

Article

An Ecological Risk Assessment of Sediments in a Developing Environment—Batticaloa Lagoon, Sri Lanka

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Abstract: The land-sea interface is considered as a threatening environment due to anthropogenic development activities. Unplanned developments can cause effects on important ecosystems, water and human health as well. In this study, the influence of rapid regional development on the accumulation of trace elements to the sediments of an important ecosystem, Batticaloa lagoon, Sri Lanka was examined. Surface sediment pollution status and ecological risk was compared with that of the recent sedimentary history of about 1 m depth. Sediment core samples were collected and analyzed for grain size, organic matter and carbonate contents and trace elements (As, Pb, Zn, Cu, Ni and Cr) by the X-Ray Fluorescence (XRF) technique. The chemical results of core samples and recently published data of surface sediments of the same project were evaluated by pollution load index (PLI), potential ecological risk index (PERI) and sediment quality guidelines (SQG). Except for Cr, all other elements in cores show lower concentrations than the SQGs confirming the high Cr contents as recorded in the most of other Sri Lankan sediments. The sediment cores indicate an unpolluted, low ecological risk sedimentary history for all core sampling locations, whereas most of the surface sediments of the lagoon are less polluted with low potential ecological risk. Present anthropogenic practices and illiteracy of this rapid developing region can damage the green environment and hence environmental management planning is suggested for a sustainable future.

Keywords: trace element pollution; ecological risk; sediment cores; surface sediments; Batticaloa lagoon



Citation: Adikaram, M.; Pitawala, A.; Ishiga, H.; Jayawardana, D.; Eichler, C.M. An Ecological Risk Assessment of Sediments in a Developing Environment—Batticaloa Lagoon, Sri Lanka. *J. Mar. Sci. Eng.* **2021**, *9*, 73. <https://doi.org/10.3390/jmse9010073>

Received: 10 November 2020

Accepted: 16 December 2020

Published: 13 January 2021

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1. Introduction

Trace element accumulation in aquatic systems is a prioritized problem since bioaccumulation and biomagnification cause toxic effects on ecosystems as well as on human health [1,2]. Coastal environments have been paid more attention since they are the ultimate locations for transportation and accumulations of anthropogenic sourced toxins. Semi-enclosed coastal bodies such as lagoons are important ecosystems as they provide goods and services to the economy, society, heritage, aesthete and science [3]. Numerous research studies have been carried out in such coastal environments in different regions of the world to document and establish the levels of spatial and temporal changes of sedimentation in those areas. Specially, ecological status of sediments is addressed in coastal environments since terrestrial and marine sediment budgets are diluted and deposited in marine margins, which are characterized by more unique ecologies [4–8].

United States Environmental Protection Agency (USEPA) has nominated a list of trace elements that are toxic in desired concentrations, including Ag, As, Ba, Be, Cd, Co, Cr, Cu,

Hg, Mn, Mo, Ni, Pb, Sb, Se and Zn which was expanded later by several authors [9,10]. The contamination status of the above elements is measured using several contamination indices such as Contamination Factor (CF), Pollution load index (PLI), Ecological risk index (Er), potential ecological risk index (PERI) and sediment quality guidelines (SQGs) [11–16].

The quality and quantity of trace element accumulations in sediments depend on the sediment mineralogy, sediment texture and physical makeovers [17–19]. In addition, the depositional condition of sediments varies when subjected to the physical landforms on coastal environments [17,18]. Therefore, it is important to study the pollution levels and ecological status of different regions of the world, which is useful for sustainable environmental managements.

Batticaloa is the third largest lagoon of Sri Lanka with a surface area of 168 km² [20]. This lagoon is located in eastern coast of Sri Lanka and exposed to the Bay of Bengal. The depth of the shallow areas is about 0.3 m, whereas in lagoon mouth regions it is recorded as 6.5 m [20]. The southern zones of the lagoon are freshwater dominant whereas northern zones are salt-water dominant [21]. The lagoon is naturally surrounded by salt marshes, mangroves, grass beds and a network of channels [22]. The ecosystem of the lagoon is characterized with freshwater and marine habitats and, therefore, it can be considered as a productive marine nursery for the western Bay of Bengal.

