Journal of Food and Agriculture 2016, 9 (1 & 2): 24 – 38

DOI: http://doi.org/10.4038/ jfa.v9i1-2.5204

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

A.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.

Environmental Studies Division, National Aquatic Resource Research & Development Agency, Crow Island, Colombo15, 01500, Sri Lanka
** deeptha.amarathunga@gmail.com*

Keywords: Aquatic invertebrate, Gin River, Suspended sediment, Water quality

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 km^2 of catchment area and the average annual flow into the sea is *ca.* 2000 million m^3 (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).

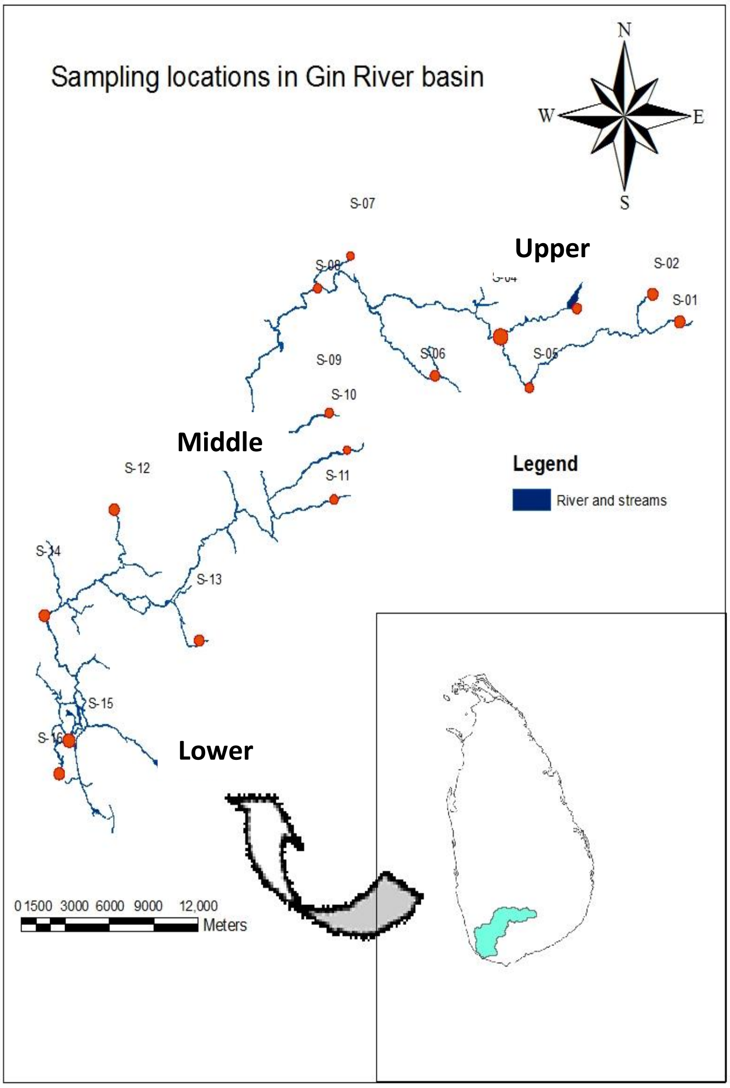

Figure 1. Sampling locations along the Gin river basin.

S-01- Gongala, S-02- Stream on ITN Tower Road at Sinharaja Forest in Deniyaya (Singha-ITN), S-03- Kandilpana, S-04- Mederipitiya (Mederipit), S-05- Deniyaya Bridge (Deniya-brid), S-06- Dellawa, S-07- Duli Ella, S-08- Neluwa, S-09- Kanneli Ela (Knneli Ela), S-10- Nanikitha, S-11- Udugama, S-12- Kahaduwa, S-13- Baddegama (Baddega), S-14- Waduramba (Wadura), S-15- Paranathotupala (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).

Suspended 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/m^2 were used for statistical analysis.

