211 acres out of which 117 acres is already utilized for construction of industries.

River Singye Chhu originates from the deep virgin forest located above Ragaytung (fig. 1). The river flows through the industrial area of Pasakha. To observe the impact of industries on water quality of River Singye Chhu, sampling of benthic macro-invertebrates was done from six sites, two each from upstream of the industrial area (sampling sites I and II), within the industrial area (sampling sites III and IV) and downstream of the industrial area (sampling sites V and VI). Figure 1 depicts the sampling sites at upstream, within industrial area and downstream of River Singye Chhu.

Figure 1: Location of different sampling sites at Pasakha study area



The study was carried out during the year 2009-2010 beginning from January. The benthic macro-invertebrates were studied during three different seasons namely, pre-monsoon, monsoon and post-monsoon.

Collection of Benthic macro-invertebrates

The shallow locations of less than 1m depth of the river were selected for the study of benthic macro-invertebrates. The sampling sites at upstream represent the reference or control point. In order to carry out comparison of macro-invertebrate communities attempts were made to choose similar habitat features - similar bottom substrate, depth and flow velocity - for all sampling sites. The substrate chosen contained mainly gravel, cobbles, sand and clay. The substrate samples were analysed to find out its contents.

A simple random sampling was done in all the stations for collection of benthic macro-invertebrates. The random sampling was also carried out in different substrates, current velocities, depth and temperature to cover the density of benthic macro-invertebrates. Three replicate sampling units per station were carried out during each period. The Surber or Square foot stream bottom sampler was used to collect benthic macro-invertebrates. The overall method of sampling, as described in Standard Method for Water and Wastewater Analysis (APHA, 2005) was followed.

The collected benthic macro-invertebrates were placed in a shallow white tray with water for sorting. By using a hand lens and dissection microscope the organisms were separated into different taxonomic categories. The references used for taxonomic work were Pennack, (1953) and (1978); Thorp and Covich (1991); Ward and Whipple (1992). The organisms were sorted and kept in vials filled with 70% ethanol. All procedures followed were according to APHA (2005).

Analysis of Population

The benthic macro-invertebrate diversity index was calculated using the Shannon and Weiner (1963) index $(\bar{H})$:

Shannon and Weiner diversity index

$$(\bar{H}) = -\sum_{i}^{s} \left(\frac{ni}{N}\right) \log \left(\frac{ni}{N}\right)$$

Where,

$(\bar{H})$ = Shannon Weiner index of diversity;

= Total number of individual of a species;

N= Total number of individuals of all species

The density and diversity of aquatic insects were calculated with the help of Microsoft Excel statistical package (XLSTAT 2009).

Results

The benthic macro-invertebrates present at upstream, within the industrial area and downstream of Pasakha industrial area were represented by the members of phylum Arthropoda, Mollusca and Annelida. The Phylum Arthropoda has been represented by class Insecta and Malacostraca; phylum Mollusca by class Gastropoda and phylum Annelida by class Hirudinea and Oligochaeta. The benthic macro-invertebrates present during the study period were of 11 taxonomic orders of Plecoptera (stoneflies), Ephemeroptera (mayflies), Trichoptera (caddisflies), Coleoptera (aquatic beetles), Diptera (true flies), Odonata (dragonflies), Decapoda (crayfish), Amphipoda (scuds), Basommatophora (snails), Archynchobdellida (leeches) and Lumbriculida (worms).

Benthic macro-invertebrate population during pre-monsoon

During pre-monsoon, 4974 individuals/m^2 benthic macro-invertebrates were collected from three locations

namely, upstream of industrial area, within the industrial area and downstream of industrial area. They belonged to 11 taxonomic orders and 40 taxonomic families. The highly sensitive benthic macro-invertebrates belonged to the taxonomic order of Trichoptera, Ephemeroptera and Plecoptera. The moderately sensitive benthic macro-invertebrates belonged to the order of Coleoptera, Odonata, Decapoda and Amphipoda. The pollution tolerant benthic macro-invertebrates belonged to the taxonomic order of Lumbriculida, Archynchobdellida and Basommatophora.

