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# Ecological health of the Kamala River Basin 2019

A project of the South Asia Sustainable Development Investment Portfolio (SDIP)


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This report is a revision of an internal report prepared by Drs Tachamo-Shah and Shah for the State of the Kamala Basin study (that study to be published 2020).

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## Ethics

The activities reported herein have been conducted in accordance with CSIRO Social Science Human Research Ethics approval 12/17.

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**SDIP's goal** is increased water, food and energy security in South Asia to support climate resilient livelihoods and economic growth, benefiting the poor and vulnerable, particularly women and girls

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## Acronyms

| | |
|---|---|
| APHA | American Public Health Association |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| FNU | Formazin nephelometric units |
| L | Litre |
| LULC | Land Use Land Cover |
| masl | Meters above Sea Level |
| mg | milligram |
| MW | Megawatt |
| NDWQS | National Drinking Water Quality Standard |
| NPR | Nepalese Rupee |
| NTU | Nephelometric Turbidity Unit |
| RHC | River Health Class |
| TDS | Total Dissolved Solids |
| USEPA | United States Environmental Protection Agency |

# Executive summary

Rivers are an integral part of water resources, providing habitats to wildlife, supplying water for sustenance of livelihood, nourishing floodplains and being a key parameter to socio-economic development.

**Ecological assessment** uses biological elements living in the hydrological systems as these respond to all stressors including hydrological-morphological changes. Such assessments help to identify the dominant stressors, which threaten river ecosystems under surveillance and aid in determination of the level of ecosystem degradation.

The Kamala River Basin originates in the Mahabharat range and is heavily dependent on monsoon rainfall. Water availability varies substantially across seasons. A wide range of human actions such as waste dumping along the river, river bed extraction, cremation, vehicle river crossing and water diversion have dominated along the Kamala River, causing a deterioration in ecological status.

**This study** was conducted to determine the ecological health of the Kamala River and identify the primary stressors. It provides an overview of water quality, benthic macroinvertebrates and river health of the Basin. Water quality parameters and benthic macroinvertebrates were collected during winter and spring seasons in 2019. Seasonal variations in river discharge and physico-chemical parameters were observed mainly along the main river channel. Parameters such as pH and conductivity were within the range for water use for irrigation and aquaculture, respectively. Alkalinity and hardness parameters exceeded the upper level for aquaculture.

**Findings**: A total of 84 taxa, representing 61 families, belonging to 19 orders of benthic macroinvertebrates were recorded in the river. Benthic macroinvertebrate community assemblage was mainly dominated by orders Ephemeroptera (19%), Trichoptera (16%) and Diptera (16%). Variability in taxonomic richness between seasons was recorded only in the upstream sites: Gaung and Kamalamai streams. Richness declined from upstream to downstream of the river in both seasons, while abundance showed different trends between seasons. Abundance declined from upstream to downstream during the winter season but increased during the spring season.

River health was classified as high to fair, moving from upstream to downstream:

- The upstream section of the Gaung stream was classified as having high ecological status.
- Kamalamai stream and Kamala River to Bhiman were classified as having good ecological status.
- Downstream sections of the river were classified as having fair ecological condition.

**Morphological degradation caused by river bed extraction** was identified as the major stressing factor along the mainstem of the Kamala River.

**Recommendations:** Actions that can be implemented immediately to improve the river health of the Basin include:

1. develop environmentally friendly guidelines for extraction of sand and gravels
2. develop a Basin irrigation strategy so that river baseflow is maintained for aquatic ecosystems and downstream communities
3. implement proper sewage and waste management systems.

Studies to build the evidence base needed to support informed decision making within the Basin are required, including:

1. long-term research considering seasonal change
2. flood inundation and vulnerability mapping
3. quantification of stressors along the river
4. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and e-coli testing to determine the water quality (and its classification)
5. land use impacts on river ecosystems and biodiversity.

# 1 Introduction

Nepal is blessed with thousands of rivers. Based on the nature of origin, rivers are classified into three major categories (NDRI, 2016): Himalayan rivers; Mahabharat rivers and Terai rivers. Himalayan rivers originate from Himalaya and are snow-fed rivers with a significant amount of discharge even in dry seasons. Mahabharat rivers originate from the mid-hills of Nepal; are rainfall/spring/groundwater-fed, with much less discharge in dry seasons, while Terai rivers originate from Churia Hills of Nepal, characterized by monsoonal flash floods and almost no flow in the dry seasons.

Rivers are unique ecosystems that provide ecosystem services such as provisioning, regulatory, supporting and cultural services. However, due to unplanned and unmanaged exploitation of freshwater resources along with other natural resources, many rivers have become stressed. The Kamala River Basin is not an exception. The river is highly modified from river bed extractions, water diversion and abstractions. Natural stressors like flashfloods, surface runoff, landslides, are mostly climate driven, while discharge of effluents (industrial, agricultural, residential), waste dumping, hydro-morphological degradation are development driven (Carpenter et al., 1998; Ren et al., 2003; Singh et al., 2004). However, these stressors and their intensity, vary from location to location along the river course (Tachamo Shah and Shah, 2013). Hence, spatial and temporal studies of ecological (biological, physico-chemical and hydro-morphological) characteristics along with their stressors are essential to better understand and evaluate river health. This study was carried out in the Kamala River Basin in Nepal, to document spatial and temporal variability in hydrological regimes, stressors, aquatic biodiversity and river health.

## 1.1 Research objectives

For the purposes of this report, the research objectives were three-fold:

- to prepare an inventory of macroinvertebrates along the longitudinal gradient of the Kamala River;
- to evaluate river health and prepare a river quality map of the Kamala River;
- to document existing stressors affecting benthic macroinvertebrate community structure.

# 2 Study area

The Kamala River originates upstream of Chiyabari, Sindhuli at an elevation of around 1200 masl. (Figure 1). The catchment area of the River is 2183 km$^2$ to the India-Nepal border with a length of ~117 km[1]. The River Basin lies mostly in Sindhuli, Udayapur, Siraha and Dhanusha districts of Nepal forming a border between Siraha and Dhanusha. Tawa, Baijnath, Mainawati, Dhauri, Soni, Balan, Trisula, and Chadaha Rivers are the major tributaries of the Kamala River. More than 60% of the Basin is below 500 m, about 30% is between 500-1000 m while the rest lies above 1000 m.

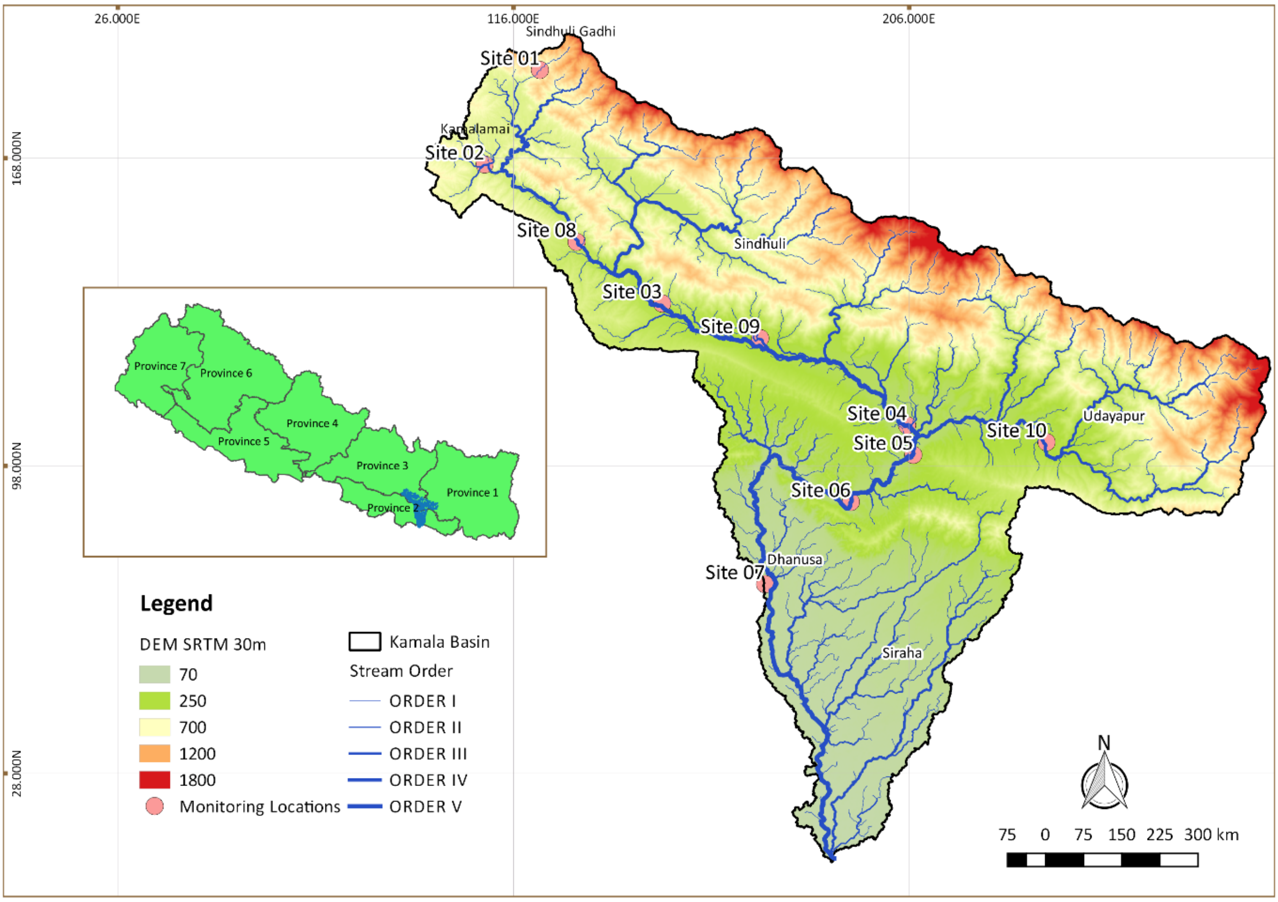


Figure 1 Kamala River Basin with altitudinal gradient, stream order and assessment sites

[1] Area and length of the Kamala watershed were derived from the USGS Shuttle Radar Topography Mission (SRTM) 30m Digital Elevation Model (DEM). We used QGIS 2.18.11 with SAGA GIS for the processing. SAGA is a QGIS plugin that is used for extensive vector and raster manipulations. Firstly, the DEM was downloaded and used as a base map. Next, sinks were filled using the Fill Sink (Wang and Liu, 2006) module. Then, flow accumulation and channel (stream) networks were delineated - a threshold of 06 was judged to provide the right amount of detail for our research. Finally, the area of the basin was calculated using the 'Upslope Area' module; with pour point set around 400–500 m before the Indo-Nepal border.

