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WEB-BASED SPATIAL INFORMATION SYSTEM TO SUPPORT COLLABORATIVE LAHARS DISASTER MANAGEMENT

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ABSTRACT

After the 2010 eruption of Merapi, some areas at Sleman Regency experienced with lahars disaster. Many agencies have their own responsibility to overcome the problems in collaborative work. Nevertheless, it is lack of spatial/GIS data support on their decision making as well as on their communications. The main objective of this research was to develop spatial information system to support collaborative lahars disaster management especially for response and recovery phase of the impact on infrastructures at Sleman Regency. Questionnaires and semi-structured interviews were used to investigate their need of the spatial data and the data availability. Basically respondents agreed that spatial data is important in their communication and decision making support. Specifically, the application is utilized with specific spatial analysis tools to support decision making processes. The users' evaluation of the prototype resulted that almost all of respondents give a good mark to the system.

Keywords: Lahars, WebGIS, SDSS, and MCDA

ABSTRAK

Letusan Gunung Merapi tahun 2010 telah mengakibatkan beberapa wilah di Kabupaten Sleman mengalami bencana lahar dingin. Beberapa institusi pemerintahan yang terkait memiliki peran masing-masing untuk mengatasi bencana ini. Namun demikian, data spatial untuk membantu mereka dalam mengambil keputusan maupun dalam komunikasi masih kurang. Tujuan utama dari penelitian ini adalah untuk mengembangkan sistem informasi keruangan untuk mendukung pengambilan keputusan dalam manajemen bencana lahar khususnya pada tahap tanggap darurat dan pemulihan di Kabupaten Sleman. Pengambilan data menggunakan angket dan wawancara terstruktur untuk mengetahui kebutuhan user dan ketersediaan data spatial. Hasilnya menunjukan bahwa pada dasarnya responden setuju bahwa data spatial sangat penting dalam komunikasi dan mendukung pengambilan keputusan. Secara khusus aplikasi yang dikembangkan dilengkapi dengan analisis spatial untuk mendukung kebutuhan tersebut. Hasil evaluasi bersama pengguna dari institusi terkait menyatakan bahwa responden pada umumnya memberikan penilaian yang baik terhadap aplikasi ini.

INTRODUCTION

Indonesia is one of developing countries which are very vulnerable to various hazard [*Voight et al.* 2000; *Lavigne,* 2000]. One of them is Merapi volcano. The latest eruption occurs in 2010 was said by authorities to be the largest since the 1870s. The eruption began in late October 2010 and continued into November 2010. During the period, the activity of Merapi was culminated when numerous pyroclastic flows down to the populated area at lower slope (www.wikipedia.org). Almost 50 thousand people located in high risk area. Meanwhile, 354 people of them ware loosed their life and 240 were injured [*BNPB*, 2010].

Nowadays, the eruption of 2010 Merapi Mountain has stopped, but the secondary disaster can be serious disruptions afterwards. In this case, lahars flow is considered to be widely damaging disaster. After the eruption some area of Sleman were experienced with lahars disaster mainly in the surrounding of Opak, Boyong, Kuning and Gendol River. The following table presents the lahars disaster events after the 2010 Merapi eruption. The data was taken from several online publications and reports. It can be seen that lahars disaster caused damage on various important infrastructure such as settlement, bridge, agricultural and irrigation infrastructure, and so forth.

Table 1. Several Lahars Disaster Events at Sleman after The 2010 Merapi Eruption at Sleman Regency

Nr	Date	Location	Disaster Impact	Source
1.	29/11/2010	Kayen Village, Sindumartani, Ngemplak, Sleman	50 houses were severely damaged and two houses moderately damaged	http://regional.kompas.com/
2.	26/12/2010	Cangkringan, Sleman	500 households were evacuated, hundreds hectare paddy field are fulfilled by volcanic material.	http://sdaem.slemankab.go.id/
3.	3/01/2011	The surrounding of Opak River, Sleman	The surrounding of Opak River, Sleman	http://fokus.vivanews.com/
4.	19 and 22/03/2011	Somewhere at Sleman	Damages on dikes and irrigation infrastructures	http://www.antaranews.com/
5.	1/05/2011	Gendol and Opak River	150 households were impacted and evacuated, several house damaged	http://regional.kompas.com/

In addition, some report said that lahars disaster will be serious threat for several years later after the eruption (www. metrotvnews.com, merapi.combine.or.id). The prediction was projected from the abundance of volcanic material at the upslope of Merapi Mountain. Kali Gendol (Gendol River) is considered to be dangerous during rainstorm events because it contains the amount of deposit.

Furthermore, about 83 units of Sabo dams were damaged (www.jogjatv.tv).

Sabo dams were developed in order to reduce the risk from lahars disaster [www.globalfmjogja.com; *Shaleh*, 2011; *Putro*, 2011]. Sabo is a system to control lahars flow using certain construction relating to the function [*Yakota*, 1983 cited by *Putro*, 2011]. There are 204 units Sabo dam at Sleman Regency. The dam were distributed along several rivers. By the damage of several Sabo dams will lead to the more serious lahars disaster in the future [Shaleh, 2011].

