ANALYSIS OF EFFECTIVE RAINFALL INTENSITY AND WORKING RAINFALL FOR BASIC WARNING CRITERIA DEVELOPMENT ON LAHAR FLOW EVENT

Fitriyadi
Integrated One Gate Service Agency of Cimahi, West Java, INDONESIA
Email: yadi_fitri@yahoo.co.uk

ABSTRACT

After the eruption of Mount Merapi in October-November 2010, at least 140 million m3 volcanic material piled on the back of Merapi and some flows shortly on and after the eruption through the rivers that disgorge on peak of Merapi. To date, the impact from the silting of the river and falling volcanic material from the top of Merapi cause lahar flood which swept through areas far enough from the peak of Merapi. Given the dangers and impact caused by the lahar flow, as well as the limitations of existing data, the simplest method by perform rainfall data analysis is expected to predict lahar flow events in Gendol river.
The analysis method performed by setting of standard rainfall for warning and evacuation were used for prediction of sediment disasters based on Guidelines for Development of Warning and Evacuation System Against sediment Disasters in Developing Countries, published by the Ministry of Land, Infrastructure and Transport, Infrastructure Development Institute - Japan, namely: (1) specifies serial rain which total amount of rain ≥ 80 mm, (2) Calculations on working rainfall (RW) and working antecedent rainfall (RWA), (3) Calculation on effective rainfall (RE), effective time, and effective rainfall intensity (IE), (4) Make a graph of effective rainfall intensity and working rainfall, (5) Predict the potential for debris flow by calculating the probability of debris flow occurrence on Gendol river.
The research results showed that the number of reviewed serial rain with total value ≥ 80 mm is 9.28% of the whole serial rain, and 12.5% of them caused lahar flow in Gendol River. Debris flow occurrence probability on total rainfall amount of ≥ 80 mm that may occur on Gendol River amounted to 1.89%. This value represents less possibility of debris flow in Gendol River, this is due to the rain conditions in the Gendol Watershed different from the situation in Japan as well as the limitations of the available data. It is recommended for further research on the limitation of total rainfall in accordance with the conditions in Gendol Watershed by considering other parameters becoming the lahar flow controller factor. Further, it is necessary to perform the analysis using rain catchment method by averaging rainfall values on each of serial rain.

Keywords: lahar flows, working rainfall, Gendol River

1 INTRODUCTION

Material from Mount Merapi eruption produced pyroclastic flows, lava and lahar flows that can lead to disaster on people, land degradation, and other infrastructure damage. After Mount Merapi eruption in October-November 2010, at least 140 million m3 of volcanic material deposited on the back of Merapi and some flows shortly on and after the eruption through the rivers that disgorge on peak of Merapi. To date, the impact from the silting of the river and falling volcanic material from the top of Merapi cause lahar flood which swept through areas far enough from the peak of Merapi. Given the dangers and impact caused by the lahar flow, as well as the limitations of existing data, the simplest method by perform rainfall data analysis is expected to predict lahar flow events in Gendol river.

This study aimed to: 1) develop graphic correlation between rainfall intensity and cumulative rainfall from a series of rain to determine whether or not the possibility of debris flows on Gendol, 2) determine the probability of debris flows in a series of rain that may occur in Gendol River.

The scope of this research are: 1) the catchment area which reviewed is Catchment Area Gendol with an area of 24 Km2, 2) rainfall data used are taken from the three raingauge stations closest with Gendol watershed and considered to represent the characteristics of rainfall in the Gendol watershed within 6 last years (1996 - 2011), that are Deles, Sorasan and Batur raingauge stations, 3) rainfall data analysis performed by the method of setting the standard rainfall for warning and evacuation are used to predict sediment disasters based “Guidelines for Development of Warning and Evacuation System Against sediment Disasters in Developing Countries”, published by the Ministry of Land, Infrastructure and Transport Infrastructure Development Institute - Japan, 2004, 4) Discussion of early warning criteria is limited to the phase of correlation graphs preparation between rainfall intensity with cumulative rainfall from a series of rain and to determine probability of debris flows event in a series of rain may occur in Gendol River

2 LITERATURE REVIEW

Lahar is a rapid movement of water and the mixture of solid material such as large rocks, sand, gravel and vomit forth from the volcanic eruption (Smith and Fits, 1989 in Haryono, 2011).