## 2.1 Land use

The Kamala River Basin is mainly covered by forests (54%) and agricultural land (35%) with small areas of shrublands, grasslands, and barren land, and a very small residential (built-up) area (0.1%)(ref 2010 column in Table 1; and map, Figure 2). While there are no significant changes of land use in the Kamala River Basin in the last three decades (Table 1), a significant amount of change is expected by 2020 due to foreign employment and urbanization (GoN, 2016).

Table 1 Percent land cover of Kamala River Basin over three decades (extracted from the land use/land cover data published by ICIMOD, 2010)

| Land cover | 1990 | 2000 | 2010 |
|---|---|---|---|
| Forest | 58 | 55 | 54 |
| Shrubland | 3 | 4 | 4 |
| Grassland | 4 | 5 | 4 |
| Agricultural land | 32 | 31 | 35 |
| Barren land | 2 | 4 | 2 |
| Water bodies | <1 | 1 | <1 |
| Snow/Glaciers | >0.1 | 0.1 | 0.1 |
| Built-up | 0.2 | 0.1 | 0.1 |

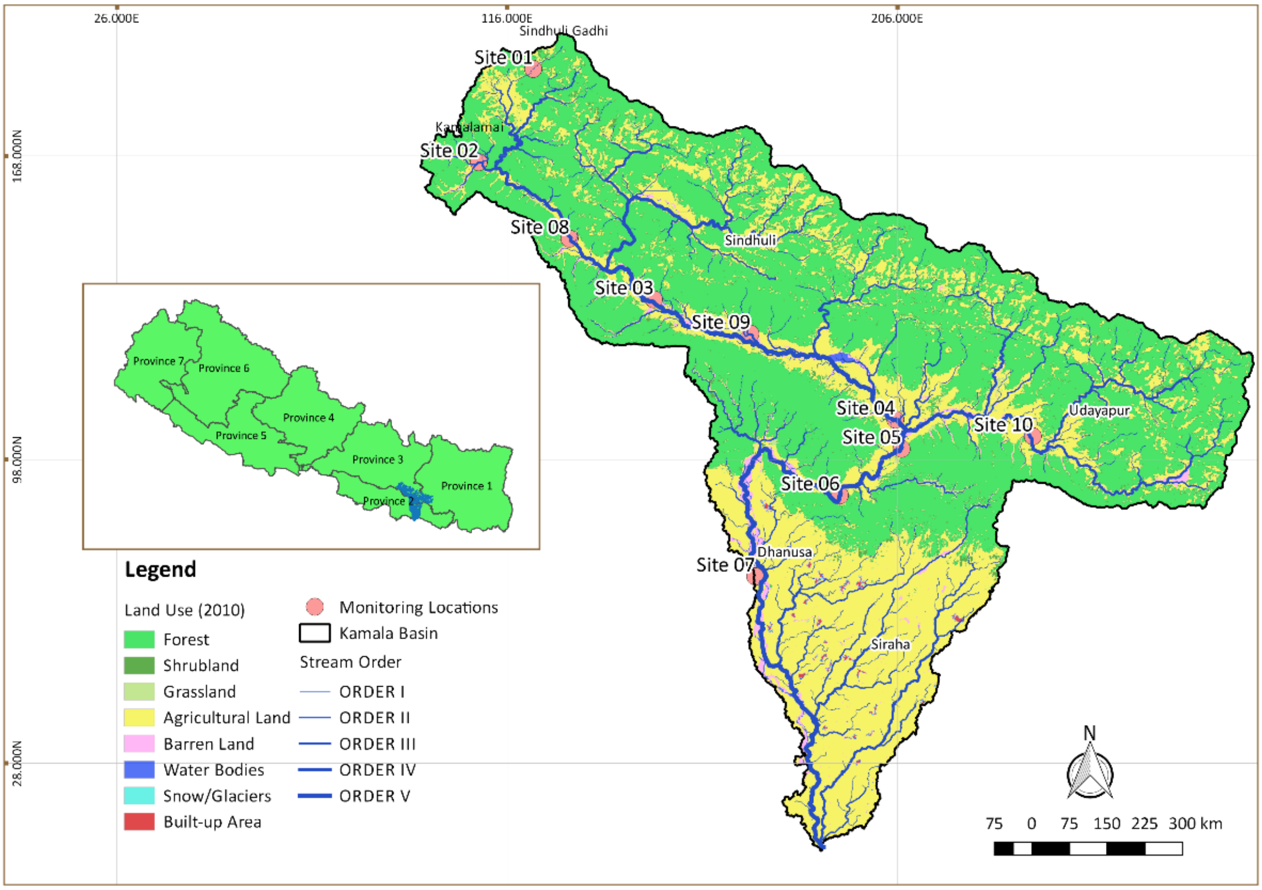


Figure 2 Kamala River Basin land use (land use data extracted from ICIMOD, 2010). The 10 numbered sites on the map identify the study sites, which are described in Section 3

## 2.2 Climate

There are three meteorological stations, located at Sindhuli Gadi, Janakpur airport and Udayapur Gadhi. These stations measure air temperature and precipitation. Five precipitation stations measure rainfall across the Basin. Annual average temperature is around 24 $^{o}$C (three meteorological stations) and average annual rainfall is around 1681mm in the Basin (NDRI, 2016). With 80% of the annual rainfall being confined to monsoon, seasonal variation of rainfall is very high in the Basin. Similarly, the upper north-western side of the Basin is wetter in comparison to the drier north-eastern side (NDRI, 2016).

## 2.3 Hydrology

Annual average discharge of the Kamala River Basin is around 100 $m^3$/s (Joshi and Shrestha, 2008) and minimum and maximum discharge is mostly during April (17 $m^3$/s) and August (303 $m^3$/s), respectively (Shrestha, 2016). During monsoon season, extreme discharge leads to overbank flow and branching within the Kamala River Basin.

According to the Sunkosi-Kamala Diversion Project, a part of the SaptaKosi High Dam Project, 72 $m^3$/s of water is planned to be diverted from Sunkoshi River to Kamala River through a ~17 km tunnel with possibly 61.4 MW of hydropower generation along this point on the Kamala River (Jha, 2013). Another 32 MW of hydropower is expected to be generated as a result of regulating this diverted water approximately 20km from Chisapasi (Jha, 2013). This diversion will support year-round irrigation for nearly 160,000 ha of agricultural land in Saptari and Sarlahi districts.

## 2.4 Geology

The geology of the Kamala River Basin can be divided into the Mahabharat range, the Siwalik range and the Plains. The upper catchment of the Kamala River Basin lies in the Jurassic strata, which is composed of black shales and argillaceous sandstones, probably from the eastern continuation of spite shales (NDRI, 2016). Similarly, the Siwalik deposits consist of alluvial detritus deposited by rivers and streams. These regions are comprised of clay, sand and gravels which have been subjected to extraordinary weathering and are thus susceptible to heavy erosion. The fragile geological nature of the Siwalik range has resulted in the production of high loads of sediment with approximately 7 million tonnes deposited annually into the Kamala River Basin (Thapa and Pradhan, 1997). The Plains region consists of a succession of sand beds with varying textures of silt and clay with occasional gravels.

## 2.5 Biodiversity

Previously, 64 species of birds belonging to 10 orders and 31 families have been reported in the Basin (Parajuli, 2013). Out of them, 52% are of order Passeriformes, 22% of Ciconiiformes, 8% of Coraciiformes, 6% of Falconiformes, 5% of Columbiformes, 2% of Gruiformes and Piciformes each and 1% of Psittaciformes, Cuculiformes and Anseriformes.

# 3 Study sites

Seven sites were selected for the winter season sampling (January 2019) and an additional three sites (total 10 sites) for the spring season (May 2019). Eight sites were distributed in the main channel and two sites in the tributaries (Table 2). Sampling sites along the Kamala River are presented in Figure 2 and Figure 3. The Chiyabari site is downstream of the Guang stream in Sindhuli, which later joins the Kamalamai stream immediately after Kamalamai Temple. Downstream further it is called the Kamala River.

