4. INTEGRATED ASSESSMENT OF RESERVOIR SEDIMENTATION IN UPPER BRANTAS BASIN, INDONESIA

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Abstract: Storage loss is one of many types of sedimentation problems that can affect reservoirs. As reservoirs age and sediment continue to accumulate, sediment-related problems will increase in severity. At any dam or reservoir where sustainable long-term use is to be achieved, it will be necessary to manage sediments as well as water such as erosion control and management strategies. However, such strategies are hampered by lack of understanding of the linkages between sources erosion and downstream deposited sediment. Therefore, an integrated assessment is important for targeting the available resources.

In this study, the proposed integrated methods to asses the reservoir sediment was done. First, the quantitative quantity analysis will give sediment yield and estimate the susceptible area to erosion. Then, it followed by the qualitative analysis of x-ray powder diffraction on sediment samples in order to get mineral compositions. Using the hierarchical cluster analysis, the binary matrix of mineral composition was analyzed to get sediment fingerprinting. Results of Upper Brantas basin show good relationship with field observation data and remote sensing data.

Key words **:** *reservoir sedimentation, USLE, XRD, mineralogy, clustering, sediment fingerprint*

1. INTRODUCTION

Most natural river reaches are approximately balanced with respect to sediment inflow and outflow. Dam construction dramatically alters this balance, creating an impounded river reach characterized by extremely low flow velocities and efficient sediment trapping.

Storage loss is one of many types of sedimentation problems that can affect reservoirs. Operation of storage reservoirs is severely impacted by time half the volume has been deposited, but severe sediment-related problems can appear when only a small percentage of the storage capacity has been lost. As reservoirs age and sediment continue to accumulate, sediment-related problems will increase in severity and more sites will be affected[1)].

At any dam or reservoir where sustainable long-term use is to be achieved, it will be necessary to manage sediments as well as water. However, such strategies are hampered by lack of understanding of the linkages between sources erosion and downstream deposited sediment. Therefore, an integrated assessment is important for targeting the available resources.

In the upper-part of Brantas river basin, Sengguruh and Sutami reservoirs, the most important of facilities to enhance water in dry season and flood control in rain season, are located[2)]. The total catchment area is about 2000 km^2. The area is divided into 5 sub-basins based on the main tributaries (Brantas Origin or Sumber Brantas, Amprong, Bango, Lesti and Metro), as shown in Fig.1.

The Sengguruh reservoir serves as sediment controller for Sutami reservoir. Recently the effective storage of Sengguruh reservoir has declined much and threatening Sutami reservoir at future. Currently, some

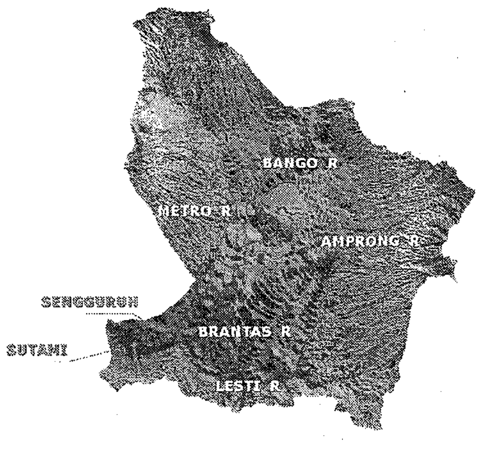

Figure.1 The Upper Brantas Basin

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researchers are interested doing research on it[3,4].

2. OBJECTIVES OF STUDY

The main objectives of this study are:

To predict the amount of potential erosion and sediment yields.

To fingerprint the reservoir sedimentation in the basin.

3. METHODOLOGY

In order to establish the appropriate countermeasures, the origin of sediment deposited in reservoir is needed to be identified and inventoried. The integrated assessment of reservoir sedimentation is done by quantitative analysis of sediment yields to predict the sediment budget of basin area, followed by the qualitative assessment of sediment properties from vulnerable areas to find the most contribute sub-basin and locations of sediment origin. The statistical approach is used to date the erosion processes and to fingerprint the sediment sources.

