Suspended Sediment Concentration and its Impact on Aquatic Invertebrates in the Gin River, Sri Lanka

A. D. Amarathunga* and R.W. Fernando

ABSTRACT

Understanding the level of suspended sediment is important for the management of aquatic fauna and flora. This study focused on the impact of suspended sediment concentration (SSC) on aquatic invertebrates in the basin of Gin river, Sri Lanka. Sixteen sampling locations along the river basin were used for data collection. Water temperature, dissolved oxygen, pH, electrical conductivity, turbidity and SSC were determined using standard laboratory methods. Aquatic invertebrates were collected using Kick sampling and stone lifting methods and they were identified using keys. Statistical analyses were done by Principal Component Analysis, factor analysis and descriptive analysis techniques. The water temperature and dissolved oxygen concentration in the Gin river basin were 25.76 ± 2.4 °C and 6.85 ± 6.1 mg/l (mean ± SD), respectively. The mean turbidity in the basin was 10.09 ± 16.1 NTU (mean ± SD). The SSC increased towards middle and lower catchments. Thirty nine different aquatic invertebrate taxa were recorded. A higher diversity of aquatic invertebrates was recorded with lower SSC in upper catchment. A negative relationship was evident between SSC and number of aquatic invertebrate species. High SSC had a negative impact on aquatic invertebrate diversity in the Gin river basin. A positive correlation was present between SSC and turbidity and therefore, a model was developed to predict SSC using turbidity data.

INTRODUCTION

Hydrological processes, such as flood pulse and geomorphological processes, including sedimentation and erosion are key processes of natural river systems. The environmental gradients and natural disturbance regimes that characterize these open systems make them complex and diverse systems which are sensitive to human activities (Bornette et al., 1998; Ward et al., 2002). Furthermore, the replacement of forest with impervious surfaces during urbanization can have significant effects on watershed hydrology and riparian functions. A decrease in water quality is generally reflected by an increase in particulate matter in streams (Webb and Walling, 1992; Mulliss et al., 1996). The composition and concentration of particulate matter in the aquatic environment are affected by the source and pathway of sediment input (Webster et al., 1990; Eisma, 1993).

Sediment discharge increases when the product of water discharge and suspended sediment concentration (SSC) increases. Additionally, the mobility of coarse material tends to increase with the larger flow velocities associated with larger discharges (Gray et al., 2000). Besides,
pollutants such as pesticides and trace elements adsorb to sediment particles and are deposited in the downstream (Duddridge and Wainwright, 1981; Amarathunga and Futuba, 2014). The eroded soil is washed with the runaway water and make sediment in the bed of the reservoirs. It causes massive reduction of water capacities with time and spilling out of reservoirs following a few inches of rainfall. Therefore, suspended sediment has been recognized as an important contaminant affecting water resources (Osterkamp et al., 1998).

Land use and rainfall are major factors affecting river suspended sediment concentrations in Sri Lanka. Several studies have shown that, the water quality in many rivers is rapidly deteriorating (Azmy et al., 2010; Amarathunga and Sureshkumar, 2013; Amarathunga et al., 2013a; Amarathunga et al., 2013b; Amarathunga, 2014; Amarathunga and Futaba, 2016). Therefore, it is essential to elucidate the effect of suspended sediment concentration on aquatic invertebrates under different land use patterns in river basins. The soil erosion rate increases with human activities in the area, especially with agricultural activities. Soil erosion intensity changes according to the crops cultivated in the basin (Chandrasekera, 2000; Foucher et al., 2014). In Sri Lanka, alternative uses of land in a given agro-ecological environment under different technologies, cultural and management practices, lead to significantly different rates of on-site loss of soil resulting from erosion (Näsström and Mattsson, 2009; Amarathunga et al., 2010; IUCN, 2016).

Rates of sediment deposition in reservoirs and floodplains can be determined from empirical measurement. However, only a limited number of sites have been monitored while the net rates of deposition or loss from other potential sinks and sources are largely unknown (Meade and Parker, 1985; Stallard, 1998; Trimble and Crosson, 2000). Because of land use changes and intensive agricultural practices, sediment-bound pollutants are transported from upstream to downstream and settle (Amarathunga, 2014; Amarathunga and Futaba 2014). Less attention has been paid and limited studies have been conducted on the impact of these sediments on aquatic invertebrates. Therefore, the present study determined the SSC, water quality parameters and aquatic invertebrate population along the Gin river basin of Sri Lanka.

