Chapter

Fingerprinting Sources of the Sediments Deposited in the Riparian Zone of the Ruxi Tributary Channel of the Three Gorges Reservoir (China)

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Abstract

The riparian zone of the Three Gorges Reservoir serves as a critical transitional zone located between the aquatic and surrounding terrestrial environments. The periodic anti-seasonal alternation of wet and dry periods results in an intensive exchange of substance within the riparian zone. The discrimination of the sources of the sediments deposited within the riparian zone is of fundamental importance for the evaluation of the soil pollution and associated environmental impacts and for the protection of the water quality in the reservoir. In this study, a composite fingerprinting technique has been applied to apportion the sediment sources for the riparian zone with different elevations, ranging between 145—155, 155–165, and 165–175 m in a typical tributary channel. From a sediment perspective, the sediments suspended from the Yangtze mainstream represent the primary sources of the riparian deposits. From a contamination perspective, the sediment input from the Ruxi tributary channel represents an important source of pollution for the riparian environment. More effective sediment and sediment-associated contaminant control plans are needed to reduce the potential environmental problems of the riparian zone.

Keywords: riparian zone, sediment source, fingerprinting, contaminant, Three Gorges Reservoir

1. Introduction

Since the full impoundment of the Three Gorges Reservoir in late 2010, a distinctive reservoir marginal landscape has been created, which is commonly known as the riparian zone [1, 2]. This zone, also named as water-level fluctuation zone [3] or littoral zone [4], is a unique artificial landscape that formed after the construction of the Three Gorges Dam on the Yangtze River. Definitely, the reservoir riparian zone refers to the elevation ranges between the base water level of 145 m in wet season for flood control and the peak level of 175 m in dry season for energy generation. Unlike the traditional riparian zones in natural river systems that were affected by irregular or occasional overbank flooding, the reservoir riparian zone is characterized by the regular water level fluctuation as a result of the reservoir impoundment [5].

The riparian zone of the Three Gorges Reservoir has a vertical height of 30 m, and extends ca. 663 km along the mainstream of the Yangtze River, with a total area of 349 km^2 [3]. After its generation, the riparian zone has been subjected to an annually cyclic inundation and exposure. As a critical transitional zone between the aquatic and terrestrial ecosystems, numerous environmental issues related to this zone have captured extensive attention in recent years, such as bank erosion [6], revegetation [7], sedimentation, and associated contamination [1, 2, 8].

During the impounding period of the reservoir, which typically extends from September to next June, the increased water depth and decreased flow velocity provide much opportunities for the deposition and storage of sediment and sediment-associated contaminants, both within the channel and on the areas bordering the channel, for example, the riparian zone. Despite no obvious deterioration in water quality in the mainstream of the Yangtze River, most of the tributaries have experienced serious eutrophication since the operation of the reservoir [9]. Serving as an important carrier of contaminants, the sediment deposited and subsequently stored within the riparian zone of the reservoir may also result in the pollution of the environment. Within the exposure period, which represents the wet season of the Yangtze River basin, remobilization of the contaminated sediment deposited within the riparian zones by slope and bank erosions may reintroduce nutrients and contaminants into the watercourse. Moreover, the repeated agricultural use of the riparian areas will have the potential to transmit the enriched contaminants to human via food chains. In this context, information on the source of the riparian deposits is needed for the development of environmentally sound water and sediment management strategies.

Sediment fingerprinting is a widely employed approach to quantify the relative contribution of potential sources to the target sediment, such as suspended sediments delivered either in riverine systems or at the outlet of a catchment or deposits collected from floodplains, reservoirs, wetlands, and lakes. This technique can be traced back to the 1970s, and the past 40 years has witnessed the progressive development and refinement of the approach [10]. The most important assumption underpinning the fingerprinting technique is that one or more of the physical or chemical properties (i.e., fingerprints) could clearly differentiate potential sources of the sediment. A wide range of soil and sediment properties have now been successfully used as fingerprints, including mineral magnetics, fallout radionuclides, color, geochemistry, and stable isotopes [11]. Along with the increasing number of properties being used in fingerprinting studies, there is a need to select the "best" set of properties to discriminate between sediment sources. Although a lot of statistical analyses have been tested to identify the optimum combination of those properties, one commonly adopted procedure involves a two-step process, which combined Kruskal-Wallis *H*-test as first step and discrimination function analysis as second step [12]. A recent work has also demonstrated that this two-step fingerprint selection procedure (KW + DFA) was found to be the most effective option, which provides the most reliable source apportionment results in their study catchment [13].

