# A METHOD FOR DETECTING THE SOURCE OF SEDIMENTATION USING MINERAL COMPOSITION IN SENGGURUH BASIN, INDONESIA

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X-ray powder diffraction (XRD) is widely used for geological analysis of sediment samples. In this study a method for detecting sources of sedimentation using mineral composition obtained by the qualitative phase of XRD is proposed. Possible minerals matching resulted from the Hanawalt's search-match method were arranged into binary matrix of mineral composition of each sampling site. Hierarchical cluster analysis was grouped samples into clusters based on mineral similarity and yielded a dendrogram. Using information of sample's environment, the meaning of dendrogram was derived for sediment fingerprinting.

The result showed that sedimentation sources in the Sengguruh reservoir mainly come from 10-30$^{o}$ slope of the Lesti basin and cultivated area downstream of the Brantas origin. Comparing with the field observation and satellite data, a good correlation was obtained.

***Key Words:*** *mineral composition, x-ray diffraction, sediment fingerprint, cluster analysis*

## 1. INTRODUCTION

The Brantas river is located on the East Java province, Indonesia. It flows to Java Sea through Surabaya city which is the second largest city in Indonesia. The Sengguruh reservoir, the most upstream of reservoirs in the Brantas river is facing severe sedimentation problem and threatening lifetime of the Sutami reservoir which is the most important reservoir in the Brantas river.

In response of them, there is an urgent need to improve the catchment such as erosion control and management strategies. However, such strategies are hampered by lack of understanding of the linkages between the sources of erosion and the deposited sediment. A detail of sedimentary sequence of the Sengguruh reservoir has not been reported yet, therefore the fingerprinting of sedimentation becomes the most important step to evaluate the existing countermeasures and to design an appropriate one.

Though the sediment fingerprinting is generally well done with several techniques such as isotope and radionuclide techniques[1)], the examination of $^{137}$Cs and $^{219}$Pb content in samples from the Sengguruh basin indicated that the similar study seems not applicable due to under lower limit fallout[2)]. On the other hand, the global fallout distribution of $^{137}$Cs describes that utilization of radio nuclides tracer is mostly well-done in northern hemisphere rather than in southern hemisphere due to frequency nuclear weapon test in northern part[3)]. There are also few studies utilizing radio nuclides as sediment tracer in southern hemisphere. Moreover, finding ways to assess sediment origin instead of using radio nuclides is still important as an aid for catchment management in this basin.

Sediments have been composed of many minerals and non minerals (amorphous) discharged by natural origin. A mineral is an element or chemical compound that is normally crystalline and that has been formed as a result of geological processes. They are naturally-occurring inorganic substances with a definite and predictable chemical composition and physical properties[4)]. The properties of mineral composition of sediment deposited in reservoir reflected morphological processes in the basin.

Powder X-ray Diffraction (XRD) is one of the techniques used to examine the unknown solids. The possible minerals composed in the specimen were identified by comparing with the Powder Diffraction Patterns (PDFs) database of known minerals, aided by PC-based automation that matches unknown spectrum to the catalog spectra[5]. A commercial PDFs database (174,699 minerals) is provided by International Centre for Diffraction Data (ICDD)[6]. A free database is also available (4,000~ 8,000 minerals) and sufficient for pre-study purpose[7].

Sediment cores collected from reservoir and susceptible area to surface erosion in basin were powdered and examined by XRD. The binary matrix of minerals representative in each specimen was set up. A hierarchical cluster analysis was used to group the samples based on their similarity of the mineral composition. Sediment fingerprinting was derived from the meaning of each cluster by utilizing the information of sample's environment.

On the basis of the results of qualitative phase analysis of XRD, the study described mineral composition of sediments and illustrated the temporal changes of sources sediment deposited in the Sengguruh reservoir.

## 2. MATERIALS AND METHODS

In **Fig.1**, the geology map of the area of study shows that the main tributaries (the Lesti river and the Brantas river) entering into reservoir are situated in different geological condition. In the Lesti sub-basin, it was dominated by older Holocene volcanic rock, the time period from 10,000 years ago to the present[8], and young Holocene volcanic rock was dominated in Brantas origin. Those differences of the geological condition support applicability of mineral as tracer for the sediment fingerprinting.

