The 23rd CEReS International Symposium

LANDSLIDE SUSCEPTIBILITY MAPPING USING DINSAR AND STATISTIC MODEL IN BAWAKARAENG MOUNTAIN, SULAWESI, INDONESIA.

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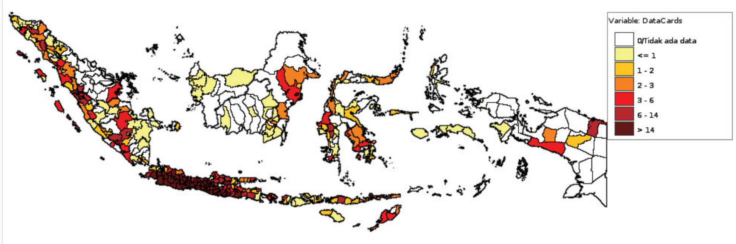
December 1-2, 2015



Total of Disaster, Victims and the Impact until Augustus 2015

Disaster Type	Number of Event	Victims (people)			Damage (unit)						
					House						
		Death & Missing	Injured	Affected & Evacuated	Heavily Damage	Moderate Damage	Lightly Damage	Inundated	Health Facilities	Worship Facilities	Education Facilites
BANJIR	375	25	6	606.655	437	150	1.357	140.526	15	51	166
BANJIR DAN TANAH LONGSOR	20	3	0	43.757	58	44	124	3.045	0	5	3
GELOMBANG PASANG / ABRASI	6	1	0	0	2	5	0	47	0	1	0
GEMPA BUMI	19	0	1	147	12	19	103	0	1	2	1
KEBAKARAN	3	0	0	0	1	0	0	0	0	0	0
KEBAKARAN HUTAN DAN LAHAN	1	0	0	0	0	0	0	0	0	0	0
KECELAKAAN TRANSPORTASI	30	70	16	2	0	0	0	0	0	0	0
KEKERINGAN	3	0	0	38.171	0	0	0	0	0	0	0
LETUSAN GUNUNG API	6	0	0	46.779	7	0	1	0	0	0	0
PUTING BELIUNG	354	20	75	4.793	1.119	1.270	4.900	81	3	20	34
TANAH LONGSOR	402	107	82	25.210	397	227	481	271	0	2	9
TOTAL	1.219	226	180	765.514	2.033	1.715	6.966	143.970	19	81	213

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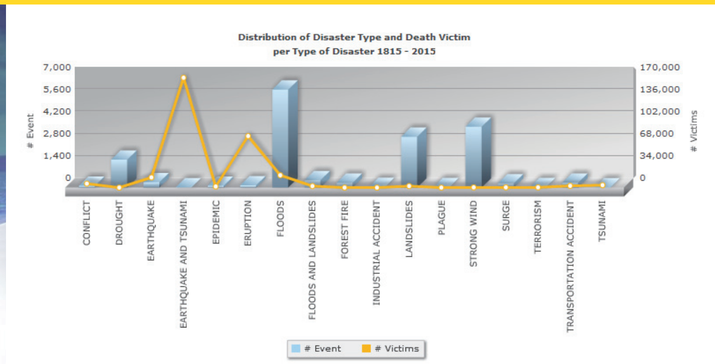
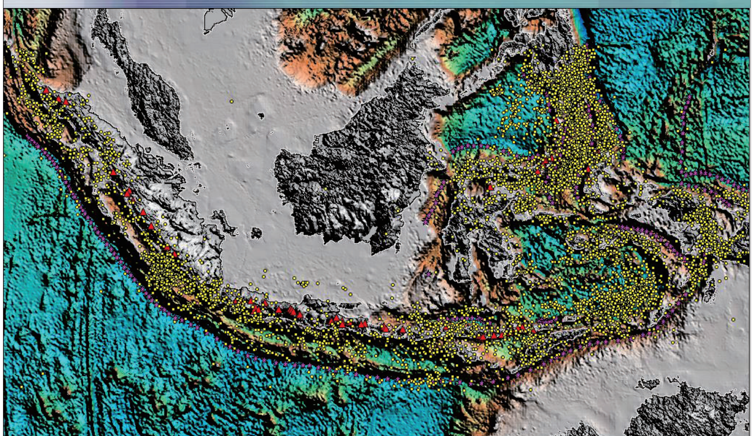
Outlines

INDONESIAN DISASTER DATA AND INFORMATION
NATIONAL DISASTER MANAGEMENT AUTHORITY (BNPB)

Pusat Data Informasi dan Humas - BNPB
Telp. 021-3442734, 3442985, 3443079
Fax. 021-3505075



