13. RELATIONSHIP BETWEEN SUSPENDED SEDIMENT AND RIVER DISCHARGE IN EXTREME VOLCANIC ENVIRONMENT CATCHMENT

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This study is focusing on the river of active volcanic territories in Kamchatka Peninsula located in Russia. The study area has a range of hydrological features which define the extreme amounts of washed sediments. It is believe that sediment transport in and to river channels in volcanic mountainous terrain is strongly influenced by climate conditions, particularly when heavy precipitation and warmer climate triggers a mud-flow in association with snow melting. High porosity of the channel bottom material also leads to the interactions between surface water which causes temporal variability of water and sediment flow. This paper concentrating on the relationship between suspended sediment discharge and river discharge in volcanic area, Kamchatka, and the results are compared with Japan and Malaysia's mountainous river. The results at this stage shows significant relationship between suspended sediment and river discharge during the snow melting seasons where warmer climate conditions triggers a mud-flow. The amount of sediment discharge in Sukhaya Elizovskaya River during the snow melting season in 2012 peaked almost 10 times higher with the same amount of river discharge in the beginning of snow melting seasons.

Key Words : *suspended sediment, sediment transport, volcanic river, river discharge*

1. INTRODUCTION

Water resulting from rainfall on land, signified mainly by rain water, follows several paths before reaching the oceans, or being recycled back to the atmosphere. Among these different venues for water, it is clear that water in rivers has the greatest effects on landscape, with its strong erosional and depositional powers. These powers depend on a number of factors such as the amount of available water, precipitation discharge, topography and terrain, basin geology, human impact and size, and amount of sediments and load one river can carry[1]. In case of volcanic environment, many of sediment discharge drivers (loss of surface materials by the erosional forces) are significantly increased compared to other mountainous areas[2)3)4)].

(1) Water streams in volcanic territory

In volcanic areas especially on the slopes of volcanoes, various types of water streams were formed here. Rivers are often confined to the ways of the lahars, which later determines the nature of runoff and sediment yield of the river. Permanent and temporary rivers (tributaries of lahar valley) is a water streams that originates in the slopes of volcano, but occurs within the different types of mountain and river beds by type of channel process which do not differ from non-volcanic areas of mountain rivers[5].

(2) Sediment load

River's sediment load in volcanic region are formed in different geomorphologic and hydrologic conditions[6]. As noted above, they may occur due to heavy rainfall, leakage of the crater lake, snowfields melting and glaciers or volcanic eruption. The total volume of sediment load is usually formed under the influence of strong fluctuations in water content, resulting in a diurnal variations and even intrahourly cost of water and sediment which can significantly exceed the intra-annual fluctuations[7].

In Kamchatka, devoid of vegetation's slopes of active volcanoes was the source of many rivers contain loose volcanic material. During the period of intense snowmelt in spring, these rivers are at full flow and have active erosive-accumulating activity. The most intensive material transport is carried out during volcanic eruptions. The sediments of the rivers are dry boulder gravel and sand material.

(3) Channel processes

Changes in the type of rivers cutting the slopes and foothill areas of the active volcanoes are associated with an alternation of the types of river valleys[8]. Seasonal fluctuations of water flow and sediment determine the variability of the channel network. The high susceptibility to eruption and at the same time maximum flow of sediment within the middle of the river volcanic areas ('dry' river beds) defines a specific mode of vertical deformation. When the surface filtration flow is in predominance with thick sedimentation, occurs material accumulation on from above. In this arrangement, the accumulation is difficult to change within the river depending on the progress of waves of surface runoff in the long-term plan (in the absence of an additional sources of solid material) erosion predominates[8].Deformation of river beds in the volcanic areas has a specific character which is due to the extremely uneven water flow. Structures of focal branching of volcanic rivers are random and were completely modified after the passage of the next flood. As a result of daily fluctuations in water flow the existence of separate flow were measured in every ten minutes[5].