The eastern part of basin is situated nearby the most active volcano, Mt. Semeru with strong strombolian activity taking place at frequent intervals of 5-10 minutes, producing billowing ash clouds of 1-2 km height and showering much of the summit cone with fresh gray ash[9], as seen in **Fig. 2**.

Within such conditions, the Semeru volcanic ash (SMR) was considered as one of the sedimentation sources. The other sources were collected from the vulnerable areas to erosion, with DK-1621 sampler, up to 30 cm in depth. In the Brantas origin sub-basin, the potential sources were the cultivation at 30$^{o}$ in the upstream (C30U), the Brantas spring area (BORG), the cultivation at 30$^{o}$ in the downstream (C30D), the bedload at Batu checkdam (BLD) and the river bank in Kendalpayak (KDP). In the Lesti sub-basin, the sources were the cultivation at 40$^{o}$ (C40), 30$^{o}$ (C30), 25$^{o}$ (C25), 10$^{o}$ (C10), the river banks (BK1, BK2), the sand mining (SND), and the bedload at Tawangrejeni (TWR). There were 3-4 samples each point and mixed together to incorporate the spatial variation. Locations of sampling site were as seen in **Fig.1**.

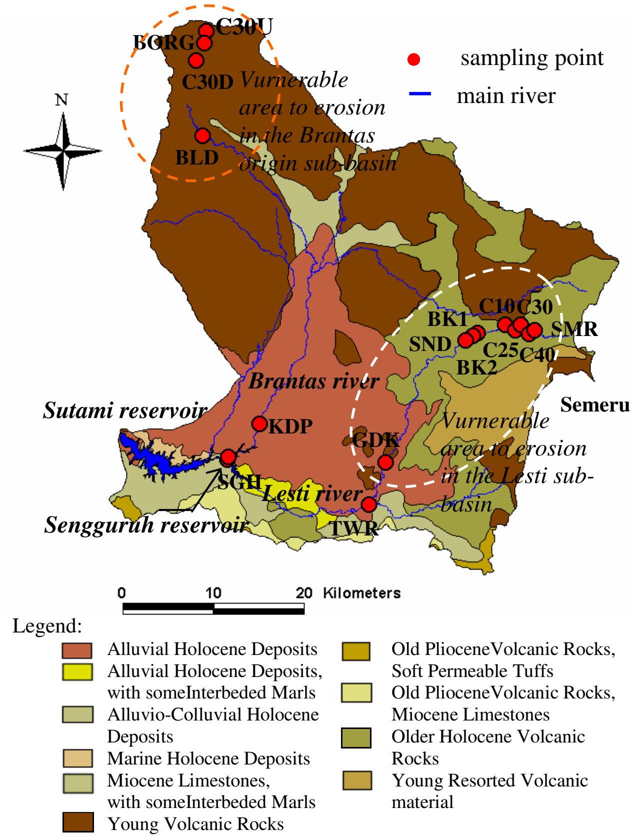



**Fig.1** Geology map and location of sampling points.

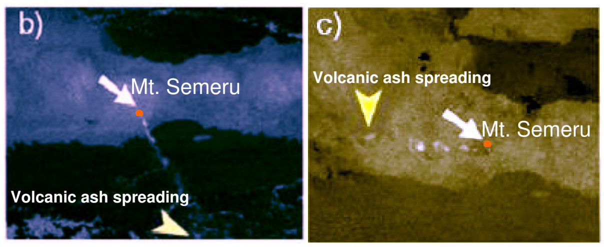



**Fig.2** Spreading of the Mt. Semeru volcanic ash varies with wind direction and weather condition, modified from *Davey et.al*[10].

In the Sengguruh reservoir, 5 meter depth of core samples (SGH) were taken with core auger sampler[11] in the Brantas reach and the Lesti reach. All of the samples were dried then powdered using mortar and pestle for less than 2μm of size to provide XRD analysis.