Background



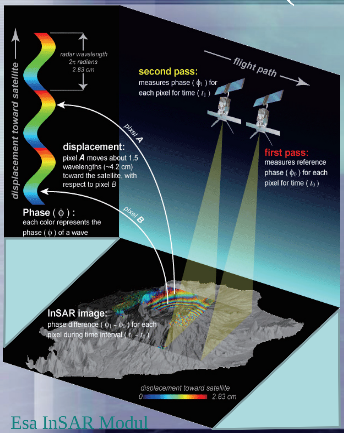
Background

- Geologically, Indonesia squeezed by three major world plates, one of the most dangerous countries regarding natural disasters.
- Many areas in Indonesia are facing natural degradation due to the insufficiency in environmental monitoring.
- Lack of spatial information supporting the decision making regarding the land condition specially when natural disaster strikes.
- It is generally quite difficult to evaluate the extent of area affected by floods or landslides.

↓

- Comprehensive database of disaster inventory

Differential Synthetic Aperture Radar (DInSAR)

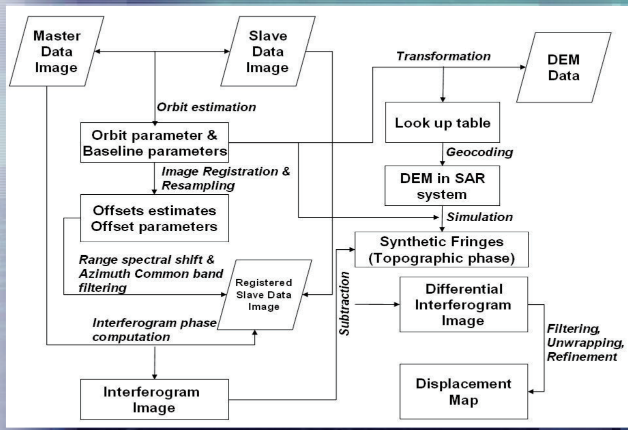


Esa InSAR Modul

- DInSAR is further process of Interferometric SAR (InSAR).
- Repeated-pass InSAR uses two SAR images from different time observations.
- InSAR exploits the phase information recorded in two SAR images to derive the geodetic information of the terrain.

DInSAR Flow Chart

Software used;
Sigmasar, ENVI 4.5 , ArcGIS 9.3,



DInSAR

- Differential interferometry synthetic aperture radar (DInSAR) → radar interferometry technique → to detect and monitor of ground deformation due to geophysical phenomena between two SAR images.
- Advantages of DInSAR
  - Large spatial coverage
  - High accuracy (centimeter to millimeter accuracy)
  - Low cost and time efficient compared to other methods
  - Detect deformation in dangerous area effectively

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DInSAR in Landslide monitoring

- Singhroy *et al.*, 1998, Research paper and book focus on Canadian and North American Region;
- Matternicht *et al.*, (Remote Sensing Landslides, Hazneth, 2005;
- Carrara et al., 1999; Use of GIS: Catani *et al.*, 2005; Tralli *et al.*, 2005; Carlosanti and Wasowski., 2006; Cascini et al., 2009 (Slow moving landslide); European Region
- Van Westen et al., 2008; The use of GIS in Landslide
- Kimura and Yamaguchi., 2008; Japan, Itaya Landslide
- Riedel and Wagler., 2008) China, Germany,
- Joyce *et al.*, 2009 New Zealand

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Research Objectives

1. Integrating optical satellite images of Landsat ETM with Synthetic Aperture Radar (SAR) data of ALOS PALSAR complemented by statistic frequency ratio model using a Geographical Information Systems (GIS) platform
2. To show the capability of DInSAR processing of showing surface displacement on the event of Bawakaraeng landslides.
3. To study landslide susceptibility in the area based on eight landslide causal factors and a landslide inventory using the frequency ratio approach
4. The information will be used to create Landslide Susceptibility Map.
5. To develop monitoring techniques of GIS-based landslide inventory database which enable real time and cost effective method.

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Study Site

- Bawakaraeng, the head of river Jeneberang, a source of water for storage for Makassar, the capital city of South Sulawesi Province (1.2 million people)
- Bawakaraeng is inactive, height of 2,803
- 26 March 2004, landslide killed 32 people and buried 1,500 hectares of rice fields, 1 elementary school
- Material amount of 235 million m^3 (Latest report CTI, 192,5 m^3)
- The affected area is causing the landslide river (catchments area) to become unstable. Every rainy season, mud at the foot of Mount Bawakaraeng are to flow into Bilibili Dam, the largest Dam in South Sulawesi in the Gowa regency.