Table 2 Study sites along Kamala River and its tributaries. Samplings at Bhiman, Dakaha Bazaar and Tawa rivers were additionally conducted in May 2019

| Site# | River name | Site name | Category | District | Province | Location | Elevation (masl) |
|---|---|---|---|---|---|---|---|
| Site01 | Guang Stream | Chiyabari | Mainstem | Sindhuli | 3 | 27.249, 85.935 | 636 |
| Site02 | Kamalamai Stream | Tinnaman | Tributary | Sindhuli | 3 | 27.171, 85.885 | 460 |
| Site08 | Kamala River | Bhiman | Mainstem | Sindhuli | 3 | 27.627, 85.5813 | 366 |
| Site03 | Kamala River | Ranibas | Mainstem | Sindhuli | 3 | 27.058, 86.049 | 276 |
| Site09 | Kamala River | Dakaha Bazaar | Mainstem | Sindhuli | 3 | 27.030, 86.139 | 245 |
| Site10 | Tawa Stream | Katari | Tributary | Udayapur | 1 | 26.946, 86.402 | 225 |
| Site04 | Kamala River | Tribeni ghat u/s confluence | Mainstem | Sindhuli | 3 | 26.945, 86.282 | 154 |
| Site05 | Kamala River | Tribeni ghat d/s confluence | Mainstem | Sindhuli | 3 | 26.935, 86.280 | 145 |
| Site06 | Kamala River | Tritiya | Mainstem | Sindhuli | 3 | 26.8957, 86.2229 | 121 |
| Site07 | Kamala River | Raghunathpur | Mainstem | Dhanusha | 2 | 26.828, 86.145 | 60 |

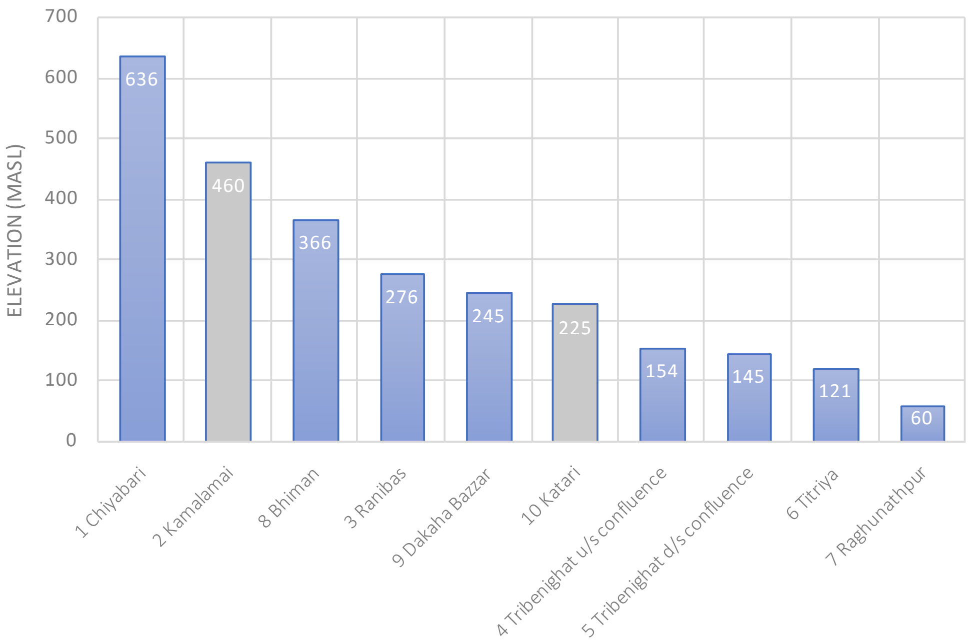


Figure 3 Elevation gradient of Kamala River sites (upstream-downstream). Chiyabari is the most upstream site while Raghunathpur is the most downstream site. The Bhiman and Dakaha Bazaar sites were added during Spring (May 2019) sampling between Kamalamai and Tribenighat. The grey bars identify the sites on tributaries

## 3.1 Site 01 –Guang stream at Chiyabari

The site at Guang stream is located at 27.249º N, 85.935º E and at 636 masl near Chiyabari in Sindhuli district (Province No. 3; Figure 4). This site is situated adjacent to the B.P Highway (right bank). The stream is perennial and spring-fed with warmer water. This site has diverse mineral habitats (boulder to sand), flow type (pool, rapid, riffle and run)with sparse riparian vegetation on both banks. About 100 m downstream of the sampling site, the river water is diverted for irrigation.

Figure 4 Site 01 – Gaung stream at Chiyabari

## 3.2 Site 02 – Kamalamai stream at Tinnaman

The site is at Tinnaman village about a kilometre upstream from the famous religious temple, Kamalamai. The river is a headwater of the Kamala River. There is a road on the right bank of the river. The sampling site was dominated by stones and pebbles with thin algal vegetation (Figure 5). The river stretch has varying flow habitats including runs, riffles, pools and rapids with sparse riparian vegetation on both banks of the river.

Figure 5 Site 02 – Kamalamai River at Tinnaman

## 3.3 Site 08 – Kamala River at Bhiman Bazaar

This river section is braided and mostly consists of sand, stones and pebbles(Figure 6). The site was highly disturbed by vehicle river crossing, and mining of stones and sand from the river bed.

Figure 6 Site 08 – Kamala River at Bhiman bazaar

## 3.4 Site 03 – Kamala River at Ranibas

This site is located at Tallo Ranibas. The site is within 2 km from Bhiman-Dudhauli road near Ranibas. The sampling habitat consisted of stones, cobbles and sand and the river water has been channelized by locals for fishing (Figure 7). The river valley is flat with similar flow types (mostly runs with a few pools). Small patches of forest lie close to the left bank and only patches of filamentous tufts were observed at the site. Ferro-sulphide reduction was observed on stones in slow flow (<0.25 m/s) river sections. No algal vegetation on stones were observed. The river stretch was heavily disturbed by sand and stones mining, particularly on the right bank. Additionally, cremation sites were present along the river banks.

Figure 7 Site 03 – Kamala River at Tallo Ranibas

## 3.5 Site 09 – Kamala River at Dakaha Bazaar

This site in Kamala River is located at Dakaha Bazaar in the Sindhuli district. The river section is braided and the site mostly consists of sand, and small portions of stones and pebbles (Figure 8). Flow consisted of 60% pools, 30% runs and 10% riffles. The river stretch was heavily disturbed by human and vehicle river crossing and extensive mining of stones and sand for construction purposes. River water is also diverted for irrigation.

Figure 8 Site 09 – Kamala River at Dakaha Bazaar

## 3.6 Site 10 – Tawa stream at Katari

Tawa stream is one of the major tributaries of the Kamala River that joins at Katari in Udayapur district (Province No. 1; Figure 9). The stream is braided, spring-fed and perennial with warm water. The site is disturbed by frequent river crossing by humans and vehicles and intensive mining of stones and sand.

Figure 9 Site 10 – Tawa stream, a tributary of the Kamala River, at Katari

## 3.7 Site 04 – Kamala River at Tribenighat (upstream ofTawa confluence)

This site along the Kamala River is located upstream of the confluence with the Tawa stream at Tribenighat in Sindhuli district. The river was braided in the upstream section of the sampling site and the river bed consists of stones and sand (Figure 10). Open defecation was common on the river banks and the site was frequently used for cremation as well. This river stretch was heavily disturbed by river crossing by people and heavy vehicles. Heavy mining of sand and stones was observed in the sampling area.

Figure 10 Site 04 – Kamala River at Tribenighat upstream of the confluence with Tawa stream

## 3.8 Site 05 – Kamala River at Tribenighat (downstream of Tawa confluence)

This site along the Kamala River is located at Tribeni Ghat of Sindhuli district (Province No. 3). The sampling site is about 500 m downstream of Tribeni Ghat, Dudhauli, after the confluence of Tawa Stream (Figure 11). Open defecation was observed in the river banks and river bank cremation was common. Due to accumulation of cremated ashes, large filamentous tufts were abundantly present. The presence of solid waste along the left bank was mainly due to regular dumping of waste by the municipality. This site is famous for festivals and rituals (Maghe Mella). River crossing by humans and heavy vehicles was very frequent. River flow was 'runtype' with a low water level. The mineral habitat was composed of stones, sand and boulders.

Figure 11 Site 05 – Kamala River at Tribenighat downstream of the confluence with Tawa stream

## 3.9 Site 06 – Kamala River at Titriya

This site is located at Titriya of Udayapur district (Province No. 1; Figure 12). The river bed was mostly sand and stones. The site was disturbed by crossing of rivers by vehicles. Cremations used to be performed regularly along the river banks, resulting in large filamentous tufts. Electric fishing was intensive at this site.

Figure 12 Site 06 – Kamala River at Titriya

## 3.10 Site 10 – Kamala River at Raghunathpur

This site on the Kamala River is located at Raghunathpur of Dhanusha district (Province No. 2; Figure 13). The river is braided and composed of three river channels, each of which is used for irrigation. In the upstream section, bridge construction was in progress with the river bed in this section excavated to support the bridge construction. The mineral habitat at the site mainly consisted of sand, with small portions of stones and pebbles. River crossing by vehicles was also very common at this location.

Figure 13 Site 10 – Kamala River at Raghunathpur (a braided section of the river)

# 4 Methods

## 4.1 Discharge measurement

Total discharge of a river is defined as the volume of water flowing in a river or water per unit time (USGS, 2016), commonly expressed in cubic meters per second (cumecs or $m^3/s$). In general, total discharge cannot be calculated directly and is calculated by multiplying cross-sectional area of the river channel by the average velocity of that channel.

A SonTek Flow Tracker handheld Acoustic Doppler Velocimeter (ADV) was used to measure stream discharge using the United States Geological Survey (USGS) mid-section discharge method (Rantz, 1982). Most channels were divided between 10 to 25 sub-sections depending upon their geometry (Figure 14). The area of each sub-section was calculated by measuring depth and width; where width is measured from half-way of the preceding point to the following measuring point. Average velocity was measured in each sub-section at a depth of 0.6 m of the total water depth by using the acoustic Doppler effect (measuring the suspended particles). Finally, total discharge was calculated by adding individual sub-section discharges (USGS, 2016).

Figure 14 Discharge measurement using SonTek Flow Tracker in Kamala River at Tribenighat before the confluence

## 4.2 Physico-chemical characteristics

A multi-parameter portable meter (Hanna Probe HI 9829 Multiparameter Meter) was used to measure pH, dissolved oxygen (DO; both in mg/L and in %), electrical conductivity (EC), temperature (temp), total dissolved solids (TDS) and turbidity (Figure 15). Furthermore, nitrate, ammonia and phosphate were measured on site using portable specto-photometers. Ammonia was measured by Hanna Instruments HI96715C ammonia medium range ISM; 0.00 to 9.99 mg/L, nitrate was measured by using HI96728C nitrate ISM; 0.0 to 30.0 mg/L range; and phosphate was measured by using HI96717 phosphate high range ISM; 0.0 to 30.0 mg/L. In addition, titration was done to measure total alkalinity, total hardness and chloride.