In the upstream sampling sites I and II, a total of 643 benthic macro-invertebrates belonging to 9 taxonomic orders were collected. Out of 643 benthic macro-invertebrates 408 (63%) belonged to highly sensitive taxonomic orders. The benthic macro-invertebrates at upstream sampling sites were represented by Trichoptera (18%), Ephemeroptera (39%), Plecoptera (6%), Coleoptera (15%), Odonata (4%), Decapoda (3%), Amphipoda (2%), Basommatophora (11%), and Archynchobdellida (2%). The benthic macro-invertebrates belonging to the taxonomic order of Ephemeroptera were found in abundance (39%), while Amphipoda (2%) belonging to class Malacostraca and Archynchobdellida (2%) belonging to class Annelida represented minimum number at upstream sampling sites I and II.

Within the industrial area sampling sites III and IV, 390 individuals/m^2 benthic macro-invertebrates were collected. The highly sensitive benthic macro-invertebrates belonging to the taxonomic order of Trichoptera, Ephemeroptera and Plecoptera were completely absent. The benthic macro-invertebrates were represented by Coleoptera (2%), Diptera (1%), Lumbriculida (9%), Basommatophora (87%), and Archynchobdellida (1%). Out of 390 benthic macro-invertebrates, Physidae (pouch snails) belonging to taxonomic order Basommatophora (321 individuals/m^2) were dominant constituting 87% whereas Diptera (1%) and Archynchobdellida (1%) were minimum in number. The pollution resistant macro-invertebrates were found dominant within the industrial area whereas the population of pollution sensitive benthos were completely absent which indicated impact on water quality.

In downstream all pollution sensitive benthic macro-invertebrates such as Trichoptera, Ephemeroptera, Plecoptera, Coleoptera, Odonata, Decapoda and Amphipoda were absent. Only pollution tolerant benthic macro-invertebrates belonging to the family Basommatophora (98%), Diptera (1%) and Lumbriculidae (1%) were present in downstream during pre-monsoon. The Physidae (pouch snails) which thrive well in polluted water dominated downstream. These pollution tolerant pouch snails were found feeding on nutrients released from food industries. Only three genera of benthic macro-invertebrates were present in downstream indicating poor diversity.

The mean of Shannon-Weiner diversity index and evenness calculated for benthic macro-invertebrates during pre-monsoon for all the six sampling stations is presented in Table 1.

Table 1: Shannon-Weiner diversity index and evenness of benthos during pre-monsoon

Sampling Station	Shannon-Weiner Diversity Index	Evenness
I	1.73806	0.79102
II	1.74751	0.79532
III	0.54327	0.78377
IV	0.39145	0.28237
V	0.09334	0.08496
VI	0.16081	0.14637

The Shannon-Weiner diversity index during pre-monsoon ranged from 1.74751 to 0.09334 attaining maximum at sampling site II and minimum at sampling site V. The diversity index showed that diversity of benthic macro-invertebrates was higher at upstream as compared to downstream. The evenness of benthic macro-invertebrates indicated similar trend which ranged from 0.79532 to 0.08496 having maximum evenness at sampling site II and minimum at sampling site V.

Benthic macro-invertebrates population during monsoon

During monsoon season, a total of 697 individuals/m^2 benthic macro-invertebrates were collected from upstream, within the industrial area and downstream. The 697 individuals/m^2 benthic macro-invertebrates belonged to 8 taxonomic orders and 28 families. The 8 taxonomic orders were Coleoptera, Odonata, Decapoda, Amphipoda, Diptera, Basommatophora, Archynchobdellida, and Lumbriculida.

