DEVELOPMENT OF X-BAND RADAR DATA-BASED SNAKELINE FOR PREDICTING SEDIMENT DISASTER

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Abstract. Sediment-related disaster are terrible disaster that can catastrophically impact to facilities and people must to keep in mind to make sediment-related disaster information that can be predicted from rainfall and response of drainage area by using snakeline. This research produce the important indices on precipitation related to debris and shows current status of the stage of response of drainage area against rainfall by using a couple of short and long term indices. It shows the water storage volume in soil layer with calculation of soil water index (SWI) by using X-band MP (Multi Parameter) rainfall radar data that has been installed at the top of Merapi Mountain (Merapi Museum). The snakeline can be used as monitoring and observation tools of SWI changes in response to rainfall intensity in Boyong river (BO-D5) and works as a database for the next research in identifying criteria for warning. Although there was no record of sediment disaster occurrence, at least from the result of snakeline it was confirmed that from June 2016 – June 2017 with 80.28 mm SWI maximum values has not yet become the maximum limit of SWI value for lahar occurrence in Boyong drainage area (BO-D5).

Keywords : long-term rainfall, short-term rainfall, snakeline, soil water index, x-band radar

I. INTRODUCTION

Merapi was erupted recently in 2010 and effected in every river around Merapi and it contain almost 140 million m^3 of sediment in the upstream after the eruption. Merapi produce pyroclastic flow, lava ejection with hot ash clouds and lahars. Pyroclastic materials that was ejected during eruption caused devastation of the side of the mountain, as well as frequent debris flows. When there is rainfall at a cetain intensity and duration, also sediment produce still provide in the upstream of merapi, it could be triggered mass movement (rock, soil, water, mud, etc) which could be affect to facilities or people and change of topography.

At 3-4 November 2010, there was heavy rain that triggered debris flow (mixtures water and rock sediment) cascading down the Kuning, Gendol, Boyong and Opak on the slope of volcano and destroyed the bridge and riverbanks. Although the upper layer of accumulated volcanic ash, which has low infiltration, is though to be washed away, it does not rule out the possibility that sediment is still there until now in that area so when it start to rain, pay attention to disaster possibility.

Hazard information on a snakeline whether sediment-related disaster risk is high or low could be informed by using X-band MP Radar (Multi Polarimetric Radar). This system facilities a sophisticated measurement based on rainfall intensity (calculated using the distribution of precipitations and the polarization phase difference) and more sensitive to rain attenuation phenomena. This sediment disaster claimed many victims so it a must to provide some technological and system support for future information provision.

The purpose of this research is to understand current stage response information of drainage area against rainfall by using short and long term indices on a snakeline (rainfall characteristics) based on rainfall indices (Rainfall Intensity (every 2 minutes) and Soil-Water Index) by using X-band Multi Parameter Radar in the upstream of each river around Mount Merapi in Boyong River. The combination of setting rainfall indices and X-band Multi Parameter Radar which is more scientific presicion of timing and location, sensitive to rain attenuation phenomena and monitoring spatial distribution of rainfall can be useful for predicting sediment disaster.

II. METHODOLOGY

A. *Research location*

This research is conducted in Boyong River around Mount Merapi as shown in Fig.1. X-band MP radar (Multiparameter Polarimetric Radar)is used for monitong rainfalls produced by Furuno Japan with WR-2100 model and have been installed in the top of Merapi Museum with a fixed observation area was set within 30 km. The database in use are from SSDM (Support System in Decision Making) as a part of IGIS-MSD Simulator and DEM data as an input for topography data is using ALOS3WD 15m (DSM type).

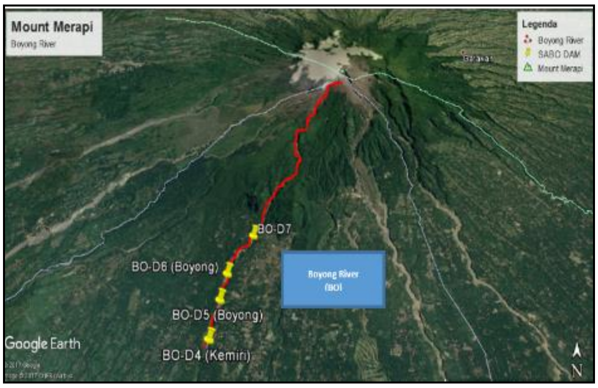

Fig.1. River flow of Boyong River with SABO DAM

B. *Rainfall indices*

The are many history of various rainfall indices used before but the development of rainfall indices always needed for establishing early warning system.

