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Impacts of Sediment Management on Socio-Economics and Environment in Mt. Merapi Area

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Abstract

In recent years, the sediment management is not only for disaster prevention function, but it also considers the environment surrounding of the target area. After a big eruption of Mount Merapi in 1969, sediment control facilities have been constructed to prevent sediment disaster in the basin. On the other hand, local people have used the sediment from Mount Merapi as one of resources through sand mining activities. The sediment disaster mitigation and sand mining activities have given the impacts on socio-economics as well as environment condition in the area. In this paper, the impacts of sediment management in the area are discussed from views of both the socio-economics and the environment aspects. From socio-economical and environmental views, it showed that the combined management between controlled sand mining and installed groundsills is preferable for sediment management in Mt. Merapi area. However, the sediment management needs to be supported by other activities such as economical development, thus the aims of the sediment management can be reached.

1. INTRODUCTION

Indonesia with the total area of 1,919,440 km^2, consists of more than 13,000 islands, 54,716 km length of coastline, lies between approximately 7^0 N and 11^0 S latitude, and between the 95^0 E and 140^0 E longitude. There are two tectonic plates passing the country, namely the Eurasian and the Indo-Australian plates [3], that makes the geography of Indonesia is dominated by volcanoes. Indonesia has 129 active volcanoes spreading across the archipelago, and Java and Bali are the most volcanically active islands. Mt. Merapi in Central Java has still actively been producing huge amount of sediment, threatening local residents. On the other hand, the sediment has given supports for regional development of local residents as well as local governments by sand mining activity. However, the negative impacts on environment also appear such as sediment trapping by the sediment control facilities and river incision. In addition, the impacts of sand mining result in negative impacts such as unstableness of existing river structures, damage to the rural road, noise, and dust. Therefore, a new concept of sediment management with considering balances between socio-economical and environmental condition is needed in Mount Merapi area. In this paper, the impacts of sediment management on the environmental and socio-economical sides are discussed. The framework of sediment management, its aim and also its impact on socio-economics will be presented generally in Chapter 2. In Chapter 3, several of proposed sediment management and their impacts will be discussed and finally, the preferable of sediment management considering socio-economics and the environment will be described in Chapter 4.

2. SEDIMENT MANAGEMENT AND ITS IMPACT

2. 1. Sediment management

Sediment management is commonly addressed to reach a condition based on some of reasons. The definition of sediment management here is an activity to control and manage sediment by dredging regulation, sediment control and mitigation structures, including under natural condition.