### (1) Analytical Method

An X-ray diffractrometer of Rigaku Geigerflex (Cu-Kα, tube voltage 25kV, tube current 20mA, equipped with RINT2000) was used to trace mineral composition of the samples, as shown in **Fig. 3**. This technique takes the bulk sample and places the powdered specimen of the sample in the holder then being illuminated by the x-rays for 5 – 60° of $2\theta$-range. When the x-ray beam hit the sample and diffracted, the distances between the plane of atoms mat constitute the sample by applying the Bragg's Law, $n\lambda=2d\sin\theta$, where $n$ is the order of diffraction; $\lambda$, wavelength of incident x-ray beam; $d$, distances between adjacent atoms ($d$-spacing), and $\theta$ the angle of incidence of x-ray beam. The characteristic of $d$-spacing generated in a typical x-ray scan provided fingerprint of the mineral present in the sample.

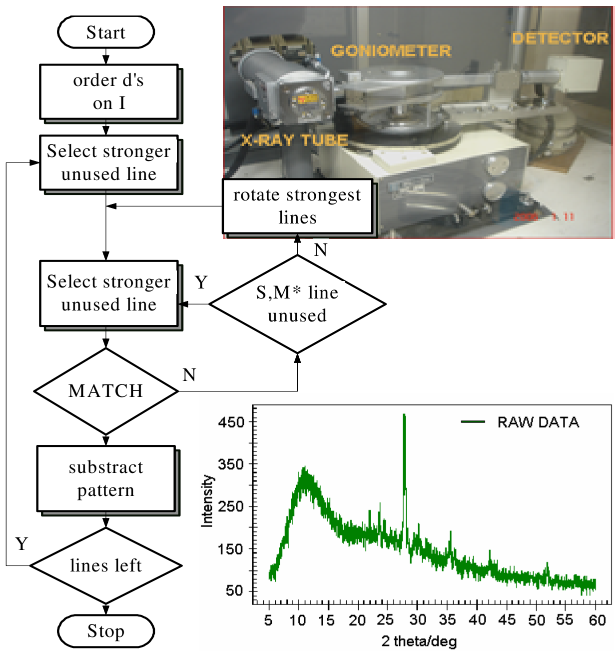



**Fig.3** The analytical method and the qualitative phases analysis of x-ray powder diffraction.

After the smoothing, removing background, K$\alpha$-2 and peak finding[12], the qualitative phase analysis was done. The 3-most intense $d$-value was used to do search-match of known minerals database by the Hanawalt's method[13].

### (2) Statistical Analysis

To examine the similarity of mineral composition, the hierarchical agglomerative cluster analysis for the binary matrix was used[14]. Cluster Analysis (CA) is an unsupervised pattern recognition technique underlying behavior of a data set without making prior assumptions about the data. Since the data was re-arranged in binary matrix, measurement of similarity or distance was measured by size difference as representative of index of asymmetry[15]. The meaning of dendrogram resulted from clustering processes were interpreted with considering the environmental condition of the sample sites and other field data. Then, the fingerprinting of erosion-sedimentation was derived.

## 3. RESULTS AND DISCUSSION

### (1) Major minerals composition

A number of possible mineral matches resulted from the Hanawalt's method with 2.5 % in error was shown in **Table 1** and **Table 2,** for the sources and the deposited sediments respectively. The alteration of depositional processes in reservoir was indicated by the variation number of minerals in each layer of the depth of core sample, as shown in **Table 2**.

**Table 1** Number of possible minerals matches for the sediment sources.

| Sub-basin | Site | Approx. distance to reservoir (km) | Num. of mineral | |
|---|---|---|---|---|
| | | | composed the sample | similar to the reservoir |
| Lesti | SMR | 49 | 13 | 4 |
| | C40 | 49 | 14 | 4 |
| | C30 | 47 | 9 | 4 |
| | C25 | 43 | 8 | 4 |
| | C10 | 43 | 8 | 4 |
| | BK1 | 43 | 14 | 4 |
| | BK2 | 43 | 27 | 4 |
| | SND | 42 | 14 | 4 |
| | GDK | 23 | 38 | 4 |
| | TWR | 18 | 7 | 4 |
| Brantas origin | C30U | 56 | 7 | 5 |
| | BORG | 55 | 15 | 3 |
| | C30D | 53 | 6 | 5 |
| | BLD | 44 | 7 | 5 |
| | KDP | 6 | 6 | 4 |