MATERIALS AND METHODS

Site Description and Sampling Locations

The Gin river (“Gin Ganga”) is a 113 km long river in the South West of Sri Lanka, with its basin source near Deniyaya and Sabaragamuwa mountain range. Gin river starts from approximately 4000 ft elevation and falls into the sea at Ginthota, Galle. The Gin river basin has 932 km² of catchment area and the average annual flow into the sea is ca. 2000 million m³ (MCM). The area lies directly in the path of south west monsoon and experiences heavy rainfall. The mean annual rainfall varies between 2000 mm to over 5000 mm. Major issues in
the basin include pollutants from intensive agricultural practices, salinity intrusion in estuarine region, lack of baseline data (eg. water quality, aquatic invertebrates), development projects (government proposed major hydropower and irrigation projects), and high tourism activities. The study was conducted from February 2009 to December 2010. Sixteen sampling locations were selected from entire river basin (Figure 1).

Figure 1. Sampling locations along the Gin river basin.

S-01- Gongala, S-02- Stream on ITN Tower Road at Sinharaja Forest in Deniyaya (Singha-ITN), S-03- Kandilpana, S-04- Mederipitya (Mederipiti), S-05- Deniyaya Bridge (Deniya-brid), S-06- Dellawa, S-07- Duli Ella, S-08- Nelawa, S-09- Kanneli Ela (Knelly Ela), S-10- Nanikitha, S-11- Udugama, S-12- Kahaduma, S-13- Baddegama (Baddega), S-14- Waduramba (Wadura), S-15- Paranathotupa (Parana-T), S-16- Sea mouth.
Sample Collection and Analysis

Sub-surface water samples were collected from middle at 50 cm to 100 cm depth in the stream and in situ analysis was done 13 times during the project period on monthly basis. Those sampling locations (Figure 1) were selected from upstream, middle stream and downstream based on gradient, flow, and anthropogenic activities (Mahazar et al., 2013; Munia, 2014).

In situ analyses were conducted for the determination of pH (pH meter Orion 260A), conductivity (Hanna portable multi-range conductivity meter-HI 8733) and water temperature. The dissolved oxygen level was measured using portable meters (Orion 830A).

Turbidity level was measured using a portable turbidity meter (Hach 2100P). Turbidity meters measure the loss in intensity of a narrow parallel beam or dual beams. Nephelometric turbidity meters measure light scattered at an angle (commonly 90° or 180°) to the beam and have been adopted by Standard Methods as the preferred method of turbidity measurement (Greenburg et al., 1999).

Collected samples were filtered and stored at 4 °C until transported to a laboratory for further analysis. Laboratory analyses were performed according to Greenburg et al. (1998).

Suspected sediment concentration (SSC) in 15 sampling locations was determined using a filtration method (Guy, 1969). The gross weight of the sample (water-sediment mixture) was determined. The total sample volume was filtered through a Whatman grade 934AH, 24 mm diameter filter which was inserted into a crucible and dried at 110 °C ± 2 °C, cooled, and weighed. The filtered sample was then dried until all visible water evaporated, and heated for 1 h at 110 °C ± 2 °C. The crucible was cooled in a desiccator at room temperature and weighed. The weight of the remaining material in the crucible (milligrams) was divided by the volume of the water-sediment mixture passed through the filter (litres) to determine the SSC of the sample (mg/l). The total load was calculated using discharge data based on Buchanan and Somers (1969).

Sampling and Identification of Aquatic Invertebrates

Surber sampling technique was used to sample the aquatic invertebrates in sampling locations (Storey et al., 1991). Kick sampling (10 times using a hand net) was done to collect aquatic invertebrates along the stream or river edge in selected sampling locations upstream, middle stream, and downstream (Storey et al., 1991). In addition, stones lifting (boulders) and collecting aquatic invertebrates (ten number of stones) in the streams and washing them to a container was practised. Identification was done using different keys (Needham and Needham, 1988; Walker et al., 2009) and results of number of individuals/m² were used for statistical analysis.
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Experimental Design and Data Analysis

The map was prepared using ArcGIS version 10 and data were analyzed by factor analysis, principal component analysis, and time series data analysis using SPSS version 20. Principal components having the eigenvalue of $>1$ were selected for analysis.