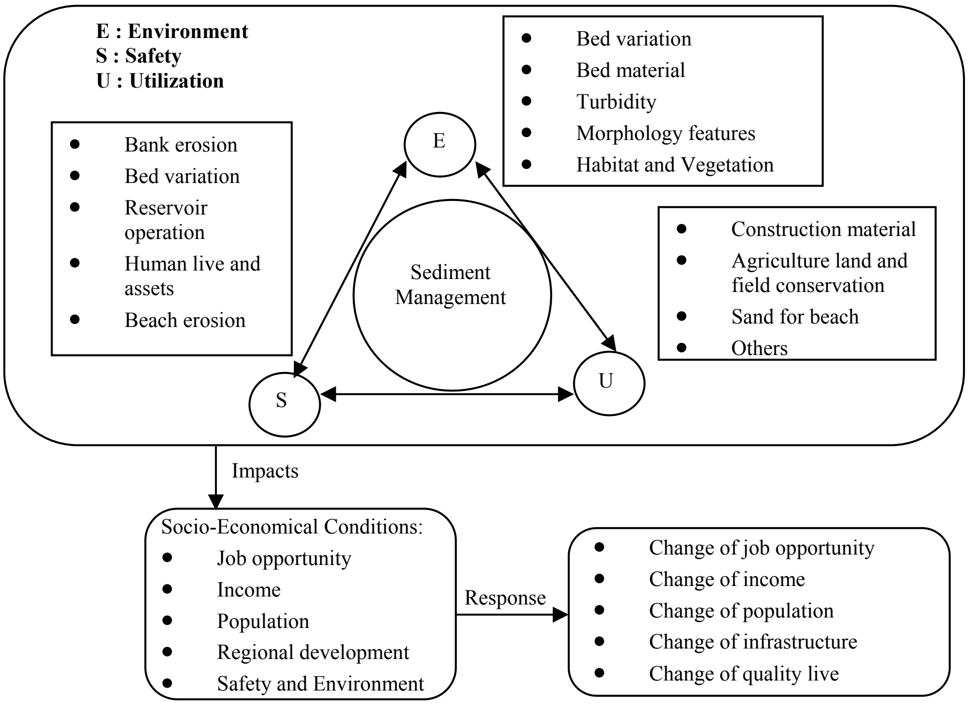


Fig. 1: A diagram of impacts of sediment management on environment and socio-economics

The interests of sediment management are commonly for safety interest, environmental interest or utility interest, depending on the stakeholders. Consequently, impact of sediment management on environment and socio-economics is also various. Regarding the environmental interests, people give attention on bed variation changes, bed material changes and morphological changes as well as turbidity. From safety interests, sediment is managed for many reasons, as securing people and assets from sediment flows, keeping riverbed variation, protecting riverbank or controlling deposited sediment in a reservoir. People also use sediment as resources, such as sediment for construction material, soil for agriculture and sand for beach. The relationship between sediment management and these interests and also their impacts on socio-economical condition is shown in Figure 1.

2. 2. Impacts of sediment management

Environmental, safety and utility interests have dependency with the each other. Changes in one interest by a sediment management will affect on the other two interests. For example, when people regulate the sand mining activity, the regulation will gives the directly impact on the utility interests. Moreover, the regulation also will change the environmental and the safety interests indirectly. The other example, if people make a policy on sediment management addressed to secure from sediment related disaster by constructing sabo works, the policy does not only giving impacts on the safety interest, but also affects on the environmental and utility interests. The sabo works will capture the sediment discharge, protecting people from disaster. The sediments will be deposited in upper site of the structures, thus reducing sediment discharge into downstream area, resulting in degradation. Hence, it is very clear that sediment management on one interest will be affect on the other interests.

Furthermore, the changes on the environmental, safety and utility interests by a policy of sediment management will cause the changes on the socio-economical condition. The socio-economical conditions in this paper are as job opportunity, income, population changes, and quality of life. One example is current situation of sediment management in Mt. Merapi volcanic area. Sediment disaster mitigation has been applied since 1930s after huge eruption in 1931. The sediment disaster mitigation has been actively prepared since 1980s by constructing sabo works in surrounding Mt. Area. Those sabo facilities have contributed to peoples' safety and assets. For example, 39 casualties and 812 lost houses were caused by debris flows from 1969 to 1976, while there was only one casualty since 1980s [1]. Moreover, the sabo facilities also have contribution to regional development by providing transportation access and irrigation facilities. Due to the condition, it is encouraged people to move for using resources on Mt. Merapi slopes area. Thus, the agriculture production increases and the population changes in mountainous area are also growing fast.

On the other hand, due to the good quality of deposited sediment, people use the sediment as a resource by sand mining activity. The activity has provided job opportunities for local people, given additional income for local people in foothill of Mt. Merapi and downstream of Progo River, and also given tax for local people. However, the activity also has given the negative impacts such as instability of river structure, river bed degradation, road damages, noise and dust. Finally, the quality of life will decrease.

2. 3. Impacts of human activity on sediment management

Sediment management in Merapi area can be categorized into two major frameworks, namely sediment management without and with human intervention. In the first option, it means that the sediment management controlled by natural conditions. If the sediment production is not too much, the condition will not cause serious problems. However, if there is huge sediment production, sediment related disaster such as debris flow or aggradation in river will take place. The human intervention is needed when the sediment production is in huge condition. Human makes intervention to control sediment flow with sediment control structures, such as sabo works and channel works.

