Identification of dominant suspended sediment sources in a river basin using X-ray florescence analysis

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1. INTRODUCTION

The transportation of materials with different chemical and physical properties from the headwaters all over a river basin up to the downstream end is a natural and indispensable mechanism to keep sound riverine ecosystem and subsequently for the whole water body. In addition, it is known that the chemical composition, grain size distribution and other features of the sediments play an important role in the state of the biological communities and their diversity [1)]

However, from the aspect of ecological system, abnormal high sediment concentrations could cause biological, chemical and physical alterations of the river properties and secondary consequences at socio-economic range, such as decreasing in fishery production, rise in water treatment processes costs and loss of reservoirs storage capacity[2),3)]. The high environmental and economical costs of these repercussions heighten the importance of developing preventive actions or countermeasures, for which a fully comprehension of the main processes and variables associated with the sediment transport (ST) is required.

Identifying the main sources within a basin and their sediment yield is a key step for the enhancement of understanding the sediment production and transportation processes[4)]. Although there are a lot of techniques with different approaches, a universal method, which enables to evaluate the ST in a river basin, does not exist. Nonetheless, fingerprint-type methods, in which different properties of the sediments from the potential sources and their sinks are evaluated, have shown to be useful in the study of the ST within river basins[5)]. For instance, Ishida, et al., (2010) applied chemical composition analysis and grain size distribution measurement to find the sources of the sediments from each sub-domain to the downstream end of a river basin with the different land uses and features in the Oromushi River basin in Hokkaido, Japan[6)].

Therefore, we made an attempt to use chemical composition analysis performed by X-rays fluorescence analysis (XRF) as a tool to identify the main sources of sediments from to the downstream end of a river basin[7)]. Also, in order to clarify the suspended sediment sources, laser diffraction analysis for the particle size distribution and the clarification of the settling velocity profile for each particle size bin computed by using the particle size distribution results are also included in the sediments characterization

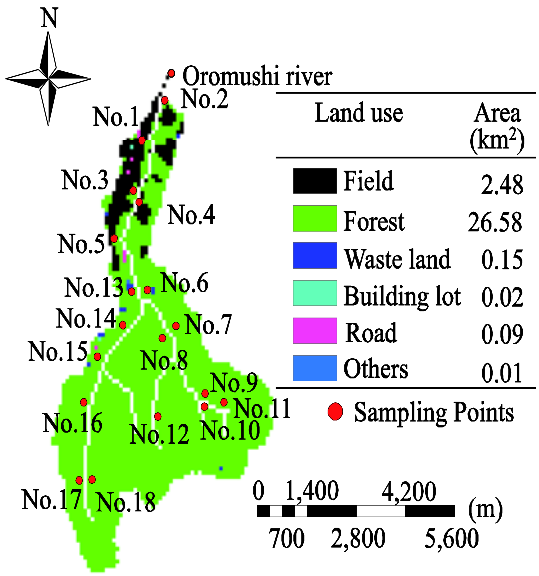

Fig.1　Oromushi river basin land use map and location of the sampling points.

2. MEHODS

2.1 SITE DESCRIPTION

The Oromushi River is a branch of the Tokoro River with a total length, basin area and mean slope of 9.7 km, 29.3 km^2 and 1/43, respectively. The river outfall location is 43 43'N and 143 47'E. This river is known for the occurrence of high suspended sediment concentration (more than 10,000 mg l^{-1}) during flood events. Two predominant land uses can be distinguished within the whole basin: forests and agricultural fields representing 80.7 % and 15.7 % of the coverage, respectively.