Immediate responses from various parties on disaster management sta-keholders take significant role to address the situation. The responsible stakeholders in these activities not only varied in locality but also in functionality. In every local administrative area can be compos-ed of several stakeholders with different responsibility for one problem (lahars disaster) such as *BAPPEDA* as spatial data provider and disaster management planning, *PU* has responsibility on infra-structures development and maintenance and so forth. Therefore, the collaboration in the disaster management activities should beinvolved various stakeholders inter and intra administrative area.

Stakeholders are considered having spe-cific problems to deal with their res-ponsibility on lahars disaster management activities.Commonly, problems on disaster management contain geographic aspect. These kinds of problems can be spatially analyzed in order to get better decision. Unfortunately, decision makers are not skilled with Geographic Information System (*GIS*) and spatial analysis at all. Based on the explanation, this research will conduct to address the problems on spatial data sharing, management and dissemination with particular spatial analysis tools as a *SDSS* on web-based Geographic Information System for supporting lahars disaster management. Specifically, this research aimed to develop web-based *SDSS* for collaborative lahars disaster management. In detail, the specific objectives of the research were (1) to design collaborative procedures using spatial data on lahars disaster management involving various parties of stakeholders; (2) to collect, organize, and integrate existing spatial data from various stakeholders on geodatabase development for supporting lahars disaster management; (3) to develop a web-based *SDSS* for collaborative lahars disaster management; (4) to test and evaluate the framework and the application prototype with the expected users.

THE METHODS

Selected Users (Stakeholders)
In lahars disaster management, mainly for physical infrastructure impact, govern-ments play the major role both in action and making decision. In general, citizen who potentially to be victim are considered to be objects (not actors) in lahars disaster management. In decision making process, they could be considerations but they have no important roles. Therefore, they are not considered as actors (stakeholders) in this research. Based on the explanation, several local governmental agencies were selected to be users (stakeholder): Agency for Disaster Management in Regency level (*BPBD*), Public Work Agency (*PU*), Regional Planning Agency (*BAPPEDA*), and Agency for Water, Energy and Mineral Resources (*SDAEM*).

Interview Processes
The information was assessed using structured questionnaire. The respondents consist of 18 people from the selected agencies considering the number of depart-ment which involve in lahars disaster management. There were two respondents selected for each department. The results were elaborated and cross checked with the semi-structured interview result which investigated also about the data and system

requirements in general views by decision makers of the agencies.

Stakeholders Roles Identification and Collaborative Procedures Development

The collaborative procedures on lahars disaster management were developed based on interview with the users. The results were formulated on conceptual model of collaborative disaster management. Unified Modeling Language (*UML*) was used to describe the model schematically. The *UML* refers to a standard language for specifying, visualizing, constructing, and documenting the object of software system, as well as for business modeling and other non-software system. *UML* offers a standard way to write a system's blueprints, including conceptual components such as actors, business processes, system's components and activities [*Putra*, 2010]. Validation will be conducted after the model has been formulated. The validation involves Agency for Disaster Management in Regency level to get feedback on the model.

Mapping Environment on the Geodatabase Development

On the geodatabase development, this research method adopted from *Burdziej* [2011] used 100x100m hexagonal grid. Those approaches are considered to be appropriate method to simplify the database. Many datasets were combined into one cell-based table in PostgreSQL/-Post*GIS* database. Each dataset can be stored into one column of the table. Afterwards, thematic maps can be created by make queries based on each column. The hexagons grid in this research were created using *Repeating Shapes for Arc-GIS* from *Jenness* [2011]. 66527 hexagons grid (100x100m) were created all over Sleman Regency area. The hexagon layers were used as surface model to represent geographic properties as well as lahars disasters related dataset which can be modeled as polygon.

On the other hand, there are several objects which should be stored and represented independently. All of infrastructures data are included in this kind of object (see Table 2). There are several infrastructures data namely road network, building, irrigation network, and bridges. In this case, each object needs its own geographic model and representation as follows:

Table 2. Geographic Model of Infrastructures Data

Nr	Object	Geographic Model
1	Road network	line
2	Irigation Network	line
3	Building	polygon
4	Bridges	point

In data storage process, every building and bridge is stored with their attributes. Differently, irrigation network and road network are stored by segments. Each segment represents object (road or irrigation) which has similar physical characteristics (attributes) such as width, type and so forth.

Web-based SDSS Development

SDSS components development approach namely model base (*MBMS*) development, geodatabase (*DBMS*) development, and user interface development (*DGMS*) was used in this research. Schematically, the research framework starts with research questions to drive the research in order to reach the objectives, followed by system development and end up with the research finding. System development is actually the main stage of the research which is contained several sub-steps namely system requirements analysis, collaborative procedures development, system design, system implementation, and system evaluation. Users' requirements were considered on the system development.

Evaluation Processes

The test and evaluation of the *SDSS*

prototype was conducted with 10. Brief overview and explanation were given before the application testing session. Afterwards, they tried to use the application for certain purposes. They filled a questionnaire as evaluation tool after the testing session. There are three main issues which were evaluated after they tried to use the prototype. The issues were referred to the ISO 9241 standard specifically the part of the interface evaluation of *Web GIS* applications [*Schimiguel, et. al.,* 2004]. The issues included: (1) interface dialog evaluation, (2) information/content evaluation, (3) dialogue interactivity evaluation, and (4) usability evaluation. Users were also asked to give feedbacks and suggestion on improving the usability of the system.