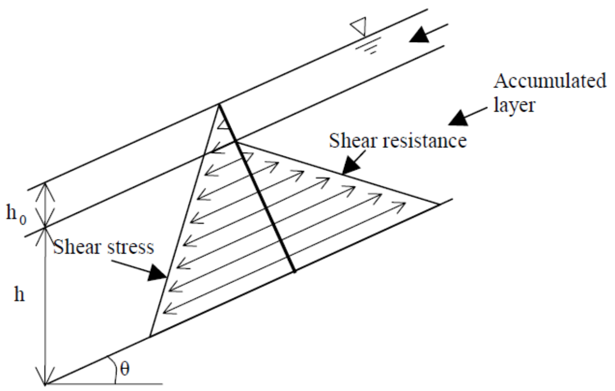
Both mechanical factors and incitant factors should be considered as the factors contributing to the occurrence of sediment disasters. The mechanical factors of debris flows are: 1) Topography of river basin, 2) Topography of river, 3) Unstable sediment, and incitant factors of debris flows are: 1) Rainfall, snowmelt, 2) Earthquake, volcanic activity.

In debris flows of the riverbed sediment accumulation type (sediment gradient type), a surface water flow is generated and its weight has a significant effect on the stability conditions of a slope. Also, as the soil mass is already saturated when a surface water flow is generated, the volumetric density of soil mass, γs, which was also used in Equation (1) is given as shown below, using the density of soil grain, σ, the density of water, ρ, and volumetric density of sediment, $C*$.

$$\gamma_s = C_* \sigma + (1 - C_*)\rho \\ = C_*(\sigma - C_*) + \rho \quad (1)$$

Accordingly, when the thickness of accumulated layer, h, and the depth of surface water flow, h_0 are used, the shear stress acting on the bottom of a soil mass, τ, becomes as follows:

$$\tau = [\{C_*(\sigma - \rho) + \rho\}gh + \rho g h_0]\sin\theta \quad (2)$$



Source : Guidelines for Development of Warning and Evacuation System Against Sediment Disasters in Developing Countries, MLIT, Infrastructure Development Institute – Japan, 2004.

Figure 1. A representation of stress distribution when a surface flow is present

On the other hand, if it is assumed that the only normal stress acting on the bottom of the soil mass is the effective stress of the soil mass, the pore water pressure existing in the soil mass can be ignored. Further, if cohesion of the soil mass is ignored by assuming it to be too small, the shear resistance, τL, becomes as shown below:

$$\tau_L = C_*(\sigma - \rho)gh\cos\theta\tan\phi \quad (3)$$

Then, the equilibrium equation between them becomes as follows:

$$[\{C_*(\sigma - \rho) + \rho\}gh + \rho g h_0]\sin\theta = C_*(\sigma - \rho)gh\cos\theta\tan\phi \quad (4)$$

If the value on the left side (shear force) exceeds that of the right side (shear resistance), a debris flow is caused. Hence, a critical slope gradient, $\theta\rho$, which distinguishes the occurrence and non-occurrence of a debris flow, is obtained by the following equation.

$$\tan\theta_P \geq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/h)}\tan\phi \quad (5)$$

Takahashi considered that only the forces that work between the grains are effective as the shear resistance, and expressed the critical gradient for the occurrence/non-occurrence of debris flows as shown below, using the grain size, d, instead of the thickness of accumulated layer, h.

$$\tan\theta_P \geq \frac{C_*(\sigma - \rho)}{C_*(\sigma - \rho) + \rho(1 + h_0/d)}\tan\phi \quad (6)$$

Within setting the standard rainfall to predict debris flows event, must be done with determining and calculating the various indices of rainfall. Rainfall indices used are; 1) A series of rain, continuous rainfall (RC), antecedent rain, antecedent rainfall (RA), 2) Working rainfall (RW), antecedent working rainfall (RWA) and deduction coefficient, 3) Inflection point A, inflection point B, 4) Initial rainfall (RI), 5) Effective rainfall (RE) , effective time, and effective rainfall intensity (IE).