Soil Water Index is used as an indicator of the increasing the risk sediment-related sediment disaster as a standar for presenting sediment disaster warning information.

Soil Water Index is a concept model that uses a calculated value of the total water depth of a three layer tank model estimated using fixed parameters for each 5-km mesh grid mesh in Japan (Okada, 2005 in Osanai et all, 2010) as shown in Table 1.

Table 1. Soil water index parameters

Tank parameter	First tank	Second tank	Third tank
Outflow Height (mm)	$L_{11} = 15$ $L_{12} = 60$	$L_{21} = 15$	$L_{31} = 15$
Outflow Coefficient (1/h)	$a_{11} = 0.1$ $a_{12} = 0.15$	$a_{21} = 0.05$	$a_{31} = 0.01$
Coefficient of Permeability (1/h)	$a_{10} = 0.12$	$a_{20} = 0.05$	$a_{30} = 0.01$

C. *Soil water index using tank model*

Tank model is hydrological model for the conversion process and the modified time-area-concentration diagram for the concentration process. Tank model using soil water index is aimed to identified the risk of sediment-related disasters and to see how much rainfall in the soil is accumulated, by dividing the ground surface into a 5 km square lattice (mesh) and calculate with each lattice but does not accurately estimate the accumulated of rainfall in the ground.The soil water index is used as an indicator of the increasing the risk of sediment-related disaster caused by heavy rain.

Soil water index is the total of the storage amount remaining in each tank. This corresponds to the amount of moisture in the soil. As it rains, rainfall will flow on the surface, flow into the river and soak into the ground.

The tank model indicate the precipitation and evaporation process into the tank-layer model as shown in fig. 2.

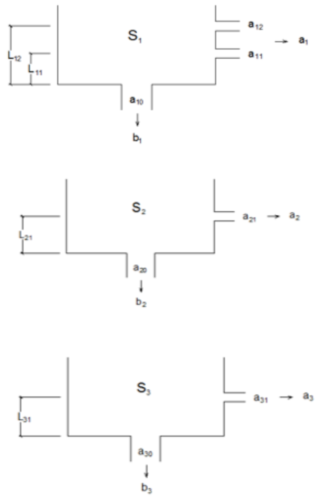

Fig. 2. Concept of Tank Model

$dS_{11} = S_1(t) - L_{11}$ (1)

$dS_{12} = S_1(t) - L_{12}$ (2)

$dS_{21} = S_2(t) - L_{21}$ (3)

$dS_{31} = S_3(t) - L_{31}$ (4)

$q_1(t) = (a_{11}.dS_{11}) + (a_{12}.dS_{12})$ (5)

$q_2(t) = (a_{21}.dS_{21})$ (6)

$q_3(t) = (a_{31}.dS_{31})$ (7)

$b_0 = RI . \triangle t$ (8)

$\triangle t = \frac{1}{30}$ (9)

$b_1 = a_{10}.S_1(t).\triangle t$ (10)

$b_2 = a_{20}.S_2(t).\triangle t$ (11)

$b_3 = a_{30}.S_3(t).\triangle t$ (12)

$c_1 = q_1 . \triangle t$ (13)

$c_2 = q_2 . \triangle t$ (14)

$c_3 = q_3 . \triangle t$ (15)

$S_1(t + \triangle t) = S_1(t) - b_1 - c_1 + b_0$ (16)

$S_2 (t + \triangle t) = S_2 (t) – b_2 – c_2 + b_1$ (17)

$S_3 (t + \triangle t) = S_3 (t) – b_3 – c_3 + b_2$ (18)

Soil water index = S1 + S2 + S3 (19)

III. ANALYSIS AND DISCUSSION

A. Identified drainage area

The original DEM file for ALOS3WD is S07452E110232_S07804E110567_ UM_DSM.tif (5m mesh, EPSG 32749) for Merapi area but it processing with change the mesh into 15m as shown in Fig.3.