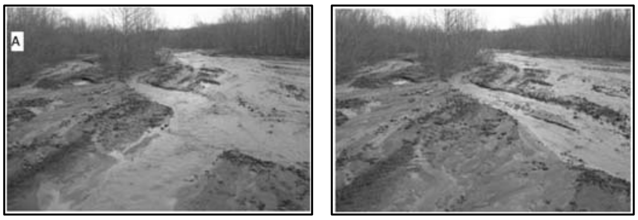

Fig.1 Daily dynamic of the volcanic river structure and its focal branching (Sukhaya Avachinskaya River) A – 26 May 2007 15:30, B – 26 May 2007 15:40 (Photo Ermakova A.S)[8]

2. STUDY AREA DESCRIPTION

(1) Brief description of study area

The Kamchatka Peninsula is located in the north-east and is the second largest in Russia. Kamchatka is a young geosynclinals area of active tectonic processes of modern and contemporary volcanism. Sukhaya Elizovskaya River flows through the territory of present active volcanic Kamchatka-Avachinskaya group of volcanoes as shown in Fig. 2.This group of volcanoes is situated in the south-east peninsula and refers to the Eastern volcanic area.

Sukhaya Elizovskaya River flows from the snowfields, located on the western slope of the Avachinskaya hill. The pool soil of Sukhaya Elizovskaya River is pretty scanty, patchy and unevenly distributed, the main type of the soil is layered volcanic wood ash and primitive soils on young volcanic-sedimentary deposits which is high porosity. The nature of this flow is largely determined by its tributaries, which are water streams that originate on the slopes of volcanoes fed by melting snows and glaciers. Length of the river is 20 km, with catchment area of 73.6 km^2 with ten permanent tributaries making the length of drainage network is 53 km.

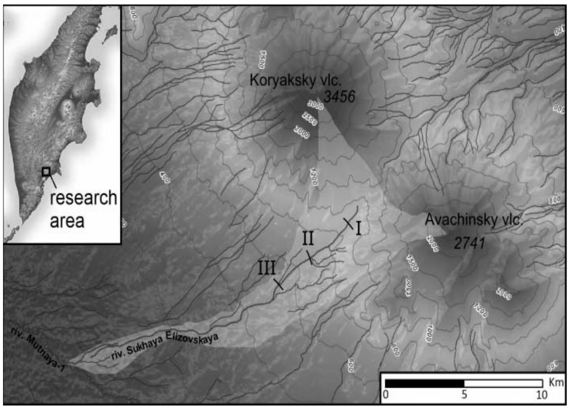

Fig.2 Location of Sukhaya Elizovskaya River

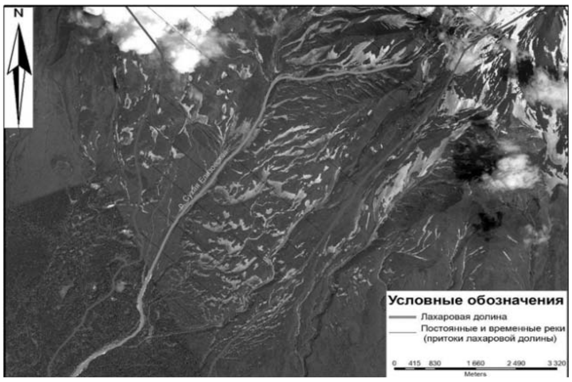

Fig.3 The Sukhaya Elizovskaya River and its river flow/runoff

(2) Gauging site and diurnal cycle

In this study, there are two sets of data that has been taken at different time and year. Fig. 4, 5 and 6 shows the situation in both period for station I, II and III. The first data was recorded from 28th July to 5th August 2012 (snow melting period). During this but long captions period, increased in daily water flow results in the increment of sediment up to ten times along mountain channels and up to thousand times in the lahar channel. The short-term fluctuations are explained by either damming of the river by collapsed ice and further dam bursting, or filtration of the surface water. During the observation period,constant water flow was stopped at night time in the upstream zone of lahar valley because of water filtration. On sunny days length of the surface stream has grown down-stream along river valley with increasing of the snowfields water loss. Maximal water losses of the snowfields at the foot of Koryaksky and Avachinsky volcanoes (with daily temperature 30º C) were usually observed around 18:00.