The Ruxi River catchment is located in the middle section of the Three Gorges Reservoir region and drains an area of 721.4 km^2. The river extends approximately 54.5 km and is a first-order tributary of the Yangtze River (**Figure 1**). This catchment is characterized by a subtropical humid monsoonal climate. The mean annual rainfall is about 1140 mm, with approximately 70% falls between May and September. The soils are purple soils and the land uses are dominated by arable land

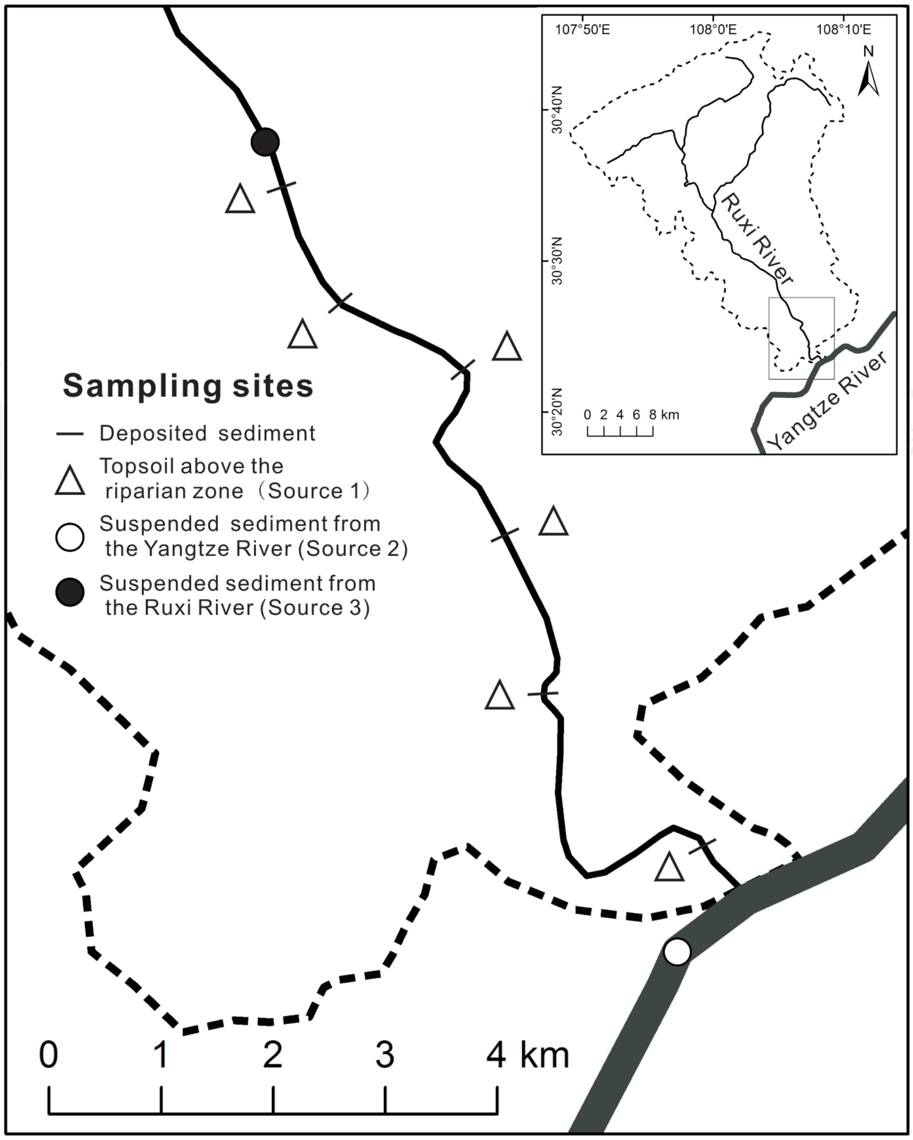

Figure 1.
The study area and sampling sites.

and woodland. The riparian zone in the Ruxi catchment covers an area of 6.4 km^2 and extends about 6 km upstream from its confluence with the Yangtze mainstream. The riparian zone is characterized by gentle slopes with the gradient less than 15° and is subjected to evident sediment deposition during the impounding period of the reservoir.

In this study, the sediment source fingerprinting technique was applied to discriminate deposited sediment sources in the riparian zone of the Ruxi tributary channel in the Three Gorges Reservoir, China. The main objectives were (i) to test the feasibility of using fingerprinting approach to estimate the relative contribution of potential sources to the sediment deposited within the riparian zone and (ii) to explore the environmental implications of sediment sources.