During the past few decades, large-scale human activities, such as poor agricultural practices and fish and prawn farming, have degraded the quality of the natural environment of the lagoon [22,23]. Presently, most of the marshes and channels have been converted to paddy lands, which are cultivated in two seasons of the year. Except for the few main city areas, surrounding areas of the Batticaloa lagoon are covered by extensive paddy lands (Figure 1). In addition, municipal waste disposals and domestic effluents are common in the places where the population is high. Field surveys on the peripheral regions of the Batticaloa lagoon noted the direct anthropogenic influences on the natural lagoon environment. Domestic effluents and municipal wastes are directly dumped in to the lagoon without any pretreatments (Figure 2). In addition, the effluents of the toilet drain pipes as well as car wash stations are directly released to the lagoon water.

The present study is carried out to show the present pollution status and ecological risk of 6 trace elements in the Batticaloa lagoon of eastern Sri Lanka compared to the past sedimentary history. The scientific data of the present study will be helpful in coastal managing systems to protect the ecosystem and to reduce the conflicts between users. Further, the results will be a baseline data for future contaminations measurements around western Bay of Bengal.

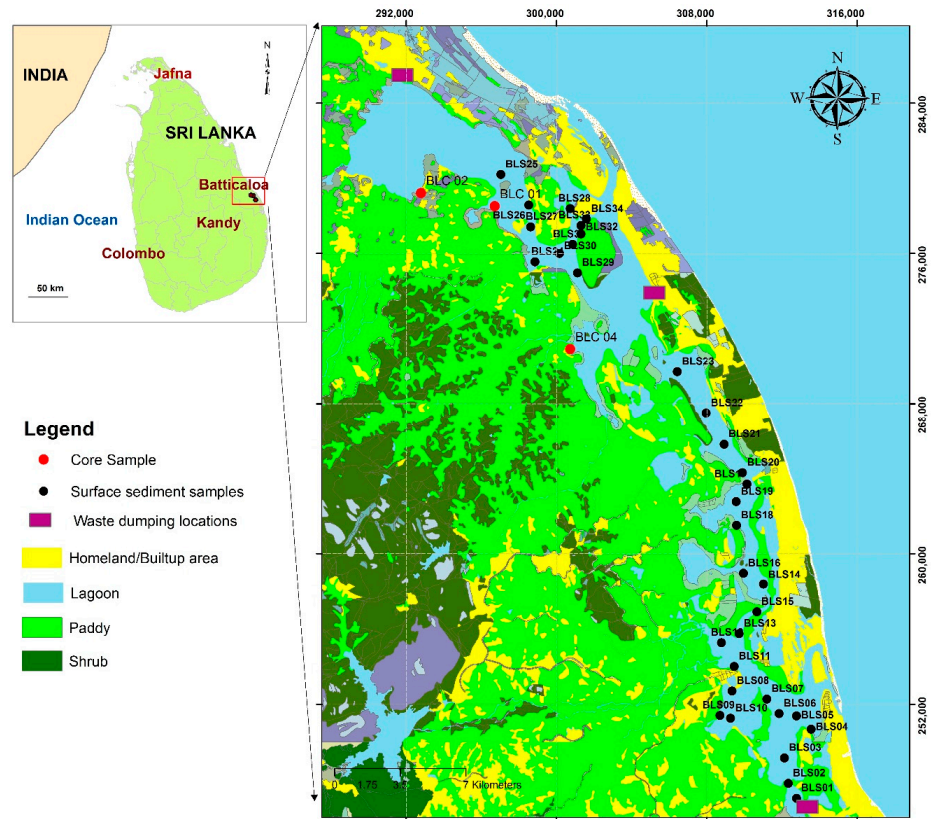


Figure 1. Sediment cores and surface sediment sampling locations of Batticaloa lagoon, Sri Lanka.



Figure 2. (a) Municipal waste disposals of *Eravour* (b) household and fishing contaminations in *Kaththankudi* (c) local toilet drain pipes of *Kaththankudi* (d) vehicle service stations are directly disposed to the lagoon water at *Kalmunei*.