Fig.4 Station I (Left: 28th July to 5th August 2012. Right: 15th to 28th June 2013)

Fig.5 Station II (Left: 28th July to 5th August 2012. Right: 15th to 28th June 2013)

Fig.6 Station III Left: 28th July to 5th August 2012. Right: 15th to 28th June 2013)

Second data was taken in between 15th to 28th June 2013 (beginning of snow melting period). During this period, all river channels were covered by snow except left tributary from the snow field at station II where it has discharge as shown in Fig. 4, 5 and 6[9]. Hence, data for station II were used to assess the relationship between river discharge and suspended sediment. Station II consists of two channel, mainstream channel and left tributary from snowfield channel. During the snow melting period in 2012, both streams had discharges but in 2013 (beginning of snow melting) only left tributary from snowfield channel had discharge whereas main channel was covered by snow.

Isotopes are variants of a particular chemical element where they have the same number of protons in each atom but differ in neutron numbers. Fig. 7 shows the temporal variations of two stable isotopes which are δO and δD in Kamchatka Peninsular and Japan. The data shown are mil enrichments of the isotopic ratios D/H and O^{18}/O^{16} relative to a mean ocean water standard, that is,

$$\delta = [(R/R^{\dagger}) - 1]1000 \qquad (1)$$

where R is either isotopic ratio and $R^{\dagger}$ is the ratio in “standard mean ocean water” (SMOW) defined relative to the National Bureau of Standards isotopic water standard[10]. Both water samples from Sukhaya Elizovskaya (r^2 = 0.987 in both years) plotted differently compared to Japanese local meteoric water line (r^2 = 0.94) because Kamchatka located at higher latitude where the water is lighter than the lower latitude[11)12)].

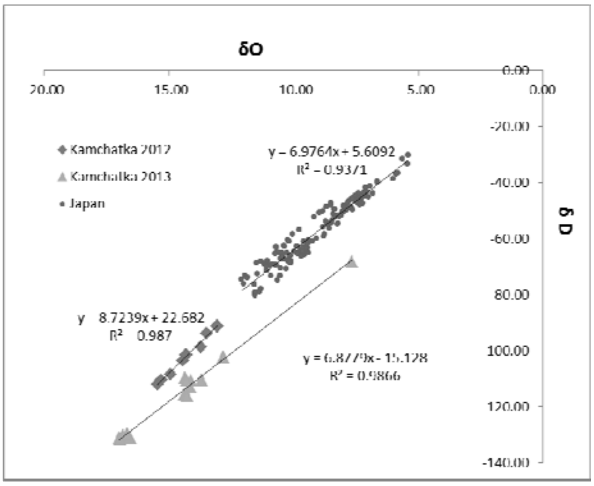

Fig. 7 Deterium and oxygen values of river water samples in Sukhaya Elizovskaya river for 2012, 2013 and Japanese local meteoric water, expressed as per millage enrichments relative to “standards mean ocean water” (SMOW).

As for the difference in both years, the source of the water samples in 2012 (snow melting period) are from river and landscaping thus the samples were enriched with heavy isotopes compositions due to evaporation and glaciers. In 2013 (beginning of snow melting), the sublimation of the ice removes the material layer by layer and therefore it could be expected then that this process would not change the isotopic composition of the remaining snowpack, unlike the situation in an evaporating water body in which the effect of surface fractionation is propagated into the residual liquid by mixing[13]. The amount of snowmelt water was small thus it is normally considerably depleted in stable isotopes[15] as compared in 2012.

Fig. 8 represents the properties of suspended sediments at Station II (middle stream for year 2012 and 2013. The data was taken at the same time for both period i.e at 10:00, 12:00 and 18:00 where maximal water losses were usually observed.