**Table 2** Number of possible minerals matches for deposited sediment in the Sengguruh reservoir.

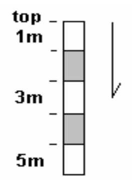
| River reach | Layer depth (m) | Num. of mineral | Remarks |
|---|---|---|---|
| The Lesti river | 1 | 6 |   |
| | 2 | 2 | |
| | 3 | 11 | |
| | 4 | 23 | |
| | 5 | 5 | |
| The Brantas river | 1 | 12 | |
| | 2 | 23 | |
| | 3 | 7 | |
| | 4 | 8 | |
| | 5 | 8 | |

**Fig.4** figured a simplification of the distribution of the major minerals as tabulated in **Table 1** and 1-m layer of minerals in reservoir as shown in **Table 2.** The unscaled background map of the sub-basins was used to draw the sampling site location. The numbers of detected minerals corresponded with the physical processes in the basin. The BORG (the

Brantas spring) and BLD (Batu checkdam) were the deposited areas in the Brantas origin sub-basin as well as in the Lesti sub-basin were C40, BK1 and BK2 (river banks), GDK (Gedokwetan checkdam). The composed minerals of the samples from those area were higher than others because of the sediment from the upstream were temporary deposited before partially released to the downstream. The slope failure in the steep slope (C40) was not directly delivered to the downstream part also. The accumulation of mineral at each process was resulted. By comparing with the minerals of the deposited sediment in the reservoir, the similar mineral to the reservoir's was identified. As an example in C30U, there were 7 minerals in the sample and 5 among of them were similar to the reservoir's.

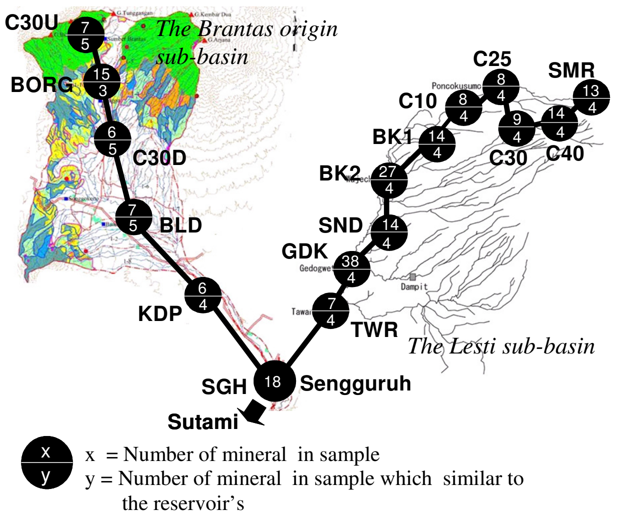



**Fig.4** Distribution of major minerals in the Sengguruh basin.

## (2) Samples grouping and temporal variation

The identified minerals were re-arranged into binary matrix of representative mineral in each site, such as **Table 3**. The common minerals found in all of the samples were Petitjeanite, Scorzalite, Smrkovecite, Sanidine Scorzalite, Sanidine and Preisingerite.

**Table 3**. Portion of the binary matrix of representative minerals of sediment sources in the Lesti reach.

| MINERAL | SGH | TWR | GDK | SND | C10 | SMR |
|---|---|---|---|---|---|---|
| Albite | 0 | 0 | 0 | 0 | 1 | 0 |
| Labradorite | 0 | 0 | 1 | 0 | 1 | 0 |
| Petitjeanite | 1 | 1 | 1 | 1 | 1 | 1 |
| Anorthite | 0 | 0 | 1 | 1 | 1 | 1 |

*Note : 0 = absent , 1 = present*

The results of the clustering analysis were drawn as dendrograms in **Fig. 5** and **Fig. 6**. This procedure attempted to identify relatively homogeneous groups of cases by measuring the distance or similarity. The horizontal axis was the distance (rescaled into 0-25) obtained by size difference method. Cases with the lowest distance (or highest similarity) were merged into a cluster. The vertical axis indicated label and case number of sample sites (eq. BLD was 4, C30U was 1, etc).