2. Materials and methods

2.1 Sediment source classification

The identification and the classification of the potential sediment sources within a catchment or river basin is of fundamental importance for a successful application of the fingerprinting approaches. The sources have been classified based on the source type (e.g., surface or sub-surface erosion, areas under different land use) or on spatial location (e.g., sub-catchments or geological units). Despite that most existing studies have focused on discriminating sources types [10], information on spatial source, for example tributary sub-basins, might be more important at larger scales [14].

Three spatially differentiated sources have been identified in this study to apportion their contribution to the sediments deposited within the riparian zone of the Ruxi tributary channel. Firstly, the upside soils above the 175 m elevation level have the possibility to be moved downward as a result of surface erosion associated with rainfall events and agricultural disturbance, which therefore provide a potential source (Source 1) of the sediment. Secondly, the suspended sediments transported by both the mainstream of Yangtze River (Source 2) and the upstream Ruxi River (Source 3) are also likely to be deposited and stored within the riparian zone during the impounding period of the reservoir.

2.2 Sample collection

Representative samples of the deposited sediments have been collected from the riparian zone at six sections along the Ruxi River by using artificial grass mats as sediment traps. At each section, the 30 m high riparian zone has been subdivided into three intervals of elevation (145–155, 155–165, and 165–175 m). For each interval, one small piece of plastic mat with an area of 1 × 1 m has been fixed to the soil surface with steel pins prior to inundation. The time-integrated deposited sediments have been sampled between September 2015 and June 2016, encompassing a complete inundation and exposure period of the riparian zone.

At each section for deposited sediment collection, surface soils (0–2 cm) have been grabbed at locations with actively eroding signs and immediately above the 175 m elevation level. To increase the representativeness of the source samples, several subsamples have been collected within the vicinity of each sampling location and then mixed to produce a composite sample (n = 6).

The collection of fluvial suspended sediments (Source 2 and Source 3) has been undertaken monthly from September 2015 to June 2016. One time-integrating sediment trap has been deployed in the main channel of the Yangtze River, which is located at approximately 1 km upstream from the confluence with the Ruxi River (**Figure 1**). The trap consists of a floating barrel fixed at 1.5 m below the ambient water surface. Using the same method, suspended samples of the Ruxi tributary have been collected from a site near the center of the river channel cross section. This sampling site was located about 5 km upstream of the tributary. Totally, 18 samples of the suspended sediment transported by both the Yangtze mainstream (n = 9) and Ruxi River (n = 9), which representing Source 2 and Source 3, respectively, were collected.

It is noted that, however, the specific flow regulation mode of the Three Gorges Dam leads to remarkable difference in water level residence time and inundation duration between different elevations within the 30-m-height zone. Typically, water level rises rapidly from 145 to 175 m during the period spanning from mid-September to early October; then, it remains at the peak level until late January. Subsequently, water level retreats gradually to the 145 m base level in early June, which then maintain around this level until next inundation period (**Figure 2**). Therefore, deposited sediment sources from the suspended material originating from the mainstream and tributary vary temporally with the variation of water levels. In the case of the 145–155 m elevation, the inundation duration lasts for nearly 9 months. For the upper 155–165 and 165–175 m elevations, the riparian zones are submerged for about 6 and 4 months, respectively. In the case of the