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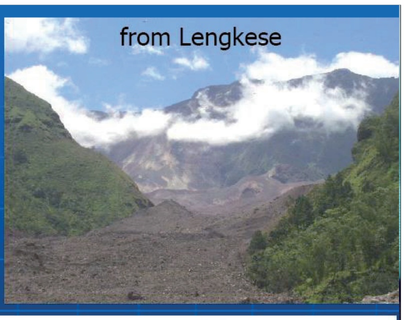
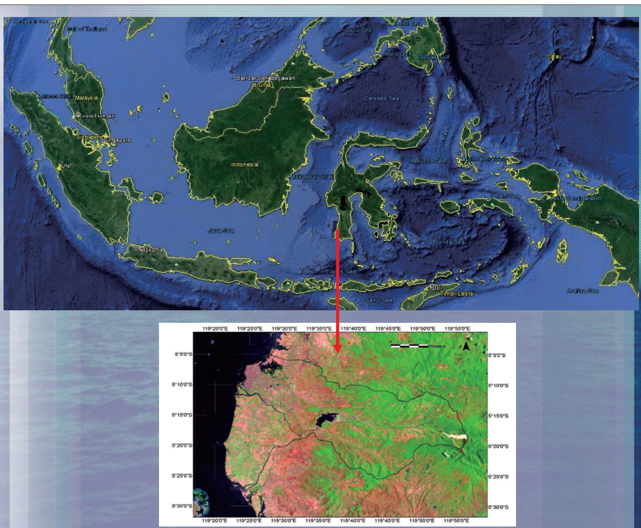
Pushed out Debris





Cause of The Landslide

- Topographic features to be a primary geomorphologic cause
- There was no conspicuous rainfall on the three days preceding the landslide. Also, the occurrence of an earthquake is not confirmed.
- Mechanical factors enhanced the landslide are the tremendous height of the side wall of the caldera ; fragility of the bedrock of the side wall; and susceptibility to erosion of the accumulated sediment inside the caldera. *Sabo Group, 2005*
- Combination of long term (physical properties) and short term triggering factors, high incident of rain prior to the event. 1.5 times higher (815 mm) than average (547mm) for 28 years. (latest report of Sabo Team)

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Collapsed Caldera Wall

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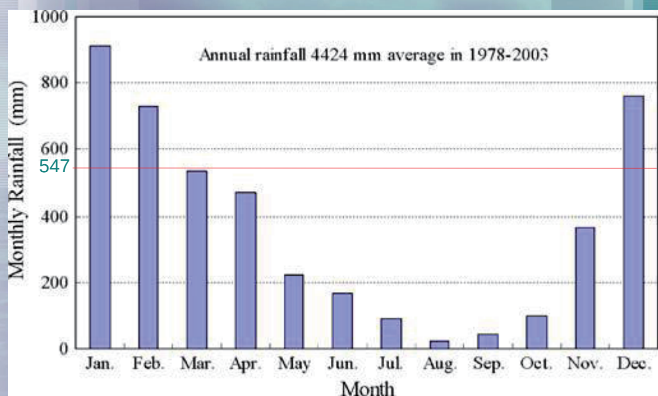
Monthly average rainfall at the Malino from 1978 to 2003 (Tsuchiya et al)



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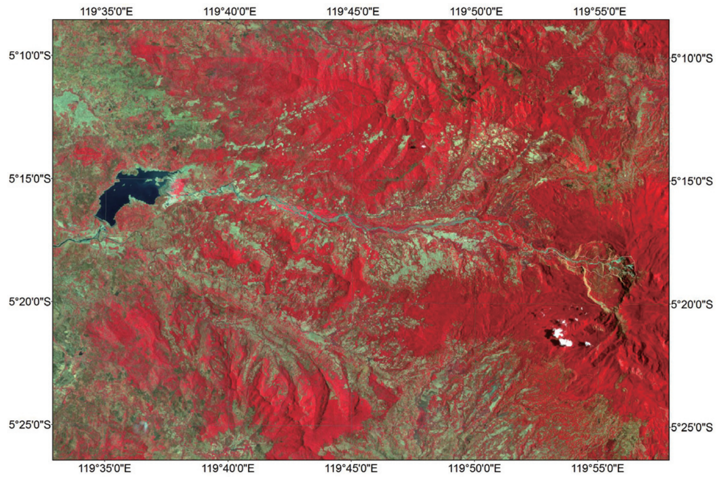
Prediction of Future Collapse

- Open Crack at Collapsed Area



Crack along the wall

Open Cracks and V

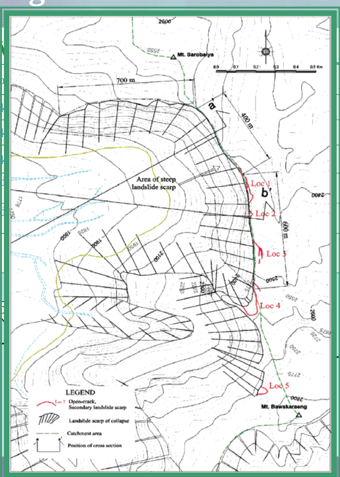
Risk in decades

Location Number	Classificatio	Potential Collapse Volume (V=L*W*H/2)
1	Open Crac	300,000 m^3
2	Open Crac	60,000 m^3
3	Open Crac	390,000 m^3
4	Secondary Lan Scarp	450,000 m^3
5	Secondary Lan Scarp	150,000 m^3
Total		1,350,000 m^3