RESULTS AND DISCUSSION

Water Quality Parameters

The study revealed that mean water temperature and dissolved oxygen concentration in the Gin river basin were $25.76 \pm 2.4 ^\circ C$ and $6.85 \pm 6.1$ mg/l (mean $\pm$ SD), respectively. The mean turbidity in the basin was $10.09 \pm 16.1$ NTU (mean $\pm$ SD) and the recorded highest value was $110.0$ NTU near the sea mouth sampling location on April 2010. Ammonia-N and Nitrate-N varied between $0.001$ mg/l - $1.92$ mg/l and $0.092$ mg/l - $6.76$ mg/l, respectively. Nitrite-N and orthophosphate varied between $0.001$ mg/l - $0.019$ mg/l and $0.015$ mg/l - $5.89$ mg/l, respectively.

Suspended sediment concentration and turbidity are key parameters to understand the level of impact to productivity in a water body. It also has an impact on dissolved oxygen concentration in water by sediment-oxygen demand (Eisma, 1993). In addition, suspended sediment influences on nutrient concentration, including nitrate nitrogen, ammonia nitrogen, nitrite nitrogen and dissolved phosphate in water.

The boxplot in Figure 2 illustrates SSC from different sampling locations along the Gin river basin. The SSC tended to increase towards lower catchment. It also indicates a higher variability in SSC in lower catchment. Thus, the middle and lower catchments bring high amount of suspended sediment than the upper catchment.

Figure 3 depicts the variation in suspended sediment loading across the study period at Baddegama sampling location.

Relationships among Aquatic Invertebrate Population and Water Quality Parameters

Thirty nine different aquatic invertebrate genera/species were recorded in the Gin river basin (Table 1).

Suspended sediment concentration in different catchments (upper, middle and lower) is illustrated in the Figure 4. The river water consists of suspended sediments which are bound to various organic and inorganic pollutants. These sediments are re-suspended into river water with dilute pollutant concentration and desorption of the pollutants into the water will occur (Dunnivant and Anders, 2006). Therefore, pollutants affect the abundance of aquatic invertebrates in streams and rivers (Wood et al., 2002).

The middle and lower catchments had higher levels of SSC compared to upper catchment (Figures 2 and 4). Correlation matrix illustrates a positive moderate linear correlation among SSC, turbidity and water temperature (Table 2). Increased duration of exposure to sediment potentially results in increasing harm to fish, life cycle stages,
and to other aquatic organisms (Newcombe and Mac Donald, 1991; Newcombe and Jensen, 1996; Caux et al., 1997; BCMELP 1998; Birtwell, 1999; CCME, 1999).

Three components (SSC, water temperature and turbidity) are greater than the eigenvalue 1 and those represent 73.2% of variation explained in the data (Table 3).

Based on the statistical analysis, Figure 5 shows the dendrogram which explains the relationship with species diversity and sampling locations in the basin. Dellawa, Duli Ella, ITN tower area at Deniyaya, and the Gongala mountain sampling locations recorded the highest diversity of aquatic invertebrates.

Table 1. Aquatic invertebrates recorded in the Gin river basin

| No. | Species                  | No. | Species                  |
|-----|--------------------------|-----|--------------------------|
| 1   | Neoperla sp.             | 21  | Hirudinea spp            |
| 2   | Heptagenia sp.           | 22  | Neurobasis chinensis     |
| 3   | Baetis sp.               | 23  | Trithemis festiva        |
| 4   | Choroterpes sp.          | 24  | Orthetrum pruinosum      |
| 5   | Cheumatopsyche sp.       | 25  | Indothemis limbata       |
| 6   | Helicopsyche sp.         | 26  | Elattoneura tenax        |
| 7   | Molanna sp.              | 27  | Orthetrum triangular     |
| 8   | Naucoris sp.             | 28  | Orthetrum chrysis        |
| 9   | Anisops sp.              | 29  | Orthetrum glaucum        |
| 10  | Gerris sp.               | 30  | Ceriagrion cerinorubellum|
| 11  | Rhagodotarsus sp.        | 31  | Orthetrum sabina         |
| 12  | Aulonogyrus sp.          | 32  | Euphaea splendens        |
| 13  | Cybister sp.             | 33  | Hydrometra sp.           |
| 14  | Simuliidae sp.           | 34  | Pinaus spp.              |
| 15  | Chironomidae sp.         | 35  | Brachythemis contaminata |
| 16  | Atherixlantha sp.        | 36  | Libellago adami          |
| 17  | Hydra sp.                | 37  | Libellago greeni         |
| 18  | Ceylonthelphusa sp       | 38  | Ischnura elegans         |
| 19  | Planarian sp.            | 39  | Anaciaeshna donaldi      |
| 20  | Mollusks spp             |     |                          |
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**Figure 2.** Suspended sediment concentration (SSC) from different sampling locations of Gin river basin