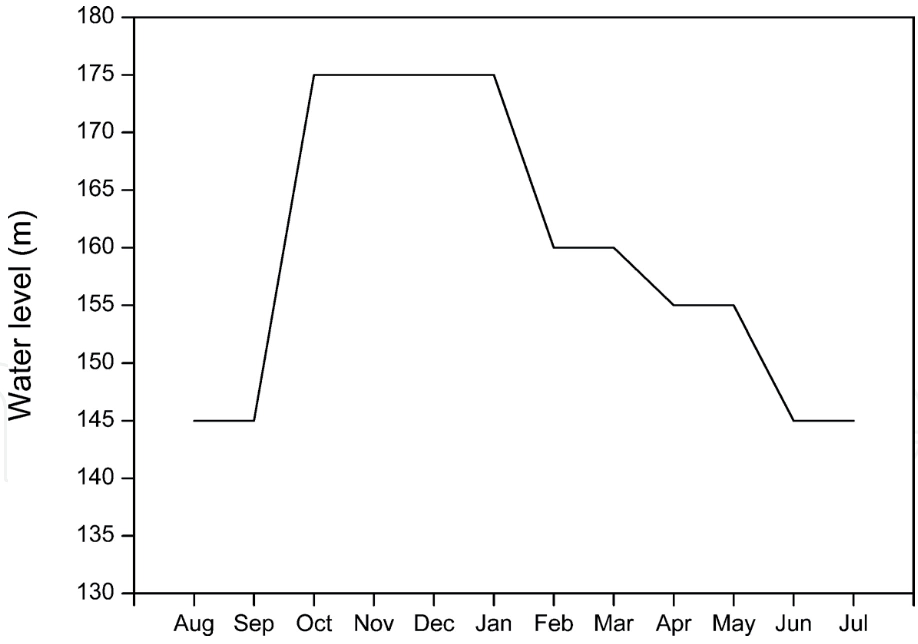

Figure 2.
Dynamic of water levels with the inundation period of the Three Gorges Reservoir.

Source 1, however, the eroded material has the equal chance to be transported downward and stored within different elevations. In this context, sediment sources have been allocated according to the submerging and sampling periods with the exception of Source 1.

2.3 Laboratory analysis

The deposited sediment collected on each mat has been rinsed using deionized water and recovered by sedimentation and centrifugation. After being retrieved from the traps, the suspended sediment samples (Source 2 and Source 3) have been also obtained by setting and centrifugation in the laboratory. In the case of the composite topsoil samples, stones and visible plant debris have been discarded before being dried.

All samples have been air-dried at room temperature, gently disaggregated using a pestle and mortar and screened through a 2-mm sieve. Subsamples of the <2 mm fraction of the target deposit were measured firstly to determine the grain size distribution using a laser diffraction granulometer (Mastersizer 2000, Malvern Instruments). Prior to analysis, the samples were pretreated with 10% H_2O_2 and 10% HCl to remove organic matter and $CaCO_3$, respectively, and then dispersed with ultrasound for 2 minutes. The obtained results have revealed that the deposited sediments collected from the riparian zone with different elevation levels were dominated by silt and clay particles, in which over 90% of the sediment was <63 μm in size. Consequently, all source material and deposited sediment samples were sieved to <63 μm to obtain a comparable grain-size faction between source and sediment material. Subsequent analyses were restricted to the <63 μm fraction.

A total of 18 potential fingerprinting properties were selected for analysis. Concentrations of TOC and TN were measured using a vario MACRO cube element analyzer (Elementar, Germany) after the removal of $CaCO_3$ using 10% HCl. Other elements, including TP, K, Mg, Na, Ca, Fe, Al, Cr, Mn, Ti, Zn, Cd, Co, Cu, Ni, and Pb, were determined using ICP-OES and ICP-MS following a microwave-assisted digestion with HNO_3 and HF. Duplicates, method blanks, and standard reference materials (GBW07401) were used for quality assurance and control.

Property	145–155 m				155–165 m				165–175 m			
	S1	S2	S3	Target	S1	S2	S3	Target	S1	S2	S3	Target
TN	0.725	0.407	0.114	0.430	0.725	0.131	0.009*	0.910	0.725	0.496	0.009*	0.451
TOC	0.180	0.299	0.052	0.432	0.180	0.074	0.006*	0.625	0.180	0.625	0.699	0.825
TP	0.490	0.405	0.656	0.537	0.490	0.723	0.359	0.843	0.490	0.204	0.521	0.747
Fe	0.074	0.994	0.795	0.745	0.074	0.948	0.861	0.470	0.074	0.899	0.648	0.160
Al	0.071	0.549	0.975	0.133	0.071	0.376	0.523	0.910	0.071	0.297	0.923	0.206
Ca	0.114	0.020*	0.003*	0.516	0.114	0.005*	0.001*	0.927	0.114	0.594	0.350	0.722
Mg	0.667	0.987	0.684	0.207	0.667	0.723	0.573	0.388	0.667	0.676	0.616	0.696
K	0.167	0.982	0.978	0.235	0.167	0.758	0.911	0.432	0.167	0.387	0.973	0.042*
Na	0.569	0.006*	0.116	0.396	0.569	0.094	0.272	0.878	0.569	0.817	0.150	0.052
Ti	0.323	0.811	0.052	0.384	0.323	0.861	0.066	0.177	0.323	0.641	0.259	0.574
Mn	0.371	0.951	0.260	0.637	0.371	0.966	0.666	0.000*	0.371	0.993	0.504	0.811
Co	0.694	0.636	0.466	0.726	0.694	0.655	0.256	0.101	0.694	0.326	0.404	0.648
Cu	0.043*	0.247	0.003*	0.253	0.043*	0.507	0.024*	0.806	0.043*	0.131	0.015*	0.027*
Cr	0.999	0.134	0.608	0.945	0.999	0.118	0.339	0.717	0.999	0.077	0.390	0.961
Zn	0.071	0.927	0.566	0.206	0.071	0.020*	0.729	0.936	0.071	0.013*	0.037*	0.867
Pb	0.213	0.221	0.087	0.946	0.213	0.420	0.180	0.608	0.213	0.544	0.738	0.101
Cd	0.021*	0.963	0.800	0.868	0.021*	0.341	0.505	0.688	0.021*	0.152	0.142	0.407
Ni	0.114	0.542	0.561	0.835	0.114	0.626	0.431	0.074	0.114	0.686	0.259	0.748