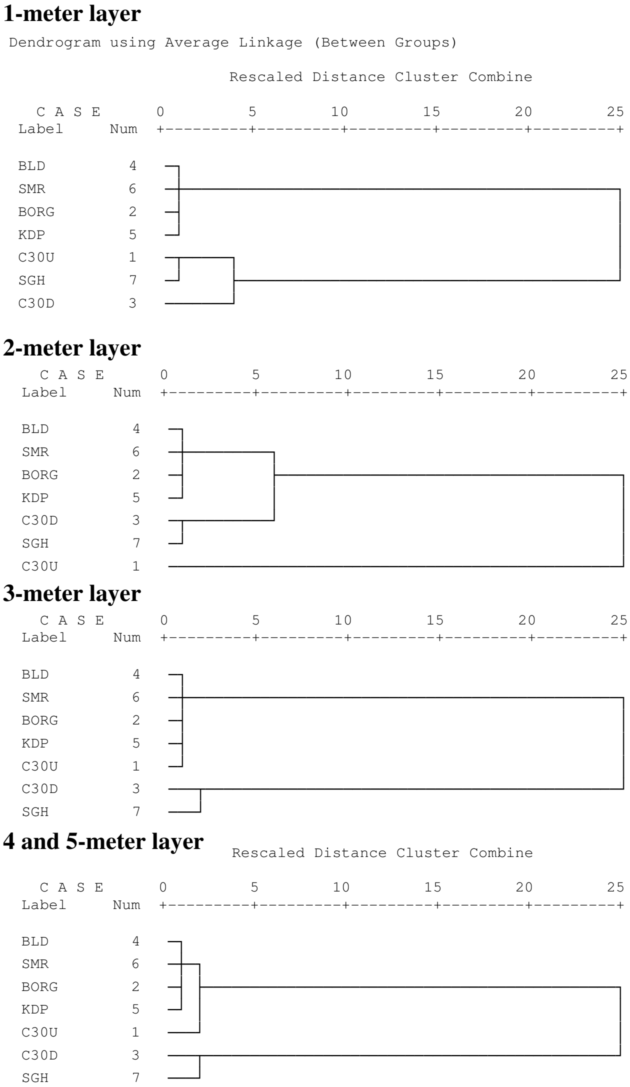



**Fig.5** Dendrograms showing clustering the sources of sediment and the deposited material in the Brantas river reach of the Sengguruh reservoir.

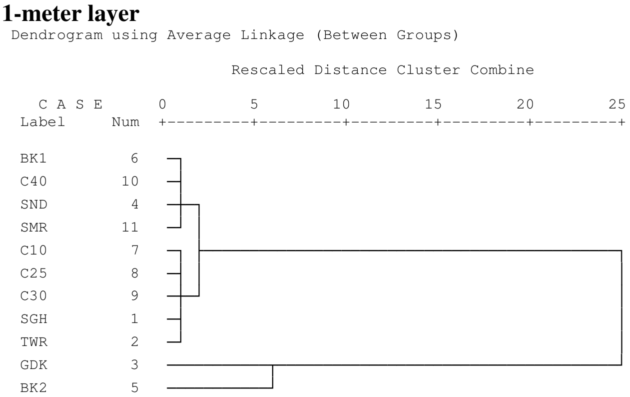
The meaning of the dendrograms for the sediment deposited in the Brantas river reach was interpreted with the following descriptions. At 1-m layer depth of reservoir sediment, the sources mostly came from cultivated area of 30$^{o}$ at the headwater of the Brantas origin (C30U). Currently, the cultivation of 30$^{o}$ in the downstream of Brantas origin gave less contribution of sediment to the downstream.