RESULT AND DISCUSSION

Multi-Stakeholder Problems and Their Roles on Lahars Disaster Response and Recovery

The problems which involved various parties of stakeholder on lahars disaster management are illustrated briefly on the following figure. The diagram was formulated from the interview result with stakeholders. Among the selected stakeholders (actors), *BPBD* has significant role mainly in coordination and facilitate activities to conduct their responsibilities. In detail, each actor has their responsibilities and roles as part of lahars disaster management as described in the following figure.

Figure 2 describes the relation between lahars disaster impact to infrastructures. In general, there are three elements of infrastructures which are potentially threatened by lahars namely roads and bridges, settlements (housing), and irrigation infrastructures. If the in-frastructure damaged by the lahars, each actor is responsible for solving their own problems. In some cases, their activities relate to the other agencies as

collaboration. However, there are several non-technical problems on their collaborative working environment as said by respondent from *BPBD.*

Firstly, it is weak in coordination among agencies. Secondly, there is a paradigm that disaster management activities are domain of *BPBD*. The other agencies usually waiting for command to take action. Thirdly, it is lack of synergism. Sometimes, each agency work for their agency's goals not for broader goals that involve the other agencies. Lastly, it is lack of data sharing among agencies. This situation is not only caused by organizational cultural condition but also by the lack of human resources who are capable on data handling skill mainly for spatial data. The condition relating with human resources was reported completely by *Putra* [2010] that 40% of local agencies at Sleman Regency do not have GIS-skilled staff. Interestingly, 54.54% of them have *GIS* operator but in minimum number (1-2 person/agency). As further informa-tion, up to now, *GIS* is not yet fully implemented in *BPBD* for spatial data management.

The roles of each agency were actually divided based on their main task. There are several roles which were identified during interview processes. The roles of each agency were listed in the following table.

Collaborative Lahars Disaster Management

The collaborative procedures were for-mulated from interview result improve-ed with literature review of relevant regulation. The results were modeled using *UML* to give understandable flow diagram to human as well as computer software in the following figure.
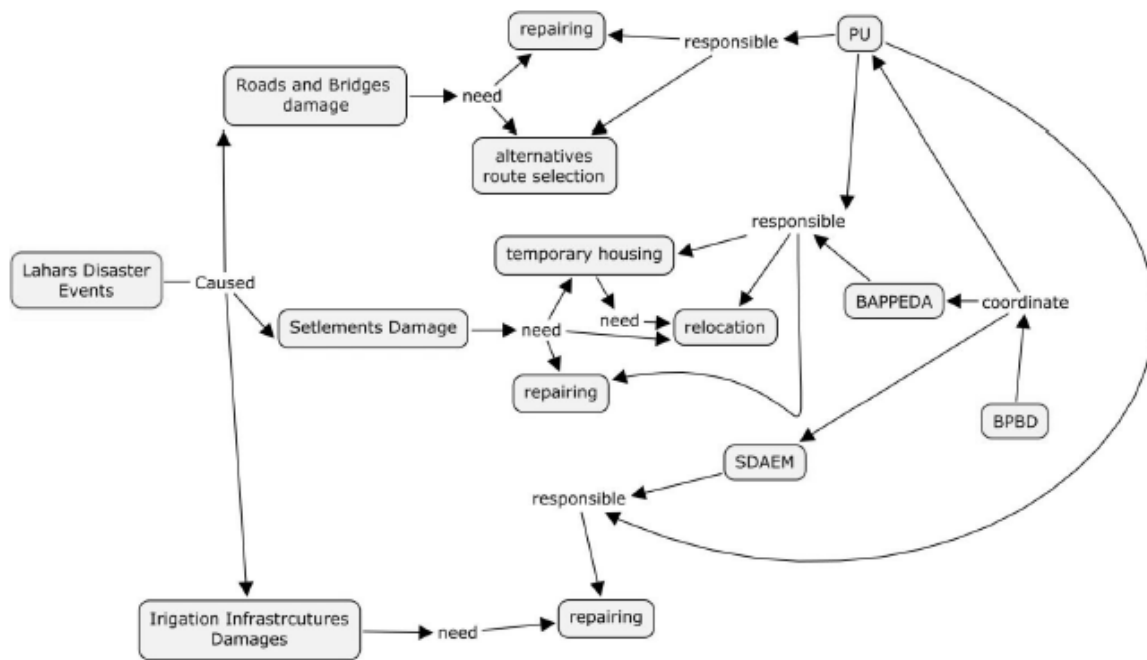
Figure 2. Multi-Stakeholders Problem Responsibility

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The roles of each agency were actually divided based on their main task. There are several roles which were identified during interview processes. The roles of each agency were listed in the following table.