Statistically significant values at $P \leq 0.05$.

Table 1.
The results of the Shapiro-Wilk test for normality.

Elevation level (m)	Properties passed the range test
145–155	TN, TOC, TP, Na, Ti, Mn, Cr, Zn, Pb, Cd
155–165	TN, TOC, TP, Ca, Mg, Na, Ti, Mn, Cu, Cd
165–175	TN, TOC, TP, Fe, Al, Ca, Mg, K, Na, Ti, Mn, Cu, Cr, Pb, Cd

Table 2.
Fingerprinting properties passed the range test for different elevation levels in the riparian zone.

145–155 m			155–165 m			165–175 m		
Property	*H*-value	*P*-value	Property	*H*-value	*P*-value	Property	*H*-value	*P*-value
TN	13.814	0.001*	TN	11.275	0.004*	TN	8.857	0.012*
TOC	14.658	0.001*	TOC	11.275	0.004*	TOC	8.857	0.012*
TP	14.487	0.001*	TP	12.329	0.002*	TP	9.736	0.008*
Na	9.937	0.007*	Ca	12.784	0.002*	Fe	4.295	0.117
Ti	16.275	0.000*	Mg	11.368	0.003*	Al	1.929	0.381
Mn	14.656	0.001*	Na	9.697	0.008*	Ca	11.429	0.003*
Cr	5.889	0.053	Ti	11.699	0.003*	Mg	8.000	0.018*
Zn	10.926	0.004*	Mn	12.784	0.002*	K	1.529	0.466
Pb	12.010	0.002*	Cu	3.029	0.220	Na	5.618	0.060
Cd	13.469	0.001*	Cd	12.501	0.002*	Ti	8.324	0.016*
						Mn	11.000	0.004*
						Cu	4.524	0.104
						Cr	4.614	0.100
						Pb	10.629	0.005*
						Cd	10.315	0.006*

Statistically significant values at $P \le 0.05$.

Table 3.
The results of applying the Kruskal-Wallis H-test to the fingerprint property dataset for different elevation levels in the riparian zone.

2.4 Sediment source discrimination

The measured values have been firstly tested for normality prior to proceed with the statistical selection of potential fingerprint properties [15]. Particle size and organic matter correction factors were not included in this study to avoid the risk of over-correction of the tracer values [16, 17]. **Table 1** shows that some properties exhibit non-normal distribution. Nonetheless, the majority of the fingerprint properties for source and target samples in different elevation levels have passed the Shapiro-Wilk test, confirming that these data were normal in distribution. Since the number of samples in this study is relatively small and the mean values are more sensitive than the median, the median values for individual properties in both source and target samples are used for further analyses.

One fundamental assumption underpinning the sediment source fingerprinting techniques is that the tracer properties, which were selected to discriminate between sources, should behave conservatively during mobilization and delivery through the catchment system [14]. Although the conservative behavior of the

Elevation level (m)	Step	Fingerprint	Wilks' λ	Cumulative % source type samples classified correctly
145–155	1	Cd	0.367	62.5
	2	Ti	0.138	91.7
	3	Mn	0.088	95.8
155–165	1	Mg	0.277	61.1
	2	Mn	0.075	94.4
	3	TP	0.026	100.0
	4	TOC	0.014	100.0
165–175	1	Ca	0.016	100.0
	2	TN	0.001	100.0
	3	TP	0.001	100.0

Table 4.
The optimum composite fingerprint for different elevation levels in the riparian zone established using stepwise discriminant function analysis.

tracer properties is complex and difficult, if not impossible, to quantify, a modified range test was applied to ensure that the median concentration for each tracer associated with the target falls within the range of median concentrations of that tracer associated with the potential sources [18]. The potential fingerprinting properties, which passed the range test for each elevation level, are listed in **Table 2**. It has been recognized that such a range test is simply a method of selection to exclude the properties suffering a significant change during the transport within the fluvial system; thus, complete absence of tracer property transformation (i.e., conservative behavior) is not guaranteed [19].