Several previous studies by performing rainfall data analysis methods to predict the occurrence of debris flows, among other:

a) Sensitifitas Parameter Karakteristika Sedimen Terhadap Permulaan Gerak Aliran Debris pada Sistem Torensial (Wardoyo W, Faisal Fathani T, Legono D, 2010).
b) Temporal and Spatial Characteristics of Rainfall on The Southwest Slope of Mt. Merapi in Indonesia (Yasuhiro S, Hirofumi S, Haryanto, 1995).

c) Analisis Karakteristik Temporal Dan Spasial Hujan Untuk Mendukung Sistem Peringatan Dini Bencana Di Wilayah Lereng Merapi (Ansita Gupitakingkin Pradipta, 2011).
d) Community Based Warning and Evacuation System against Debris Flow in the Upper Jeneberang River, Gowa, South Sulawesi (Sutikno Hardjosuwarno, 2008).

3 RESEARCH METHODOLOGY

3.1 Research Locations

In this study, the location of the watershed reviewed is Catchment Area Gendol which the area of 24 km2, administratively located in Sleman district, Yogyakarta Special Region Province. Given the volume of material results in late 2010 eruption that accumulated in the upper Gendol River and some occurred cold lahar flows events, so the Gendol river area defined as study location.

3.2 Data Availability

This study uses secondary data obtained from various sources. The data provided in this study among are: 1) location of rain gauges stations, 2) rainfall data, 3) debris flow event data in river Gendol.

3.3 Data Processing

Stages of data processing performed in this study were:

a) Series of rain determination;
b) Calculation of working rainfall (RW) and working antecedent rainfall (RWA);
c) The calculation of effective rainfall (RE), effective time, and effective rainfall intensity (IE);
d) Charting of effective rainfall intensity and working rainfall;
e) Potency of debris flow predictions.

3.4 Setting of Standard Rainfalls

Due to the limited debris flow event data available which has not been obtained the exact timing of debris flows and only date listed on debris flows event, then in setting of standard rainfall for estimating debris flows disasters used method B. Method A can be used if the exact time of debris flows event is known, because in method A using 1-hour rainfall intensity before the debris flows occur for the Y axis.

4 RESULT AND DISCUSSION

4.1 Total Rainfall

Calculation of total rainfall was conducted by grouping rain event into a series of rain. A series of rain consists of several rain events with an interval less than 24 hours. If the interval rain event each other exceeds to 24 hours, it is not counted as a series of rain. Terms series of rain which could be trigger the debris flows is a series of rain with minimum high of 80 mm (Guidelines for Development of Warning and Evacuation System against Sediment Disasters in Developing Countries, MLIT, Infrastructure Development Institute – Japan, 2004).

After having obtained series of rain with a total high of 80 mm or over, the total series of rain combined with antecedent rainfall from d1 to d7 days before series of rain. For more details, it presented in Figure 2

Based on series of rain charts in Figure 2, can be calculated RWA value from Deles raingauge station. After rain data processing from Deles raingauge station into series of rain with total amount of 80 mm or over, its known numbers of series of rain turns does not exist according to date of the debris flows events in Gendol River. Therefore, most of the rainfall data processing is done from Batur and Sorasan raingauge stations.

Based on Batur and Sorasan raingauge stations data processing obtained 6 (six) series of rain with total depth of 80 mm or over corresponding with the data on debris flows event in Gendol river. The data events are presented in Table .1

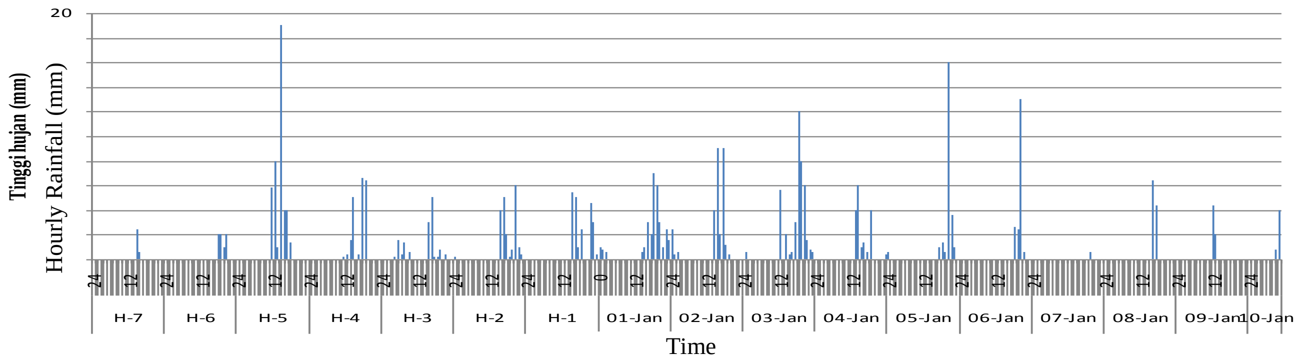


Figure 2. A series of rain from Deles Raingauge Station, 25/12/2005 9:00 am to 10/01/2006 10:00 am