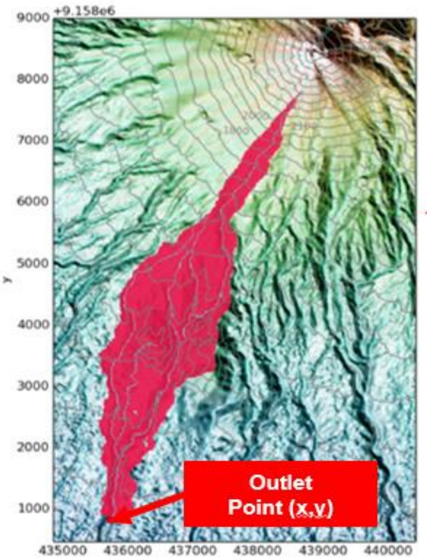

Fig.3. The result of identified drainage area by using ALOS3WD 15 m.

As identified in Table 2, the drainage area has ID name and the result of above processing is ESRI shape files, geotiff of drainage area and text of outlet points coordinate contains .dbf, .prj, .shp, .txt, .shx, .tif format whis is will be used for extracting XMPR data for next process as identified fig.4.

Table 2. Identity for Boyong drainage area

Identity of River	
River name	Boyong River
ID name	ID_1-0-0-0-0
Outflow control point	SABO BO-D5
Latitude position	-7.609552
Langitude position	110.417386

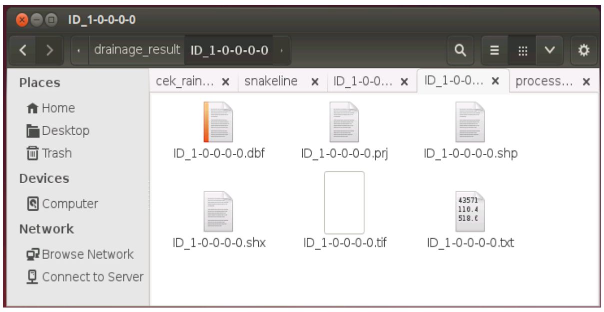

Fig. 4. Format file from the result of identified drainage area

B. Extracting XMPR data in drainage area

For extracting rainfall data by identified drainage data, ERSI shape file of a set of .shp, .shx, .prj is necessary then overlaying drainage data (geotiff/shapefile) and rainfall data (geotiff) with some script and make another script contains command to call them. The result after extracting rainfall data is .txt file format which contains time series in each drainage area which identified in Fig. 5 and area information of clipped drainage area as shown in Fig.6.

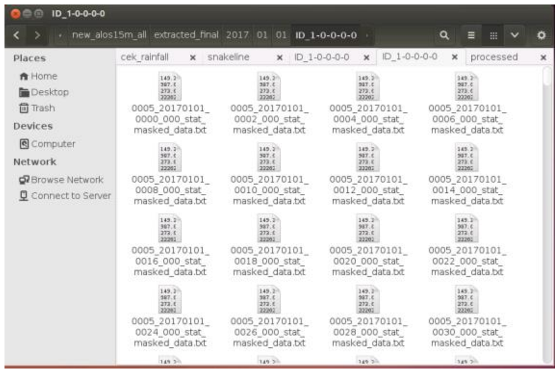

Fig. 5. Result of extracting rainfall data

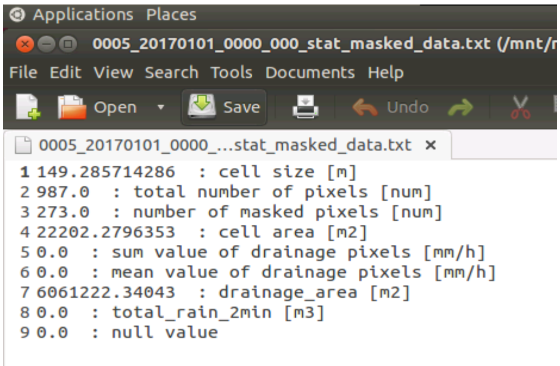

Fig.6. Area information of clipped drainage area

C. Hyetograph

The result of extracting rainfall is time series of rainfall data which are consist of average rainfall intensity, total rainfall drainage & area. Some command are used by using script (shellscripts) to make rainfall series as shown in Fig. 7 and hyetograph ON October 20th as shown in Fig.8.