A two-stage statistical procedure [12] was then applied to the source material properties passing the range test to identify the composite fingerprints that provide a good discrimination between sources. During the first stage, the Kruskal-Wallis *H*-test was used to select properties exhibiting significant differences ($P \leq 0.05$) between the individual sources (**Table 3**). Properties passing the Kruskal-Wallis *H*-test are then tested, in stage two, by stepwise multivariate discriminant function analysis (DFA) to identify the optimum combination of tracers for discriminating the source groups (**Table 4**). In this stage, each fingerprint property was selected based on the minimization of Wilks' λ and a probability value for parameter entry of 0.05.

3. Results

A frequentist-based multivariate mixing model [12] was applied to assess the relative contribution of the three potential sources to the deposited sediment samples collected from each designated riparian zone. In this method, the proportions P contributed by the m individual sources s are quantified by minimizing the sum of the squares of the residuals (R_{es}) for the n tracer properties involved, where:

$$R_{es} = \sum_{i=1}^{n} \left(\frac{C_{di} - \left(\sum_{s=1}^{m} C_{si} P_s \right)}{C_{di}} \right)^2 \quad (1)$$

and C_{di} is the concentration of tracer property i in the deposited sediment sample, C_{si} is the concentration of tracer property i in source group s and P_s is the relative proportion from source group s. Note that two constraints are imposed on the mixing model: (a) the relative contributions from the individual sediment sources must lie between 0 and 100%, and (b) these contributions sum to 100%.

The mixing model was optimized using the OptQuest algorithm in Oracle's Crystal Ball software. To address the uncertainties associated with representation of the sources and targets by single property values (e.g., mean or median), Student's t-distributions were assigned for each source (C_{si}) and target sediment property (C_{di}) using measured median as location and the product of standard deviation and $n^{-1/2}$ as scale parameter, where n is the number of samples [20]. The proportional contribution for each source was repeatedly solved for 1000 times using a Latin Hypercube sampling method.

The results of Latin Hypercube sampling procedure documented that the estimates of sediment contribution to the riparian deposits from the individual sources involved limited uncertainty bands of ±0.5–0.7% at the 95% level of confidence. Consequently, the proportional source contributions are reported as absolute median values in the following section when comparing and explaining the results.

The robustness of the optimized solutions of the mixing model was assessed using a goodness-of-fit (GOF) function, which compares the actual fingerprint property concentration measured in target sediment with the corresponding values predicted by the model, based on the optimized percentage contribution from each source group [21]. The GOF function is defined as:

$$GOF = 1 - \left[\frac{1}{n}\sum_{i=1}^{n}\frac{\left|C_{di} - \sum_{s=1}^{m} C_{si} P_s\right|}{C_{di}}\right] \tag{2}$$

Figure 3 presents the median contributions from individual source types to the deposited sediment samples collected from the riparian zone with different elevation level. The GOF values range between 0.88 and 0.95, indicating that the modeling results are acceptable. The sources of the suspended material from the Yangtze mainstream (Source 2) contributed the most proportion (>40%) to the deposited sediment for all three elevation levels of the riparian zone. There were, however, clear evidence of significant contrasts between the contributions from the other two sources (i.e., sources 1 and 3) for the 145–155 m elevation level and the other two upper elevation levels. In the case of the sources of topsoil above the riparian zone (Source 1), the estimated contribution to the lowest 145–155 m deposits was only about half of those to the other two upper elevation levels. In the case of the sediment input from the Ruxi tributary (Source 3), the relative contribution decreased with increasing elevation, despite that the values were comparable between the upper 155–165 and 165–175 m levels.

4. Discussion

4.1 Sediment source apportionment

A good discrimination between the sources (**Table 3**) and high levels of correct classification of source type samples (**Table 4**) were provided by the two-stage statistical procedure following the normality and conservatism tests. More particularly, the source contribution estimation produced by the mixing model has generated high values of GOF and limited levels of uncertainty. The results indicate that reliable estimates of sediment source contribution were obtained by using the fingerprinting technique in this investigation.