Generally, the purpose of sabo works is to protect mountain area by controlling the excess sediment discharge. The sabo works will provide adequate disaster prevention function. However, the problems related environmental will appear, because the structures cause river incision and capturing almost of sediments, resulting degradation in downstream site. The sediment that has been deposited must be removed in order to maintain the disaster prevention function. In order to decrease its negative impact, sabo dams are equipped with fish way, thus, fish can travel up and down. Some time the sabo dams are equipped with a slit. At the normal condition, sediment discharge can flow trough the structures.
Channel works are constructed to prevent river degradation in order to make river structure facilities in stable condition. Same with sabo works, the structures also cause the river incision, thus people provide fish way in this structure. In Mt. Merapi area, it is very often that people use the sediments as a resource. The activity can be use as tool to prevent flooding or to maintain the prevent function of sabo work. But if the activity is very excessive, the new problem will occur as riverbed degradation and river morphological changes.

3. SCENARIOS OF PROPOSED SEDIMENT MANAGEMENT

3. 1. Hydraulic condition

As described in Section 2, it shows that the sediment management in Mt. Merapi area causes some impacts on safety, utilization and environment as well as socio-economics. In this chapter, we discuss the impacts of various option of sediment management, especially in lower Progo River. The sediment management here is simulated under some scenarios which shown in **Table 1**. Case 1 shows the sediment management under natural condition or without human intervention. In Case 2, the sediment management by controlled sand mining activity is considered. Cases 2a and 2b show the condition under sand mining volume regulated at the same amount of sediment production and 50% of sediment production, respectively. The condition under sediment management by the groundsill installation and sand mining regulation is described in Case 3. Case 3a shows that the sand mining volume is about $1.44x10^6m^3$/year and the sand mining volume in Case 3b is $0.72x10^6m^3$/year. One dimensional variation model is used to perform riverbed changes. The hydraulic condition is set up as follows. The water discharge using the annual average discharge is $83.1m^3/s$, the river width using the average river width is equal to 200 m, the length of channel is 30 km, the initial slope is 0.0015 and the initial grain size of bed material refers to DGWR report, 2001.

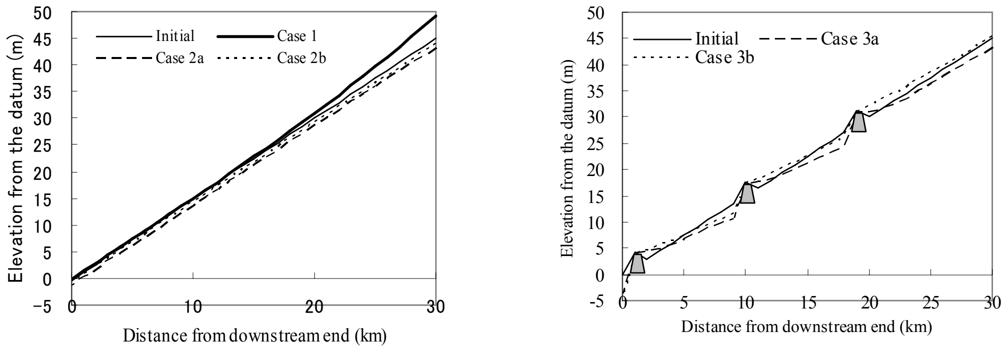
3. 2. Results of riverbed variation

The results of all scenarios are shown in Figure 2. Under a natural condition, river bed aggradation is occurred. At the upper boundary, aggradation depth reached 4 m in 10 years. This situation causes the negative impact on safety interest, because people are threatened by flood disaster. It indicated that the sediment discharge from upper area needed to control. In Case 2, the sediment discharge into downstream is controlled by sand mining.

Table 1: A set scenario of sediment management

Cases	Sediment Control Structure	Sandmining volumes (m^3/year)
1	No	No
2.a	No	$1.44x10^6$
2.b	No	$0.72x10^6$
3.a	Groundsills	$1.44x10^6$
3.b	Groundsills	$0.72x10^6$

River bed degradation took place when sand mining volume is equal to the sediment production or 50% of the sediment production. In 10 years, degradation depth at upper boundary for Case 2a and 2b are 1.5 m and 0.8 m, respectively. The both conditions cause the positive impact for utility interest, especially sand as material construction, but in other hand these condition will give negative impact in Agriculture. From environmental interest, especially Case 2a, the sediment management will give negative impact for environmental due to degradation or riverbed material changes. In order to keep the riverbed, the sediment using groundsill and sand mining regulation is considered. Under sediment management using groundsill as shown in Case 3, if all sediment production is taken as sand mining, the bed degradation will occur, especially in downstream site of groundsills. In 10 years, the degradation at upper boundary is estimated at 1.5 m. As sand mining volume is 50 % of the sediment production, the bed degradation in upper boundary can be protected by the installed groundsills as well as in middle part. However, the degradation process in downstream site of groundsill is needed to require attention, especially in lower area. Based on discussion in above, Case 3b can be used as the sediment management which is acceptable from environmental, safety and utility interests.