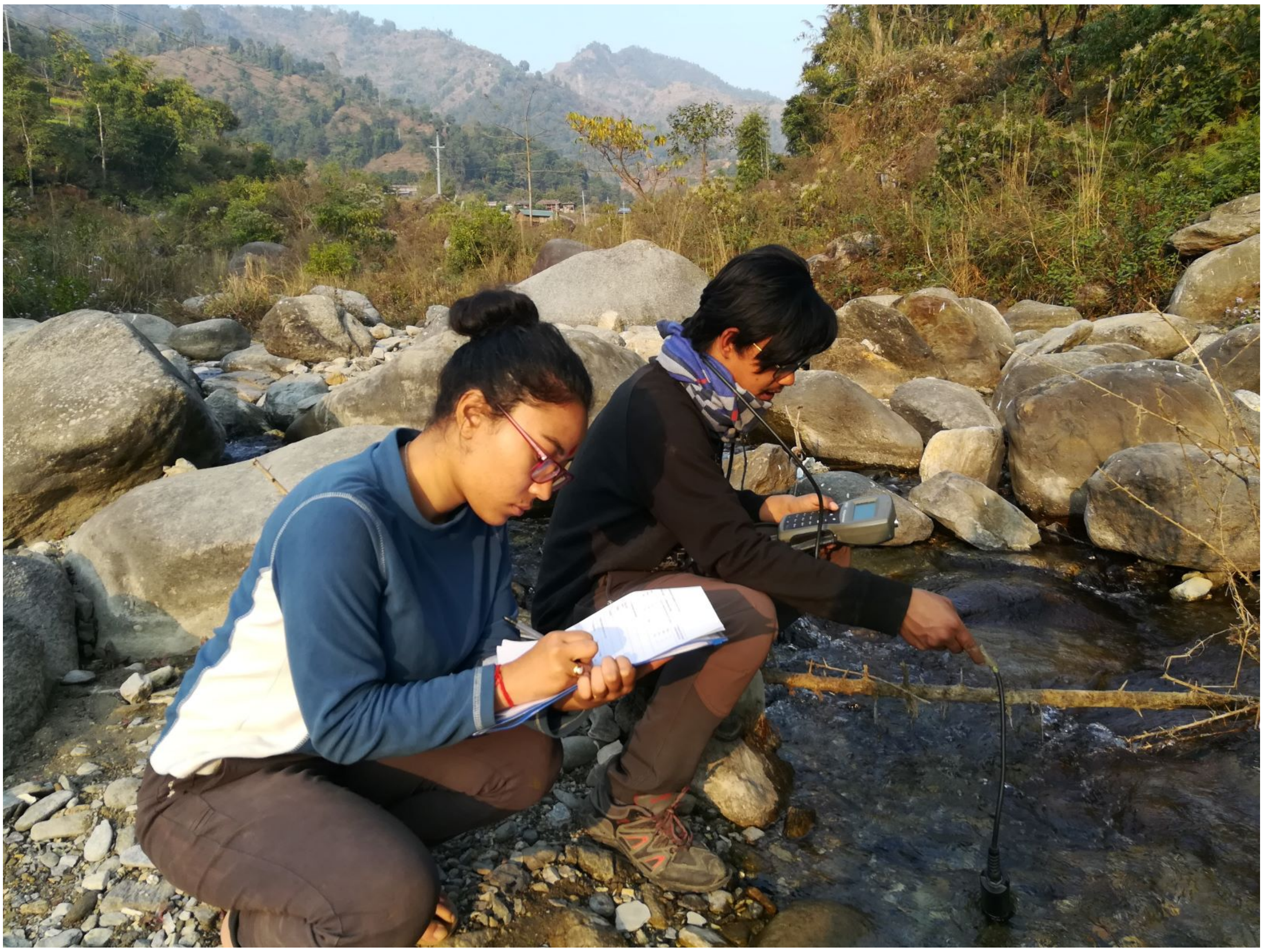

Figure 15 Water quality parameter measured using a multi-parameter portable meter (Hanna Probe HI 9829 Multiparameter Meter)

## 4.3 Benthic macroinvertebrates

Benthic macroinvertebrates were collected using a hand (sampling area of 0.0625 $m^2$; mesh size of 500 µm) following the multi-habitat sampling approach from 100 m river stretch in a site (Figure 16). In total 10 sub samples were taken from the most-dominant micro-habitats covering at least 10% of habitat coverage (Tachamo Shah et al., 2015). Habitat less than 10% coverage was not sampled. Sub samples were transferred into a half-filled bucket and rinsed with water. Coarse materials like twigs, leaves, stones and cobbles were removed. The composite sample was then transferred into a labeled plastic container and preserved in 95% ethanol.

In the laboratory, samples were well washed using tap water in 500 µm mesh net. The samples were transferred into a white enameled tray where benthic macroinvertebrates were sorted from sediment. The benthic macroinvertebrates were identified into the lowest possible taxonomic level (genus and family) using stereo-microscope.

Figure 16 Benthic macroinvertebrate sampling using hand net (sampling area of 0.0625 $m^2$; mesh size of 500 µm)

# 5 Results

## 5.1 Discharge

Kamala River discharge shows a very strong linear increase from the headwaters and then downstream ($R^2$=0.89) (Figure 17). Topography, rainfall, morphology, geology, number of tributaries, among others are some of the factors that affect hydrological characteristics. Similarly, human-induced physical changes like damming, water withdrawal, construction activities impact hydrological characteristics of rivers. Significant increase in river discharge between the two Tribenighat gauges (i.e. upstream and downstream of Tawa confluence) is due to the water entering the Kamala River from Tawa stream at Tribenighat, Sindhuli. The highest discharge (4.82 $m^3/s$) was observed at Tribenighat after the confluence while the lowest (0.03 $m^3/s$) was recorded in Gaung Stream at Chiyabari during the winter season. Variability in discharge was not observed for the Gaung and Kamalamai streams, while high variability was observed between seasons along the Kamala River after the confluence of Gaung and Kamalamai streams (Figure 17). Both river width and river depth show a steady increase from the headwaters and then downstream. Maximum width and discharge were recorded at the Titriya site.

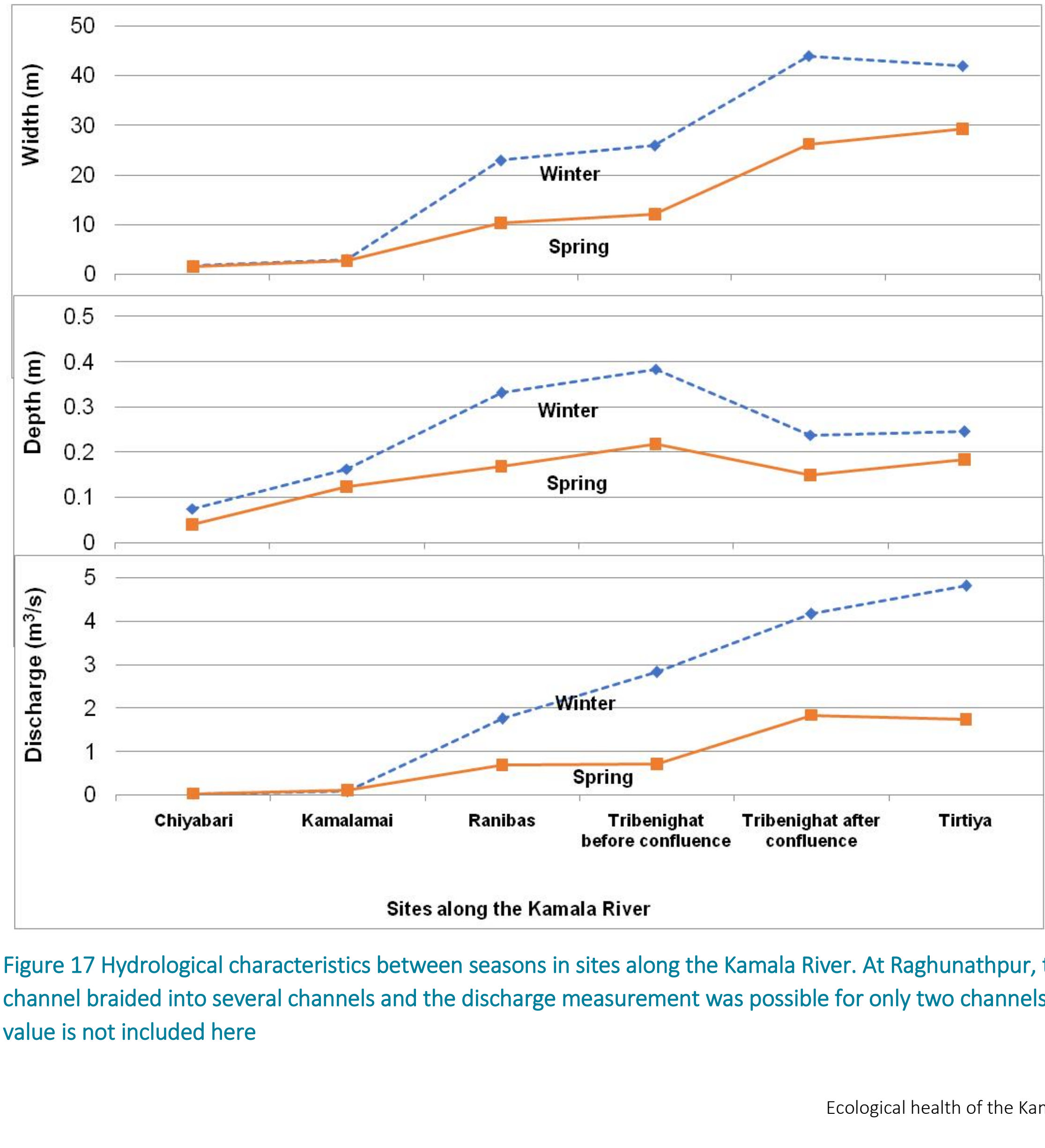


Figure 17 Hydrological characteristics between seasons in sites along the Kamala River. At Raghunathpur, the river channel braided into several channels and the discharge measurement was possible for only two channels, therefore, the value is not included here

## 5.2 Physico-chemical parameters

Physical-chemical parameters are important aspects of river ecosystems that affect abundance and diversity of faunal communities in ecosystems (Bagenal, 1978). Figure 17displays seasonal changes in physico-chemical parameters along the Kamala River. Except for temperature and turbidity, all the parameters were higher during the winter season than during the spring season.