At 2-m layer depth, it showed that the cultivation of 30$^{o}$ (C30U) at the upstream of the Brantas origin became outlier. It mean during the period in the past there was no high rate of surface erosion or deforestation, only the cultivation of 30$^{o}$

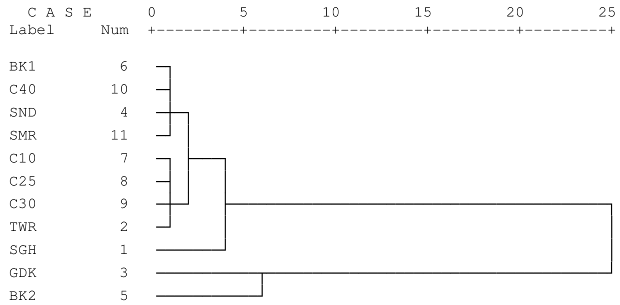
downstream of the Brantas origin (C30D) played as main sources of reservoir sedimentation. Meanwhile, in the 3-m, 4-m and 5-m layer depth, they showed that cultivation of 30$^{o}$ downstream of the Brantas origin were the main sources of the reservoir sedimentation. Probably there were no significant landuse changes or deforestation occurred.

Likewise the Brantas sub-basin, the same manner for the Lesti sub-basin was done.

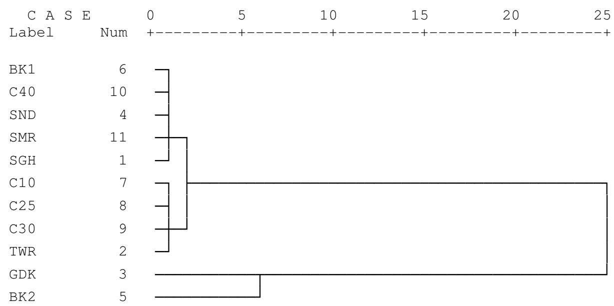
**1-meter layer**



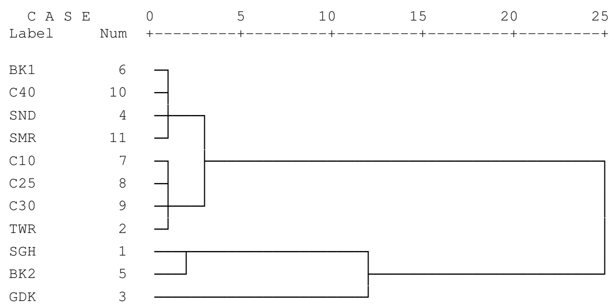

**2-meter layer**




**3-meter layer**




**4-meter layer**




**5-meter layer**

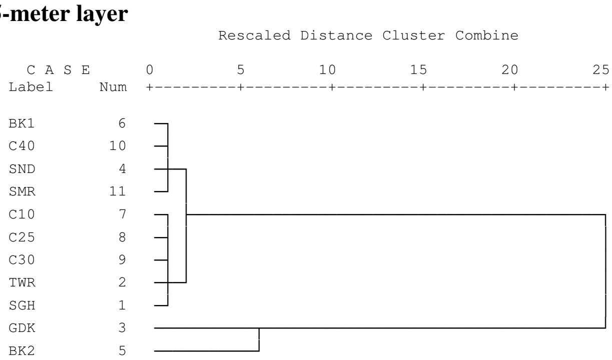



**Fig.6** Dendrograms showing clustering the sources of sediment and the deposited material in the Lesti river reach of the Sengguruh reservoir.

Compare with the deposited sediment in reservoir at 1-m depth in the Lesti river reach, the sources/area of SMR, C40, BK1, and SND became one group. It corresponded to areas with no high rate of surface erosion occurred as indicated by the similarity of minerals composition to the Semeru volcanic ash. Since the sources/area of C10, C25, C30, TWR and SGH became members of the other group, it associated with the deposition areas and the sources of the reservoir sedimentation. The sources/area of BK2 and GDK became another exclusive group which corresponded with locations of the erosion materials which temporary trapped and partially released to downstream.

At 2 meter layer depth of the deposited sediment, groups were almost similar to 1-m layer depth, except SGH became far among others. Probably during this certain period, there was no sediment sources came from the upstream and mainly came from the local bank erosion at the reservoir vicinity.

Results from 3-m layer depth showed that the sedimentation in reservoir mainly came from the high slope cultivation / landslide or the excessive sand mining as indicated by group of SMR, C40, BK1, SND and SGH. On the other hand, C10, C25, C30 and TWR gave less contribution to the reservoir sedimentation.