(a) (b)

Fig. 2: Impacts of sediment management on riverbed variation in 10 years

3. 3. Degree of risk of river structures

Based on the results of riverbed changes, the impacts of sediment management on socio-economics and environment will be discussed more detail in Section 4. The parameters to measurement the impact of sediment management on socio-economics are job opportunity, tax income for local government as well as degree of risk of river structures such as piers bridge, irrigation facilities and embankment. The definition of degree of risk in this paper is ratio between the depth of riverbed variation and the depth of critical value, which is shown in equation 1. The depth of critical value of bridge pier assumed is about 2.1 m [4] for degradation and 3.0 m for aggradation cases. The depths of critical values of embankment are 1.5 m and 3.0 m for degradation and aggradation cases, respectively. The critical value for irrigation intake is decided at 0.4 m for degradation case and 1.5 m for aggradation case.

$$The\ risk\ deg\ ree = \frac{The\ depth\ of\ riverbed\ changes}{The\ depth\ of\ critical\ value} x100\% \qquad (1)$$

4. RESULT AND CONCLUSION

4. 1. Impacts of sediment management on environmental

The influence of sediment management to environmental change is measured by changes of riverbed elevation and the riverbed material. The riverbed material changes is indicated by changes in the average diameter of the riverbed material. Figures 3a and 3b show the riverbed variation and the riverbed material changes at the upstream boundary for each case, respectively. In Case 1, the riverbed elevation increases 4.04 m in 10 years. Change of the riverbed material in Case 1 is not so big, the mean diameter changes from 1 mm to 2 mm, due to the impact of sediment supply from upstream. For Cases 2a and 3a, the riverbed elevation decrease fastly in the first year, until reaching a depth of 2 m, but it is relatively constant in subsequent years. In the first year, the mean diameter of riverbed material changes from 1 mm to 7 mm. Due to the formed armor layer at the end of the first year, the armoring layer protects the riverbed thus the degradation is not so deep in subsequent years. In Case 2b, degradation occures fastly during first year and it tends to increase in the following years. In 10 years, the degradatin reaches 0.82 m. The mean diameter of riverbed material changes fastly during half first year, from 1 mm to 2.25 mm, then the mean diameter tends to not change in the following years. In Case 3b, degradation takes place in the first year, then the riverbed elevation tends to increase due to the impact of the installed groundsill in the subsequent years. The aggradation depth at tenth year is 0.56 m. Similir with Case 2b, in Case 3b the mean diameter of riverbed material also changes fastly during the first year, from 1 mm to 2.22 mm, then the mean diameter tends to not change in the following years. Based on the result as desribed at above, Case 3b is better than the other cases from environmental view.

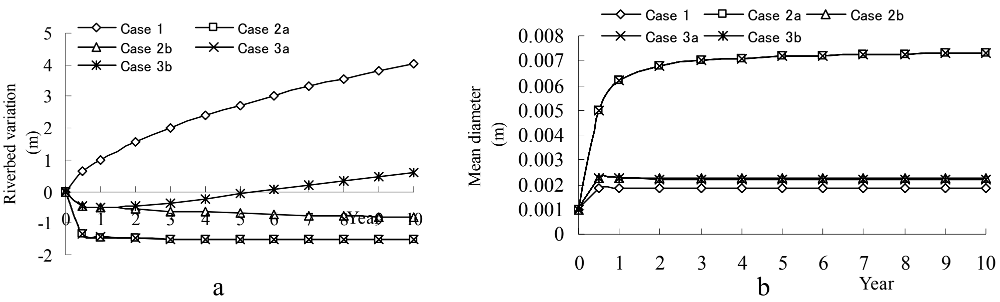


Fig. 3: Impacts of sediment management on a. riverbed variation and b. bed material change