Table 3. Identification of Roles of Agencies in Lahars Disaster Management

Nr	Agencies	Roles
1	BAPPEDA	Disaster area mapping Formulating action plan Provide related spatial data
2	BPBD	Damage assessment Coordination Facilitate disaster management activities among agencies
3	PU	Infrastructure provider Road networks evacuation Relocation and housing
4	SDAEM	River channel infrastructure evacuation River channel infrastructure normalization (reparation)

source: primary data

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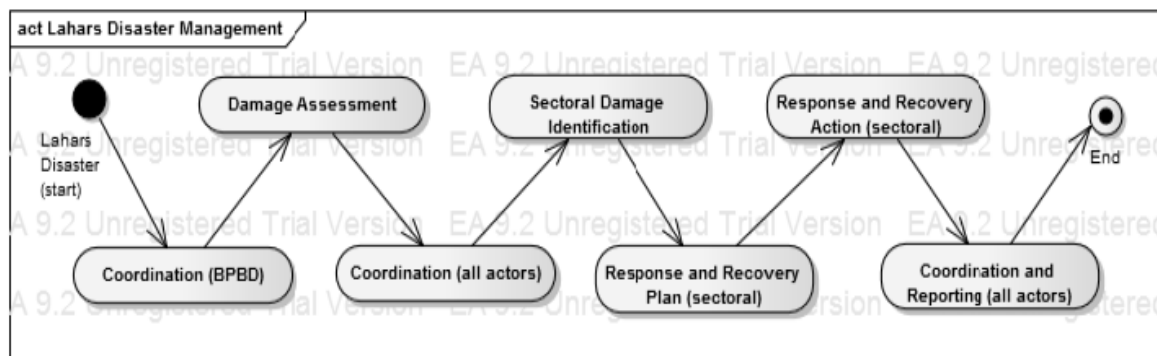

Figure 3. General Procedures in Lahars Disaster management

Figure 3 describes the general procedures in lahars disaster management. It is start with lahars disaster event at certain areas. As further information, lahars disaster has different character with another. The disaster events are relatively more predictable than the others, so that human victims can be minimized. But, it is difficult to avoid destruction in infrastructure. It was described by some respondent that during rainstorm events, all potential rivers are monitored by communities. The involvement of communities in disaster management also reported by *Sartohadi* [2012]. Therefore, when the debris flow from upslope Merapi arises, warning alert can be sent quickly to the citizens in the surrounding.

BPBD as coordinator and facilitator of disaster management activities at local level make internal coordination in the agency to solve the impact. To give information and identify the damage, then *BPBD* make observation to impacted area/infrastructures. At certain condition, *BPBD* invite all involved actors to make coordination followed with damage assessment mainly to identify the damage based on their specific responsibility. Afterwards, each agency will make response and recovery plan and action based on their responsibilities. The result should be coordinated and reported to convince that all infrastructures can be normally operated.

The Roles of Spatial Data for Stakeholders Communication on Lahars

The general opinion about data sharing and accessibility are described in the following figures. All decision makers from selected agencies agreed that spatial data is important in their communication. Investigation on respondents' opinion of the use of spatial data for lahars disaster management purposes informed that the majority of the usage is for supporting instrument in decision making processes, followed by problem analysis and tools for survey respectively (Figure 4). Unfortunately, they are realized that it is practically very limited and not adequate to fulfill their need. Some respondent also stated that it is difficult to implement spatial data communication due to human habit. Although, almost all respondents stated that spatial data from the other agencies is easy to access by make cooperation among them, because almost all agencies make publication of their data. However, commonly they know spatial data availability at the other agencies by asking directly to the agencies. Spatial data sharing via certain information system e.g. web portal is very limited.
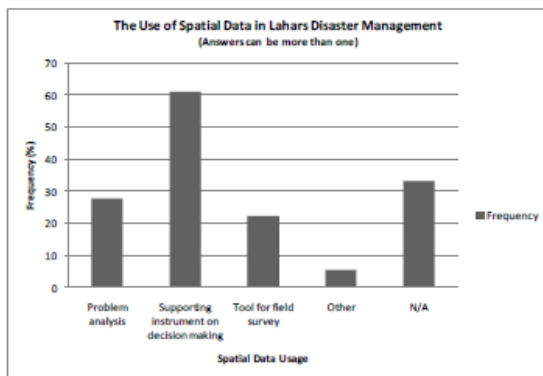

Figure 4. The Usage of Spatial Data in Lahars Disaster Management

Analysis of Specific Requirements Spatial of Data and the Availability

As explained in the previous section, spatial data is important for supporting decision making process and problem analysis. In detail, there is several information required during decision making processes. On the other hand, the questionnaires analysis resulted that almost all respondent agree with proposed spatial elements of geodatabase. In addition, some respondents also suggested involving several dataset namely landuse map, evacuation map, lahars disaster magnitude map, morphological map. Moreover, the requirements of spatial data elements can be analyzed also from required information list. The list has been selected which are relevant with lahars disaster management on infrastructure impact. To summarized, all the spatial data needed on lahars disaster management can be simplified as follows.