2.2 FIELD OBSERVATIONS AND LABORATORY PROCEDURES

The Oromushi River basin was divided into 18 sub-domains by using geographical information system (GIS) data such as land use, surface soil type, vegetation, and so on (**Fig.1**). Three soil samples of about 1125 cm^3 (15 cm *15 cm *5 cm) were collected from each of the 18 sub-domains on the surroundings of specific patches considered as erosion-prone areas and subsequently potential sources of sediments (i.e. steep slopes, poor vegetation or no vegetation covered areas) by using garden scoops. Special care was taken not to contaminate the specimens when sampling between sites by cleaning the tools thoroughly and by using double sealed labeled plastic bags to store the samples. In contrast to the soil samples among the sub-domains, a soil sample of about 4500 cm^3 was taken from the riverbed of the downstream end of the basin. Because of the low depth and slow flow conditions in this area, this sample was assumed to be the accumulation of the sediments transported from the sub-domains located at the upper regions.

In the laboratory procedures, the three samples from each sub-domain were well-mixed into one unique sample per sub-domain, in an attempt to represent the spatial heterogeneity of the soil. Laboratory experiments were conducted to determine the chemical and physical properties of each sample. Firstly, laser diffraction analysis was conducted to obtain the particle size distribution and their settling velocity. As a first step, samples were sieved through a 710 μm mesh and solutions with a sediment concentration of approximately 1500 mg l^{-1} were prepared by using a 2 % sodium hexametaphospate $(NaPO_3)_6$ solution as deflocculant agent. The settling velocity was computed from the time series of particle size distribution[8)].

Secondary, XRF analysis was performed on samples sieved with distilled water through a 63 μm mesh followed by 24 hours of drying at 105 °C and break up of soil flakes by a pestle and mortar. Then samples were placed into a muffle furnace and burned at 750 °C for 1 hour in an effort to oxidize compounds and eliminate the organic matter. A particle size of 63 μm was used for the XRF analysis because we pay attention to the fine sediments, which corresponds to the criteria between silt and sand. For the analysis, samples were displayed inside 8 mm polyvinyl chloride rings and machine-pressed under 12 tons for 1.5 minutes until a coin-shaped specimen with smooth surface was obtained. The XRF measurement was conducted by using wavelength dispersive X-ray fluorescent instrument (XRF; S8 Tiger, Bruker AXS) and the concentration of the specimens were calculated using the fundamental parameter algorithm installed in the instrument.

All the instruments and sample holders used during the analysis were cleaned with ethanol at 99.5 % to avoid the inter-sample contamination.

3. RESULTS AND DISCUSSION

3.1 PARTICLE SIZE DISTRIBUTION AND SETTLING VELOCITY

Two different types of sub-domains were considered in this study: agricultural fields and forests. The former corresponds to sub-domains 1 and 3, while the latter corresponds to sub-domains 2, 4-18. **Fig.2** shows the particle distribution results for representative sampling sites from both types of sub-domains and the downstream end whose number was given as station 0.

These results suggest that there is a difference in the physical features between the two types of sub-domains. As shown in these plots, the sediments from agricultural fields and from the downstream end are mainly composed by particles with a diameter of 10 μm while the ones taken from forest are by 60 μm. This fact states the existence of a relationship between land use and particle size distribution that can be used as a differentiation property in the selection of the main sediment sources[9)].

The settling velocity profiles and the suspend sediment time series confirm this difference. As shown in **Fig.3** by using similar initial suspended sediment concentration for both the agricultural field and forest representative samples