4. 2. Sediment management impacts on socio-economics

4. 2. 1. Job opportunity and tax income

The influence of sediment management on socio-economical conditions are shown in Figure 4. The datas in 1999 are used as the initial data for analysis in this paper [2]. In Figure 4a describes a cumulative of loss of job opportunity for 10 years. Job opportunity here is intended job opportunity for sand miners in the area surounding the slopes of Mt. Merapi. In Case 1, if all production sediments are flowed into the downstream, it means that sand mining should be prohibited totally. This condition will cause the loss of job opportunitiy for inhabitant of about 21.022 people every year. Thus the loss of job opportunity is for 210,220 in 10 years. This condition needs attention from the government to create the substitute job, if the sediment manajemen is set as Case 1. Moreover, local governments will also lose additional tax income of 1,014 million rupiah every year as shown in Figure 4b. In Cases 2a and 3a, the loss of job oppurtunity for local people is least compared with the other cases as well as the loss of additional tax income for local goverments. Loss of job opportunity and loss of additional tax income for both cases each year are 16,111 people and 777.1 million rupiah, respectively. The loss of job opportunity in Cases 2b and 3b every year is 18,567 and the loss of additional tax income is about 895.5 million rupiah in the both cases. Based on the result of loss of job opportunity as well as loss of additional tax income, the Cases 2a and 3a are best options, but we also should consider another aspect such as environmental impact. In addition, the differences in results between Cases 2a, 3a and Cases 2b, 3b are not so big, so that Cases 2b and 3b can also be considered as an alternative sediment management.

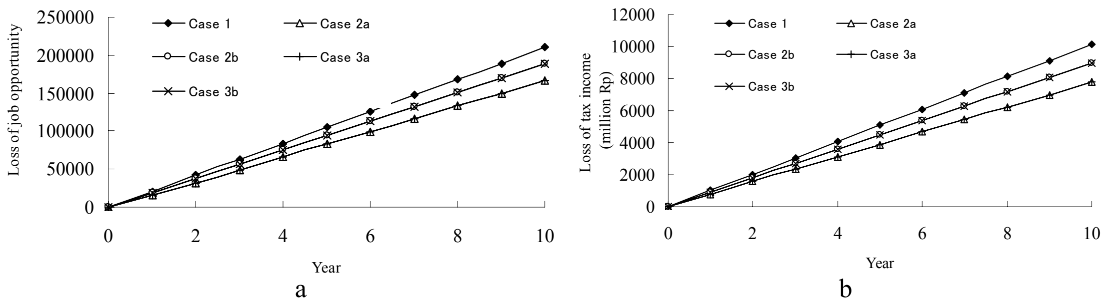
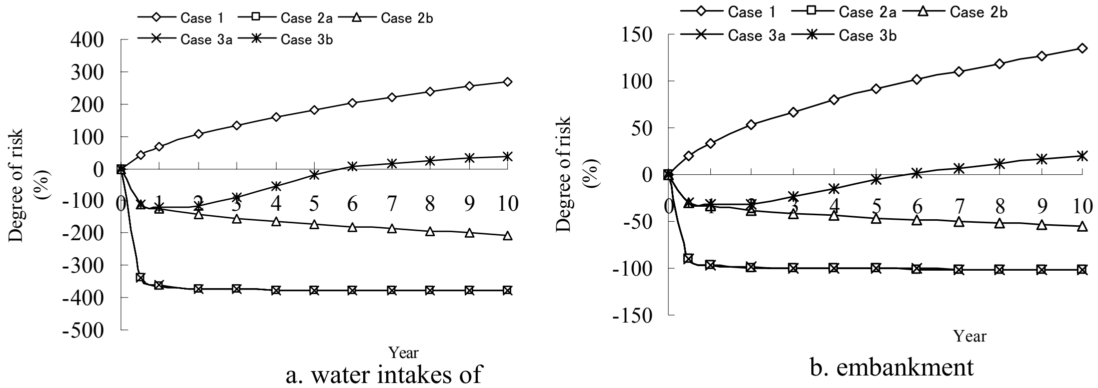


Fig. 4: Impacts of sediment management on loss of a. job opportunity and b. tax income