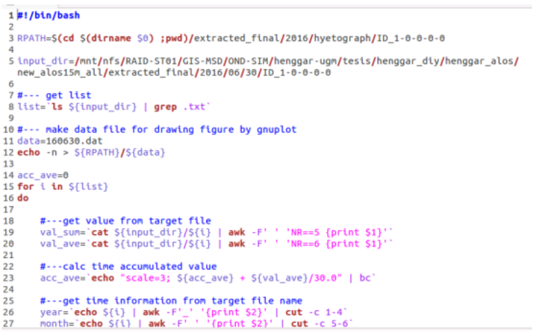

Fig.7. Script to make rainfall series

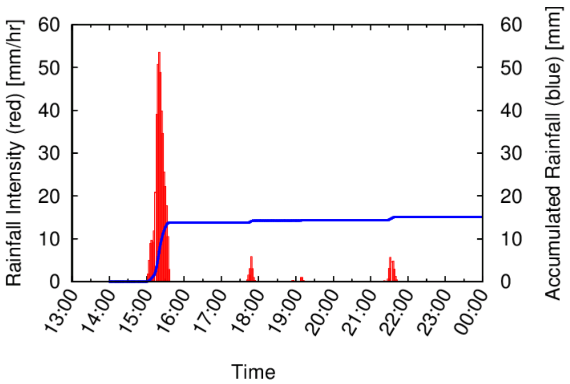

Fig.8. Hyetograph on October 20th 2016 in Boyong drainage area (BO-D5)

D. *Snakeline*

The three-layer tank model program was coded and debugged by using Fortran program that supported numerical analysis and scientific computation, structured programming, array programming, high performance computing on supercomputers and reasonable degree of portability between computer systems.

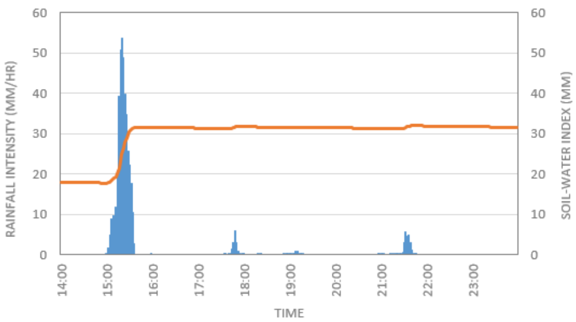

Fig. 9. The relationship of rainfall intensity (mm/hr) and soil water index (mm) on October 20th 2016 as the highest intensity during June 2016– June 2017

Figure 9 shows the relationship between time series of rainfall intensity (mm/hr) and SWI. Figure 5.29 indicates the behavior of snakeline during October 20th 2016, there were occurrence of rain with the highest intensity within several minutes and the relation with SWI. SWI is represent the concept model of soil water content and elucidate soil water content during the rainfall event. As rainfall intensity reach the highest value, soil water index will also increase. A higher value of SWI show a higher risk of sediment disaster initiation.

The snakeline in this research produced the probable SWI in Boyong drainage area and shows the current stage of response drainage correspond to non-occurrence of lahar so for the boundary of sediment-related disaster warning using the SWI standard reference values from JMA. The criteria value of SWI for issuing preliminary of sediment-disaster warning based on rainfall characteristic in Boyong drainage area. Figure 10 shows the movement of rainfall and SWI on snakeline in June 2016. The value of initial condition was set as 0 (zero) for the starting of dataset (June 2016) and assumed that the condition of soil in the beginning of dataset is dry or not contains soil water content.