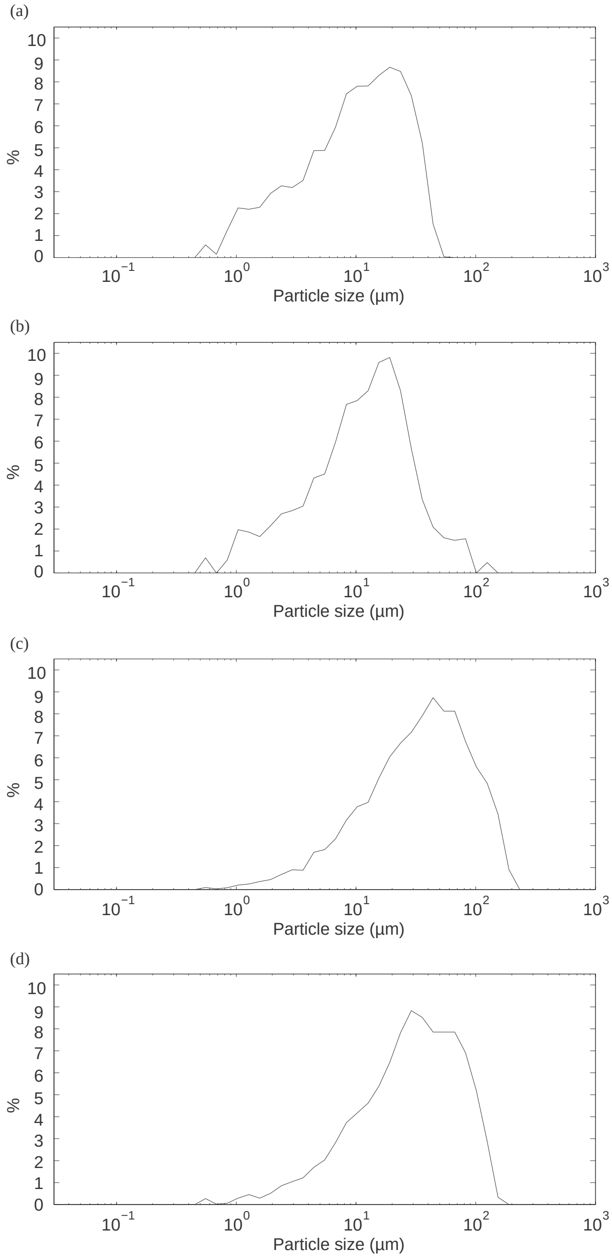

Fig.2 Particle size distributions founded at different domains within the Oromushi River basin. (a) Downstream end domain (station 0), (b) Agricultural field representative domain (station 1), (c) Forest representative domain (station 5), and (d) station 14.

(approximately 2000 mg/L) a greater amount of particles remain suspended after 1 hour of measuring for the agricultural field sample (approximately 1300 mg/L) compared to that from the forest sample (approximately 1000 mg/L).The latter is a consequence of a larger number of small particles with a diameter around 10 μm or less. The plots in the second row show the comparison between the settling velocity profiles obtained from the laboratory tests (lab), Stokes' and Rubey's equations, which demonstrates that the settling velocity obtained from the experiments is much smaller than their theories.