Furthermore, the river banks became the major sources of sedimentation in reservoir at 4-m layer depth formation. During this period, there were almost no high rate of erosion occurred in the other sources. Likely, the processes at 5-m layer also occurred in 1-m layer.

### (3) Dynamic of sedimentation processes

By utilizing the results from the previous researchers[5),10),16),17)], the dynamic of erosion and the reservoir sedimentation processes were obtained. In the Lesti sub-basin, the erosion mainly occurred in the 10 – 30$^{o}$ of the cultivated area. Some landslides occurred in the steeper slope (>40$^{o}$). In the Brantas origin sub-basin, it was strongly affected by the downstream cultivation. Currently, it was modified by the upstream cultivation. Probably it was due to the landuse changes as indicated in the satellite imageries analysis by Nakagawa e*t.al*[16], as shown in **Fig.7**.

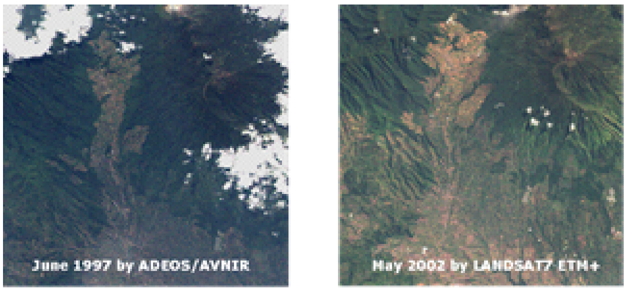



**Fig.7** Landuse changes in the Brantas origin sub-basin from satellite imagery analysis, Nakagawa et.al[16].

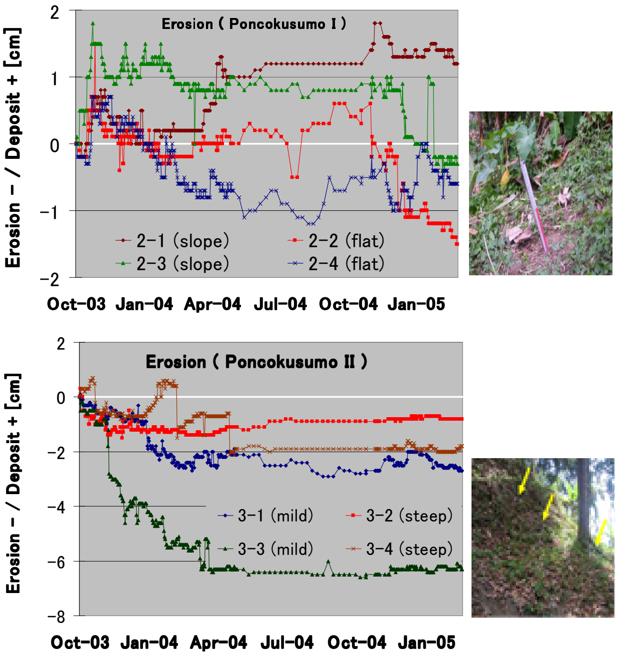



**Fig.8** Measuring erosion in the Lesti sub-basin, Oishi *et.al*[17].

**Fig.8** showed the field observation during 2003-2005 by Oishi *et.al*[17] in the Lesti sub-basin. In the Poncokusumo I, the severe erosion was occurred in the flat areas rather than in the slope area. In the Poncokusumo II, It happened in the mild slope rather than steep slope. Probably, the landslide also occurred in the steep slope (3-4 steep). They supported and verified the present results of study.

## 4. CONCLUSION

Detecting the contribution of sediment sources based on the mineral composition of the sediments by the qualitative phases analysis of XRD was successfully done. The hierarchical cluster analysis was used to examine the similarity of mineral composition to the deposited sediment in reservoir. The identification of the source's contribution involved various physical processes in the basin (erosion, landslide, deposition, etc).

Since the sediment is consisting of mineral and non-mineral phases, to identify its proportion are needed the quantitative phase analysis[18]. It is useful to determine the correlation between the amount of sediment deposits and their composed minerals. This further works on the quantitative phase analysis is being done.

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