4. 2. 2. Degree of risk of river structures

Indirect influence of sediment management on socio-economical conditions can be indicated by the degree of risk of river structures such as water intake of irrigation, bridge or embankment. Figure 5a shows the degree of risk of water intake of irrigation due to sediment management in the Mt. Merapi area. In Case 1, because all the production of sediment flows into the downstream, then the water intake of irrigation will eventually not function caused by a very serious agradation. At the end of the second year, water intake of irrigation water is not working totally. This situation in accordance with the condition before the sediment control structures were constructed on slopes of Mt. Merapi. In Cases 2a and 3a, because there is no sediment discharge from the slopes of Mt. Merapi, water intake of irrigation is not function at the first mid-year. This condition is caused by the riverbed degradation, thus water can not into the intake water. This phenomena in accordance with current conditions, many water intake of irrigation in downstream areas is not function due to the riverbed degradation is very seriously. If the water intakes are not function, it will indirectly cause social problems such as loss of job opportunity in field of agriculture, decreasing agriculture production and declining farmers' income. In Cases 2b and 3b, water intake of irrigation rapidly impaired in the first year, so that does not work. For Case 2b, the degree of risk of water intake of irrigation tends to be larger from year to year. But for Case 3b, the function of water intake of irrigation returned to normal due to the increase in the riverbed elevation. Based on these results, it can be concluded that the Case 3b is the best option comparing the other cases.



a. water intakes of irrigation

b. embankment

Fig. 5: Impacts of sediment management on degree of risk of river structures

In addition to affecting structures of irrigation, the impact of sediment management also affect the stability of flood control structures such as embankment. It is shown in Figure 5b. Embankment instability will lead to socio-economical impact, even though these effects are not directly. If the embankment is not function or damaged, the inhabitants will be threatened by flood in the future. In Case 1, the degree of risk of embankment tends to rise from time to time. At sixth year, the degree of risk of embankment is estimated at 100%. It means that the function of embankment to engage flood disaster is critical, thus the inhabitants threatened by flooding. In Cases 2a and 3a, the critical condition of the embankment happens in the first year. In both cases, the structure will fail to control floods caused by the degradation of the structure foundation. As a result, if the embankment collapsed, the flood disaster also threaten the inhabitant. For Cases 2b and 3b, stability of the embankment still awake. But under Case 2b, the degree of risk of embankment tends to increase, thus a critical condition will also increase in the future. Based on these results, Case 3b is predicted to give the smallest negative impact on socio-economics.

Figure 6 shows the degree of risk of a bridge pier during 10 years. In Case 1, the critical condition of the bridge pier is achieved at sixth year. In this condition, the bridge pier buried by sand, so that the bridge function is not optimal. Under this situation, people do not feel comfortable crossing the bridge, especially in flood conditions. In Cases 2a and 3a, the degree of risk of the structure is very quickly in the first year, then it increases slowly in subsequent years. In the tenth year, the degree of risk of a bridge pier in the both cases is estimated at 72%. This condition needs to get attention, because the bridge pier is near the critical condition for collapse. If the bridge collapses, it will raise negative impacts on the socio-economics as cutting traffic, disturbance of economic activity and so on. Degrees of risk for Cases 2b and 3b are 39.3% and 19.8%, respectively. Based on these results, Case 3b is considered to give the least risk to the socio-economical conditions.

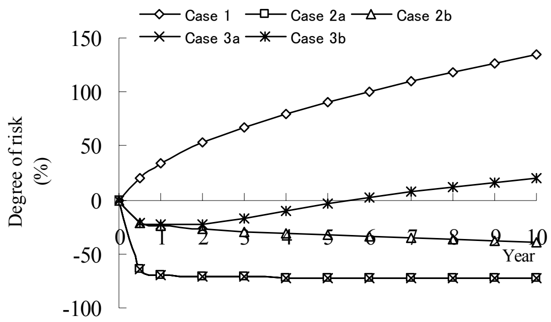


Fig. 6: Impacts of sediment management on degree of risk of bridge pier

Figure 7 shows the effect of various sediment management on socio-economical conditions. If the sediment management such present condition is maintained, it will provide great benefits in socio - economics. Local people have large opportunitiy to get a job as sand miners and local governments also get an additional tax significantly. The proposed sediment management will cause a socio-economical impacts such as reduced employment opportunities and additional revenue decline. Sediment management as in Case 1 has the greatest negative impact of socio-economical views. Cases 2a and 3a have the smallest impact on socio-economical conditions, while Cases 2b and 3b have a medium impacts. Sediment management impacts on the environment, utilization and safety of the various cases are shown in Figure 8.