Table 1. The Series of Rain on Sorasan and Batur Raingauge Station which Corresponding with Debris Flows Event in Gendol River.

No	Date Event	
	Series of rain on Sorasan and Batur raingauge stations	Debris Flows event in Gendol River
1	12 - 22 Dec 2006	21 Dec 2006
2	11 - 26 Feb 2007	23 Feb 2007
3	4 - 21 Apr 2007	19 Apr 2007
4	30 Dec 2009 - 17 Jan 2010	17 Jan 2010
5	1 – 10 Jan 2011	8 Jan 2011
6	14 – 24 Mar 2011	19 and 22 Mar 2011

From the limitations of data on drawing the graph, data processed from Deles raingauge station is used as non-occurrence rainfall and data processed from Batur and Sorasan rain gauge stations are used as occurrence rainfall.

4.2 Working Rainfall and Effective Rainfall Intensity

Working Rainfall (RW) which has been plot in the graphic is the sum of rain per event with RWA then accumulated as shown in Table 2. The RWA calculation results are used as a plot data at the X abscissa in the graphic. Effective rainfall intensity obtained by dividing effective rainfall intensity with effective time.

4.3 Rainfall Graphic Plotting Result in Gendol River

Based on processed series of rain data at Batur raingauge station which happens as written in Table 1, obtained 6 (six) point calibrated with date of debris flows event. This data used in occurrence rainfall plot and figured in Table 3. The non-occurrence rainfall and occurrence rainfall plot data result shown in Figure 3.

Table 3. Occurrence Rainfall Data (Batur and Sorasan Rain gauge Stations)

Table 2. Example of calculation RW in Deles Station 25/12/2005 9:00 am to 10/1/2006 10:00 am

Day	Amount of rain per event (mm)	Deduction coefficient (a_t)	Rain t-days before (d_t)	Total rainfall (mm)	Working rainfall (mm)	Effective Intensity (mm/jam)
d_7	3	0,007813	0,0234375			
d_6	7	0,015625	0,109375			
d_5	43,2	0,03125	1,35			
d_4	24,2	0,0625	1,5125	R_{WA} = 9,1		
d_3	10,4	0,125	1,3			
d_2	19,4	0,25	4,85			
d_1	0	0,5	0			
25/12/2005- 01/01/2006					9,1	
01/01/2006- 02/01/2006	31				40,1	
02/01/2006	25,6				65,7	
03/01/2006	0,6				66,3	
03/01/2006	5,6				71,9	
03/01/2006	35				106,9	
04/01/2006	17				123,9	
04/01/2006- 05/01/2006	1				124,9	
05/01/2006	23,6				148,5	
06/01/2006	18,6				167,1	
07/01/2006	0,6				167,7	
08/01/2006	10,8				178,5	
09/01/2006	6,4				184,9	
10/01/2006	4,8			180,6	189,7	0,83

Table 3. Occurrence Rainfall Data (Batur and Sorasan Raingauge Stations)

No.	Date of Occurrence	Time	Total Rainfall (mm)	Rainfall Intensity (mm/hour)	Station
1	21 December 2006	16:00 – 20:00	114,71	3,43	Batur
2	23 February 2007	13:00 – 17:00	110,51	3,93	Batur
3	19 April 2007	00:00 – 01:00	176, 70	1,65	Batur
4	17 January 2010	19:00 – 20:00	213,76	0,79	Sorasan
5	8 January 2011	15:00 – 22:00	66,46	5,81	Sorasan
6	22 March 2011	14:00 – 20:00	103,11	3.42	Batur
7	23 March 2011	19:00 – 22:00	111,61	3,26	Batur