Collapsed Slope

C

Secondary landslide scarp



Source: JICA Consultant Report

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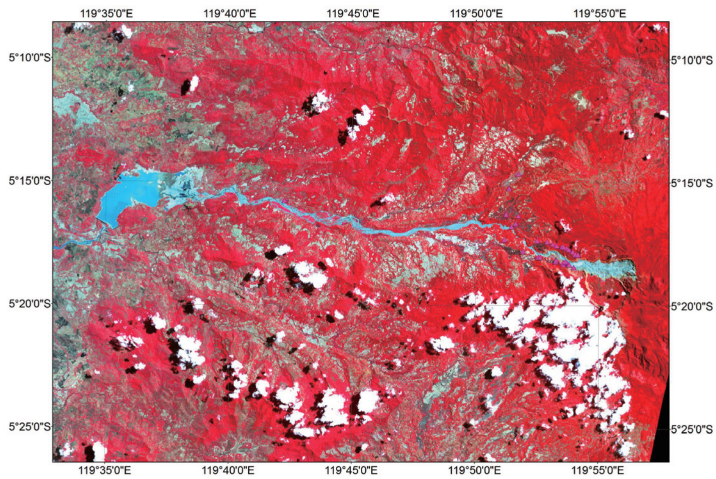

Data Used

Optical Image Data :

1. Landsat MSS, Dec 16, 1990
2. Landsat ETM, Sept 28, 2002
3. Aster, Oct 25, 2001
4. Aster, September 7, 2006
5. Landsat TM, 20 Sept 1999

SAR Data

1. JERS -1 SAR (L Band, 23.6 cm wavelength) data acquired on 19930317,19940417,19950518,19960321,19970308, and two scenes from 1998 data 19980110 and 19980818, All JERS-1 data were taken on the descending modes
2. ALOS PALSAR, purchased for 2007,2008 and 2009 data

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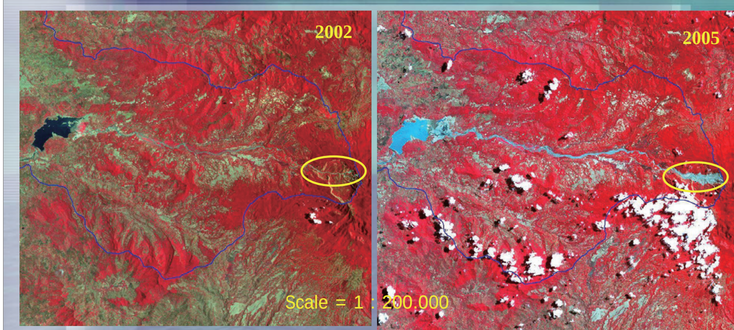
Spatial Analysis ; Visual Comparison



Cleared Vegetation, Accumulated Material, Murky water

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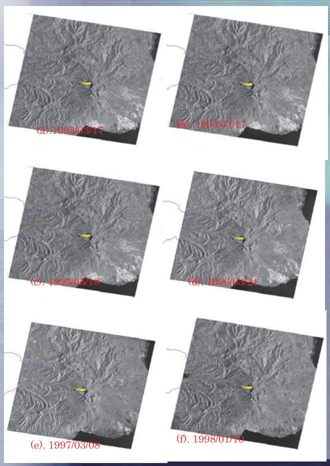
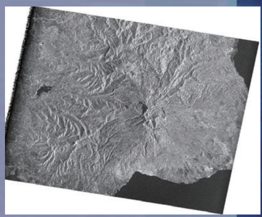
SAR Data Processing



JERS-1 Level 0 to level 1.1
Using JERSFull2Kv1

Georeferenced Intensity Image in ArcGIS
Indications of slight displacement



Sar_p_m_g(19981998)

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Factors affecting image coherence

- Baseline between the two images
- Orbital plane of the satellites when acquiring the image
- Ground condition, soil moisture, thickness of vegetation
- Resolution of DEM used in DInSAR Processing

JERS 1 Baseline Data Information

Pair (RSP 77/309)	Week Difference	Baseline (m)	Bp (m)	Bh (m)
19930317/19940417	56	1159.56	538.37	-1027
19940417/19950518	56	1384.25	1243.9	-607.4
19950518/19960321	44	424.74	250.22	-343.2
19960321/19970803	54	502.48	397.01	308
19970803/19981001	44	3382.77	2284.6	2495
19981001/19980818	36	1256.95	1130.6	-549.3