Quantitative Analysis

The most widely used method fro predicting soil loss, the Universal Soil Loss Equation (USLE) was considered to predict the sediment yields of basin area. All of parameters are easily determined using GIS. The general form of the USLE is given as follows[5]:

$$A = R\,K\,LS\,CP \qquad (1)$$

where

A is the average-annual soil loss (ton ha^{-1} yr^{-1})

K is the soil erodibility factor (ton ha^{-1} yr^{-1} per unit *R*).

K-value for typical soils in Java island is around 0.10-0.30.

LS is slope length and steepness factor.

CP is vegetation cover-practice factor.

Since USLE does not include the depositional processes, Sediment Delivery Ratio (*SDR*) has been coupled to calculate sediment in the outlet.

Qualitative Analysis

Qualitative analysis of physical properties, such as grain size distribution and mineral composition of sediment is important as far as to identify from where part of the basin or the sources of material is come from. Identification of the minerals can ordinarily be made by using X-ray diffraction and applying Bragg equation for basic calculations[6]:

$$n\lambda = 2d\sin\theta \qquad (2)$$

where n is an integer, λ is the wavelength of the X-ray, d is the interplanar spacing in the crystalline of specific material and θ is the diffraction angle.

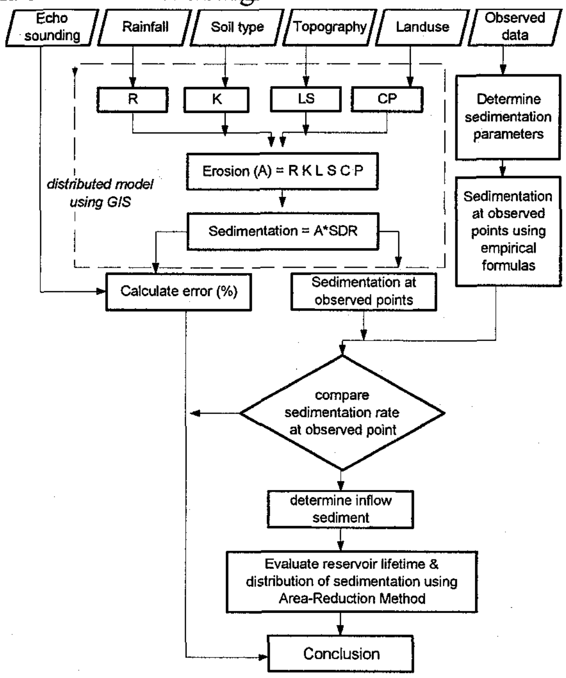

Figure.2 Quantitative analysis of reservoir sedimentation

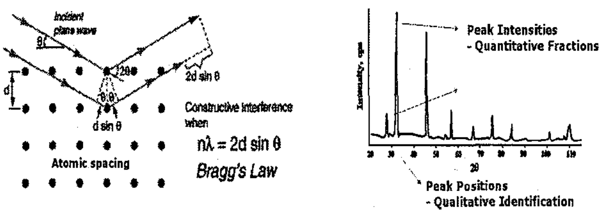

Figure.3 Mineral decomposition by X-ray diffraction

Sediment Fingerprint

Underlying principle that potential sediment sources can be characterized using a number of diagnostic physical or chemical properties, such as[7] :

Radionuclide (137Cs, 210Pb)

Cosmogenic Isotopes (10Be, 7Be)

Stable Isotopes (C-13,N-15)

Total C,N,P

Mineralogy

Magnetic Susceptibility

In this study, the mineralogy will be used to fingerprint sediment, as well as the difficulties of using chemical tracers in the basin area, as shown in Fig.4.

The mineral composition of sources is classified into groups using the cluster analysis to get meaningful information of their characteristics and fingerprint the sediment origin, as shown in Fig.5.