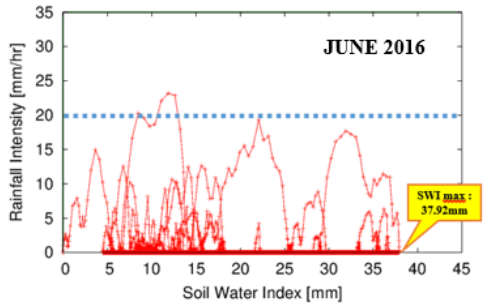

Fig.10. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from June 2016

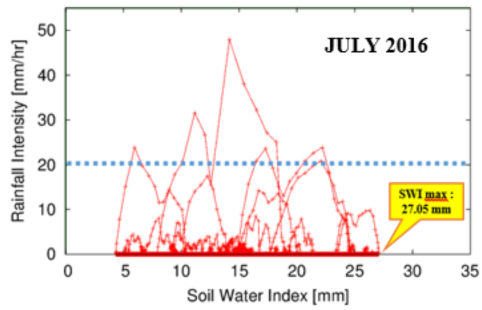

Fig.11. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from July 2016

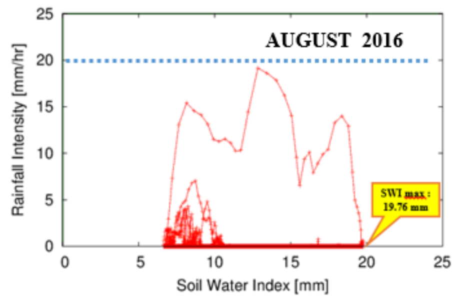

Fig.12. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from August 2016

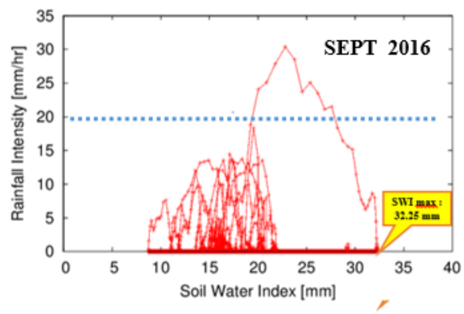

Fig.13. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Sept 2016

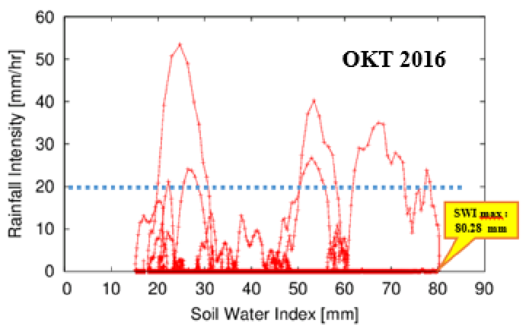

Fig.14. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Okt 2016

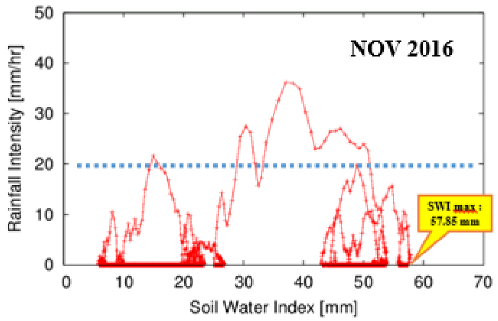

Fig.15. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Nov 2016

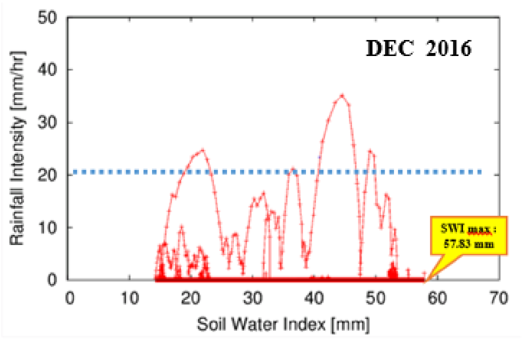

Fig.16. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Dec 2016

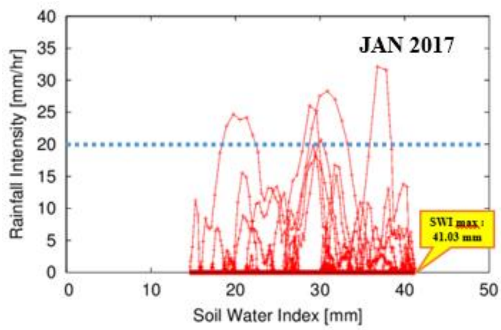

Fig.17. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Jan 2017

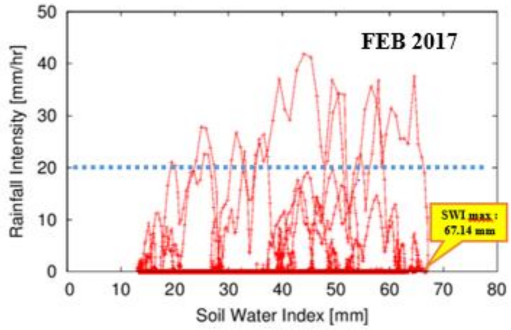

Fig.18. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from Feb 2017