2. Materials and Methods

2.1. Sampling

Sediment cores BLC 01, BLC 02 and BLC 04 were collected at the western peripherals of the Batticaloa lagoon which are populated by dense mangroves (Figure 1). Though the BLC 03 was obtained in a similar location, it was not chemically tested due to its uniformity and similarity with BLC 02. The sampling points were selected to avoid most of the human settlement effects for the sedimentation processes, to compare the natural past sedimentation with non-point source anthropogenic influences. BLC 01 was taken from the northern part of the lagoon by a distance of 5 km from the lagoon mouth which can represent the major coastal influences. BLC 02 was taken from the northern part of the lagoon, which is protected from the direct coastal effect by a sedimentary barrier. In addition, the BLC 02 sampling location represents the characteristics of river discharges. BLC 04 was taken from the central part of the lagoon which is mostly protected from the lagoon mouth and river influences. Sampling locations were carefully chosen to keep the same elevations and same water depths with respect to the global positioning system (GPS Garmin 76). Hand pushed Polyvinyl Chloride (PVC) pipes (5 cm diameter and 2 m height) were used to collect the cores. Sediments were trapped in the pipes with air tightened sealing methods. Cores were kept in a vertical position until the water was drained out following the transportation stage. Visual observations and digital photography was carried out on the splitted cores in order to identify the stratigraphy. The cores were sub-sampled in 2 cm resolutions and sealed in polyethylene bags for laboratory analysis.

2.2. Analysis

Selected sub samples of three cores were used for the granulometric analysis by oven drying them at 105 °C for 24 h. Prior to drying, samples were pretreated for removal of organic matters with hydrogen peroxide. The AS 200 digit cA sieve shaker (Retsch GmbH) was used to separate the grain sizes based on 1/4 phi intervals according to the Wentworth scale (ASTM sieves). Grain size distribution curves were plotted on selected samples to show the size distributions. The statistical parameters of grain size were obtained using GRADISAT software following the Folk and Ward [24] method for interpretations [25].

Loss on ignition was carried out in selected sub samples of the cores to determine the organic matter content (OM) and carbonate content [26]. Approximately 1 g of dry sample was heated in to 105 °C (24 h) and 550 °C (4 h) in a muffle furnace to provide OM contents. Carbonate content was calculated using the weight of heated sample up to 1000 °C.

$$OM \text{ content } \% = \frac{\text{Sediment weight at } 100 \text{ } ^\circ\text{C} - \text{Sediment weight at } 550 \text{ } ^\circ\text{C}}{\text{Sediment weight at } 100 \text{ } ^\circ\text{C}} \times 100. \quad (1)$$

Sub-samples of sediment cores of Batticaloa lagoon were prepared for X-Ray Fluorescence spectrometry (XRF) (RIX 2000) at Shimane University, Japan. The analysis method is the same as that described by Adikaram et al. [23]. All samples were oven dried (105 °C for 24 h) and sieved to remove gravels and organic/inorganic materials above 2 mm size fraction. The dried samples were crushed using a RETSCH ball mill at the Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka. The homogenized powdered samples were packed in sealed polyethylene bags and transported to Shimane University in Japan for trace element analysis. In the XRF laboratory, powdered samples were pressed into a disk with a 200 kN force for 60 s. Next, the disk was analyzed for selected trace elements (As, Pb, Zn, Cu, Ni and Cr) using a Rigaku RIX-2000 spectrometer equipped with an end window 4.KW Rh-anode X-ray tube. Instrumental calibrations, sample preparations and concentrations of the elements were determined by the Press powder method [27]. Average error for these elements was less than 10% and the range of uncertainties for each element was based on the standards of Geological Survey of Japan [27].

The above chemical results of sediment core samples of Batticaloa lagoon were compared with published data of same elements in the surface sediments which were collected

and analyzed in same period [23]. In addition, following ecological risk indices were calculated for all sample types including the surface sediments.

2.3. Assessment of Ecological Risks

2.3.1. Sediment Quality Guidelines

Geochemical sediment quality inspections were done considering freshwater and marine sediment standards [23]. SQGs were used to interpret the contamination of elements with respect to environmental concerns [12,13]. The total chemical concentration of six elements (As, Cr, Cu, Ni, Pb and Zn) at each sampling location was compared with reference values of Threshold Effect Concentration (TEC) and Probable Effect Concentrations (PEC) of consensus-based freshwater ecosystem SQGs [12]. Values in between TEC and PEC are rarely or occasionally making adverse effects on organisms and above PEC are making adverse effects for a wide range of organisms [12]. The recommended values of concentration of heavy metals in marine sediments by International Atomic Energy Agency [28] were also used to evaluate the metal concentrations standards.

2.3.2. Pollution Load Index (PLI)

Contamination factor (CF) is an elemental ratio of concentration of each metal in the sediment with concentration of those particular metals in the background [11]. Since the regional background values have not documented, general upper continental crust (UCC) values were used as backgrounds [29].

$$CF = \frac{CM_{Sediment}}{CM_{background}}, \tag{2}$$

where, *CM* is the metal concentration.