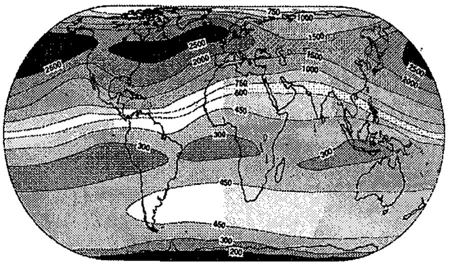

Figure. 4 Global distribution of **137Cs** Fallout rate

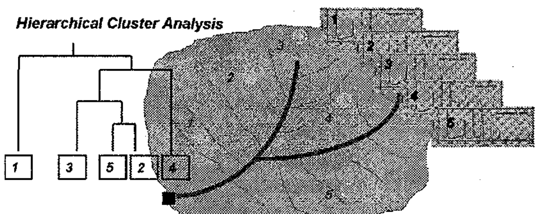

Figure.5 Hierarchical Cluster Analysis

4. RESULTS AND DISCUSSIONS

The annual sedimentation in the Sengguruh reservoir was estimated around 2,148,000 ton, and Sutami reservoir was 1,707,600 ton. Compare to observed data, the percentages error in volume of sedimentation were given as 9.5% and 13.6% respectively[8,9]. As results, it was found that the Brantas origin sub-basin and Lesti sub-basin gave high contribution, as shown in Fig.6.

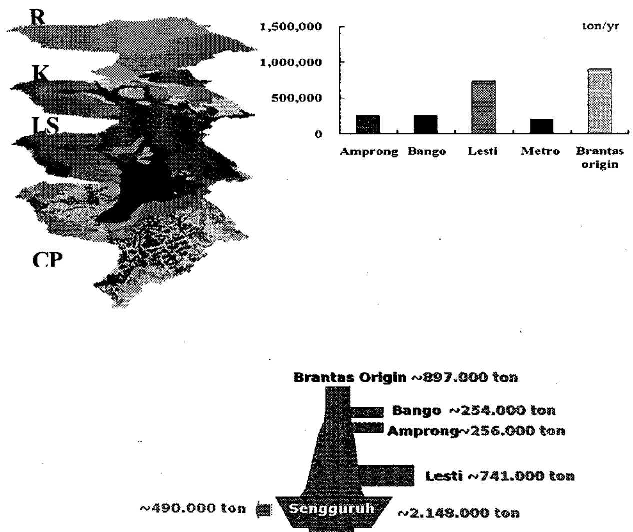

Figure.6 Quantitative prediction of sediment yield by USLE and estimation of sediment budget in Upper Brantas basin

The sediment distributions in the reservoirs are estimated using Area-Reduction Method that recognizes the sediment distribution in reservoirs[10]. Results shows that their effective storages were estimated will be full of sediment in 2.78 years for Sengguruh reservoir and 147.6 years for Sutami reservoir in case of no countermeasures done, as shown in Fig.7.

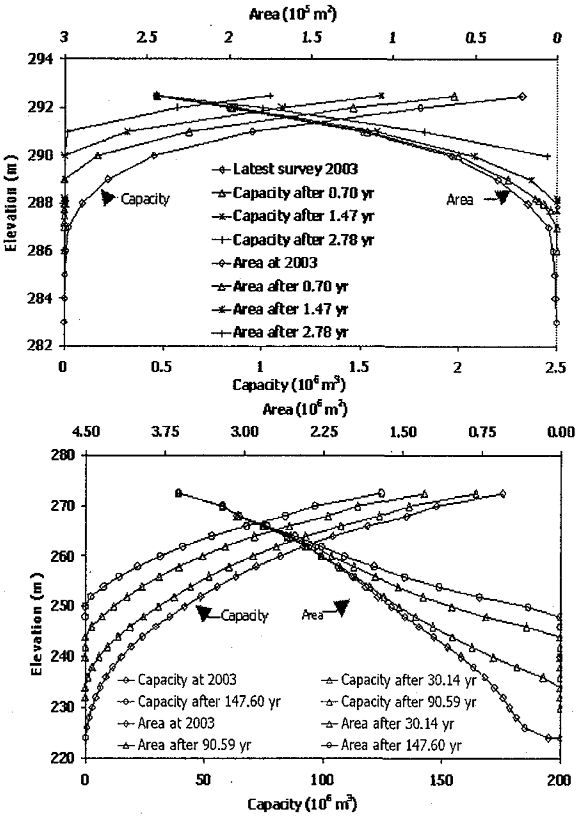

Figure.7 Estimated distribution of sediment in Sengguruh (up) and Sutami (down) reservoirs