3.2 Chemical composition analysis by XRF

The XRF analysis revealed that the samples were mainly

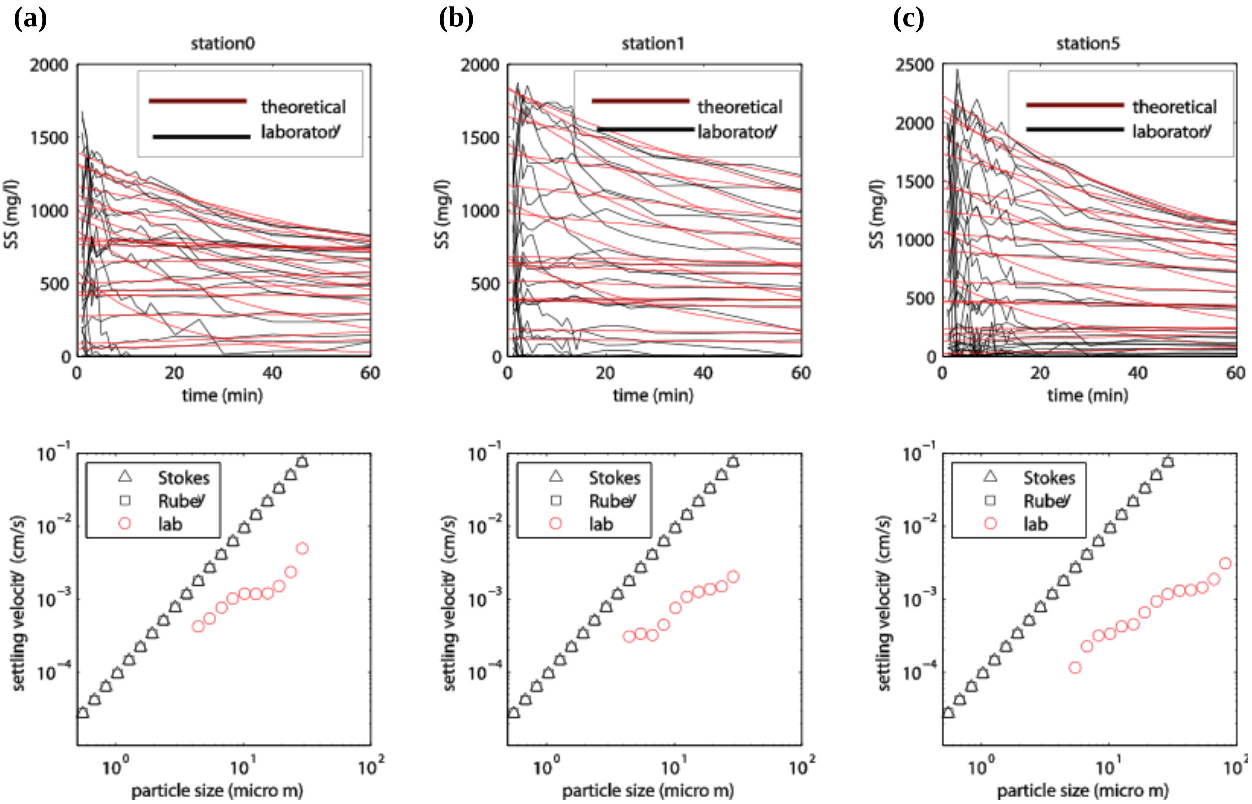

Fig.3 Suspended sediments times series and settling velocity profile and their comparison to the theoretical models of Stokes and Rubey.(a) Downstream end (station 0), (b) Agricultural field representative domain (station 1), (c)Forest representative domain (station 5).