The pollution load index (*PLI*) is calculated using the *CF* values that provide comparative means to measure the level of pollution in different locations [16].

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n}, \tag{3}$$

where, *CF* is the contamination factor and *n* is the number of elements. If sediments are polluted *PLI* > 1 and for non-polluted *PLI* < 1 [16].

2.3.3. Potential Ecological Risk Index (PERI)

The PERI is specially proposed to assess the contamination levels of coastal sediments with respect to toxicity of some selected contaminants [11,30].

$$PERI = \sum Er, \tag{4}$$

$$Er = Tr \times CF \tag{5}$$

where, *Er* is the ecological risk factor, *Tr* is the toxic response factor and *CF* is the contamination factor. The standard values for *Tr* for As, Pb, Zn, Cu, Ni and Cr are 10, 5, 1, 5, 5 and 2 respectively.

The quality of *Er* was suggested by Hakanson [11], where: *Er* < 40 is low potential ecological risk; 40 < *Er* < 80 is moderate ecological risk; 80 < *Er* < 160 is considerable ecological risk; 160 < *Er* < 320 is high ecological risk and *Er* > 320 is a very high ecological risk. The *PERI* < 90 is low potential ecological risk; 90 < *PERI* < 190 is moderate ecological risk; 190 < *PERI* < 380 is considerable ecological risk and *PERI* > 380 is a very high ecological risk.

3. Results and Discussion

3.1. Stratigraphy

Core samples BLC 01 and BLC 02 show unique distribution throughout the length of the core, while BLC 04 indicates different sedimentation processes between 18–36 cm

depth. A dark brown to black color organic matter-rich layer is observed in BLC 04 from 18 to 36 cm depth. The OM content of BLC 01 and BLC 02 varies between 0.8–1.5 wt. % and 1.6–2.6 wt. % respectively showing a minimal to unvarying distribution (Figure 3). The dark color organic matter rich layer of BLC 04 shows higher OM contents (ranging from 9.1–15.0 wt. %) than the other sediment units of the same core (0.8–4.9 wt. %). Carbonate contents for both BLC 01 and 02 cores are less than 1%. The organic matter rich unit of the BLC 04 indicates comparatively high carbonate content following the similar trend of OM in distribution indicating its sudden deposition nature with a different force.

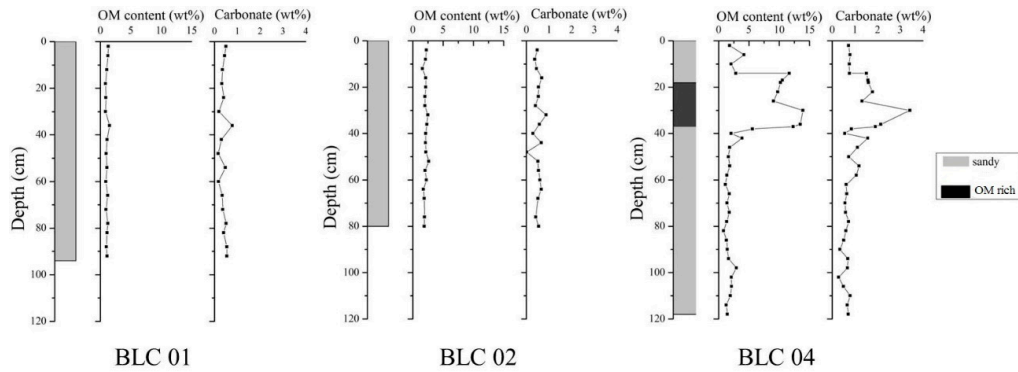


Figure 3. Stratigraphy, organic matter content (OM) and carbonate contents of sediment cores, Batticaloa lagoon.

Significantly, all sediment cores of Batticaloa Lagoon indicate very low clay fraction indicating 7% as the maximum for all cores (Figure 4). BLC 01 and BLC 02 cores show similar grain size distribution with high medium to coarse sand contents. The very coarse sand fraction of those cores decreases upward. In average, the grain size of BLC 04 indicates more than 50% of coarser fractions. The organic matter rich layer displays highest very coarse sand fraction and very fine sand fractions indicating a sudden sediment deposition for the unit. Recent studies found that the sedimentation rate of Sri Lankan lagoons is varying between 0.1–0.2 mm/yr considering both eastern and western parts of the island [31,32]. Hence it can be suggested that the above sudden event of the organic matter rich layer would have been deposited before about 900–1800 years. Probably a cyclonic event of the Bay of Bengal region would have been deposited this interesting organic matter rich layer.