Table 4. Simplified Spatial Data Requirements

Nr	Required Spatial Data
1	Village administrative boundaries
2	Sub-district administrative boundaries
3	Road network
4	Bridges
5	Settlement (housing)
6	Rivers network
7	Hazard zonation map (KRB)
8	Lahars spreading
9	Barrack/temporary housing
10	Bridges condition/status
11	Landuse map
12	Lahars risk map
13	Slope map

source: primary data and analysis

Meanwhile, the quistionaire result stated that 67% of respondents experienced with availability of spatial data to support their decision making. There are several dataset investigated available in the agencies for supporting lahars disaster management mainly for infrastructure impact. However, the datasets are varied in scale and newness. The issues related to spatial data

standard were broadly explained by *Matindas et al.* [2004] also specifically reported by *Putra* [2010] and *Santosa et al.* [2007]. It is quite reasonable, if "Yogyakarta Single Base Map" was being established lately. The problem not only related to cartographical standard but also techniques on reporting data. There are many important data informed with geographically unspecific location.

Design of Criterion Weighting and the Decision Rule

Based on the analyses, it can be defined several problems which are commonly faced during lahars disaster management decision making processes which are suitable to be solved with Multi-criteria Decision Analysis (*MCDA*) approach as follows: (a) select the suitable area of temporary housing, (b) select priority of road reparation, (c) select priority of bridges reparation, (d) select priority of irrigation channel reparation. In this case, temporary housing site selection was used as example of the design and implementation on the system.

In the spatial analysis processes, users can assign the weight of each criterion based on their preferences. Furthermore, users can make modification of the criteria and or the constraint such as add, eliminate or substitute the criteria based on their individual or institutional scenarios. Rating Method [*Malczewski,* 1999] was adopted in this system. This method assigns the weight of each criterion based on the basis of predetermined scale, for example, a scale of 0 to 100 can be used to express the importance level from less importance to most importance respectively. The result is relative criterion weights among the selected criterion. Afterwards, the relative weights are used to generate *SQL* query to perform the decision rule. The query result will be delivered to client and visualized on the map. It is also allowed to save the scenario. Therefore, the

scenario can be used in the future or made scenario sharing with other users.

The decision rule is using *Simple Additive Weighting Method*. This method is used to handle multi-attribute decision making. Basically, the decision rule evaluates each alternative e.g. A_i using following formula [*Malczewski,* 1999]:

$$A_i = \sum_i w_i x_{ij}$$

where x_{ij} is the score of the alternative with respect to the jth attribute, and the weight w_i is

a normalized weight, so that the $\sum w_i = 1$. The result will be selected the most preferred alternatives which has maximum value of A_i.

Design and Implementation of Web-based SDSS for Temporary Housing Site Selection

Haryana, Nahdhiyatul, and Prihantarto [2012] said that there are several parameters can be used on temporary housing site selection namely landform, landuse. It is also stated that hazard zone considered to be natural constraint on the selection. Based on the explanation, it can be analyzed several evaluation criteria map on site selection for temporary housing development as follow: (1) slope, (2) landuse, (3) access to population, and (4) local road access. The set of constraints map in this analysis include: (1) hazard zone (*KRB*), and, (2) conservation zone.

The following table illustrates the criterion data and the weighting. In the system prototype the weight and score of each criterion will based on user input (preference). The option will be given on combo box option from 1 to the number of criterion or alternatives.

Table 5. Criterion Weighting Illustration

Nr	Code	Criterion	Alternatives	Criterion Weiht	Alternatives Weight
1	S	Slope steepness	0- 2%	ws	X_1
			3-7%		X_2
			8-13%		X_3
			14-20%		X_4
			21-55%		X_5
			>56		X_6
2	L	Landuse type	dry farming	wL	X_{L1}
			wet Farming		X_{L2}
			Scrub or bare		X_{L3}
			land		X_{L4}
			forest		X_{L5}
			settlements		X_{L6}
			cultivation		
3	P	Access to population	0-200m	wP	X_{P1}
			200-400m		X_{P2}
			>400m		X_{P3}
4	R	Access to local road	0-100m	wR	X_{R1}
			100-200m		X_{R2}
			>200m		X_{R3}

If the constraints are stated as C1 and C2 and provided in binary data (1 for suitable site, for forbidden zone) then the decision rule to evaluate the site suitability (Atemporary housing) for temporary housing can be formulated as follows:

$$A\textit{temporary housing} = ((wS * xSj) + (wL * xLj) + (wP * xPj) + (wR * xRj))*C1*C2$$

where j indicates number of alternative. Based on the formula can be identified that the value will return to 0 if located on the forbidden zone. Whereas the most suitable locations will have value 1.