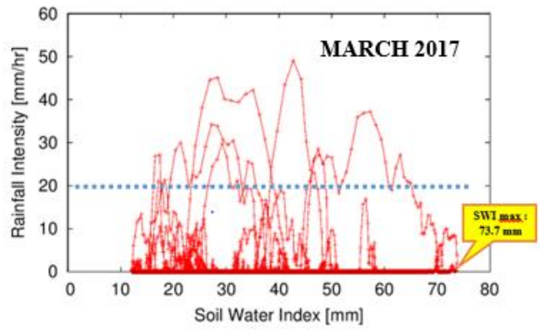

Fig.19. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from March 2017

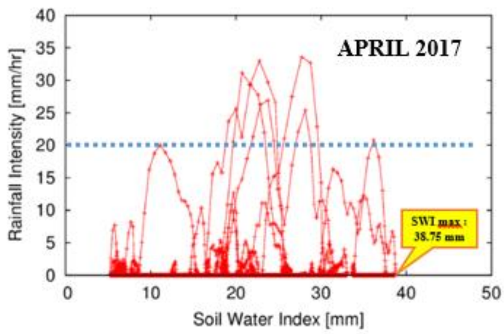

Fig.20. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from April 2017

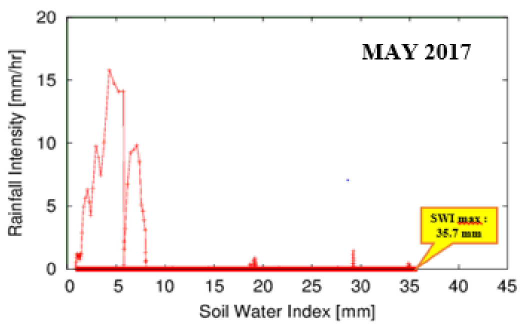

Fig.21. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from May 2017

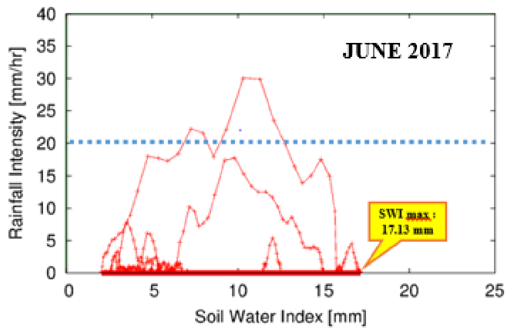

Fig.22. Snakeline of rainfall intensity and SWI in Boyong River (BO-D5) from June 2017

Figure 10 until Figure 22 shows the behavior of SWI in response of time series changes on snakeline. The changes in SWI and a higher value of SWI shows higher risk closely related to sediment disaster. Figure 17 shows although there is no rainfall occur, the SWI still show the value which then gradually decreased due to phenomena of soil water content as influenced by present and antecedent rainfall. The rainfall then increased the SWI to its maximum value resulting in a mass movement.