Bp Perpendicular element of the baseline

Bh Paralel element of the baseline

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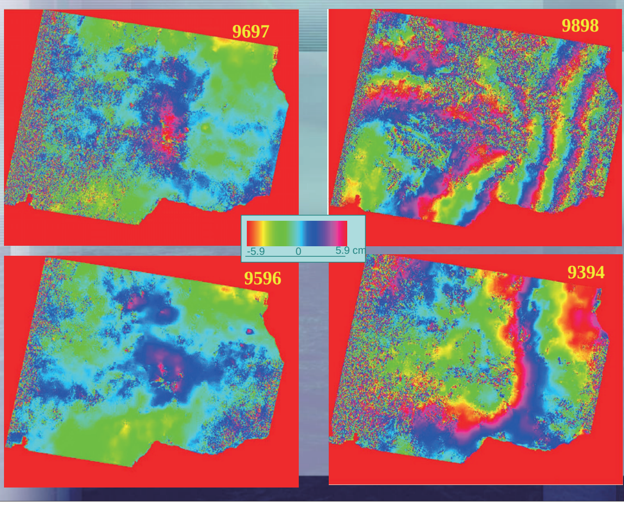
Comparison of 4 datasets



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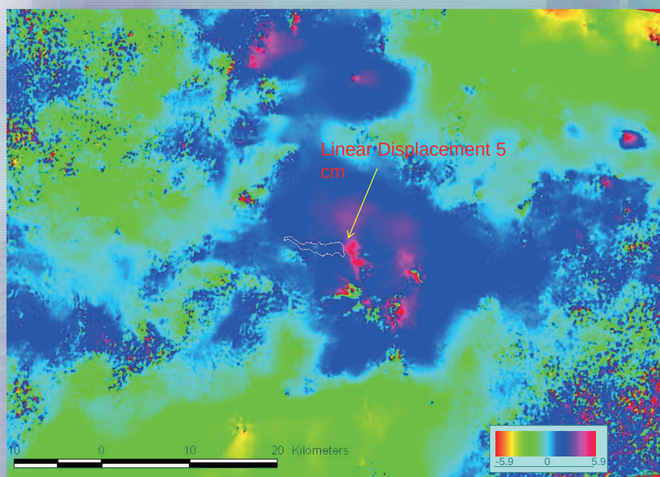
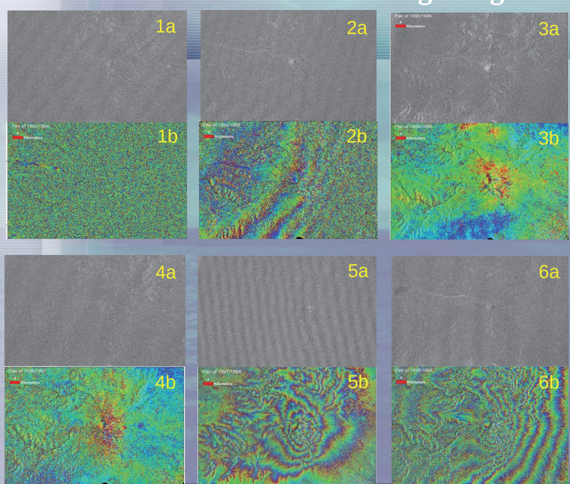
JERS-1 SAR Data, 19951996



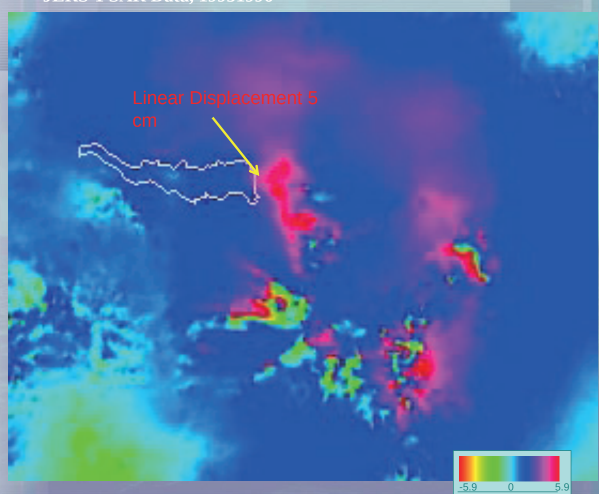
JERS-1 SAR DInSAR Processing Images



(a) coherence image of the six pairs of DInSAR processing result. area. (b) DInSAR Images from 6 different pairs.