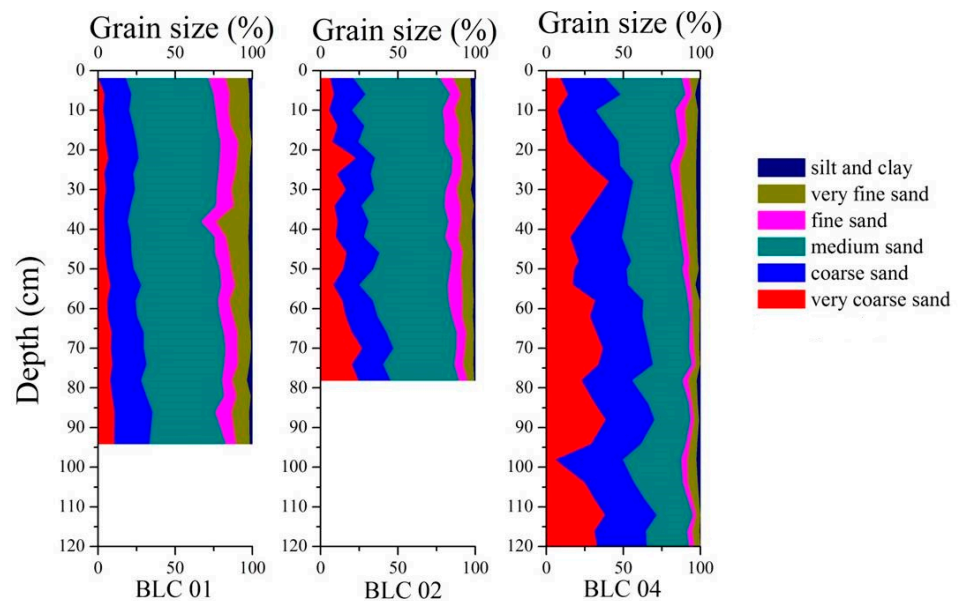


Figure 4. Grain size distribution of sediment cores obtained from Batticaloa lagoon.

3.2. Trace Element Concentrations

The vertical profiles of concentration of six trace elements in Batticaloa lagoon cores are shown in Figure 5. In addition, statistical summary of element concentrations of sediment cores as well as surface sediments is tabulated in Table 1 [23]. Regardless of the sampling location, the concentration of three sediment cores shows similar distribution except the organic matter rich layer of BLC 04. BLC 01 indicates high concentrations for Pb, Zn, Cu, Ni and Cr for the top 2 cm depth. It can be suggested that the anthropogenic effects of the development activities of the Batticaloa main city could be the reason for this enrichment as the sampling location is near to the Batticaloa city.