Experimental Design and Data Analysis

The map was prepared using Arc GIS ver-10 and data were analyzed by factor analysis, principal component analysis, and time series data analysis using SPSS ver-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 ± 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) 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	*Anaciaeschna donaldi*
20	Mollusks spp		

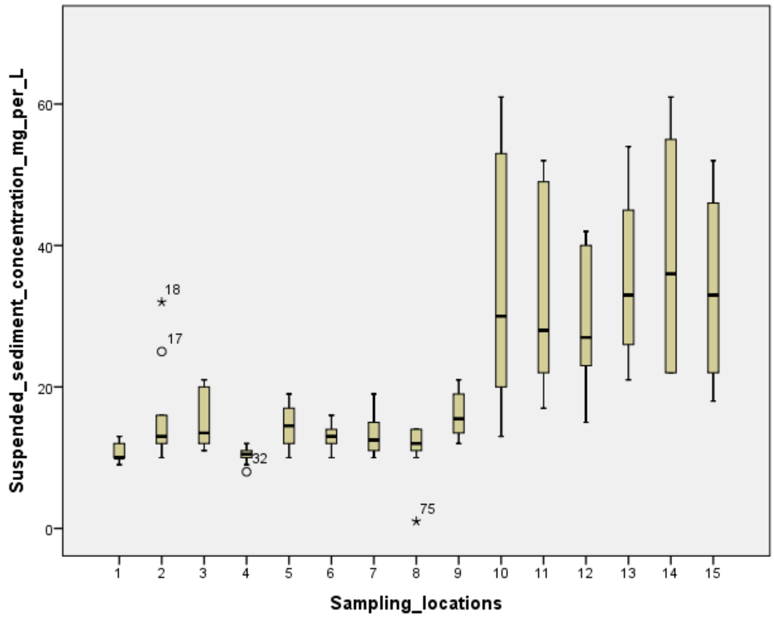

Figure 2. Suspended sediment concentration (SSC) from different sampling locations of Gin river basin

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- Neluwa, 14- Baddegama, 15- Parana-T.

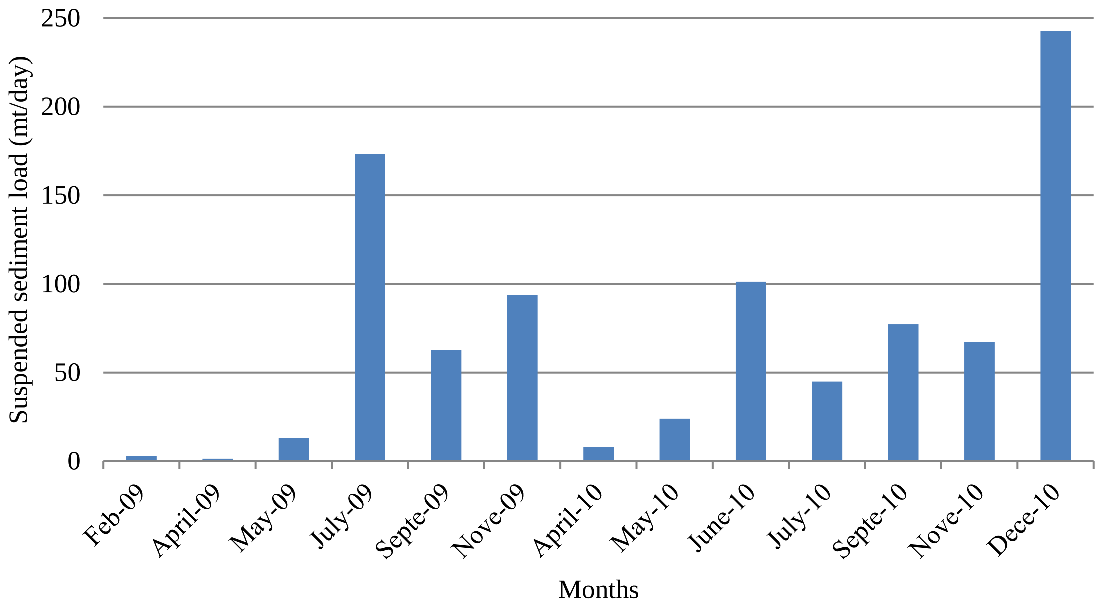

Figure 3. Suspended sediment load from Baddegama sampling location of the Gin river basin during 2009 and 2010