The following figures visualize example of input criterion and constraint maps for temporary housing selection. Figure 5a to 5e are the criterion maps while 5e and 5f are the constraints. As previously explained, all the data is actually stored as attributes in one table i.e. hexagon layers. Nevertheless, the application prototype allow to visualize each attribute as thematic map as depicted in the previous figures. The dataset was referred to several existing data with certain geoprocessing in *ArcGIS 9.3*.
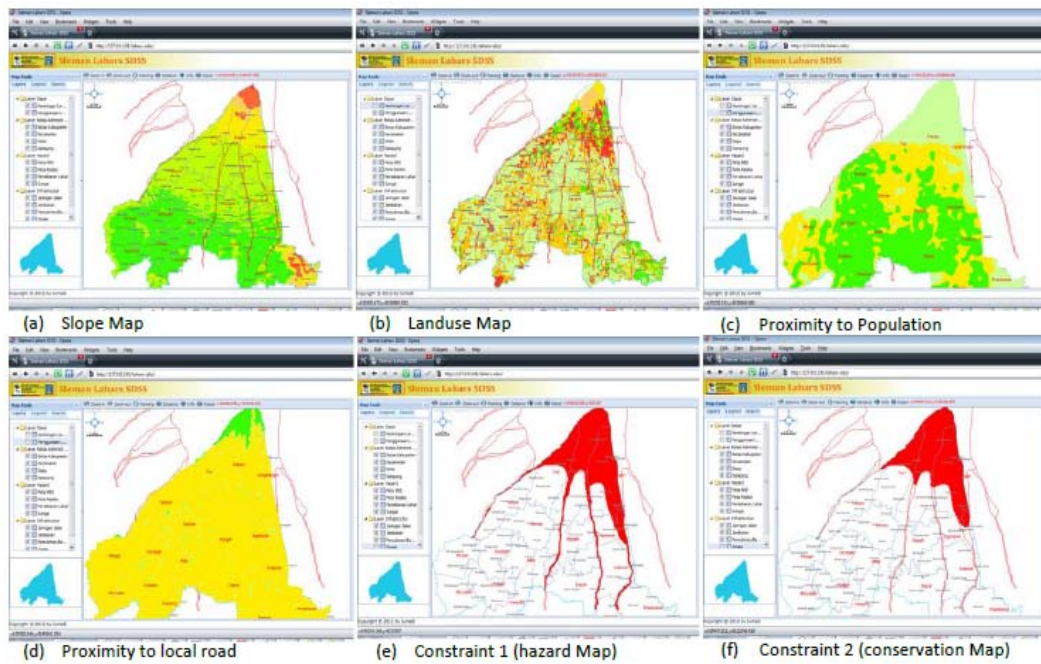
Figure 5. Examples of Input Data on Temporary Housing Site Suitability Selection

In the site selection processes, the application used three main steps: assigning weight of each criterion, calculating the normalized weight, and run and visualize the result on the map, each step will performed in different window which were called sequentially. In the first window, users can make weighting scenario based on their preference using scale of 0 to 100. The following Figures describe the scenario development and the statistical result.
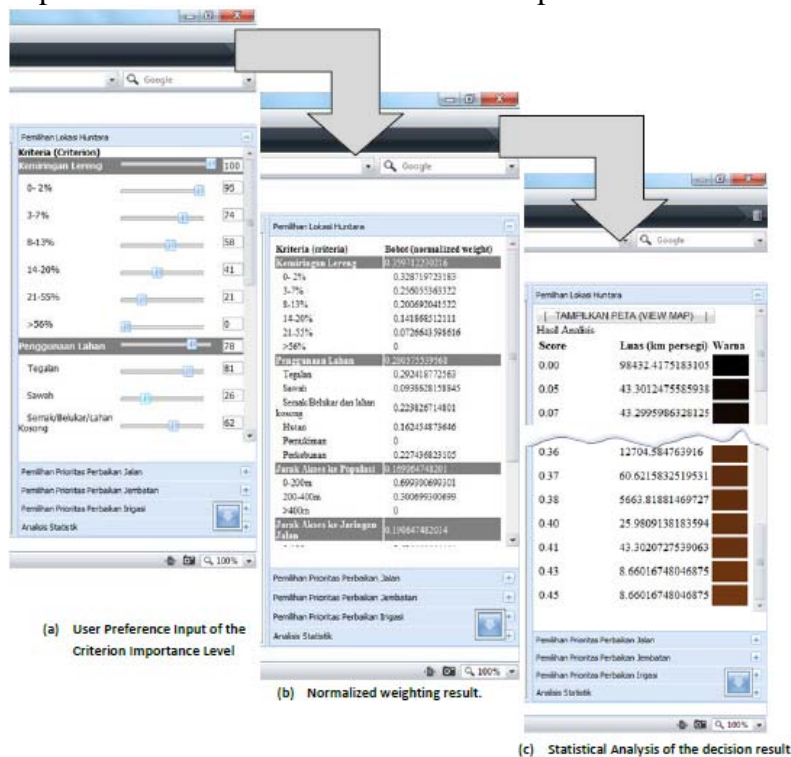