1. 93/94,
2. 94/95,
3. 95/96,
4. 96/97,
5. 97/98
6. 98/98.

JERS-1 SAR Data, 19951996



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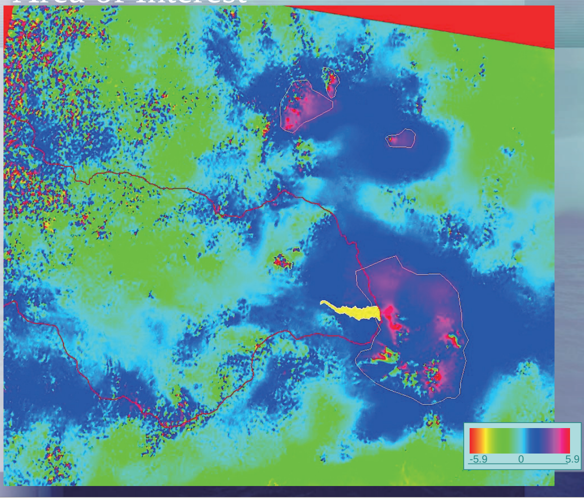
Area of Interest



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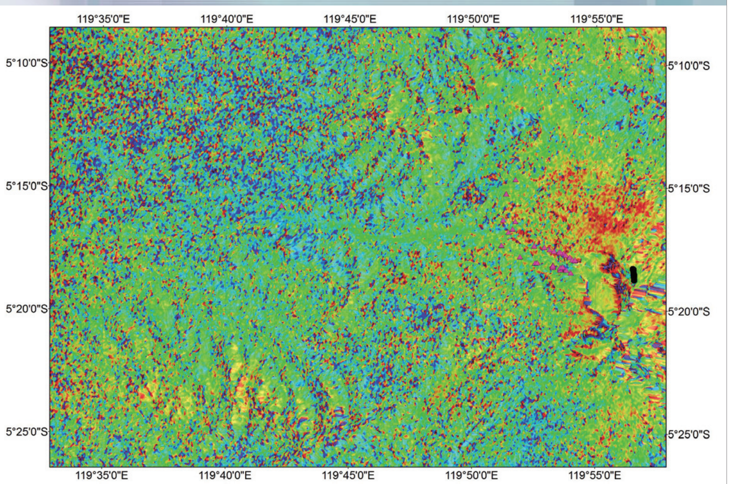
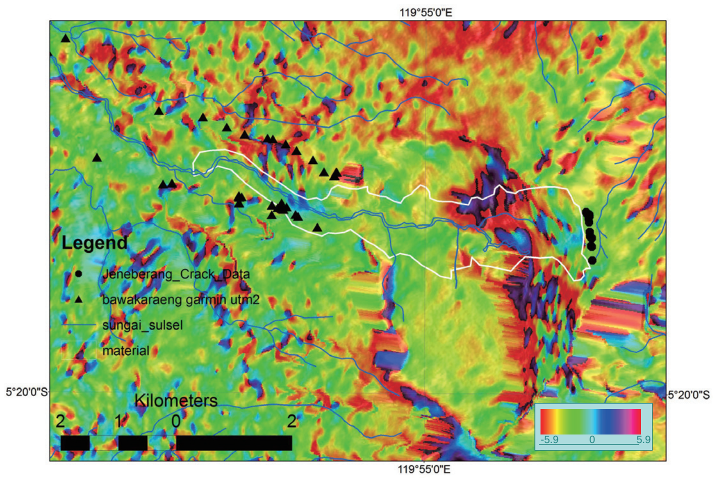
Crack Locations and Measurement

LOCATION	X (m)	Y (m)	Length (cm)	DISPLACED
Crack1-1	826088	9412862	78.5	11.8
Crack1-2	826109	9412822	87.0	5.0
Crack1-3	826144	9412818	87.5	20.9
Crack1-4	826149	9412786	280.0	26.0
Crack1-5	826135	9412754	0.0	0.0
Crack1-7	826140	9412686	0.0	0.0
Crack1-8	826152	9412516	0.0	0.0
Crack1-9	826152	9412516	189.5	24.0
Crack2-1	826186	9412404	0.0	0.0
Crack2-2	826179	9412410	0.0	0.0
Crack2-3	826189	9412414	0.0	0.0
Crack2-4	826159	9412442	0.0	0.0
Crack3-1	826187	9412260	137.0	9.3
Crack3-2	826176	9412280	0.0	0.0
Crack3-3	826184	9412262	107.0	0.0
Crack4-3	826196	9412024	328.0	244.3