At upstream sampling sites I and II, a total of 463 individuals/m^2 benthic macro-invertebrates belonging to 9 taxonomic orders were collected. The benthic macro-invertebrates at upstream sampling sites were represented by Trichoptera (9%), Ephemeroptera (23%), Plecoptera (6%), Coleoptera (23%), Odonata (1%), Decapoda (12%), Amphipoda (7%), Basommatophora (13%), and Archynchobdellida (6%). Out of nine taxonomic groups of benthic macro-invertebrates, Ephemeroptera (23%) and Coleoptera (23%) were found abundant, while Odonata (1%) were minimum in number.

In the industrial area sampling sites III and IV, only 97 individuals/m^2 benthic macro-invertebrates belonging to 7 taxonomic orders were collected. The benthic macro-invertebrates in the industrial area sampling sites were represented by Coleoptera (15%), Diptera (3%), Decapoda (7%), Amphipoda (10%), Basommatophora (55%), and Archynchobdellida (4%).

The benthic macro-invertebrates belonging to the taxonomic order Trichoptera, Ephemeroptera and Plecoptera which are considered to be highly pollution sensitive were completely absent. The Basommatophora (55%) were found in abundance within the industrial area, while Diptera(3%) had minimum representation.

Only 97 individuals/m^2 benthic macro-invertebrates were collected in industrial area during monsoon as compared to 463 individuals/m^2 collected at upstream during the same season. The reason for the decrease could be attributed to release of effluents from industries, high turbidity, and destruction of their habitats. Only pollution tolerant benthos belonging to the family Syrphidae (4%), Physidae (84%) and Lumbriculidae (12%) were present in downstream during monsoon. The highly sensitive and moderately sensitive benthos were completely absent in downstream.

In pre-monsoon season, a total of 4974 individuals/m^2 benthic macro-invertebrates were collected, whereas; during monsoon only 697 individuals/m^2 were collected. The decrease in density and diversity of benthic macro-invertebrates during monsoon could be due to high velocity and turbidity of water. The availability of food is also an important factor governing the abundance of benthos (Uyanik *et al.,* 2005).

The mean of Shannon-Weiner diversity index and evenness calculated for benthic macro-invertebrates during monsoon for all the six sampling sites is presented in Table 2.

Table 2: Shannon-Weiner diversity index and evenness of benthos during monsoon

Sampling Sites	Shannon-Weiner Diversity Index	Evenness
I	1.9930	0.9584
II	1.9313	0.8790
III	0.1844	0.0948
IV	0.2103	0.3034
V	0.1169	0.1687
VI	0.8236	0.7496

The Shannon-Weiner diversity index calculated for benthic macro-invertebrates ranged from 1.9930 – 0.1169 attaining maximum index at sampling site I and minimum at sampling site V. The upstream showed higher diversity as compared to downstream. The evenness of benthic macro-invertebrates ranged from 0.9584 – 0.0948 with maximum evenness at sampling site I and minimum at sampling site III.

Benthic macro-invertebrates population during post-monsoon

During post-monsoon, 730 individuals/m^2 benthic macro-invertebrates belonging to 11 taxonomic orders were collected. The 11 taxonomic orders were further subdivided into different families showing different composition and distribution. Insecta from phylum Arthopoda was the most diverse class having seven orders and 33 families identified.

During post-monsoon, at upstream sampling sites I and II 506 individuals/m^2 benthic macro-invertebrates were collected. Out of 506 benthic macro-invertebrates collected 283 (56%) were highly sensitive. The upstream sampling sites were represented by the benthic macro-invertebrates belonging to taxonomic orders of Trichoptera (25%), Ephemeroptera (27%), Plecoptera (9%), Coleoptera (8%), Odonata (8%), Decapoda (4%), Amphipoda (3%), Basommatophora (14%), and Archynchobdellida (2%). The species belonging to order Ephemeroptera (27%) were found abundant whereas Archynchobdellida (2%) were found minimum in number. The upstream sampling sites were dominated by pollution sensitive benthic macro-invertebrates.