(a)

(b)

(c)

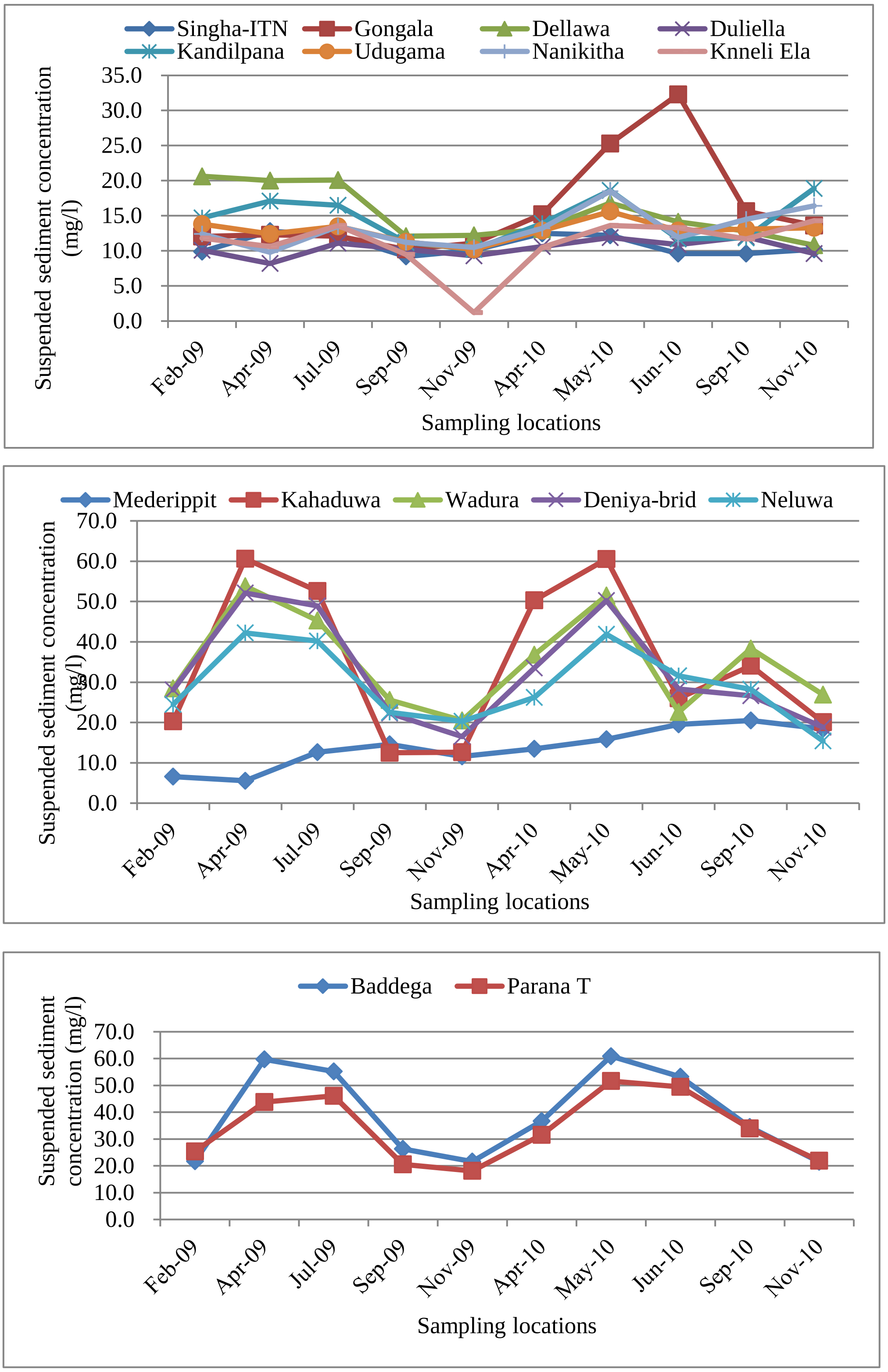

Figure 4. Suspended sediment concentration (SSC) in the Gin river basin during 2009 and 2010. (a) SSC in upper catchment, (b) SSC in middle catchment, (c) SSC in lower catchment