The following Table 3 shows SWI reaches to maximum as response to rainfall in each month and information for preliminary SWI standard reference value of sediment disaster occurrence (alarm warning) that was set by JMA (120 – 160 mm).

Table 3. SWI changes in each month in Boyong drainage area

No	Month-Year	Rainfall intensity max (mm/hr)	Rainfall condition	SWI max (mm)	Rank of SWI max	Excceding SWI standard value (120-160 mm)
1	Jun-16	23.18	LL	37.92	8	Not exceeding
2	Jul-16	47.97	SH	27.05	11	Not exceeding
3	Aug-16	19.15	SL	19.76	12	Not exceeding
4	Sep-16	30.37	LH	32.25	10	Not exceeding
5	Oct-16	53.51	LH	80.28	1	Not exceeding
6	Nov-16	36.19	LH	57.85	4	Not exceeding
7	Dec-16	35.13	LH	57.83	5	Not exceeding
8	Jan-17	32.09	LH	41.03	6	Not exceeding
9	Feb-17	41.86	LH	67.14	3	Not exceeding
10	Mar-17	49.11	LH	73.7	2	Not exceeding
11	Apr-17	33.59	LH	38.75	7	Not exceeding
12	May-17	15.79	SL	35.7	9	Not exceeding
13	June-17	30.08	SH	17.13	13	Not exceeding

Based on the result of SWI changes and rainfall conditions were classified into 4 types, short duration-high intensity (SH), short duration-low intensity (SL), long duration-high intensity (LH), long duration-low intensity (LL). According to the result in Figure 5.27, it was assumed that the rainfall > 20 mm/hr is categorized as high intensity.

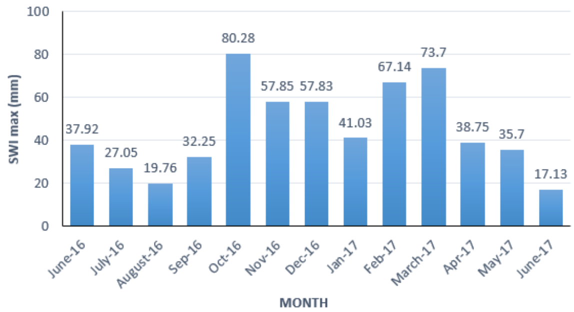

Fig.23. SWI max changes in Boyong drainage area (June 2016 – June 2017)

October 2016 until March 2017 shows the rapid increase in SWI changes correspond to rainfall conditions tend to be higher and continuously, due to rainy season, than other month but still not exceeding the standard reference value that was set by JMA. The research is using criteria that was set by JMA due to lack of sediment disaster occurrence data within dataset range and of course, the criteria for warning should be set based on rainfall data recorded as triggering disaster and the occurrence of disaster itself in Boyong drainage area.

Table 3 shows the long duration-high intensity (LH) events occur in September 2016 – April 2017. It shows that long duration-high intensity (LH) type associated with a gradual rise and subsequent constancy of SWI. As rainfall intensity reach the highest value, soil water index will also increase. A higher value of SWI show a higher risk of sediment disaster initiation. A rapid increase in SWI reflects a sporadic intense rainfall and a rapid increase in SWI combined together with high SWI values leads to sediment disaster. Therefore, in such extremely long rainfall events and phenomena of rainfall condition, continuous and accurately observation of the changes in the SWI is necessary. Since the long duration-high intensity (LH) type is greatly influences the SWI changes, so this type needs to be paid attention for sediment disaster prediction. This condition can be used as preliminary consideration for sediment disaster monitoring.

The SWI has been used in Japan for nationwide sediment disaster warnings. This research is trying to implement the SWI on snakeline for Boyong river (BO-D5) to show current status of the stage of response of Boyong drainage area against rainfall.