In industrial area sampling sites III and IV, a total of 84 individuals/m^2 benthic macro-invertebrates belonging 7 taxonomic orders were collected. The industrial area was represented by benthic macro-invertebrates belonging to taxonomic orders Coleoptera (3%), Diptera (6%), Decapoda (2%), Amphipoda (1%), Basommatophora (39%), Lumbriculida (42%) and Archynchobdellida (7%). Within the industrial area pollution sensitive benthic macro-invertebrates belonging to the taxonomic order Trichoptera, Ephemeroptera and Plecoptera were completely absent. The industrial area was dominated by benthic macro-invertebrates belonging to taxonomic order Lumbriculida (42%).

In downstream, pollution tolerant benthic macro-invertebrates belonging to the family Syrphidae (24%), Physidae (20%) and Lumbriculidae (56%) were present. The pollution sensitive benthos were completely absent in downstream. The downstream sampling sites were also dominated by benthic macro-invertebrates belonging to taxonomic order Lumbriculida (56%).

The upstream had rich biodiversity of benthic macro-invertebrates as compared to industrial area and downstream. The absence of sensitive benthos in downstream indicated that the quality of water had deteriorated. The mean of Shannon-Weiner diversity index and evenness calculated for benthic macro-invertebrates during post-monsoon for all the six sampling sites is presented in Table 3.

Table 3: Shannon-Weiner diversity index and evenness of benthos during post-monsoon

Sampling Sites	Shannon-Weiner Diversity Index	Evenness
I	1.8699	0.8510
II	1.9571	0.8907
III	1.0609	0.6591
IV	0.9818	0.7082
V	0.9875	0.8988
VI	0.9050	0.8237

The Shannon-Weiner diversity index of benthic macro-invertebrates during post-monsoon ranged from 1.9571–0.9050 having maximum diversity index at sampling site II and minimum at sampling site VI. Similarly, evenness of benthic macro-invertebrates followed similar pattern ranging from 0.8988 – 0.6591 showing maximum evenness at sampling site V and minimum at sampling site III.

Figure 2 depicts variation in Shannon Weiner diversity index at upstream, industrial area and downstream of Singye Chhu during pre-monsoon, monsoon and post-monsoon. The values of diversity index in six sampling sites during pre-monsoon were in the order of I < II > III > IV > V < VI, during monsoon I > II > III < IV < V < VI whereas during post-monsoon the trend is I < II > III < IV < V > VI.

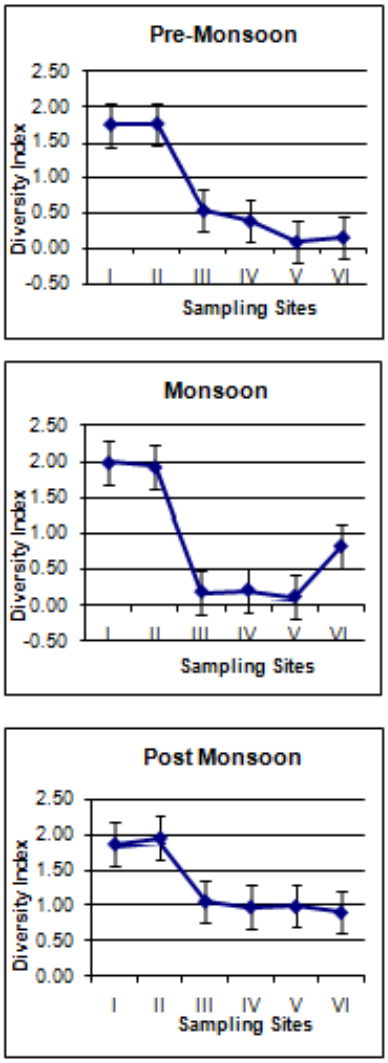
The water quality decreased as the river flowed downstream through the industrial area. The diversity and evenness of benthic macro-invertebrates also decreased with decline in river water quality. The upstream site which had relatively better water quality was abundant with sensitive groups such as Ephemeroptera, Plecoptera and Trichoptera. Upstream sites also had the highest Shannon diversity index for aquatic macro-invertebrates and decreased in downstream. The resistant groups such as Syrphidae, Psysidae and Lumbriculidae dominated downstream sampling sites having lower water quality.