Crack Locations Pictures



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MATERIAL AND METHOD

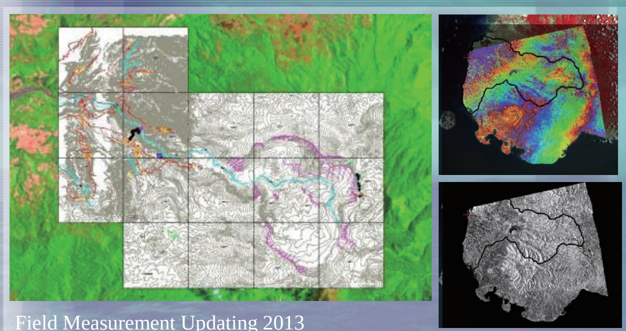
- Landslide Susceptibility Map was created using the probabilistic frequency ratio (FR) model
- All the landslide causal factors were basic factors to create landslide map analysis
- In Fr approach, if Fr > 1 it indicates the factors greater influence and Fr < 1 indicates its low influence
- $\text{Fr} = \frac{PixclL(ij)/\sum PixL}{Pixcl(ij)/\sum Pix}$

  (Where, $PixclL(ij)$ number of pixel with landslide within class i of j parameter, $Pixcl(ij)$ Number of pixel in class i of j parameter, $\sum PixL$ total pixel of j parameter, and $\sum Pix$ total pixel of the area)
- $\text{LSI} = \sum Fr(ij)$

Slope in Degree	Number of Landslide	% Landslide	Number of pixel in class	% class	% Frequency ratio
0-5	5	0.049	9,268	2.15	0.02
5-10	156	1.515	58,871	13.63	0.11
10-20	337	3.273	79,753	18.46	0.18
20-30	1,572	15.268	170,312	39.43	0.39
30-40	2,204	21.406	84,474	19.56	1.09
40-50	2,535	24.621	21,316	4.94	4.99
> 50	3,487	33.868	7,941	1.84	18.42
	10,296	100	431,935	100	

Future Research using ALOS PALSAR

ALOS Palsar 2008-2009



Field Measurement Updating 2013

ALOS Palsar Data, 20070809 20080926 20090929

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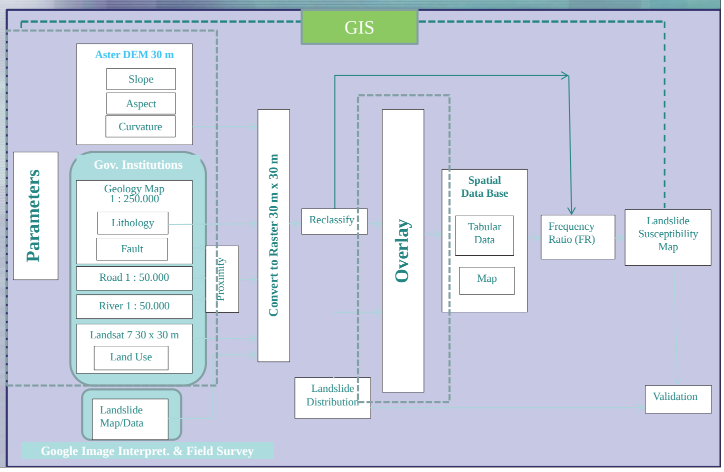
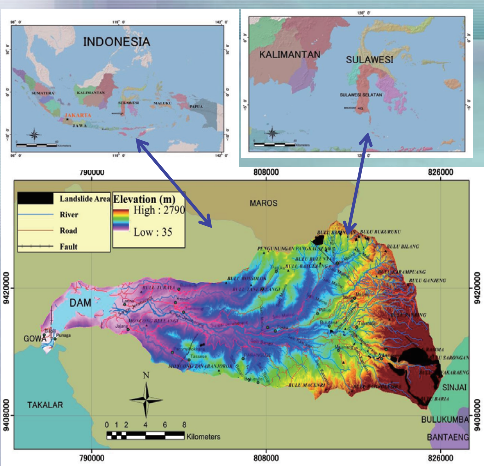
MATERIAL AND METHOD