Average **water temperature** ranged from 15.1 to 22.14°C during winter and from 26.5 to 34.6°C during spring. River temperature between 20–32°C is suitable for the majority of freshwater species (Boyd, 1990). River temperature varies with diurnal and seasonal variation in atmospheric temperature (Kundanagar et al., 1996), elevation, weather, number of tributaries, pollution, and presence of chemicals. For most sites, water temperature was below the upper limit for warm water fishes (Figure 18a).

The average **pH** value ranged between 8.13–9.41 for winter and 6.42–7.78 for spring. pH was found within the NDWQS range (6.5–8.5) at all the sites for spring, while it exceeded in all sites except Kamalamai stream in winter (Figure 18b). pH exceeded the aquaculture and effluent release standards (6.5–9) for both the Tribenighat after confluence and Titriya sites. pH below 5.0 and above 9.5 are not suitable for the majority of freshwater species (APHA, 1976).

Average **dissolved oxygen** (DO) ranged from 7.51–14.12 mg/L during winter and 4.96 -9.24 mg/L during spring. DO values are below the standards for intermediate warm water fishes and exceeded the upper limit for cold water fishes (USEPA, 2000) for the sites downstream of Tribenighat after confluence (Figure 18c). This makes sense as these sites are located in the lowlands while the river itself originated from Siwaik-Churia where water temperature is relatively higher than snow-fed rivers. Temperature and DO are inversely proportional to each other. DO concentration below 2 mg/L cannot sustain life; however, above 5 mg/L is ideal for sustaining diverse freshwater species (USEPA, 2000).

Average **electrical conductivity** (EC) ranged from 83 to 388 µS/m for winter and from 107 to 429 µS/m for spring (Figure 18d). EC represents the concentration of ions in water. Conductivity was recorded well below the upper limit for aquaculture(Nepal Water Quality Guidelines for Aquaculture, 2008).

Total **alkalinity** ranged between 60–260 mg/L for winter and 25–46 mg/L for spring. Total **hardness** ranged between 80–212mg/L for winter and 112–162 mg/L for spring. Both of these parameter values in the Kamala River mainstem exceeded the upper level for aquaculture (Nepal Water Quality Guidelines for Aquaculture, 2008) (Figure 18e,f). In general, hardness in water regulates pH and toxicity of metals and hence, has greater influence on the prevailing aquatic organisms.

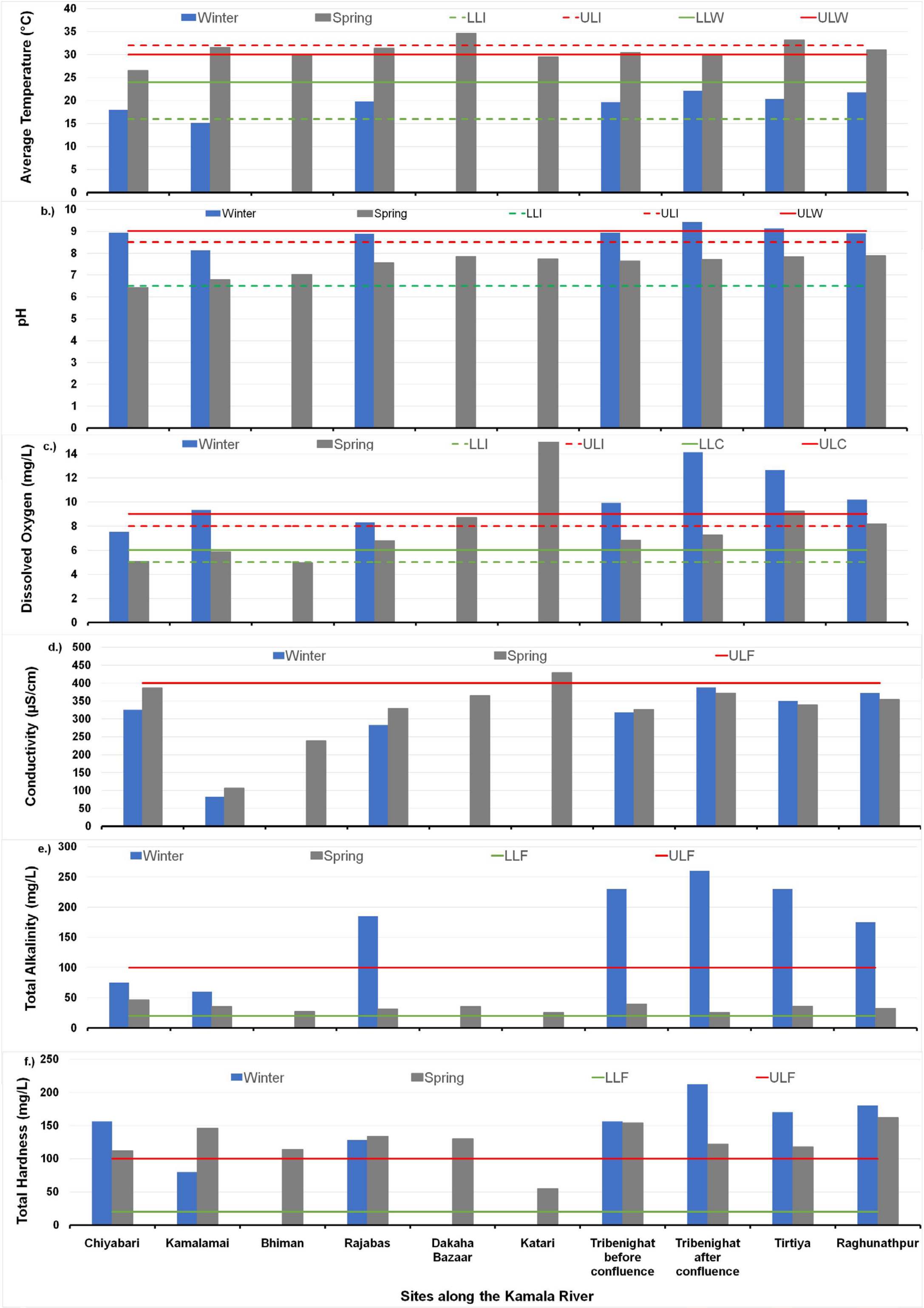


Figure 18 Physico-chemical parameters between seasons in sites along the Kamala River. LLI = lower limit for intermediate warm water fish; ULI = upper limit for intermediate warm water fish; LLC = lower limit for cold water fish; ULC = upper limit for cold water fish; LLF = lower level for aquaculture; ULF = upper level for aquaculture

**Chloride** concentration varied slightly between seasons and along the longitudinal gradient of the river (Figure 19a).

**Nitrate** and **orthophosphate** concentration did vary between seasons (Figure 19b,c). These chemicals are essential indicators of organic pollution level in aquatic ecosystems. All values lie below NDWQS standards (nitrate < 50).

**Turbidity** measures the suspended solids in water. Agricultural runoff, municipal and industrial effluents enhance turbidity in river. Suspended solids ranged from 0.8 FNU to12.6 FNU during winter and from 1.9 FNU to 69.20 FNU during spring. Turbidity was below NDWQS limits (5-10 FNU) at most sites except, Ranibas and Raghunathpur during spring. Maximum turbidity during spring might be due to minimum dilution effect from rain and soil erosion that increases the presence of particles during spring (dry) (Martinez-Tavera et al., 2017). High turbidity measured at Dakaha Bazaar and Tribenighat before the confluence might be due to continuous vehicle crossing across the river during sampling time. High levels of turbidity can simulate bacterial growth and protect micro-organisms from being disinfected (WaterAid, 2011).