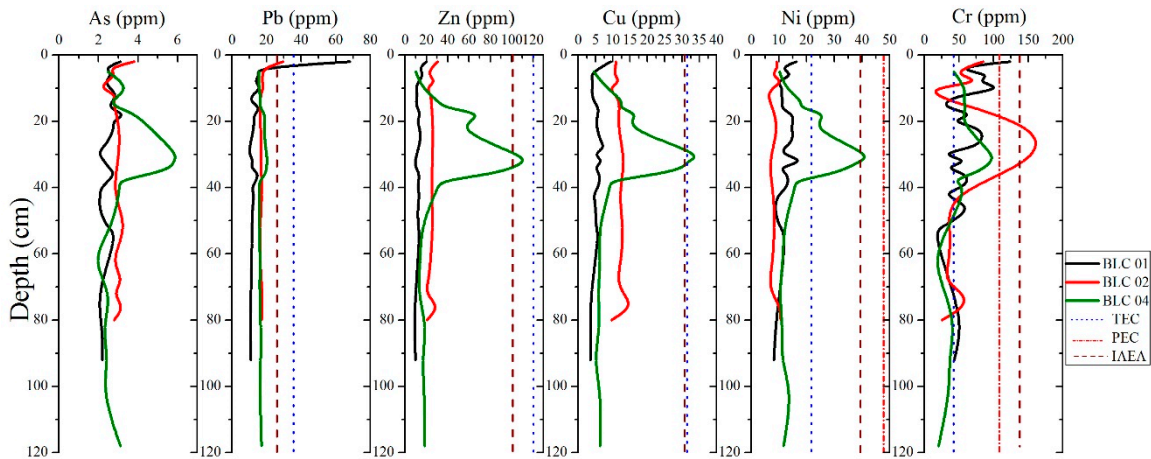


Figure 5. Vertical profiles of trace element concentrations in Batticaloa lagoon cores. Marine and freshwater sediment quality guidelines (SQG) values are marked (TEC: Threshold Effect Concentration, PEC: Probable Effect Concentrations, IAEA: International Atomic Energy Agency).

Table 1. Statistical summary of trace element concentrations in sediment cores and surface sediments, Batticaloa lagoon, Sri Lanka.

Sample		Concentration (ppm)					
		As	Pb	Zn	Cu	Ni	Cr
BLC 01	min	1.9	10.0	8.6	3.5	8.1	13.7
	max	3.4	68.1	20.1	9.4	19.9	123.7
	average	2.5	14.6	12.3	5.3	12.0	56.8
BLC 02	min	2.1	16.0	18.7	9.0	6.0	12.0
	max	3.5	18.4	32.1	15.7	11.3	168.0
	average	2.8	17.0	24.2	11.8	8.3	57.7
BLC 04	min	1.6	15.4	8.7	3.7	9.7	12.4
	max	6.0	20.3	112.7	36.2	43.1	99.1
	average	3.4	17.2	41.7	13.1	19.3	52.5
Surface sedi-ments	min	3.4	14.5	20.9	5.6	7.0	52.2
	max	9.6	26.4	155.1	216.4	41.1	145.9
	average	5.4	20.6	86.9	33.5	18.3	93.1

The enrichment of Cr is natural for the Sri Lankan context as the basement rocks of the catchment of the Batticaloa lagoon comprises Cr bearing metapelites and marble as described in other studies relevant to the catchment of Mahaweli river [33,34]. The Cr content of BLC 02 is significant in 20–32 cm depth. It could be due to the river inputs of the particular sampling area. The river Magalavatawan passes over a long distance and crosses the Highland-Vijayan boundary, which might be a reason for this significant enrichment.

The basement of the catchment of Batticaloa lagoon is in the Vijayan Complex rocks and partially cross cut the Highland-Vijayan boundary in the northern parts. Therefore,

similar sedimentary environment can be observed in Mahaweli river as the river path follows the Highland Vijayan Boundary [33,34]. Ranasinghe et al. [33] found elevated concentrations of the trace elements in the upper catchment of the Mahaweli river where the majority of the basement comprises Highland Complex rocks. However, the trace element concentrations of river mouth region of Mahaweli is comparable with that of the core samples of Batticaloa lagoon [34]. The average concentrations of surface sediments of Batticaloa lagoon indicates higher values for core samples of the same lagoon as well as the surface sediments of the river mouth regions of the Mahaweli river [34].

Compared to the developed coastal city associated environments, such as coastal areas of Brazil and coastal environments of South America, the As concentration of Batticaloa lagoon is very low [35–37]. The heavy metals concentrations (Pb, Zn, Cu, Ni and Cr) of the present lagoon is fluctuating in the minimal levels of the previously studied lagoonal environments of different regions indicating a comparative less contamination. For instance, trace element concentrations of the coastal lagoons of the Indian ocean are enriched in some regions when compared to the present lagoon [38,39].

3.3. Sediment Quality Guidelines

The overall concentrations of As, Zn, Cu and Ni of sediment cores of Batticaloa lagoon are below the TEC and IAEA values except the organic matter rich layer of BLC 04 (Figure 5). Including the organic matter rich layer of BLC 04, concentration of Pb indicates lower values than TEC and IAEA, whereas, the higher values are observed in the surface layer of BLC 01 and BLC 02. In contrast, surface sediments show lower values for both As and Pb than TEC [23]. The concentration values of Cr in all Batticaloa lagoon cores are fluctuating around TEC value. The 20–40 cm depth of BLC 02 and surface layer of BLC 01 have exceeded the PEC values for Cr. The concentration of Cr in all surface sediment samples are above the TEC values and some of them exceeded the PEC values [23].