Following with qualitative analysis of sediment sources and deposited, it was found that in Sengguruh reservoir, Brantas origin sub-basin contributed higher percentage of silt-clay particle than Lesti sub-basin. It is indicated that higher rate of surface erosion was occurred, as well as quantitative results. Moreover, sediment distribution of Lesti sub-basin contained more coarse materials, Fig.8.

Basically, sediment material was trapped in Sengguruh reservoir before it was released to Sutami reservoir as suspended load. Dempok is situated just downstream confluence of Brantas river and Metro river, Fig.9. Sediment in Dempok shows higher percentage of sand particle and has similar distribution with Metro sub-basin. Since there is no inflow other than Metro river, it indicates increasing contribution of sedimentation from Metro sub-basin. This is useful finding to evaluate the existing reservoir sedimentation countermeasures.

The major clay mineral of Sengguruh reservoir were Feldspar, Carbonate (Calcite), Kaolinite, Mica, Chlorate, Montmorillonite, Illite and Quartz. Feldspar almost dominantly came from Lesti reach and Carbonate (Calcite) from Brantas reach.

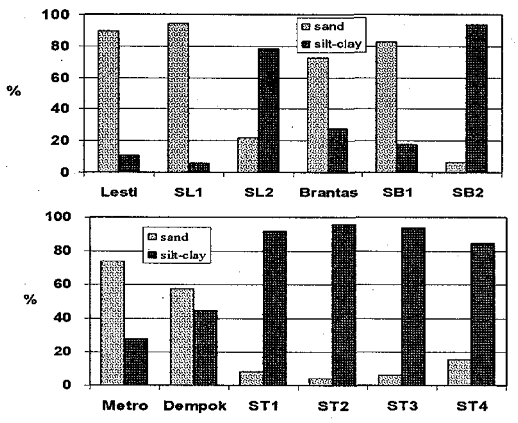

Figure.8 Grainsize distribution of sediment

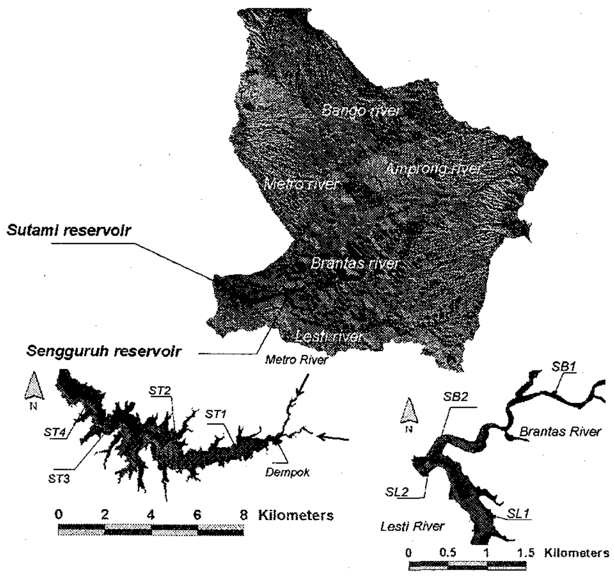

Figure.9 Sampling points of sources and deposited sediments

In Sutami reservoir, it was dominated by Feldspar, Chlorite and Montmorillonite at the reservoir entrance and Feldspar, Mica and Chlorite at the main pool.

The abundance of Feldspar in Sengguruh reservoir is associated with sand mining activities both of Brantas origin and Lesti sub-basins, because feldspar contains more silicate and most affected by sand occurrence.