1- Singha-ITN, 2- Gongala, 3- Dellawa, 4- Duli Ella, 5- Kandilpana, 6- Udugama, 7- Nanikitha, 8- Kanneli Ela, 9- Mederippit, 10- Kahaduwa, 11- Wadura, 12- Deniya-brid, 13- Nehawa, 14- Baddegama, 15- Parana-T.

**Figure 3.** Suspended sediment load from Baddegama sampling location of the Gin river basin during 2009 and 2010
Figure 4. Suspended sediment concentration (SSC) in the Gin river basin during 2009 and 2010. (a) SSC in upper catchment, (b) SSC in middle catchment, (c) SSC in lower catchment
**Table 2.** Correlation matrices of dissolved oxygen (DO), electrical conductivity (EC), pH, suspended sediment concentration (SSC), turbidity (Turb) and water temperature (WT)

|       | WT     | pH     | DO     | EC     | Turb    | SSC    |
|-------|--------|--------|--------|--------|---------|--------|
| WT    | -0.234 | -0.410 | 0.236  | 0.396  | 0.376   |        |
| pH    | 0.163  | 0.050  | -0.030 | -0.171 |         |        |
| DO    | -0.172 | -0.215 | -0.371 |         |         |        |
| EC    | 0.035  | 0.032  |         |         |         |        |
| Turb  | 0.579  |         |         |         |         |        |
| SSC   |        |         |         |         |         |        |

**Table 3.** Component matrices of dissolved oxygen (DO), electrical conductivity (EC), pH, suspended sediment concentration (SSC), turbidity (Turb) and water temperature (WT)

| Component | 1     | 2     | 3     |
|-----------|-------|-------|-------|
| SSC       | 0.779 | -0.293| 0.213 |
| WT        | 0.760 | 0.191 | -0.128|
| Turb      | 0.707 | -0.281| 0.458 |
| DO        | -0.659| -0.219| 0.194 |
| EC        | 0.252 | 0.879 | 0.051 |
| pH        | -0.331| 0.254 | 0.839 |

Meanwhile, the lowest diversity was recorded in Neluwa, Baddegama, and Paranathotupala sampling locations. Sampling locations with higher species diversity were mostly located in the upper catchment. It indicated the presence of more aquatic invertebrate species in the upper catchment with lower SSC (*cf.* Figures 2, 4, 5 and 6). When SSC was high, the species diversity of aquatic invertebrates decreased (Figure 6).

SSC analysis is costly and thus, based on the above data, a model was developed
Figure 5. Dendrogram for abundance of different invertebrate species found in upper catchment, middle catchment and lower catchment of the Gin river basin

Figure 6. Variation of aquatic invertebrate species number with suspended sediment concentration (SSC) and turbidity along the Gin river basin
to predict the SSC and suspended sediment load using turbidity data (Figure 7) and the predicted equation is presented (eq.1).

$$\text{SSC} = \frac{\text{Turbidity} \times 7.259}{8.506} \ldots \textit{(eq.1)}$$

The correlation coefficient and coefficient of determination of this model are 0.896 ($r$) and 0.802 ($r^2$), respectively. However, according to the analysis, this equation is less effective when the turbidity reading and SSC reading are extremely high. Based on above correlation, turbidity can be used for prediction of invertebrate abundance instead of SSC due to less cost involved in measuring turbidity.

**CONCLUSION**

The study revealed that the upper catchment of the Gin river basin brings low amounts of suspended sediment when compared to its middle and lower catchments. A positive correlation was found with SSC and turbidity. Mainly three principal components represented 73.2% variation from total data set in water quality parameters. A higher diversity of aquatic invertebrates was recorded with lower SSC in upper catchment. A negative relationship was evident between SSC and number of aquatic invertebrate species. High SSC has thus formed a negative impact on aquatic invertebrate diversity in the Gin river basin.

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