The source ascription results presented in **Figure 3** clearly verify that the contribution of the sediments suspended from both the Yangtze mainstream and the Ruxi

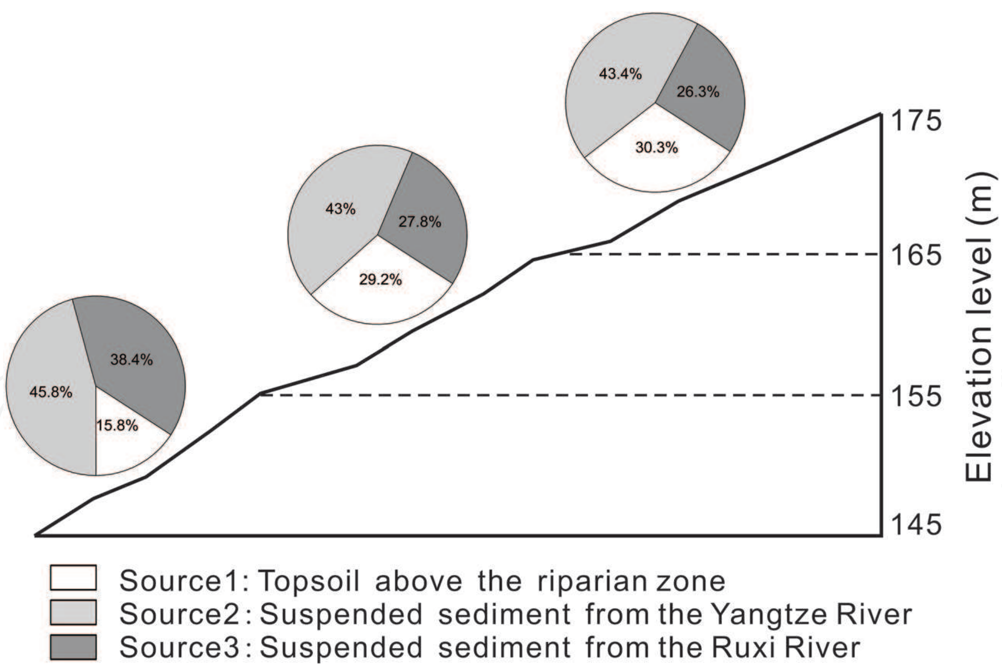

Figure 3.
The median relative contribution of each source type to the deposited sediment collected from the riparian zone with different elevation levels.

tributary channel dominate the sediments deposited in the riparian zone of the reservoir. The sediment contribution originated from these two sources occupied a total proportion of 69.7–84.2%, although there is some evidence of a declining trend with increased elevation. The highest proportional contribution documented for the lowest elevation level of 145–155 m was closely related to the longest water retention time at this level (**Figure 2**), which means that there will be more opportunities for sediment deposition.

In contrast, the proportion of the topsoil source contribution increased from 15.8 to 30.3% with the increasing of elevation. The higher contribution of the topsoil source to the deposits in upper elevation levels (i.e., 155–165 and 165–175 m) could probably be attributed to the proximity of sources to the target sediment sampling sites. During the periods September–October and April–June, which represent the end and the beginning of the wet season in the study area, respectively, sediment originating from the upper lands above the riparian zone caused by water erosion will be preferentially stored in adjacent fields as a result of gentle slope gradient. The relative contribution of this source type to the deposited sediment at the 145–155 m elevation level is therefore much less than those for the upper portions of the riparian zone.

The relatively high sediment contribution from the Ruxi tributary to the 145–155 m deposits might again be explained by the relatively longer submerging period, which last for nearly 9 months (**Figure 2**). Probably more importantly, the sediment mobilized from the upstream catchment and transferred to the Ruxi River during the wet periods September–October and April–June may be predominantly deposited within the 145–155 m level due to the impoundment of the reservoir.