3.4. Pollution and Ecological Risk

The calculated PLI values and PERI values of surface sediments of Batticaloa lagoon are graphically presented in Figure 6 with reference to the data published in Adikaram et al. [23]. The PLI values ranging from 0.74–2.42 for surface sediment samples indicating that the surface sediments are polluted except 3 locations at BLS 06, BLS 24 and BLS 31. These three locations are in the general central flow paths of the lagoon and away from the direct channel discharging zones.

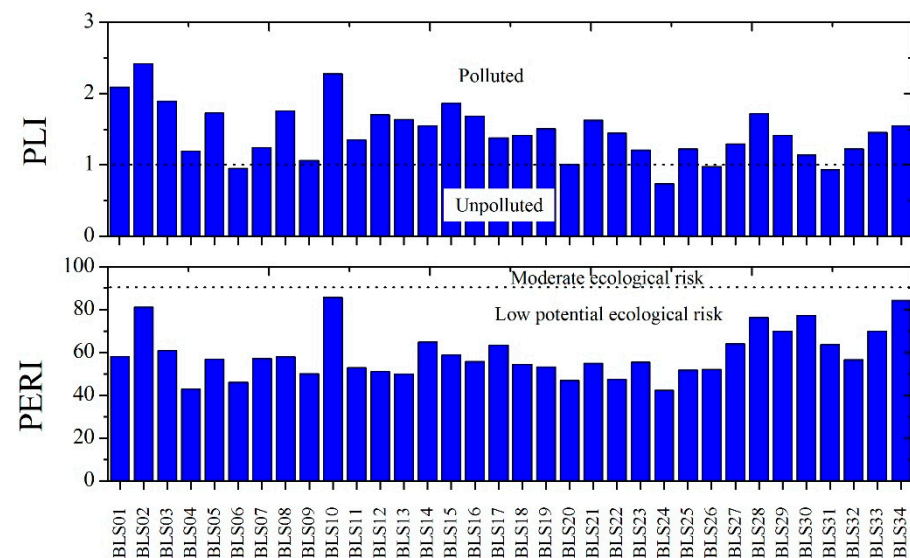


Figure 6. Pollution load index (PLI) and potential ecological risk index (PERI) for surface sediments of Batticaloa lagoon.

On the other hand, all surface sediments indicate low potential ecological risk for the Batticaloa lagoon surface sedimentation. Out of the 34 stations, BLS 02, BLS 10 and BLS 34 locations indicate higher values within the low potential ecological risk region. BLS 02 sampling location is in the southern main paddy channel discharging site at Kalmunei city area where most vehicle washing also carried out (Figure 1). The BLS 10 sampling location also represents a paddy channel that discharges at Navithanveli rural area. In addition, BLS 34 sampling locations represent the marine-freshwater dilution zone and, hence, characterized with high contents of Cr as the fresh water sources are rich in Cr [23]. The high Cr concentrations might be the reason for the high PERI values of BLS 34 station.

The values of PLI are generally low (<1) for all core sampling locations except the top layers of BLC 01 and the organic matter rich layer of BLC 04 (Figure 7). This suggests the unpolluted status for the lagoon throughout the sediment accumulated period of about 1 m depth. The average PLI values of BLC 01, BLC 02 and BLC 04 are 0.6, 0.7 and 0.9 respectively. The concentration of Pb in top layer of BLC 01 might be the reason for the pollution status in PLI calculations. In addition, the organic matter rich layer with high fine sediment content of the 18–36 cm depth of BLC 04 enriched the trace element accumulations more than the average sedimentation of the region.

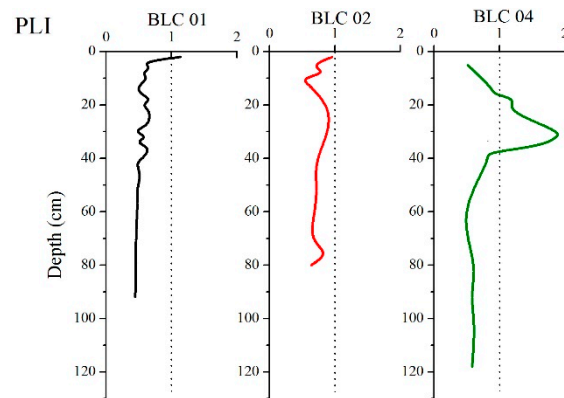


Figure 7. Vertical profiles of PLI for all core samples of Batticaloa lagoon.