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**
Correlation	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

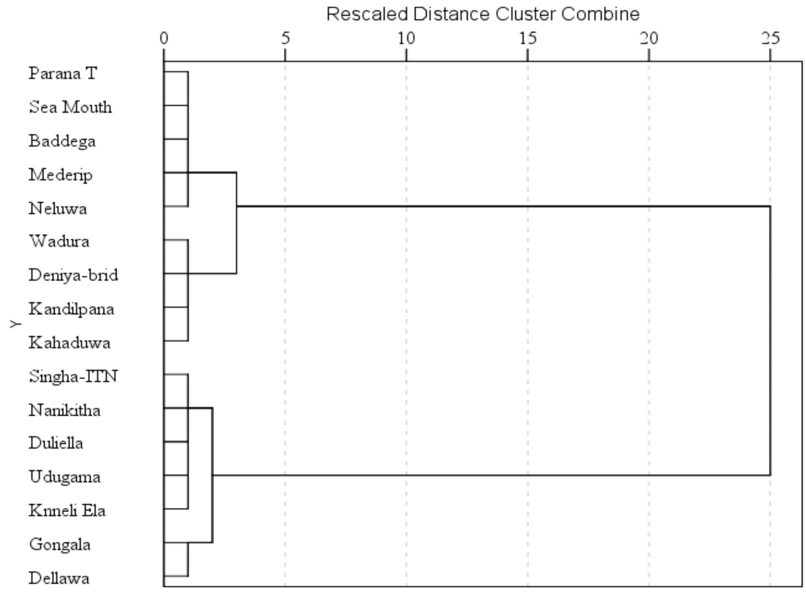

Figure 5. Dendrogram for abundance of different invertebrate species found in upper catchment, middle catchment and lower catchment of the Gin river basin

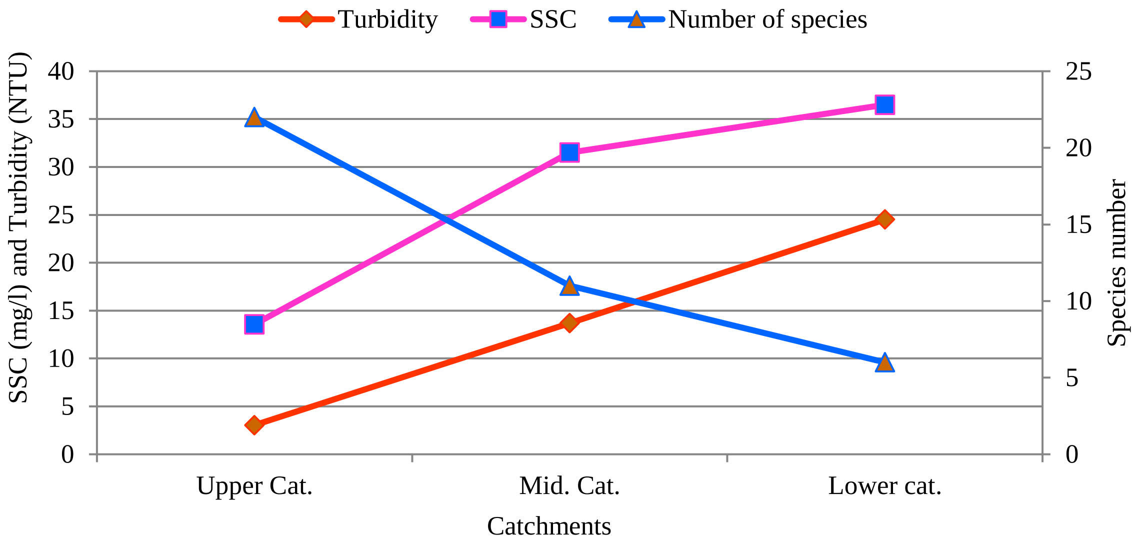

Figure 6. Variation of aquatic invertebrate species number with suspended sediment concentration (SSC) and turbidity along the Gin river basin