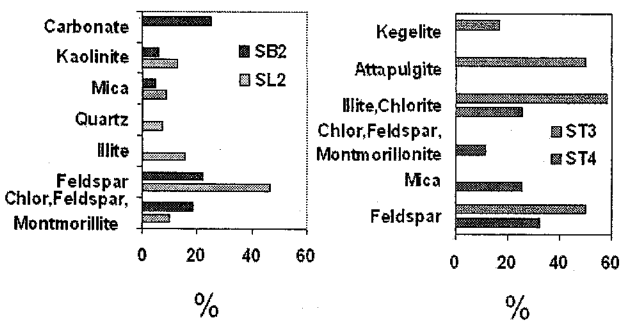

Figure.10 Major mineral composition of Sengguruh and Sutami reservoirs

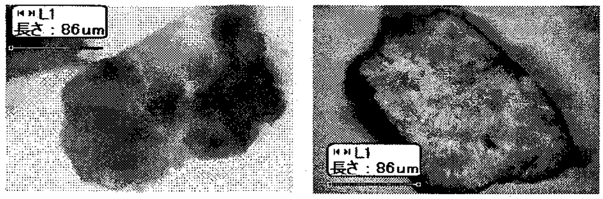

Figure.11 Properties of sediment particles under optical reflected microscope

Table 1. Portion of binary matrix of representative minerals of sediment sources by x-ray powder diffraction

Mineral Name	A	B	C	D	E	F	G	H	I	J	K
Maghemite	0	1	0	0	1	0	0	0	0	0	0
Belyankinite	0	1	0	0	0	0	1	0	0	0	1
Manganbelyankinite	0	1	0	0	0	1	0	0	0	0	0
Ordonezite	1	0	0	1	0	0	0	0	0	1	0
Ungarettiite	0	0	0	0	0	0	0	1	1	0	0
Furutobeite	0	1	0	0	1	0	0	0	0	0	0
Serendibite	0	1	0	0	0	0	1	0	0	0	0

0 = absent *1 = present*

A = Sengguruh reservoir B = Tawangrejeni C = Gedokwetan
D = Sandmining E = River Bank-2 F = River Bank-1
G = Cultivated 10⁰ H = Cultivated 25⁰ I = Cultivated 30⁰
J = Cultivated 40⁰ K = Semeru Volcanic Ash

The x-ray powder diffraction gave minerals contents, then re-arranged as binary matrix of mineral representative as Table 1.

The hierarchical clustering method of binary matrix data is used to assemble the sources based on their minerals similarity. It yielded a dendogram, Fig.12, grouping them into 2-3 statistically significant clusters. As there was ample of information of sources, the meaning of each cluster was interpreted.

For examples, in the Fig. 12, the cluster no.1 (BK1,C40,SND,SMR) corresponds to sources of sediment which relatively higher similarity with volcanic ash minerals and/or probably no high rate of surface erosion occurred as erosion surface will remove the deposition of volcanic ash from top soil. In cluster no.2, three sediment sources (C10,C25,C30) correspond to sources having high similarity of minerals content with sediment deposited in reservoir (SGH) and/or higher erosion rate occurred as result of less/no similarity with volcanic ash. Moreover, cluster no.3 (GDK, BK2) associated with sources of trapped sediment and released partially downstream, while GDK is check dam location and BK2 is riverbank at downstream sand mining activities. While other samples were done with same manners, the fingerprint of sediment sources is possible to be obtained. Also, the dating of sediment could be detected on each sub-basin.