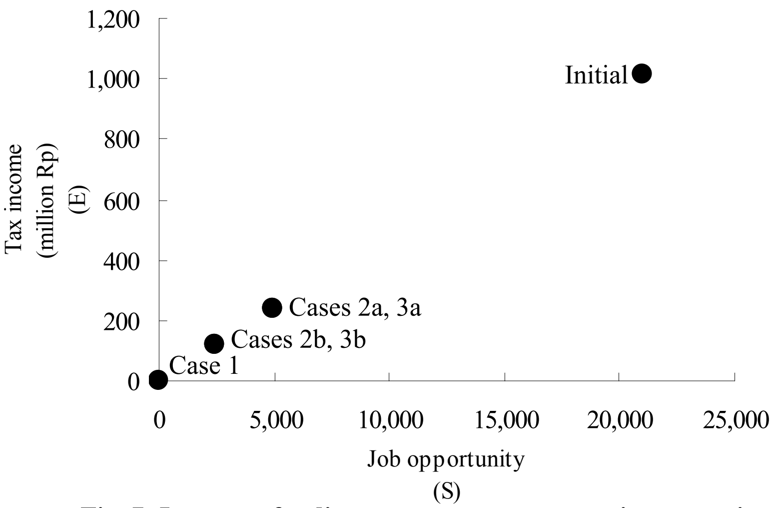


Fig. 7: Impacts of sediment management on socio-economics

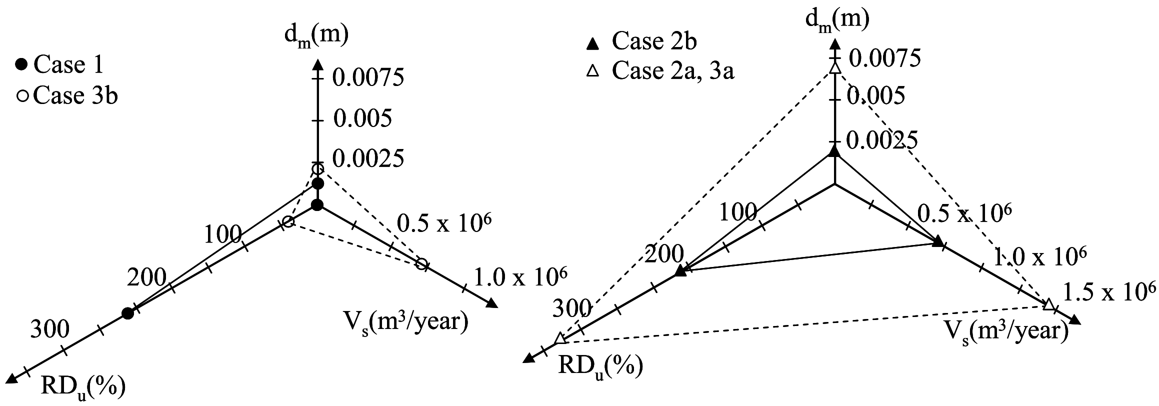


Fig. 8: Impacts of sediment management on safety, utilization and environment

Case 1 shows that the sediment management has a positive impact of environmental view (d_m), but has the most negative impact of utilization (V_s) and safety views (RD_u). Cases 2a and 3a, showing a good sediment management from utilization view, but the both cases cause the big negative impact of environment and safety. Sediment management such as Cases 2b and 3b have a medium negative impact on environment, safety and utilization. However, Case 3b has the most minimal impact.

4.2.3. Conclusion

In this paper, the impact of sediment management on socio-economics and environment in Mt. Merapi area has discussed. From socio-economical and environmental views, it shown that the combined management between controlled sand mining and installed groundsills is preferable for sediment manajemen in Mt. Merapi area. The result can be considered as helping to determine the policy of sediment management in this area.

5. ACKNOWLEDGEMENT

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