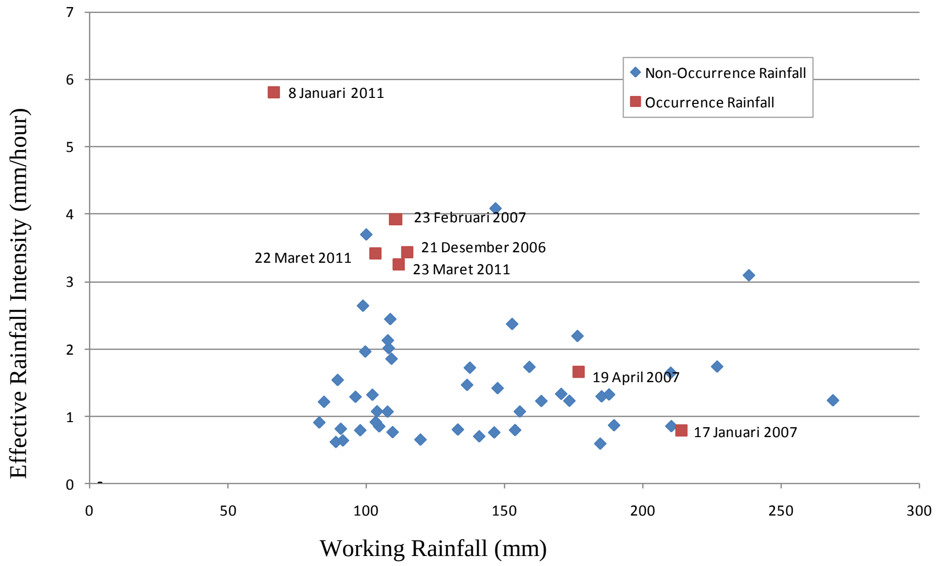


Figure 3. A series Effective Rainfall Intensity and Working Rainfall Graphic in Gendol River

4.4 Potency of Debris Flows Predictions

Based on Guidelines for Development of Warning and Evacuation System against Sediment Disaster in Developing Countries, MLIT Japan, 2004, total rainfall in a series of rain with amount of 80 mm or over or rainfall intensity with amount of 20 mm or over is requirement limit debris flows occurred. Amount of debris flow potential expressed in percent (%) which have obtained from cumulative percentage of the total rainfall in the series of rain with amount of 80 mm or over or rainfall intensity with amount of 20 mm/hour or over.

a) Debris flow event data in Gendol River which has been recorded since February 6th, 2006 to May 1st, 2011 are 34 times, and debris flow event in series of rain with amount 80 mm or over are 6 times, based on rainfall data from Batur and Sorasan raingauge stations (Table 1). From this data it was found that the percentage of debris flow event in series of rain with amount 80 mm, compared with whole debris flow event happened is 17,65%.
b) Debris flow event in Gendol River in series of rain which amount of 80 mm or over are 6 times based on based on rainfall data from Batur and Sorasan raingauge stations (Table 1), while series of rain with amount of 80 mm or over are 56 times, based on rainfall data from Deles, Batur and Sorasan raingauge stations. From this data it was found that the percentage of series of rain with amount 80 mm or over triggered debris flows, compared with whole series of rain with amount 80 mm or over is 10,71%.
c) Based on debris flows event percentage in series of rain with amount 80 mm or over, compared with whole debris flows event and percentage of series of rain with amount 80 mm or over triggered debris flows, compared with whole series of rain with amount 80 mm or over, obtained the probability of debris flows in the series of rain with total amount of 80 mm or over in Gendol river is 17,65% × 10,71% = 0,0189.

4.5 Similar Research Results in Other Area

A similar study on the prediction of the lahar flow using rainfall data has also been carried out by Sutikno, 2008, at the Jenebarang River, Gowa, South Sulawesi Province. To predict the occurrence of debris flows, standard rainfalls analysis for debris flows has been calculated using Yano method. This research produce working rainfall standard charts equation Rh = 51–0,085, which is a linear equation that separates occurrence rainfall and non-occurrence rainfall plot, which working rainfall (mm) placed as abscissa and maximum rainfall intensity (mm/hour) placed as ordinate. Plotted points which are located on the lower left of a line is non-occurrence rainfall and other plots on the right above of a line is occurrence rainfall that can trigger debris flows. Comparing number of non-occurrence rainfall plot which is located on the lower left of the standard rainfall line with whole of non-occurrence rainfall, compliance rate is 68%. This means that the accuracy of the standard rainfall for debris flows in the upper Jenebarang River is low. This is caused by the limitations of used data in the analysis, so that needs to be updated through collection and analysis data of short duration rainfall around the caldera.