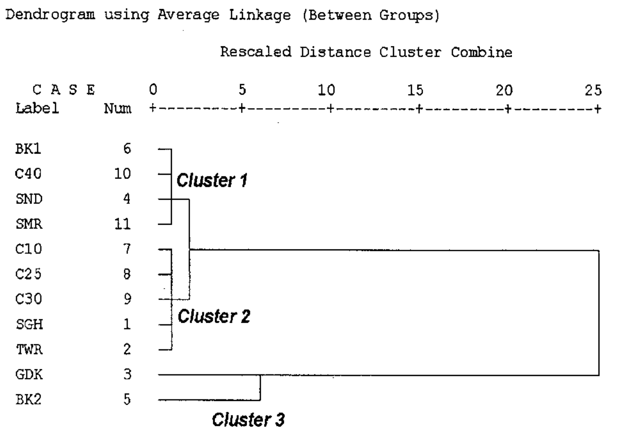

Figure.12 Portion of dendograms showing clustering sources sediment according to mineral composition

In Lesti sub-basin, the erosion has been occurred in the 25 – 30° of cultivated area as indicated as lack of similarity of volcanic minerals due to washed out by surface runoff and found deposited in flat area (river bank -1 and check dam). Some landslides probably occurred in the higher slope (>40°). At the checkdam and riverbanks some of sediment was trapped while some others were released to downstream, as indicated of Tawangrejeni minerals composition. Finally, those materials will deposit in Sengguruh reservoir, Fig.13.

In Brantas Origin sub-basin, in the past sediment in Sengguruh reservoir was strongly affected by downstream cultivation. Recent land use changes and/or deforestation at upper area of Brantas origin have been changed the reservoir sediment composition.

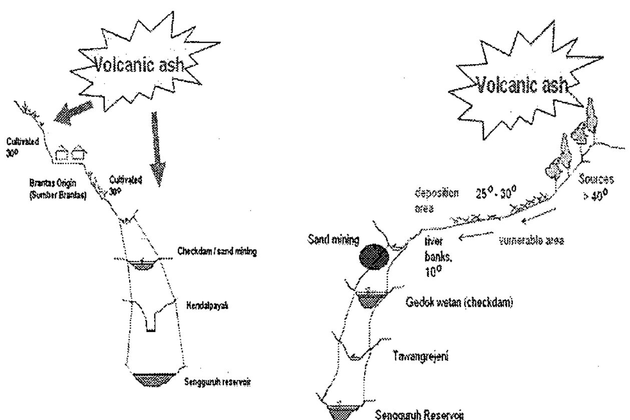

Figure.13 Illustration of erosion-sedimentation processes in Sengguruh reservoir (left figure is Brantas origin, right figure is Lesti sub-basin)

Obviously seen, the erosion material from upstream cultivated area was deposited nearby the Brantas spring first until enough flash flood delivered it to downstream area.

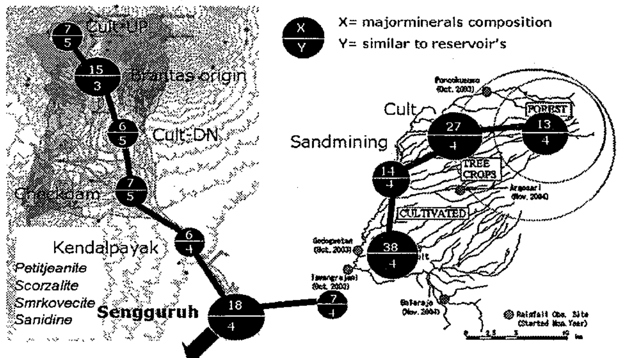

Figure.14 Major mineral distribution of sediment sources in Sengguruh reservoir

As the analysis of satellite imageries by Sayama et.al[3], It shows no severe expansion of cultivation land in the in Lesti basin during 1997–2002. However, in Brantas origin sub-basin, some deforestation in headwater was found. Thus, these findings also supported the sediment fingerprints from mineralogy analysis.