Discussion

The absence of pollution sensitive benthic macro-invertebrates in downstream clearly indicated that there is impact on water quality. The impact on water quality can be attributed to release of effluents from industries into River Singye Chhu. Similar results were obtained by Trevor *et al.* (2010) in Mazai stream, Zimbabwe. At upstream of Mazai stream industrial area, pollution sensitive macro-invertebrates included Trichoptera and Plecoptera which were highly susceptible to pollutants indicating good water quality was present (Allan, 1995). In downstream of industrial area, pollution tolerant species such as Chironomids, Nematodes, Simuliidae and leeches were present. These organisms can survive under extreme pollution conditions including low oxygen level (Micheal and Kelso, 2007). The downstream was found inhospitable as the pollution tolerant macro-invertebrates showed very low species richness.

According to Uyanik *et al.* (2005) physical environment, water quality and food availability are the important factors governing the abundance and distribution of benthic macro-invertebrates. The presence of pollution sensitive species at upstream and pollution tolerant species downstream is a pure indication of deterioration of water quality downstream. The statistical analysis of data suggested that the sampling sites fit the following interpretation. Sampling

Figure 2: Graph showing variation in Shannon Weiner diversity index during pre-monsoon, monsoon and post-monsoon



site I and II have relatively clean water, whereas at sampling site III and IV, some impact on water quality was observed due to industrial activities. Major deterioration of water quality was observed at sampling site V and VI due to discharge of industrial wastes.

Duran (2006) studied water quality using benthic macro-invertebrates and physico-chemical parameters of Behzat stream in Turkey between September 1998 and September 2002. The study confirmed that upstream supported a more diverse community than downstream. He also observed low macro-invertebrate abundance during summer in downstream. The study carried out at upstream and downstream of Singye Chhu revealed similar results.

Corkum (1989) reported that good water quality referred to high abundance of sensitive benthic macro-invertebrates (Ephemeroptera, Plecoptera, Trichoptera) and low conductivity. Similar results were obtained from

upstream of Singye Chhu where relatively clean water was available throughout the year. Marques *et al.* (1999) stated that in downstream the poor water quality and decline in ecosystem health is revealed by low level of biodiversity and consequently dominance of pollution tolerant species belonging to the taxonomic order Oligochaeta, Diptera and Lumbriculida. The downstream water received organic nutrients from agriculture runoff and effluents from industries. The Pasakha industries have food processing and beer manufacturing unit which release effluents containing nutrients into downstream. The Physidae thrive well in nutrients released from the industries.

Trevor *et al.* (2010) assessed the impact of industrial effluent discharged in Mazai stream, Zimbabwe through physico-chemical parameters and also by bio-monitoring of benthic macro-invertebrates. The result of the assessment showed that pollution sensitive taxa such as Hemiptera, Trichoptera, Coleoptera and Odonata were dominant at upstream while downstream was dominated by pollution tolerant species such Chironomids which tallied with the present findings.

The values obtained from the benthic macro-invertebrates indices showed similar results at upstream and downstream of River Singye Chhu. The statistical analysis showed a trend towards gradual impact in water quality, and a peak was observed after industrial effluent discharge. Hence, the results of the study support the hypothesis that the use of benthic macro-invertebrates as indicator in the water body is an effective methodology for the assessment of water quality.

Conclusion

The study confirmed that pollution sensitive benthic macro-invertebrates were dominant in upstream and pollution tolerant species dominated the industrial area and its downstream. The absence of pollution sensitive species in industrial area and its downstream indicated impact on water quality.

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