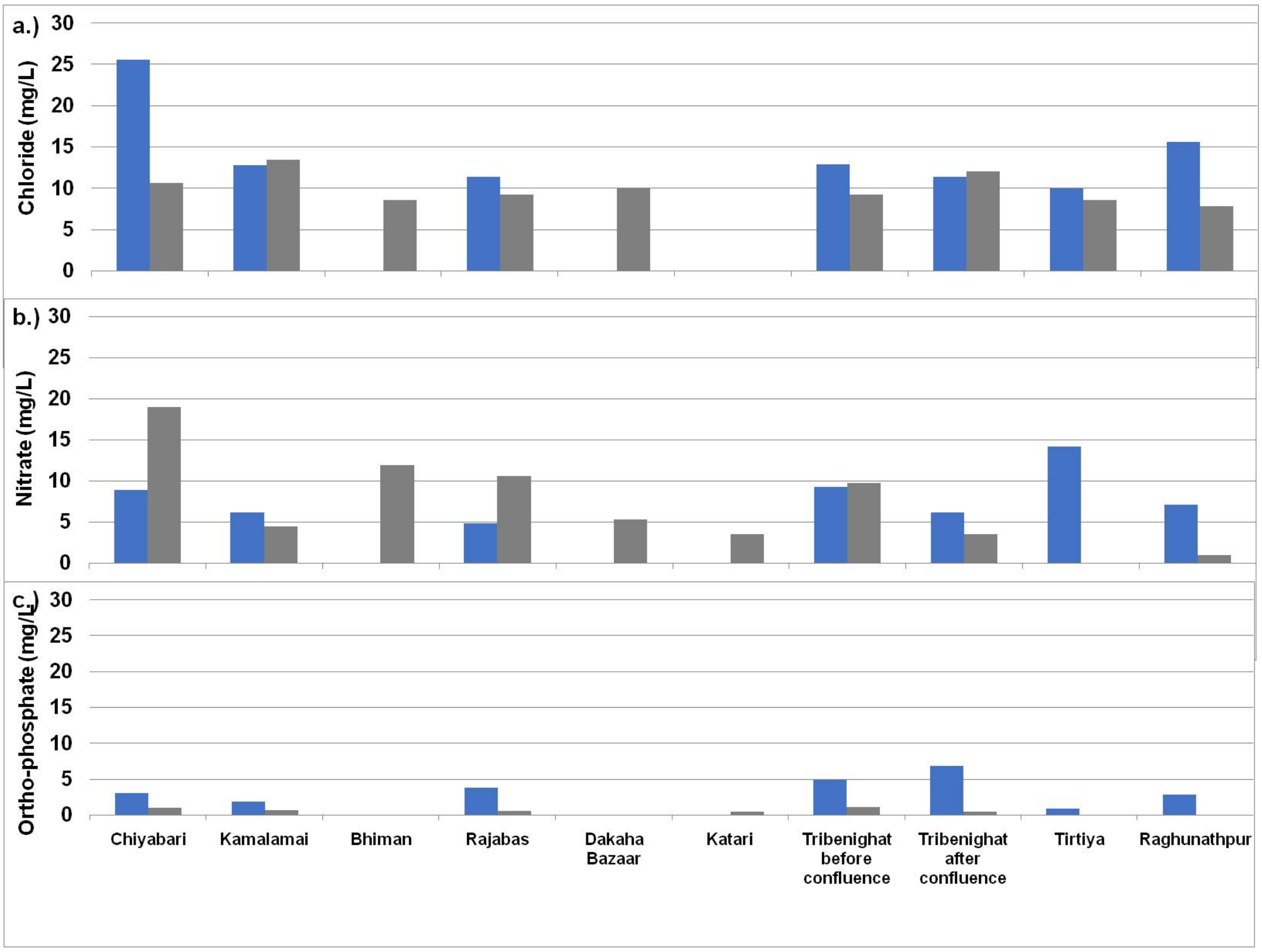


Figure 19 Chemical parameters between seasons in sites along the Kamala River

## 5.3 Benthic macroinvertebrate assemblages

A total of 84 taxa representing 61 families of 19 orders were recorded across the study sites (Figure 20). Ephemeroptera (19%) was the most dominant order followed by Trichoptera and Diptera (16% each) (Figure 20). These orders are important groups of benthic macroinvertebrates assemblages (Tachamo-Shah and Shah 2013; 2012; Milner et al. 2015). Ephemeroptera and Trichoptera dominated in sites of Churia-hills while Mollusca was mainly recorded at Dakaha Bazaar and Tawa stream. Only one family of each order Megaloptera and Lepidoptera was recorded and was the least diverse.

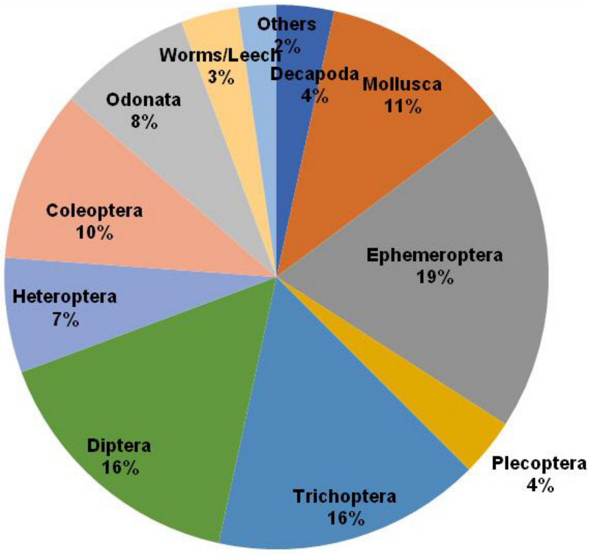


Figure 20 Benthic macroinvertebrates composition in the Kamala River. 'Others' represent order Megaloptera and Lepidoptera

High variation between winter and spring seasons was observed only in Gaung stream at Chiyabari. This might be due to habitat heterogeneity in the river, as increase in the number of microhabitats embraces diverse macroinvertebrates (Bhandari et al., 2018). Maximum taxa richness and abundance were documented in Gaung stream at Chiyabari during winter season (Figure 21a). Taxa richness declined from Chiyabari to Raghunathpur while abundance showed different trends (Figure 21a). High variability in abundance was recorded in most of the study sites (Figure 21b) but seasonal variability was observed only in tributaries and lower reaches of the river. This might be due to decrease in river discharge from winter to spring as reduced river discharge lowers the suitable habitats including dissolved oxygen in a river that favour tolerant species.

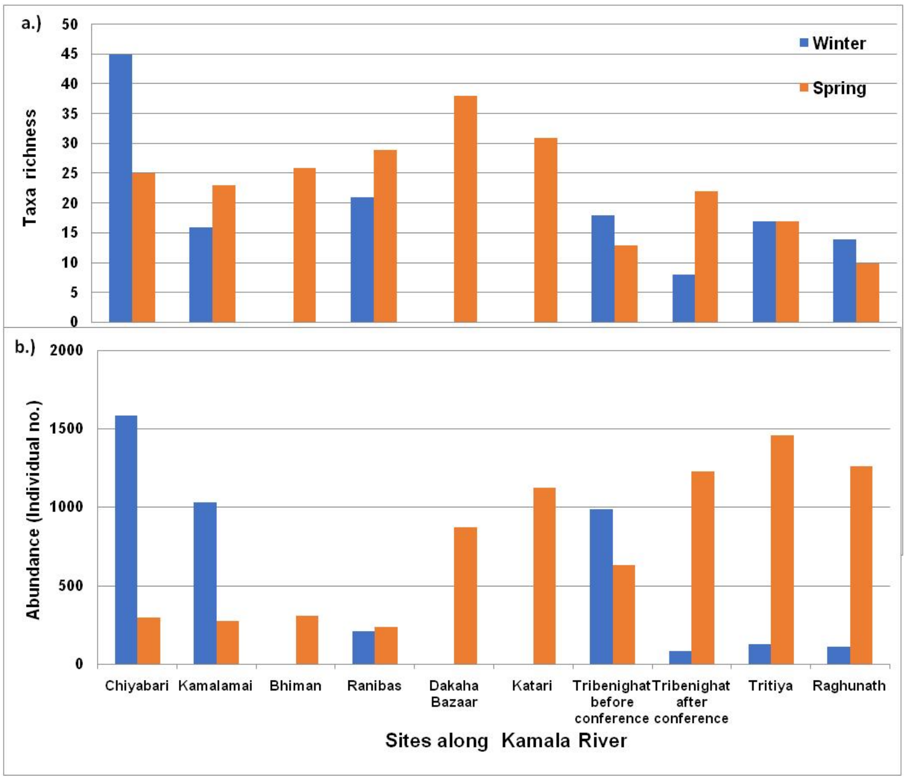


Figure 21 Taxa richness (no. of taxon) and abundance (count) in study sites along the Kamala River

## 5.4 River health

In this study, the Ganges River System Biotic Score (GRSbios)was used to calculate the river health class. The GRSbios is an abiotic score catalog covering more than 486 taxa whereby scores range from 1 to 10 according to the ecological preference of each taxon, 1 indicating tolerant taxa and 10 indicating sensitive taxa. The average score per taxon (ASPT) value provides the classification basis for the river health classes (RHC) (Table 3).

Table 3 GRSbios river health classes (from Nesemann, 2006)

| Class code | Class name | Degree of pollution |
|---|---|---|
| I | High | None to minimal |
| II | Good | Slightly |
| III | Fair | Moderately |
| IV | Poor | Heavily |
| V | Bad | Extremely |

This method was adopted as it has been used successfully by the authors to assess the ecological status of running waters elsewhere in Nepal (e.g. Tachamo-Shah and Shah, 2012). Sites fell into the top three classes (I, II, III) as mapped in Figure 22. Gaung stream, was classified as RHC I where many sensitive taxa such as *Rithrogena* spp. *Iron* spp., *Paragnetina* spp., Euphaeidae, *Hydropsyche* spp. and *Platybaetis* spp. were recorded. *Platybaetis* spp. is a rare taxon that occurs mostly in singular numbers in many of the recorded streams (Tachamo-Shah, 2011). The taxon has been reported from small streams to medium sized rivers of Stream Order 3-4 (Tachamo-Shah, 2011) and across Nepal from east to west (Tachamo-Shah et al., 2020). Kamalamai stream and Kamala River up to Bhiman were classified as RHC II. The remaining stretches of the Kamala River were classified as RHC III. The sites with RHC III were mainly dominated by moderately tolerant taxa (Figure 22). Human activities such as sand and gravel mining, vehicle crossing and waste dumping along the bank prevailed in the downstream sections of the Kamala River.