For the sediment accumulation vs, size distribution, the figure shows the variations of size distribution occurs in 2012 where the snow melting periods occurs as accumulation goes higher whereas for 2013 (in the beginning of snow melting period), the size distribution is so small even when the accumulation is high due to the snow. Same reasons apply to the frequency distribution vs. particle sizes. Whereas for number of particles vs. size of particles, 2013 recorded higher number of particles for a small sizes in between 0.01 to 0.2mm whereas for 2012, the smallest size of particles is recorded somewhere around 0.1 to 0.45 mm. This is because during the beginning of snow melt period, as mention previous paragraph, almost all river channels upstream were covered by snow hence only a small amount of particles were moved For 2012 where the snow melting, the water flow increase therefore the sediment transport took place from upstream to downstream bringing multiple sizes to the downstream.

3. METHODOLOGY

Suspended sediments are responsible in water quality as a vector for contaminants within river systems[15]. To successfully carry out this study, data on suspended sediment concentration and stream discharge were collected and derived from the gauging station. In order to analyse the data, the sediment rating curve takes care of the discharge dependent variations of suspended sediment concentration[16] was used.

Hence, the rating curve which is a precise form of power method to regress stream discharge and suspended sediment by plotting on log-log graph to get the exponential relations of the form:

$$Q_s = aQ_w^{\ b} \tag{2}$$

Where Q_s is suspended sediment in m^3/s, Q_w is stream discharge in m^3/s, a is intercept and b is a slope of the rating plot respectively.

4. RESULTS AND DISCUSSION

Three exponential graphs of suspended sediment (m^3/s) and river discharge were plotted for both periods as shown in Fig. 9. For main channel in 2012, the graph shows huge variation of suspended sediment when the discharges is only around 10 to 30 (m^3/s) at the main channel. By plotting the tread line, the slopes were around 4.2 whereas for left tributary during the same period, the discharge was varied but compared to suspended sediment where the slope is only 0.25. This can be explained as main stream bed is thick fluvial sediment bed containing loose bed materials whereas for left tributary, the bed is consist of gravel and boulders[17]. For left tributary in 2013, the relationship between suspended sediment and river discharge is stable due to the low concentration in sediment and the water is limpid. To achieve the objective by comparing the relationship between suspended sediment and river discharge for volcanic mountainous with other mountainous area in Japan and Malaysia, a famous figure of suspended sediment vs. river discharge for major river in japan
by Ministry of Land, Infrastructure and Transportation of Japan has been restructured as shown in Fig 13.

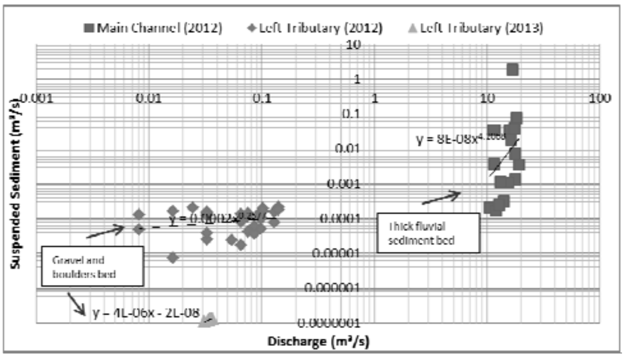

Fig. 8 Suspended sediment versus river discharge at station II for both periods

Two rivers in Japan which are Saru and Kurobe River, and Lebir River (a tributary of Kelantan River) located in north east of Malaysia also has been included in this analysis. We can see the comparison among the rivers in Kamchatka Peninsula, Japan and Malaysia. Relationship between suspended sediment and river discharge for Kurobe River show a very high concentration as this river is known for extreme mountainous river in Japan[9].