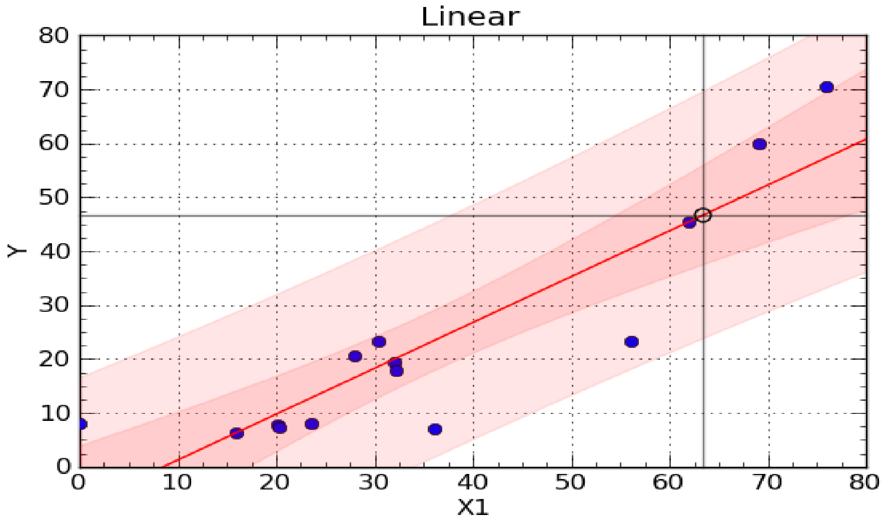

Figure 7. Correlation between suspended sediment concentration (SSC; y-axis) and turbidity (x-axis)

to predict the SSC and suspended sediment load using turbidity data (Figure 7) and the predicted equation is presented (eq.1).

$$\mathrm{SSC} = \frac{\mathrm{Turbidity}\ \ \mathrm{X}\ 7.259}{8.506} \ldots..(eq.1)$$

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.

REFERENCES

Amarathunga, A.A.D., Weerasekara, K.A. W.S., Sureshkumar, N., Azmy, S.A.M. and Shirantha, R.R.A.R. (2010). Total suspended solids and turbidity co-relation and its impact on aquatic community in Kotmale sub-catchment in the Upper Mahaweli watershed in Sri Lanka. In *Proceedings of the Symposium on Water Resource Research in Sri Lanka*, University of Peradeniya, Sri Lanka, 115-124.

Amarathunga, A.A.D. and Sureshkumar, N. (2013). Assessment of water quality of major streams in the Madu Ganga catchment and pollution loads draining into Madu Ganga from its own catchment. *Journal of the National Aquatic Resource Research & Development Agency of Sri Lanka*, *42*: 27- 46.

Amarathunga, A.A.D., Jinadasa, S. U. P. and Azmy, S. A. M. (2013a). Sedimentary characteristics and status of water quality in Polwatta River, and Weligama Bay in Sri Lanka. *Journal of Environmental Professionals Sri Lanka*, *2*(1): 38-51.

Amarathunga, A. A. D., Weerasekara, K. A. W. S., Sureshkumar, N., Azmy, S. A. M., Wickramaarchchi, W. D. N. and Kazama, F. (2013b). Behaviour and loading of suspended sediment and nutrients from river basins in the hilly catena under intensive agriculture cropping: A case study in Upper Kotmale Basin in Sri Lanka. *Journal of Environmental Professionals Sri Lanka*, *2*(2): 13-31.