Figures 8 and 9 show the prevailed ecological risk of core sampling locations for the lagoon. The average elemental ecological risk (Er) indices of sediment units of the lagoon are in the order of As>Pb>Ni> Cr>Cu>Zn (Figure 9) and all of locations are below the low potential ecological risk level (40). The total potential ecological risk index (PERI) of trace elements in each sampling location is below the low potential ecological risk level (90) of the index. The organic matter rich layer of BLC 04 also indicated the low potential ecological risk signaling its harmless nature for the environment. BLC 01 is the lowest risk location where the high water circulations washout the metal concentrations.

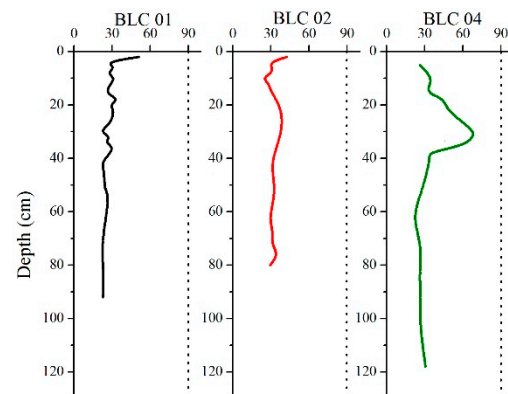


Figure 8. Vertical profiles of PERI for all core samples of Batticaloa lagoon.

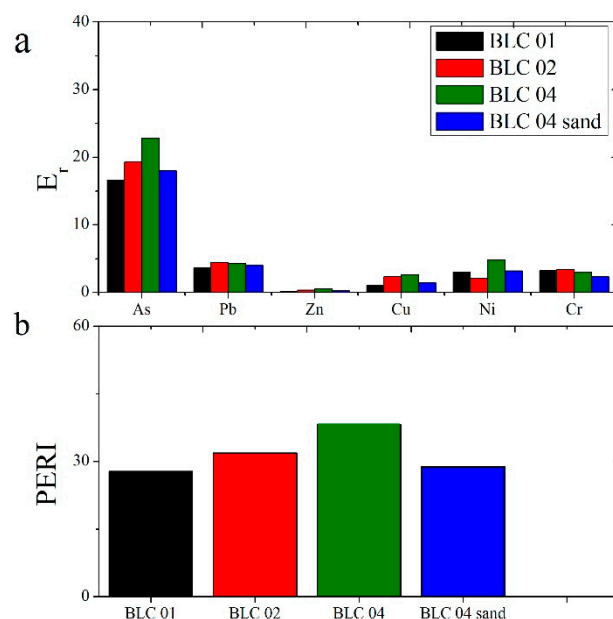


Figure 9. (a) Average ecological risk index of each elements and (b) average potential ecological risk index for the sediment cores of Batticaloa lagoon.

4. Conclusions

The study on potential ecological risk and sediment pollution of Batticaloa lagoon, Sri Lanka establishes that the lagoon surface is exposed to a trace element pollution environmental change with compared to the recent history. The surface sediments are less polluted in PLI calculations with a low potential ecological risk for As, Pb, Zn, Cu, Ni and Cr. Paddy channel discharging sites and places near the lagoon mouth indicate polluted but low ecological risky environments. The agricultural practices of the area as well as the chemistry of the basement rock of the present environment might be the reason for the environmental risk development of the Batticaloa lagoon. In addition, accumulation of untreated waste disposals will also cause an adverse effect to the natural environment of the lagoon in future which need to be addressed considering the temporal and point source measurements. Therefore, environmental management planning is suggested for the present environment for a sustainable development.

Author Contributions: M.A. performed the experiment, analyzed the data and drafted the manuscript. A.P. and D.J. guided and supervised the experiments and analysis. H.I. assisted with performing the XRF analysis. C.M.E. reviewed the manuscript for English as a native speaker. All authors have read and agreed to the published version of the manuscript.

Funding: The research was financially supported by University Grant Commission, Sri Lanka (Grant No. UGC/DRIC/PG/2014AUG/SEUSL/01).

Acknowledgments: The authors highly appreciate Shimane University, Japan, for access to the XRF facility. Head of the Department of Geology, University of Peradeniya and Head of the Department of Physical Sciences, South Eastern University of Sri Lanka are also acknowledged for providing the laboratory facilities.

Conflicts of Interest: The authors state no conflict of interest.

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