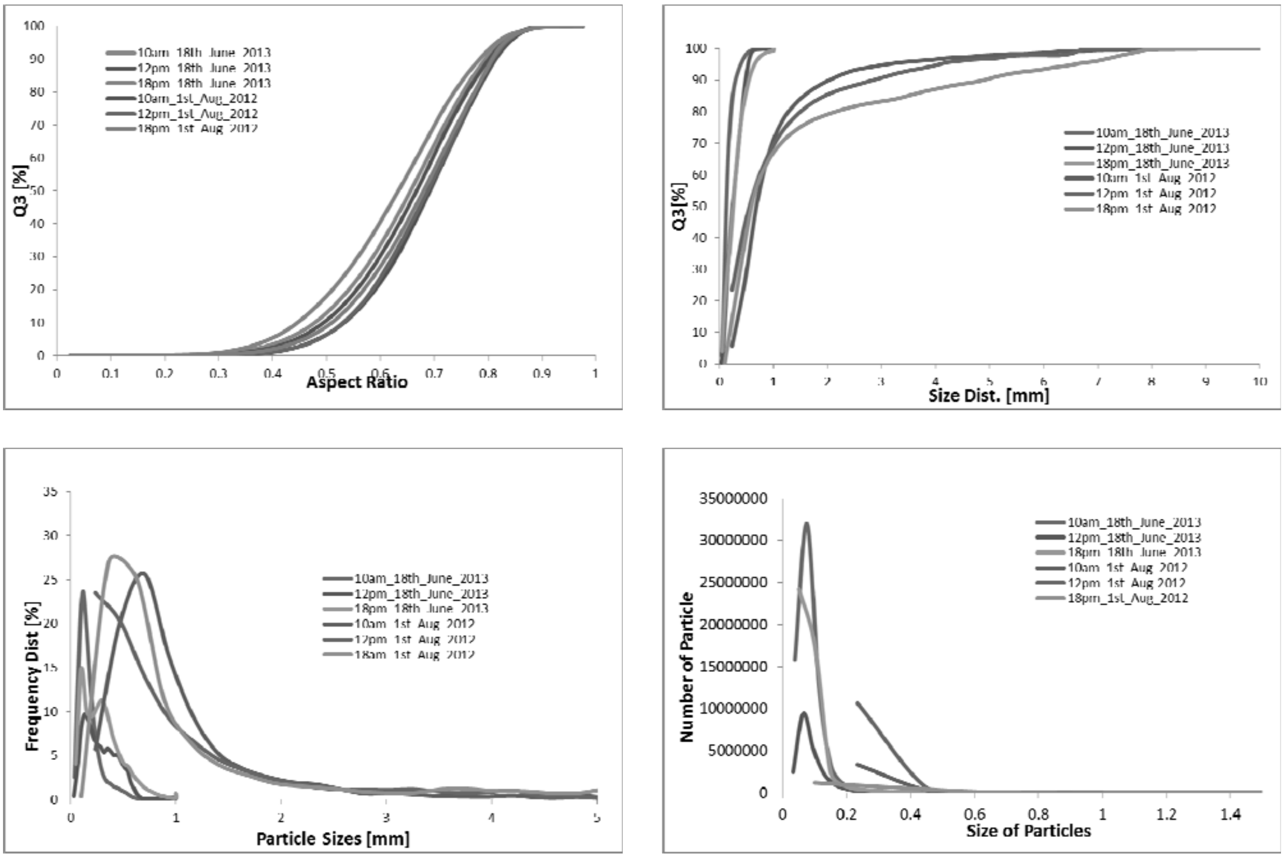

Fig. 9 Sediment particles properties at Station II for 2012 and 2013

5. CONCLUSION

Discharge is vital in determination of suspended sediment discharge. However, it is worthy of note that there are other factors other than discharge responsible for determination of suspended sediment discharge. These factors include snow melting and volcanic activities in the case of volcanic rivers (diurnal cycle). The geology of the catchment also plays an important role in defining the discharge of the area.Based on the assessment, we can conclude that there is a significant relationship between these two variables during the snow melting season. From the analysis, it is shown that sediment transport in and to river channels in volcanic mountainous terrain is strongly influenced by climate conditions, particularly when warmer climate triggers a mud-flow in association with snow melting. The amount of sediment discharge in Sukhaya Elizovskaya River during the snow melting season in 2012 can peak up to 10 times with the same amount of river discharge compare during the beginning of snow melting period in 2013. This is due to the high porosity of the channel bottom material also leads to the interactions between surface water which causes temporal variability of water and sediment flow.

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