Figure 6. Weighting Scenario and the Statistical Result

Figure 6a depicted the screenshot of user preferences input form. It can be seen that each criterion and each alternatives is followed by weight selector (slider) which contains value 0 - 100. After the scenario executed, system will post the preferences input to rating module. The normalized weighting results will displayed in the form such depicted in Figure 6b. In this from user can continue the scenario run process by clicking the "next" button. This process will load decision rule module to make suitability index. The result will be presented such Figure 6c. Overall score, total area of the score and the color on the map will be presented on this form. The result also can be visualized on the map as presented in the following figures.
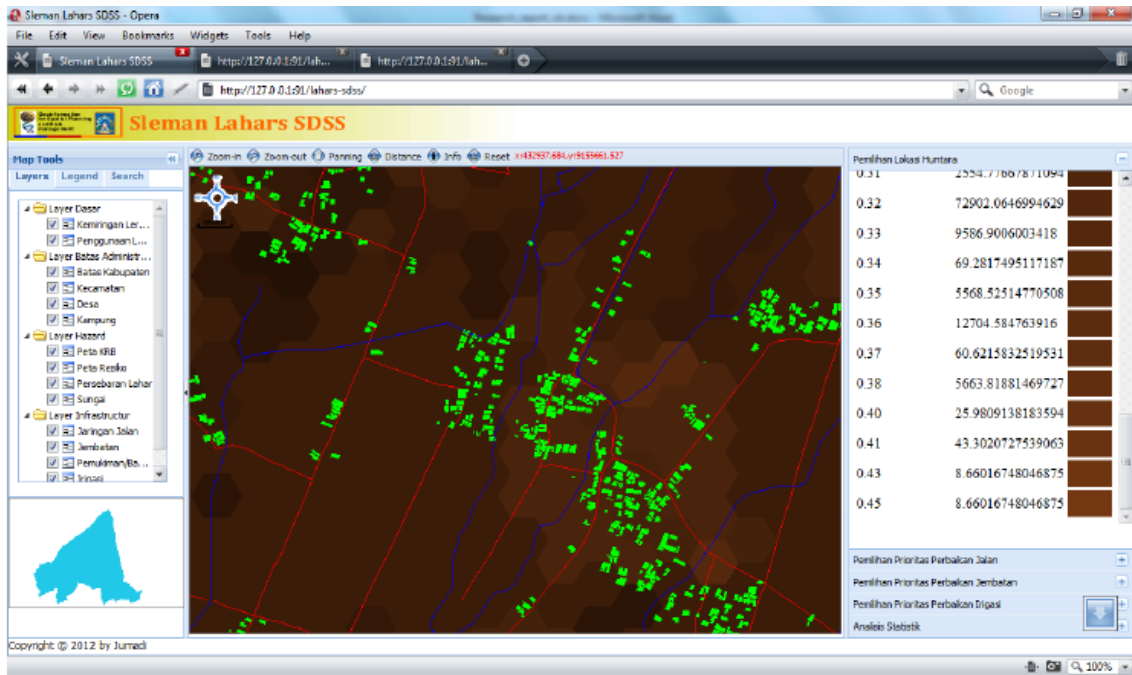

Figure 7. Example of Temporary Housing Site Selection Scenario Result

On the figure can be seen that the hexagon shape clearly presented if the map is zoomed to certain scale. The brightest hexagons indicate that the sites are the most suitable area for such purpose.

Making the data and scenarios shareable to the other users and the other application is the important part in collaborative disaster management. By this feature, user can publish what they found and decide to the other users and discuss the most appropriate decision. Difference users, in this case, might have difference preferences on the decision scenario processes, so that they have difference result. However, in some collaborative action they should apply the decision in the same case. Such problem need the involvement of decision maker, on making decision based on the decision analyses result. On the other hand, some users also can use the decision analysis result for the other application to make further analysis. Sharing the scenario result through *WFS* is applicable on this system. Figure 8 provide the example of scenario sharing to Quantum GIS using (Figure 8c) using *WFS* link (Figure 8b) which was generated from the system after scenario execution (Figure 8a).
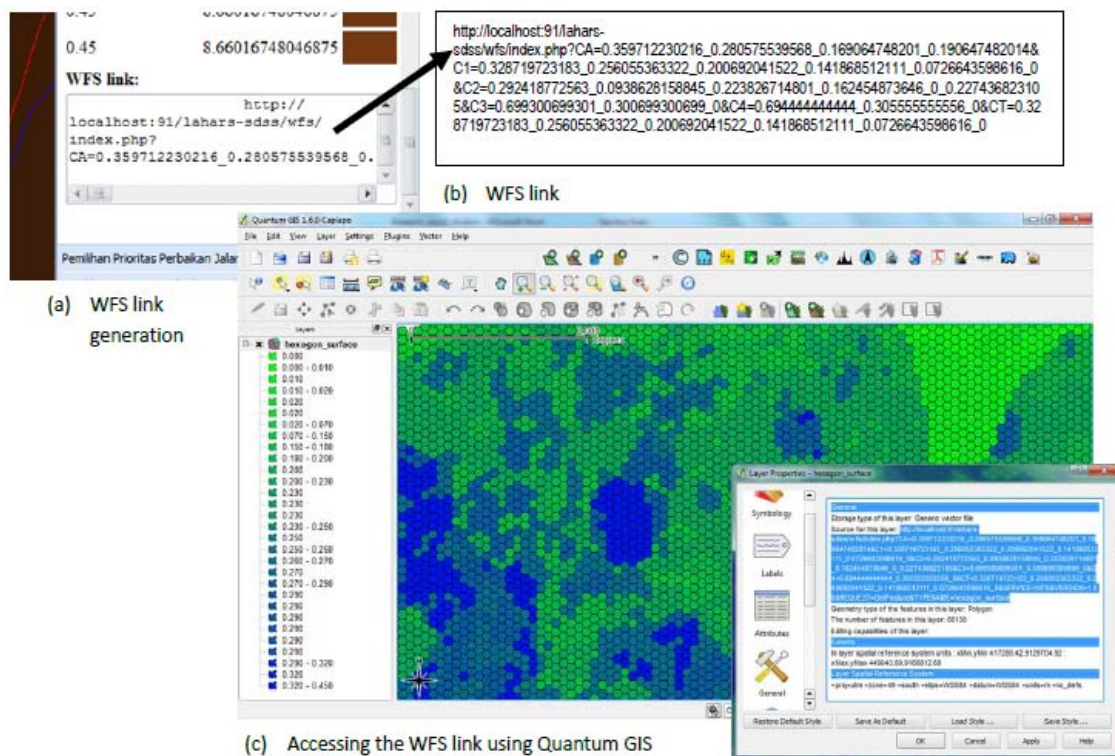
Figure 8. Example of Scenario Sharing with Other GIS Software using WFS