4.2 Environmental implications for sediment source contribution

The information on the relative contribution of potential sediment sources can also be used to evaluate the relative importance of the contributions of sediment-associated nutrients and contaminants [22]. **Figure 4** compares the mean element concentrations for the riverine suspended sediments (sources 2 and 3) and local

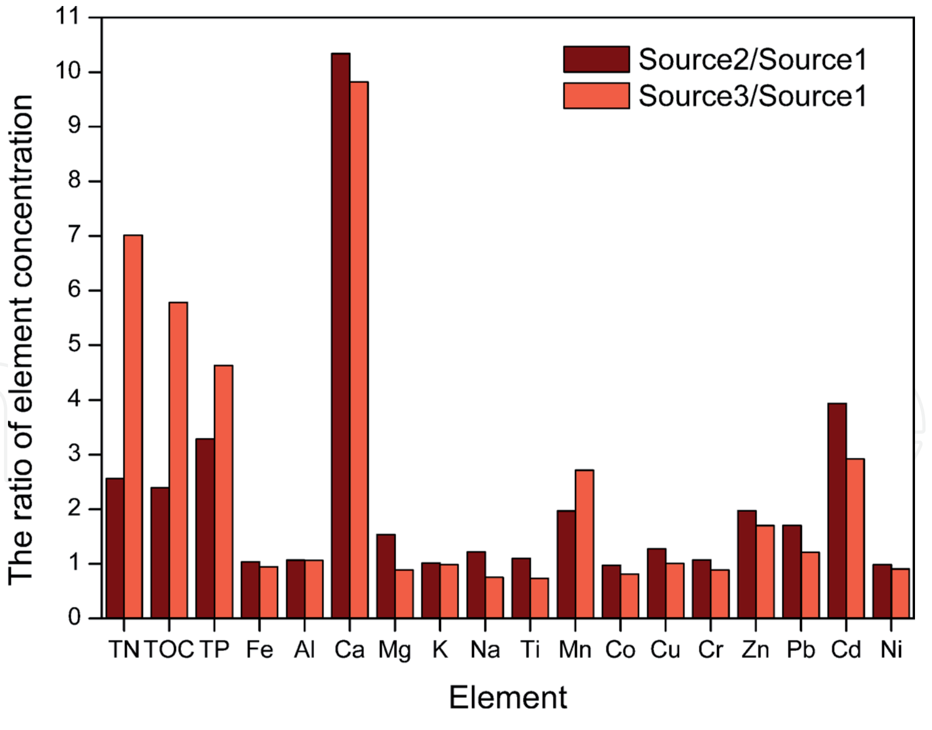

Figure 4.
The ratio of mean concentrations of individual element in suspended sediment collected from the Yangtze River (Source 2) and the Ruxi River (Source 3) to that of the topsoil above the riparian zone (Source 1).

topsoils (Source 1) during the whole sampling period. The presented results show that for all the nutrients (TN, TOC, TP) and some heavy metals (e.g., Mn, Zn, Pb, Cd), the average element concentrations in the suspended fluvial sediments were significantly higher than that one of the local soils. Combining this information with the relative contribution of the suspended fluvial sediments to the riparian deposits, it can be inferred that the sediment-associated nutrients and contaminants transported from both the Yangtze mainstream and the Ruxi tributary represent dominant sources of the contaminants deposited within the riparian zone. Recent studies have documented elevated levels of nutrients [23] and heavy metals [23–25] in the riparian zone of the Three Gorges Reservoir. In this context, the accumulated deposition and storage of fine-grained sediment and associated nutrients and contaminants within the riparian zone of the reservoir may exert negative environmental impacts on aquatic ecosystems and the agricultural use of riparian lands. Moreover, the nutrients and contaminants that stored within the riparian zones may have great potential to be reintroduced into the river system by future bank erosion and/or release to the water column accompanying the annually cyclic soaking.

5. Conclusions

The regular closure in dry season and the water drainage in rainy season of the Three Gorges Dam on the Yangtze River have resulted in significant sedimentation and enrichment of sediment-associated nutrients and contaminants in the reservoir riparian zone. Against this background, the fingerprinting approach was applied to assess the sources of sediment that deposited within the riparian zone of a tributary after the impoundment of the reservoir. Despite significant contrast of sediment contribution from individual sources that was documented for different elevation levels of the riparian zone, the sediments suspended from the Yangtze mainstream was demonstrated to be the primary source of the riparian deposits. From a contamination perspective, however, the sediment input from the upstream tributary also represents an important source of pollution to the riparian environment.

Although it should be recognized that the result reported is limited in temporal and spatial scopes in that only one-year sampling campaign and one single catchment was involved, the findings, combining with the information on previous studies, emphasize the need to take targeted sediment and contaminant management strategies to control the potential environmental problems in the reservoir riparian zones. Further attempts were required to explore the use of sediment fingerprinting approach to assess the sources of sediment-associated nutrients and contaminants in this area.

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Conflict of interest

The authors have declared that no conflict of interest exists.

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