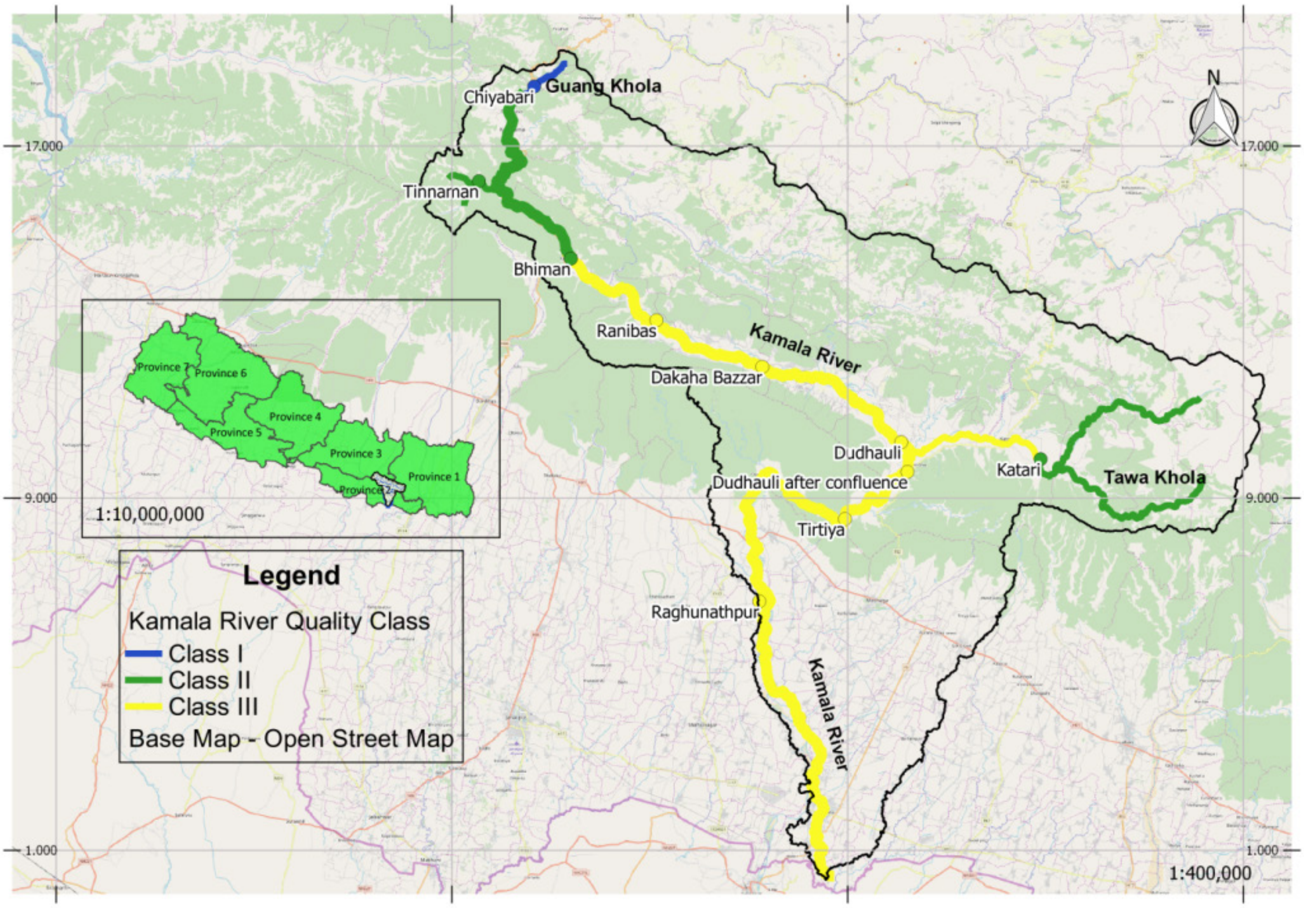


Figure 22 River health map of the Kamala River

### 5.4.1 Sensitivity of benthic macroinvertebrates

Sensitive taxa richness declined from upstream to downstream in the Kamala River (Figure 23). Moderately tolerant taxa richness was abundant in the middle reaches and declined in lower reaches of the river. Though river morphology was found to be highly deteriorated due to river channelization and river bed extraction in most of the sites along the mainstem of the river, tolerant taxa richness did not vary across the sites. This might be due to the fact that the assigned taxa tolerance score is developed in reference to organic pollution rather than morphological degradation which might have overestimated the ecological status of the river (Tachamo-Shah and Shah, 2012).

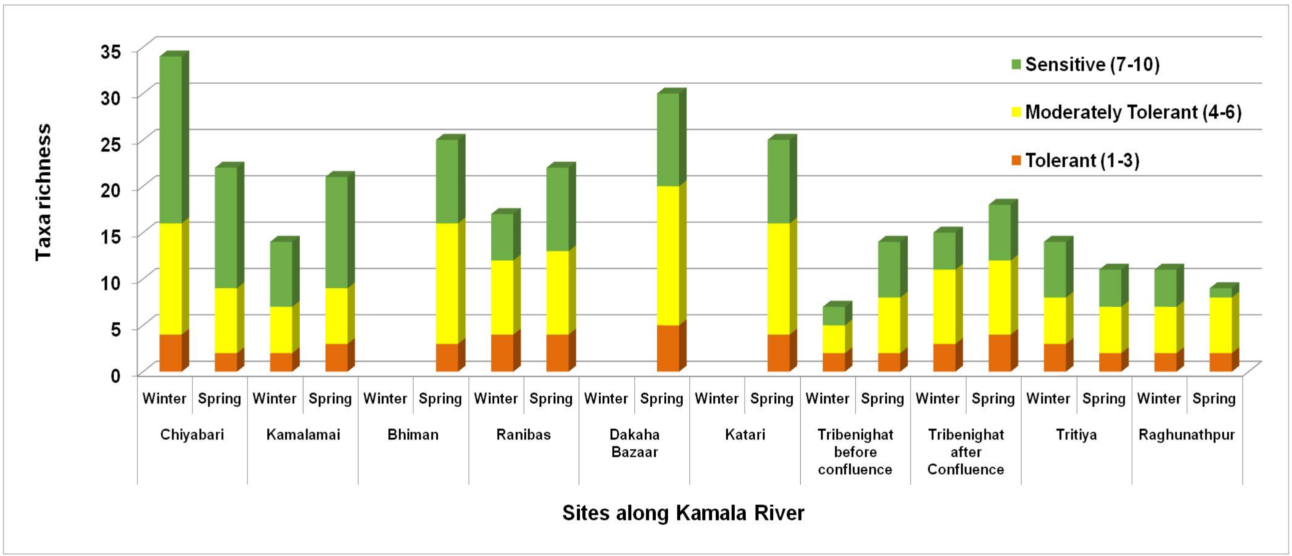


Figure 23 Taxonomic composition of benthic macroinvertebrates in relation to their taxon tolerance score

A study conducted in western Nepal revealed that taxa richness does not vary significantly with alteration in flow regimes (Tachamo Shah et al., 2020). Nevertheless, abundance of tolerant taxa increased progressively from upstream to downstream of the river (Figure 24). This finding corroborated with other research findings in which abundance of macroinvertebrates was found to be sensitive to altered flow regimes (Tachamo Shah et al., 2020). Decreased in river discharge generally reduce suitable habitats for sensitive macroinvertebrates as these organisms require optimal oxygen concentration which reduces with low flow. Reduced in river discharge in spring season with the same level of human activities all year round has lowered the taxa richness in the most downstream sites; however some tolerant taxa such as *Caenis spp.*, *Cheumatopsyche spp.*, and Chironominae have increased total abundance.

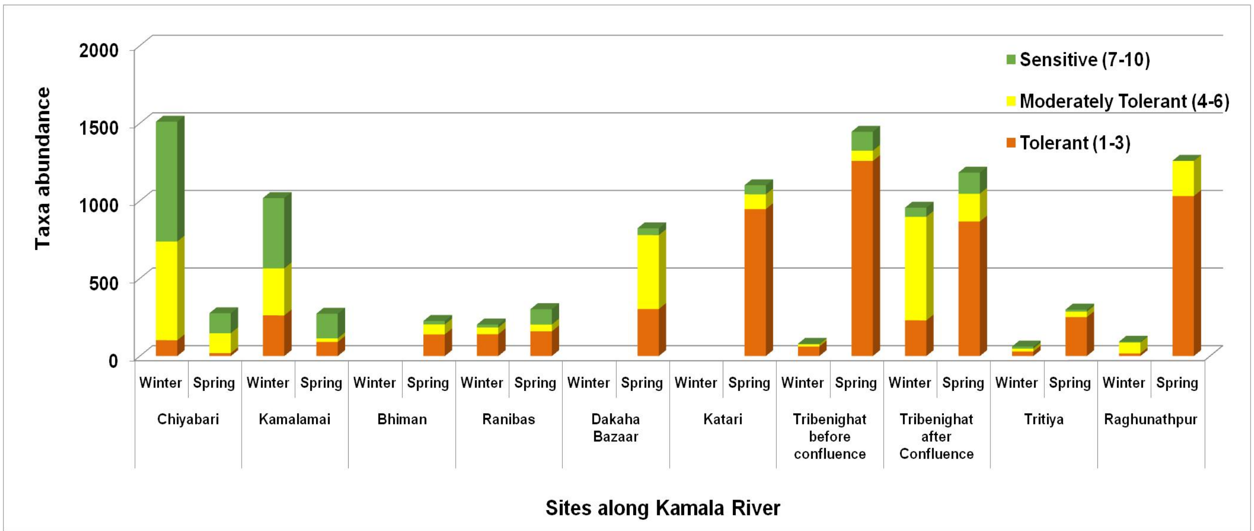


Figure 24 Taxonomic composition of benthic macroinvertebrates in relation to their taxon tolerance score

# 6 Uses of the river

While not an objective of the study, we observed many ways in which the local people use the river at the study sites. Some of these observations are included here as they demonstrate how closely the river is linked to the livelihoods of the local people.

The majority of riparian community-based inhabitants catch fish, using traditional methods (Figure 25) for household consumption.

Figure 25 Local people fishing in the river at Ranibas

Market value of some fish species is high; for example, *Garra* spp.(local name: Budhana) – 300 NPR/kg, *Labeo rohita* (local name: Rohu)- 300 NPR/kg, Guha 550 NPR/kg, *Mastecembelus* spp. or *Magronathus* spp. (local name: Bam) – 600 NPR/kg, *Wallago attu* (local name: Buhari) – 600NPR/kg, and Botia spp. (local name: Baghi) – 700 NPR/kg.

Nets, poison, electric currents, and river blocking are commonly used for catching fish. More recently, local municipalities have begun monitoring river sections to penalize the individuals who use poison for fishing.

People use the river water for washing clothes, household chores, home garden, irrigation, recreational use, fisheries, bathing, wallowing/animal bathing, rituals and festivals while they access drinking water through wells, pump, and municipal supply. Ponds, and springs are some of the other sources of drinking water in the Basin.

River water is often diverted by households for irrigation. For example, vegetable crops require water from a daily to weekly basis while seasonal crops require water on monthly or seasonal basis.

# 7 Conclusions and recommendations

The Kamala River provides various ecosystem services such as provisioning, regulating, supporting and cultural. The multiple use of the river was observed in the entire river stretch from upstream to downstream. Among others, hydro-morphological alteration was one of the prime factors that has impacted river ecosystems. In comparison, river health was poor during the spring season compared to the winter season.

Three actions that can be implemented immediately to improve the river health of the Basin are:

1. develop environmentally friendly **guidelines** for extraction of sand and gravels
2. develop a **Basin irrigation strategy** so that river baseflow is maintained for aquatic ecosystems and downstream communities
3. implement proper **sewage and waste management** systems.

Longer term study to build the evidence base to support informed decision making within the Basin is needed, including:

- long-term research considering **seasonal change**
- flood **inundation** and **vulnerability** mapping
- quantification of **stressors** along the river
- Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and e-coli testing to determine the **water quality classification**
- **land use impacts** on river ecosystems and biodiversity.