5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

After performing research of effective rainfall intensity and working rainfall on lahar flows event in Gendol River and considering the foregoing discussion, it can be several conclusions as follows:

a) Percentage of debris flow event in series of rain with total amount of 80 mm or over, compared with the whole of debris flows event occur amounted to 17.65%. Percentage of series of rain with a total amount of 80 mm or over that caused debris flow, compared with the whole series of rain with total amount of 80 mm or over is equal to 10.71%. Gendol River amounted to 1.89%.

b) Occurrence probability value of debris flows in series of rain with a total amount of 80 mm or over in Gendol watershed amounted to 1.89%. This means from the number series of rain with total amount of 80 mm over, the possibility of debris flows is very small. That amount represents less possibility of debris flows in river Gendol, this is due to several things, including:
   1) rainfall data analysis was conducted by setting of standard rainfalls based on Guidelines for Development of Warning and Evacuation System Against Sediment Disasters in Developing Countries (MLIT Japan, 2004), but the rainfall and sediment characteristic in the Gendol river watershed is different with the situation in Japan,
   2) the limited data available, both on daily rainfall data from raingauge station or recorded lahar flows event data, so that the lahar flows is not a lot going in the series of rain with total amount of 80 mm or over, and conversely, there are records of lahar flows events happening on the series of rain with total amount below 80 mm.

c) Research results comparison with a similar study conducted by Sutikno, 2008, showed that the accuracy of the standard rainfall for debris flows prediction, either by using Method B in the Guidelines For Development of Warning and Evacuation System Against Sediment Disaster in Developing Countries (MLIT Japan, 2004) or using Yano Method (Yano et al, 1985 in Sutikno, 2008) is still low. This is caused by limitations of data used in the analysis, so that needs to be updated through the collection and analysis of rainfall data, as well as enter other parameters that influence the debris flows event.

5.2 Recommendations

By considering the results of these studies then some related suggestions:

a) Need the further research on the limits of inflection point A and inflection point B for Merapi area,

b) To make effective rainfall intensity and working rainfall in Gendol river graphic is better using fainfall data throughout nearby stations include Plawangan, Deles, Batur, Sorasan and other nearby raingauge stations for non-occurrence rainfall data processing,

c) In determining the occurrence probability of lahar flows in Gendol watershed should not only based on rainfall data calculations, also need to calculate other parameters becoming lahar flows controller factors, such as watersheds topography, slope of stream and characteristics of sediment in the watershed.

REFERENCES

Ansita G. P., 2011, *Analisis Karakteristik Temporal dan Spasial Hujan untuk Mendukung Kriteria Peringatan Dini Bencana di Wilayah Lereng Merapi*, Tugas Akhir, Jurusan Teknik Sipil dan Lingkungan Fakultas Teknik Universitas Gadjah Mada, Yogyakarta.

Haryono, 2011, *Banjir dan Aliran Debris*, Bahan Kuliah MPBA Universitas Gadjah Mada, Yogyakarta.

Ministry of Land, Infrastructure and Transport (MLIT). Infrastructure Development Institute. Japan, 2004, *Guidelines for Development of Warning and Evacuation System Against Sediment Disaster in Developing Countries.*

Sutikno H., *Community Based Warning and Evacuation System Against Debris Flow in The Upper Jeneberang River, Gowa, South Sulawesi*, 2008, Forum Geografi, Vol. 22, No. 1, pp. 13 – 26.

Takahashi T., 1991, *Debris Flow*, Disaster Prevention Research Institute, Kyoto University, International Association for Hydraulic Research, A.A. Balkema/ Rotterdam/ Brookfield.

Wardoyo W., Faisal Fathani T., Legono D., 2010, *Sensitifitas Parameter Karakteristika Sedimen Terhadap Permulaan Gerak Aliran Debris pada Sistem Torensial*, Makalah Ilmiah, UGM, Yogyakarta.