Amarathunga, A.A.D. (2014). Behaviour of Pesticides in Tropical River Basin with High Concentrated Suspended Sediment. Ph.D. Thesis. University of Yamanashi, Japan.

Amarathunga, A.A.D. and Futaba, K. (2014). Photodegradation of chlorpyrifos an organophosphorus pesticide with humic acid bounded suspended matter. *Journal of Hazardous Materials, 280*: 671–677.

Amarathunga, A.A.D. and Futaba, K. (2016). Impact of land use on surface water quality: A case study in the Gin River basin, Sri Lanka. *Asian Journal of Water, Environment and Pollution*, *13*(3): 1–13.

Azmy, S. A. M., Amarathunga, A.A.D., Shirantha, R.R.A.R. and Weerasekara, K.A.W.S. (2010). Study of nutrient variation and physico-chemical characteristics including bio-indicators of the Dik Oya Basin in Mahaweli Upper Catchment in Sri Lanka. In *Proceedings Part-II of the 15th International Symposium on Forestry and Environment*, University of Sri Jayawardenapura, Nugegoda, Sri Lanka, 25 – 32.

BCMELP (1998). *Ambient Water Quality Guidelines (Criteria) for Turbidity, Suspended and Benthic Sediments*: *Overview*. Environment and Resource Division, Ministry of Environment, Lands and Parks, British Colombia.

Birtwell, I.K. (1999). *The Effects of Sediment on Fish and Their Habitat*. Canadian Stock Assessment Secretariat, 99/139.

Bornette, G., Amoros, C., Piegay, H., Tachet, J. and Hein, T. (1998). Ecological complexity of wetlands within a river landscape. *Biological Conservation, 85*: 35–45.

Buchanan, T.J. and Somers, W.P. (1969). *Discharge Measurements at Gaging Stations: U.S. Geological Survey Techniques of Water-Resources*

Investigations, Book 3, USGS.

CCME (1999). *Canadian Environmental Quality Guidelines*. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba.

Caux, P.Y., Moore, D.R.J. and MacDonald, D. (1997). *Ambient Water Quality Criteria for Turbidity, Suspended and Benthic Sediments in British Columbia: Technical Appendix*. British Columbia Ministry of Environment, Lands and Parks, Water Quality Branch, Victoria, BC.

Chandrasekera, C.M.M.M.K. (2000). Investigation of Hydrological Responses to Land Use Changes in Two Sub Catchments of the Upper Mahaweli Catchment, Unpublished M.Phil Thesis. Postgraduate Institute of Agriculture, University of Peradeniya, Sri Lanka.

Duddridge, J.E. and Wainwright, M. (1981). Heavy metals in river sediments-calculation of metal adsorption maxima using Langmuir and Freundlich isotherms. *Environmental Pollution Series B, Chemical and Physical*, *2*(5): 387-397.

Dunnivant, F.M., and Anders, E. (2006). *A Basic Introduction to Pollutant Fate and Transport: An Integrated Approach with Chemistry, Modeling, Risk Assessment and Environment Legislation*. John Wiley & Sons, Inc. New Jersey, USA.

Eisma, D. (1993). *Suspended Matter in the Aquatic Environment*. Springer-Verlag, Berlin, Germany.

Foucher, A., Blanes, S.S., Evrard, O., Simonneau, A. and Chapron, E. (2014). Increase in soil erosion after agricultural intensification: evidence from a lowland basin in France. *Anthropocene* (Elsevier), *7*: 30-41.

Gray, J.R., Glysson, G.D., Turcios, L.M. and Schwarz, G.E. (2000). *Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data*. USGS.

Greenburg, A.E., Rhodes, T.R. and Lenore, S.C. (1998). *APHA Standard Methods for the Examination of Water and Waste Water*, 20th edition, APHA/AWWA/WEF, USA.