Evaluation Result

The evaluated items were based on ISO 9241 part 10, part 12 and part 13 [*Schimiguel, et. al.,* 2004]. The most striking features of the result are that 50% users felt that the interaction speed to the system was too low. It can be seen also that only 50% of users agreed that the mechanisms of the system were adapted to the user's language, cultural and individual knowledge. On the other hand, almost all users (80%) agreed that the contained information fulfill what they need. Nevertheless, the information content still needs to be improved as they were suggested. Moreover, the dialogue interactivity evaluation result showed that almost all users agree with the evaluation statement. Interestingly, only 70% of respondent agreed that menu map is clearly structured and ordered in the *SDSS* application prototype.

Finally, almost all users (80%) agreed that the application is useful to support decision making processes especially on response and recovery phases as they are now dealing with, but there are several feedbacks and suggestions: (1) distinguishing features among users with different interest. (2) involvement of citizen in the system such as participatory mapping tools on this system, (3) implementation of governmental regulation on the system, (4) the speed of application also becomes important issues during the evaluation processes. (5) the used data in this system should be updated with the new one because high dynamicity of lahars, (6) It was also recommended to provide data synchronization tools with provider. By this mean, the change of data from the sources can automatically update the data in the *SDSS* server, (7) Several respondents argued that the usage of "Yogyakarta Single Base Map" is not adequate for this system. They found that there are several differences in boundary digitations between the dataset and their own dataset, (8) Some additional map also suggested by several users, for

example: spatial planning map, evacuation route map, and so forth, (9) Lastly, some of them advise to improve the tools and the interactivity so that they application easy to use. A respondent said the application arrangement should be modified not too similar with conventional GIS application.

CONCLUSIONS

Based on the research objectives, there are several results can be concluded as follows:

1. *BPBD* has significant roles mainly in coordination and facilitate activities to conduct their responsibilities. Once the infrastructure (roads, settlements, or irrigation networks) damaged by the lahars, each actor is responsible for solving their own problems to work collaboratively. There are several roles which were identified during interview processes starting with lahars disaster event at certain areas. Each agency makes response and recovery plan and action based on their responsibilities. On their collaborative work, all decision makers from selected agencies agreed that spatial data is important in their communication. Unfortunately, they are realized that it is practically very limited and not adequate to fulfill their need.

2. Several data requirements were identified in this research. In the development of geodatabase (*DBMS*), the data contained physical condition such as slope, landuse, hazard, proximity to road network and so forth stored into hexagon grid table as mapping unit to simplify querying processes. While infrastructures data stored independently as line

or point type according to the suitable model for the infrastructure e.g. point for bridge, line for road networks. Beside spatial data, the infrastructures data also contain the properties and the condition of the infrastructure. In fact, the quistionaire result stated that 67% of respondents stated that spatial data is available in their agencies to support their decision making. However, investigation result indicate that the datasets are varied in scale and newness. Yogyakarta Single Base Map was used on this system to solve the problem. Unfortunately, the differences the dataset and their own dataset were found.

3. The application development mainly elaborated the three components of *SDSS* namely *DBMS, MBMS* and *DGMS* into simple web-based *GIS* application. In this case, the application prototype was developed based on the user requirements and the current applicable procedures in disaster management. Several decision making situation that need decision support tools were identified such as the highest priority of road reparation, bridge reparation and irrigation channel reparation. In this application, rating method was used on the *MBMS* to define users' preferences while Simple Additive Weighting Method was used as decision rule. The geodatabase and the *MBMS* was visualized as web-based interactive user interface (*DGMS*) to make the application operable. Furthermore, Web Feature Service was implemented to make the system widely interoperable.

4. The test and evaluation of the SDSS prototype was conducted.

On the evaluation processes, brief overview and explanation were given before the application testing session. Afterwards, they tried to use the application for certain purposes. They filled a questionnaire as evaluation tool after the testing session. There are three main issues which were evaluated after they tried to use the prototype. The issues were referred to the ISO 9241 standard specifically the part of the interface evaluation of Web GIS applications. Almost all of them give a good mark to the system. However, some suggestion and feedbacks need to be accommodated to make the system fully implementable and user friendly. The main notes to improve the usability of the system are: user privilege management, speed of the application, features simplification, citizens involvement as participatory *GIS*, data completeness and newness, and data synchronization.

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