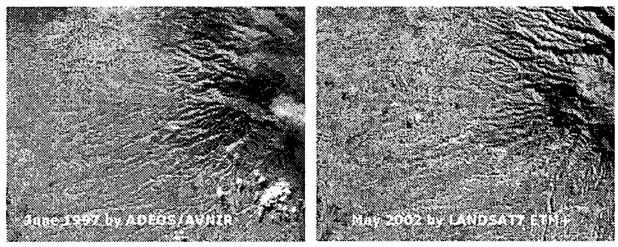

Figure.15 Landuse changes in Lesti sub-basin from satellite imagery analysis

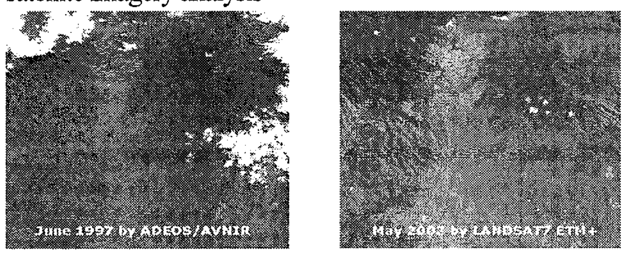

Figure.16 Landuse changes in Brantas origin sub-basin from satellite imagery analysis

The field observation with erosion gauges during 2003-2005, Oishi et.al[11] was used to verify the results of sediment fingerprint by mineralogy analysis. Fig.17 shows that erosion in nearly flat areas of cultivation was more severe occurred than in the slope. Also in Fig.18, in the forest the mild slope (3-3 mild) erosion much occurred than steep slope. Somehow, the landslide occurred in the steep slope (3-4 steep). All of observations gave better supports of clustering of erosion sources.

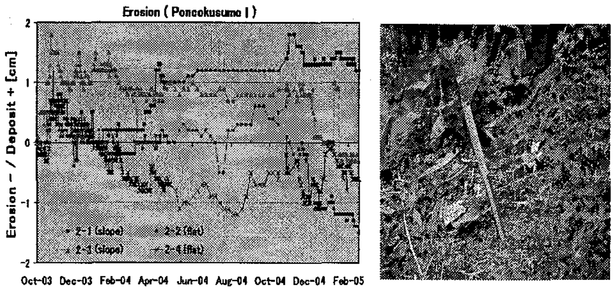

Figure.17 Dynamical erosion in Lesti sub-basin and erosion gauge used, *Oishi et.al, 2005.*

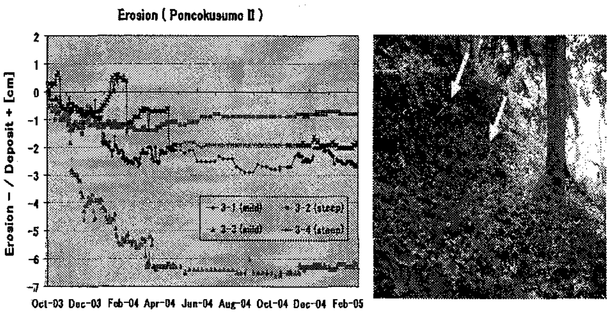

Figure.18 Dynamical erosion of forest area in Lesti sub-basin, yellow arrow is array of erosion gauges, *Oishi et.al, 2005.*

Since there are no more field observations in the Brantas origin sub-basin, the verification is done using satellite imageries only. Further, the similar observations are needed also to get better understanding the erosion processes in the sub-basin.

5. CONCLUSSION

Integrated assessment of reservoir sedimentation is successfully performed by quantitative and qualitative analysis of sediment-sources in the basin area. The USLE was quick method and gave good results in prediction of sediment yields roughly. Then, qualitative of vulnerable sources were followed by mineralogy decomposition using X-ray powder Diffraction. It was powerful to identify the major minerals composition among sources and deposited. The statistical approach could be done to fingerprint the sediment based on the binary matrix of minerals representation in each sources.

Based on obtained information, it is possible to design a future and optimal countermeasures of reservoir sedimentation in Sengguruh. For example, in the Lesti sub-basin, the priority of sediment countermeasures should be done on the cultivation areas which have 30-25° by rotating vegetation plan or suitable vegetation type, since soil being protected. Also in the Brantas origin sub-basin, the deforestation in headwater of Brantas spring should be recovered soon, while the practice factor of cultivation in downstream of brantas spring should be managed properly.

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