Guy, H.P. (1969). *Laboratory Theory And Methods for Sediment Analysis: U.S. Geological Survey Techniques of Water-Resources Investigations Report 01-4217*. USGS.

IUCN (2016). *Conservation of soil resources. IUCN programme on Restoring Traditional Cascading Tank Systems Technical Note No. 6*. International Union for Conservation of Nature, Colombo, Sri Lanka and Government of Sri Lanka.

Mahazar, A., Othman, S.M., Kutty, A.A. and Desa, M.N.M. (2013). Monitoring urban river water quality using macroinvertibrate and physico-chemical parameters: Case study of Penchala river, Malaysia. *Journal of Biological Sciences, 13*(6): 474-482.

Meade, R. H. and Parker, R. S. (1985). Sediment in Rivers of the United States, In: *National Water Summary 1984, U.S. Geological Survey Water-Supply 2275*, U.S. Government Printing Office, Washington, DC. 49-60.

Mulliss, R.M., Revitt, M. and Shutes, R.B. (1996). The impacts of urban discharges on the hydrology and water quality of an urban watercourse. *The Science of the Total Environment, 189/190*: 385-390.

Munia, H. A. (2014). The Role of Upstream Water Use on Water Stress in Transboundary River Basins: A Global Analysis. M.Sc. Thesis. Aalto University, Finland.

Nässtrröm, R. and Mattsson, E. (2009). *Country Report Sri Lanka. Land-use Change and Forestry at the National and Sub-National Level. Focali Report - 04*, Gothenburg.

Needham, J. G. and Needham, P. R. (1988). *A Guide to the Study of Fresh Water Biology*. 5th edition. Comstock Publishing Company, Ithaca, New York.

Newcombe, C. P. and Macdonald, D. D. (1991). Effects of suspended sediment on aquatic ecosystems. *North American Journal of Fisheries Management*, *11*(1): 72-82.

Newcombe, C. P. and Jensen, J. O. T. (1996). Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. *North American Journal of Fisheries Management*, *16*(4): 693-727.

Osterkamp, W.R., Heilman, P. and Lane, L.J. (1998). Economic considerations of a continental sediment monitoring program. *International Journal of Sediment Research*, *13*: 12-24.

Stallard, R. F. (1998). Terrestrial sedimentation and the carbon cycle. *Global Biogeochemical Cycles*, *12*: 231- 57.

Storey, A.W., Edward, D.H.D. and Gazey, P. (1991). Surber and kick sampling: a comparison for the assessment of macro-invertebrate community structure in streams of south-western Australia. *Hydrobiologia*, *211*: 111-121.

Trimble, S.W. and Crosson, P. (2000). U.S. Soil Erosion Rates – Myth and Reality. *Science*, *289*: 248-250.

Walker, K. F., Madden, C. P., Williams, C. R., Fricker, S. R, Geddes, M. C., Goonan, P. M.,Kokkinn, M. J., McEvoy, P. K., Shiel, R. J. and Tsymbal, V. (2009). Freshwater invertebrates. In*:* J. T. Jennings (Ed.), *Natural History of the Riverland and Murraylands*, Royal Society of South Australia Inc, 283-305.

Ward, J.V., Tockner, K., Arscott, D.B. and Claret, C. (2002). Riverine landscape diversity. *Freshwater Biology, 47*: 517–539.

Webb, B.W. and Walling, D.E. (1992). *Water Quality II: Chemical Characteristics*. Blackwell Scientific, Oxford, UK, 73-100.

Webster, J.R., Golladay, S.W., Benfield, E.F., D'Angelo, D.J. and Peters, G.T. (1990). Effects of forest disturbance on particulate organic matter budgets of small streams. *Journal of the North American Benthological Society*, *9*(2): 120-140.

Wood, P. J., Gunn, J. and Perkins, J. (2002). The impact of pollution on aquatic invertebrates within a sub-terranean ecosystem-out of sight out of mind.

Archiv fur Hydrobiologie [Fundamental and Applied Limnology], *155*(2): 223-237.