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# Annexures

## Annex 1: An inventory of macroinvertebrates of sites for spring (May 2019) and winter (January 2019) season along the Kamala River. Spr= Spring; Win= Winter. Strike (*) indicates presence of a taxon in a site for the season.

| | | | Chiyabari | | Kamalamai | | Rajabas | | Tribenighat befor | | Tribenighat after ( | | Tritiya | | Raghunathpur | | Dakaha E | Tawa Kh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Order | Family | Taxon | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Spr |
| Architaenioglossa | Viviparidae | *Idiopoma dissimilis* | | | | | | | * | | | | | | | | * | |
| Arguloida | Maxillopoda | *Branchiura* | | | | | | | | | | | | | | | * | |
| Arhynchobdellida | Salifidae | *Barboni weberi* | | | | | | | * | | | | | | | | * | * |
| Basommatophora | Lymnaeidae | *Lymnea accuminata* | | | | | * | * | * | | | | | | * | | * | * |
| Basommatophora | Planorbidae | *Granulus convexiusculus* | | | | | * | * | | | | | | | | | * | * |
| Basommatophora | Planorbidae | *Indoplnorbis escustus* | | | | | | | | | | | | | | | * | |
| Coleoptera | Dytiscidae | | | | | | | | | | | | | | | | * | |
| Coleoptera | Elmidae | | * | * | | | * | * | * | | * | | * | | | | | * |
| Coleoptera | Gyrinidae | | * | * | | | | | | | | | | | | | | |
| Coleoptera | Hydrophilidae | | * | * | | | * | * | | | | * | | | | | | * |
| Coleoptera | Psephenidae | Eubrinae | | | * | | | * | | | | | | | | | * | * |
| Coleoptera | Psephenidae | Psephanoidinae | * | * | * | * | | * | * | | * | * | * | * | | * | * | * |
| Coleoptera | Psephenidae | Psepheninae | | * | | | | | | | | | | | | | | |
| Coleoptera | Scirtidae | | | * | | | * | | | | | | | | | | | |
| Coleoptera | Staphylinidae | | | * | | | | | | | | | | | | | | |
| Decapoda | Atyidae | *Caradina* | | | | | | | | | | | | | | | * | * |
| Decapoda | Palaemonidae | *Macrobrachium* | | | | | * | | | | | | | | | | * | |
| Decapoda | Potamidae | | | | | | | | | | | | | | | | * | |
| Diptera | Athericidae | | * | | | | | | | | | | | | | | | |
| Diptera | Ceratopogonidae | | | | | | * | | | | | | * | * | * | * | | * |
| Diptera | Chironomidae | Chironominae | | * | * | | * | * | * | * | * | * | * | * | * | * | * | * |
| Diptera | Chironomidae | Orthocladinnae | | * | | | | | | | * | * | | | * | * | | |
| Diptera | Chironomidae | Tanypodinae | * | * | | | * | * | | | * | * | * | * | * | | * | * |
| Diptera | Chironomidae | Tanytarsini | | * | | | | | | | | | | | | | | * |
| Diptera | Chironominae | *Stemphellina* | | * | | | | | | | | | | | | | | |
| Diptera | Empididae | | | * | | | | | | | | | | | | | | |
| Diptera | Limoniidae | *Hexatoma* | * | * | * | * | | * | | | | * | * | * | * | | | * |
| Diptera | Limoniidae | | | * | * | * | * | | | | | | | | | | | |
| Diptera | Muscidae | | | | | | | | | | | | | | | * | | |
| Diptera | Simuliidae | | * | * | | * | | | | | | | | * | | | | |
| Diptera | Stratiomyiidae | | | | | | | | | | | | | | | | * | |
| Diptera | Tabanidae | | | | * | * | * | * | * | * | | * | * | * | | | * | * |
| Ephemeroptera | Baetidae | *Acentrella* | * | | * | * | * | | * | | | | | | | * | | * |
| Ephemeroptera | Baetidae | *Baetiella* | | * | | | | | | | | | | | | | | |
| Ephemeroptera | Baetidae | *Baetis* | * | * | * | * | * | * | * | * | * | * | * | * | | | * | * |
| Ephemeroptera | Baetidae | *Platybaetis* | * | * | | | | | | | | | | | | | | |
| Ephemeroptera | Baetidae | *Procleon* | | | | | * | | | | | * | | | | | * | |
| Ephemeroptera | Caenidae | *Caenis* | | * | * | | * | * | * | * | * | * | * | * | * | * | * | * |
| Ephemeroptera | Ephemerellidae | *Cincticostella* | | * | | | | | | | | | | | | | | |
| Ephemeroptera | Ephemerellidae | *Torleya* | * | * | * | * | * | * | | | | * | | | | | * | * |
| Ephemeroptera | Ephemeridae | *Ephemera* | | | * | | | * | | | | | * | * | | | * | |
| Ephemeroptera | Heptageniidae | *Cinygmina* | * | * | * | * | * | * | * | | | * | | * | | | * | * |
| Ephemeroptera | Heptageniidae | *Epeorus* | | * | | | | | | | | | | | | | | |
| Ephemeroptera | Heptageniidae | *Iron* | | * | | | | | | | | | | | | * | | |
| Ephemeroptera | Heptageniidae | *Notacanthurus* | * | * | | | | | | | | | | | | | | |
| Ephemeroptera | Heptageniidae | *Rithrogena* | * | * | | | | | | * | | | | * | | | | |
| Ephemeroptera | Leptohyphidae | | | * | * | * | | | | | * | | | | | | | |
| Ephemeroptera | Leptophlebiida | *Choroterpes* | | * | * | * | * | * | * | * | * | * | * | * | | * | * | * |
| Haplotaxida | Tubificidae | | | | | | | | | | | | | | | * | | |
| Heteroptera | Mesoveliidae | | | * | | | | | | | | | | | | | | |
| Heteroptera | Naucoridae | | | | * | | | * | | | | | | | | | * | |
| Heteroptera | Gerridae | | | | | | * | | | | | | * | | | | | * |
| Heteroptera | Micronectidae | *Micronecta* | | * | | | | * | | * | | * | * | * | | | * | |
| Heteroptera | Nepidae | Nepinae | | | | | * | | | | | | | | | | | |
| Heteroptera | Veliidae | | | * | | | | | | | | | | | | | | |
| Lepidoptera | Pyralidae | | | | | | * | | * | | | * | | | | | * | * |
| Megaloptera | Corydalidae | | | * | | * | | | * | | | | | | | | * | * |

| Order | Family | Taxon | Chiyabari | | Kamalamai | | Rajabas | | Tribenighat befor | | Tribenighat after | | Tritiya | | Raghunathpur | | Dakaha E | Tawa Kh |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Win | Spr | Spr |
| Neotaenioglossa | Thiaridae | *Melanoides tuberculatus* | | | | | | | * | | | | | | | | * | * |
| Neotaenioglossa | Thiaridae | *Thiara lineata* | | | | | | | * | | | | | | | | * | |
| Neotaenioglossa | Thiaridae | *Thiara scarba* | | | | | | | | | | | | | | | * | |
| Odonata | Coenagrionidae | | | | | | * | | | | | | | | | | | |
| Odonata | Cordulegastridae | | | * | | | | | | | | | | | | | | |
| Odonata | Euphaeidae | | * | * | * | | | | | | | | | | | | | |
| Odonata | Gomphidae | | * | * | | * | * | * | * | | * | | * | * | | | * | * |
| Odonata | Libellulidae | | | | | | | * | | | | * | | * | * | | * | * |
| Odonata | Macromiidae | *Macromia* | | * | | | | | | | | | | | | | | |
| Odonata | Protoneuridae | | | | | | * | * | | | | | | | | | * | * |
| Plecoptera | Perlidae | *Neoperla* | * | | | | * | * | * | | * | | * | | | | ** | * |
| Plecoptera | Perlidae | *Paragnetina* | * | * | * | | | | | | | | | | | | | |
| Sphaeriida | Sphaeriidae | | | | | | | | | | | | | | | | * | |
| Trichoptera | Brachycentrida | *Brachycentrus* | | | | | | | | | | | | | | * | | |
| Trichoptera | Glossosomatid | Agapetinae | * | * | * | | | | | | | | | | | | | |
| Trichoptera | Goeridae | *Goera* | | * | | | | | | | | | | | | | | |
| Trichoptera | Hydropsychida | *Acrtopsyche* | * | | | | | | | | | | | | | | | |
| Trichoptera | Hydropsychida | *Ceratopsyche* | * | * | * | * | * | * | * | | * | | | | | | * | * |
| Trichoptera | Hydropsychida | *Cheumatopsyche* | | * | * | * | * | * | * | * | | * | * | * | | * | * | * |
| Trichoptera | Hydropsychida | *Hydropsyche* | | * | | | | | | | | | | | | | | |
| Trichoptera | Hydroptilidae | *Hydroptila* | | | | | | | | | | | | | * | * | | |
| Trichoptera | Leptoceridae | Leptoceridae | | * | | | | | | * | | | | | | | | |
| Trichoptera | Leptoceridae | *Oecetis* | * | | | | | | | | | | | | | | | |
| Trichoptera | Odontoceridae | *Psilotreta* | | | * | | * | | | | | | | | | | | |
| Trichoptera | Philopotamidae | *Chimarra* | * | | * | * | | | | | | | | | | | | |
| Trichoptera | Psychomyiidae | *Psychomyia* | * | * | | | * | * | * | | * | * | * | | ** | * | | * |
| Unionida | Unionidae | *Lamellidens* | | | | | | * | | | | | | | | | * | |

## Annex 2: Glimpses of activities at sites noted during field trips

Traditional fishing practice in Kamala River, Kamalamai

Traditional fishing practice in Kamala River, Ranibas

Traditional fishing practice in Kamala River, Ranibas

Water storage tank along Kamalamai stream

Gravel and sand mining at Dakhaha Bazaar in Kamala River

River crossing in Kamala River

Processing of benthic samples in field

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