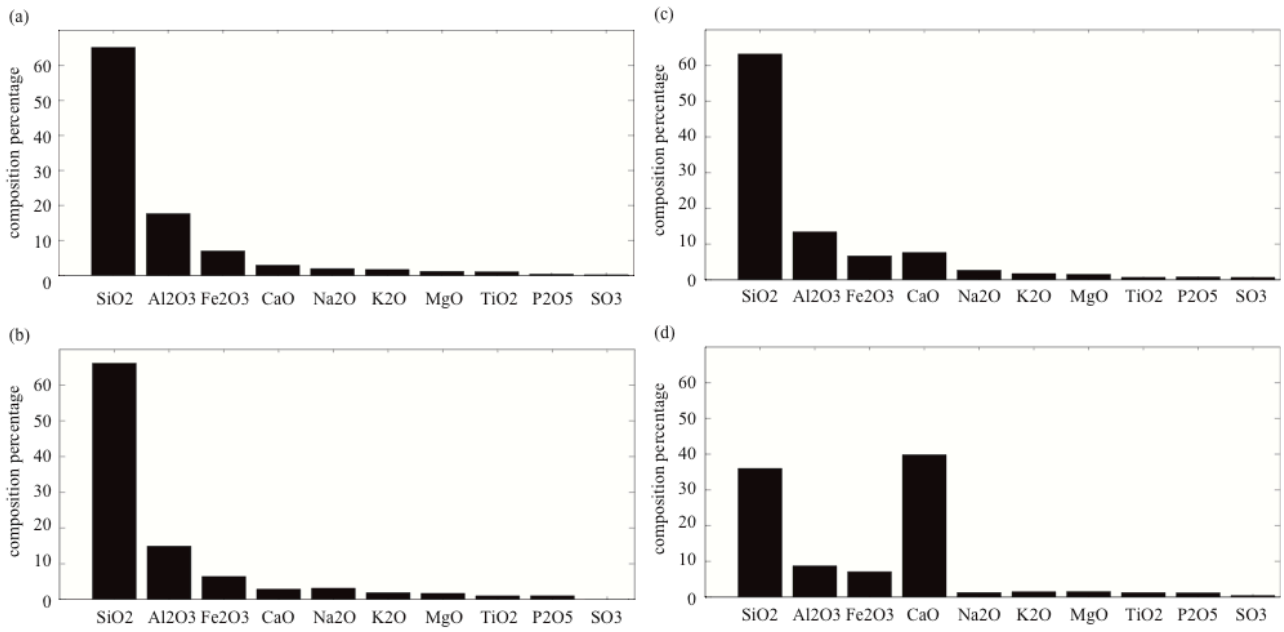

Fig.4 Composition percentages of each compound as (a) Downstream end (station 0), (b) Agricultural field representative domain (station 1), (c) Forest representative domain (station 5), and (d) station 14.

composed by SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, K_2O, MgO, TiO_2 and P_2O_5 and a minority of other compounds in small amounts (**Fig.4**). To confirm the dominant compounds statistically, principal component analysis (PCA) was applied for the soil samples.

Thereafter, the chemical composition difference between the sub-domains and the downstream end was computed with the equation (1):

$$Dn = [(SiO_{2down} - SiO_2 n)^2 + (Al_2O_{3down} - Al_2O_3 n)^2 + ...]^{0.5} \quad (1)$$

where, D*n* is the difference index for each sampled station; *n* is the concentration of the compounds at each station and *down* is the concentration of the compounds at the downstream end area.

Only the compounds select by the PCA were used to evaluate the difference between each domain and the downstream. According to these results (domains 1,2,3,7, and 11 have a greater suspended sediment contribution compared to the rest of the domains, especially domains 14 and 15 which result as the domains with the lowest contribution of sediments. It should be noted that the chemical composition percentages and particle size distributions results were presented for two representative forest-type sub-domains (See

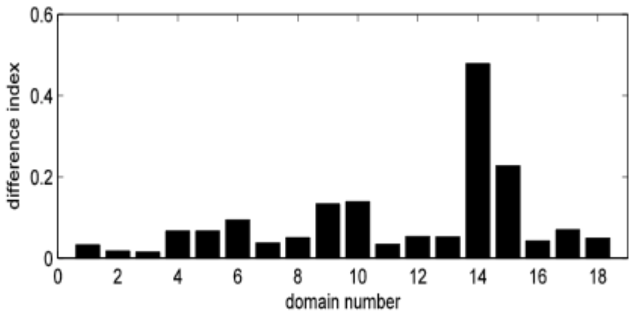

Fig.5 Difference index bar plot calculated for each domain in function of the compounds selected as tracers.

Fig. 2 and **4**). Even though their particle size distribution is very similar, their chemical composition analysis suggests their sediment contribution is completely different as shown in **Fig.5**. This fact states the importance of using particle size distribution and chemical composition analyses simultaneously for the sources identification.

4. CONCLUSIONS

In order to understand the high suspended sediments concentration episodes in the Oromushi River and their provenience a fingerprint-type method based on their chemical composition and a study about their physical features was conducted. The findings from this study suggest that:

1. As founded in previous studies there is a relationship between the land use and the particle size distribution. This fact could be used in the future application of this kind of studies especially in basins with diverse land uses. However, further study is recommended since the reasons for this phenomenon are not completely clarified.
2. Sediments samples were meanly composed by SiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, K_2O, MgO, TiO_2 and P_2O_5 according to the XRF analysis.
3. The difference index (which shows the degree of non-similarity between each domain and the downstream area) shows that domains 1,2,3,7 and 11 have a greater contribution compared to the rest of the domains, especially domains 14 and 15, those by obtaining the highest difference index are considered as domains with low suspended sediment contribution.

It is important to remark that the domains with the lowest contribution (14 and 15) are classified as forest areas and thus the vegetal cover might influence in the sediment generation while domains 1 and 3, are both classified as agricultural fields with poor vegetal cover. On the other hand the particle size distribution for the sediments founded at the downstream end results very similar to the one founded in agricultural fields, supporting the findings obtained from the chemical composition analysis.

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