The occurrence/triggering condition of sediment disaster is lying between occurrence and non-occurrence events. Several sediment disaster events are needed to decide the critical condition of triggering sediment disaster. Since there was no record of sediment disaster occurrence, the judgement of critical condition of triggering sediment disaster cannot be generated at this moment. At least from the result of snakeline, it was confirmed that from June 2016 – June 2017 with 80.28 mm SWI maximum values does not exceed the standard reference value that was set from JMA. It means for 80.28 mm of SWI value has not yet become the maximum limit of SWI value for lahar occurrence in Boyong drainage area (BO-D5). The maximum limit of SWI value can be generated if sediment disaster occurrence are available (for identifying critical line).

This snakeline can be used as monitoring and observation tools of SWI changes in response to rainfall intensity in Boyong river (BO-D5) to produce the sediment-disaster information system. This snakeline is also works as a database for the next research in identifying critical line or criteria for warning.

IV. CONCLUSION

Several conclusions for this research are as following:

1. X-band MP (Multi Parameter) rainfall radar has benefit to estimate rainfall amounts and precipitation particle size distribution. It is effective to establish precipitation estimation methodology and produce real-time public disclosure of rainfall information using the internet for preliminary sediment disaster prediction.
2. The fluctuation of time series and spatial distribution of rainfall by using X-band MP radar rainfall have produce the phenomena of rainfall condition. Based on X-band MP radar rainfall, there was a shift in the rainy season which generally took place starting in November, now shifting forward starting in October.
3. By using ALOS3WD which has temporal coverage from 2006-2011, resulted in reading of topographic data which more reflect the current state of Boyong drainage area (BO-D5) in Mt. Merapi.
4. The condition of soil water content in Boyong drainage area as represented in soil water index is used to identify the SWI changes in response between rainfall condition and recent topography.
5. The rapid increase in SWI changes from October 2016 until March 2017, correspond to rainfall conditions tend to be higher and continuously, due to rainy season, than other month but still not exceeding the standard reference value of SWI (120 – 160 mm) that was set by JMA.
6. The long duration-high intensity (LH) event occur in September 2016 until April 2017. It shows that long duration-high intensity (LH) type associated with a gradual rise and subsequent constancy of SWI and needs to be paid attention for sediment disaster prediction. As rainfall intensity reach the highest value, soil water index will also increase. A higher value of SWI show a higher risk of sediment disaster initiation.
7. Although there was no record of sediment disaster occurrence, at least from the result of snakeline it was confirmed that from June 2016 – June 2017 with 80.28 mm SWI maximum values does not exceed the standard reference value of SWI (120 – 160 mm) that was set from JMA. It means for 80.28 mm of SWI value has not yet become the maximum limit of SWI value for lahar occurrence in Boyong drainage area (BO-D5). The maximum limit of SWI value can be generated if sediment disaster occurrence are available (for identifying critical line).

V. SUGGESTION

Of all the research results, there are several suggestions for a better next research as following:

1. The recent DEM data should be used for better spatial and accurate topography to combine with X-band MP rainfall radar as World_view (Digital Globe) which has 2011 – now for temporal coverage and 2m of resolution but it should be considered since its kind of commercial DEM type.
2. The calculation of area averaged rainfall in extracting rainfall from X-band MP rainfall radar should be developed so the value of rainfall distribution in every pixel could be identified.
3. The effect of spatial resolution between drainage area and rainfall data should be considered correspond to time and scale for a better-extracted data.
4. The SWI analysis should be applied on the other drainage area to identify the behavior of SWI as a current stage response of drainage area and compare the SWI maximum in each drainage.
5. NSWI (Normalized SWI) method can be used as next research to compare the soil water content directly among places with a couple of record of SWI in the place of the past decade. NSWI value of more than one data shows the highest value of SWI over past decade, which indicates the condition most likely to initiate sediment disaster in the place.
6. The record of disaster occurrences should be applied in snakeline as the boundary of occurrence and non-occurrence rainfall to identify critical line.
7. The CL (Critical Line) and criteria for warning should be applied on snakeline to establish more accurately for sediment disaster warning information and estimate warning level. A sediment disaster alert will be issued when the CL is predicted to be exceeded by the expected rainfall.
8. The snakeline and display of dangerous drainage area should be used as real time series and always available in web systems automatically to monitor the risk of sediment disaster in several catchment.

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