Flow Chart of Process

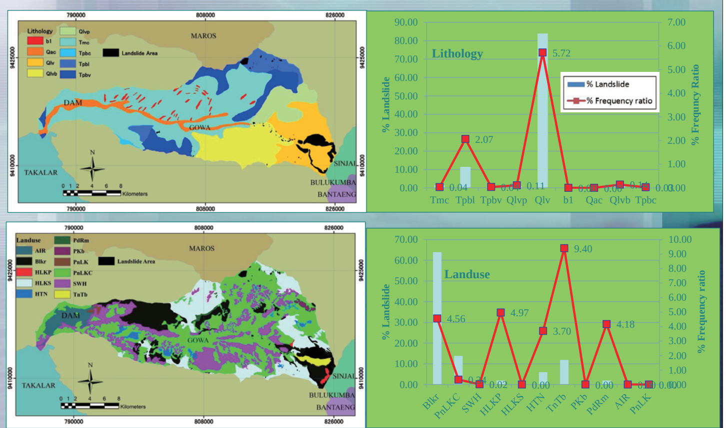


STUDY AREA

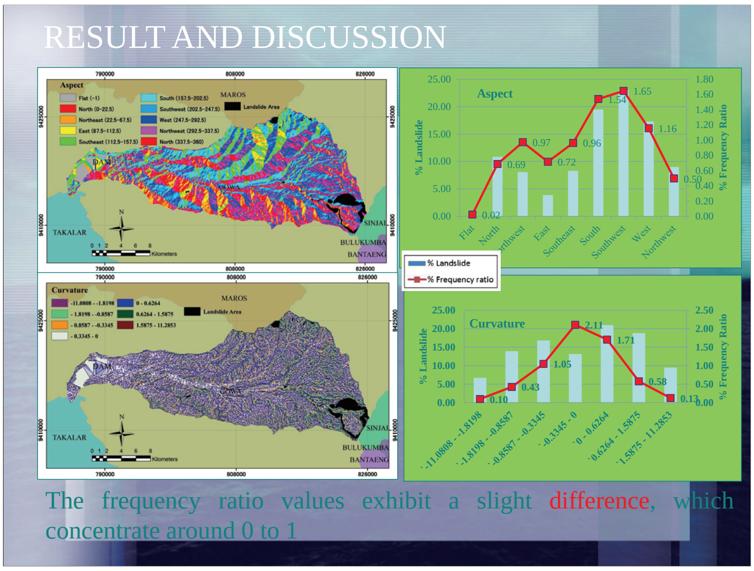


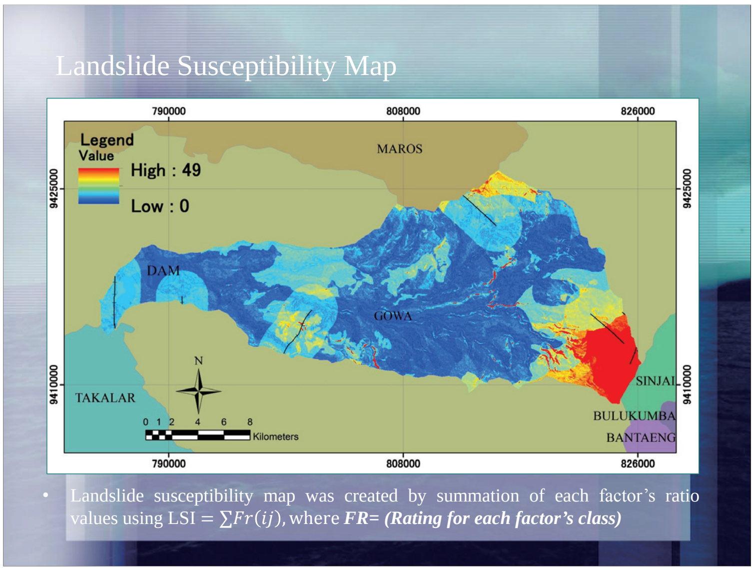
- Jeneberang watershed is located at the North-West edge of the Bawakaraeng caldera wall
- Main river length of 75 km
- Catchment area around 602 km^2

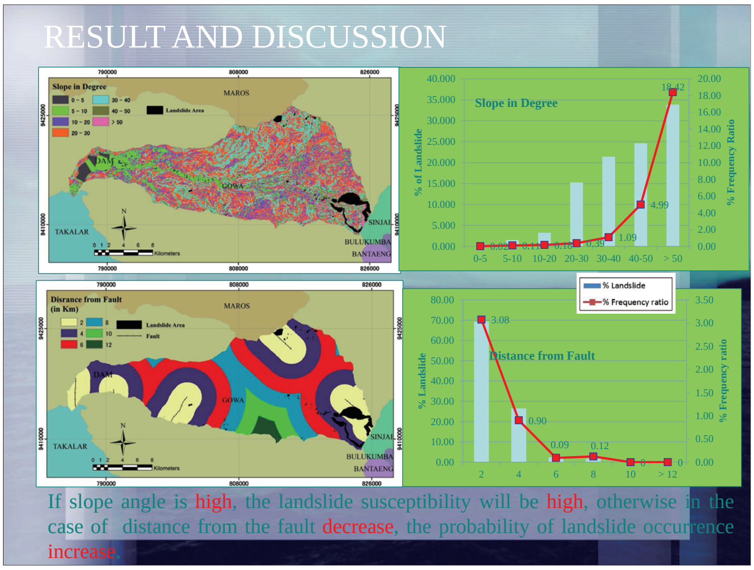
RESULT AND DISCUSSION

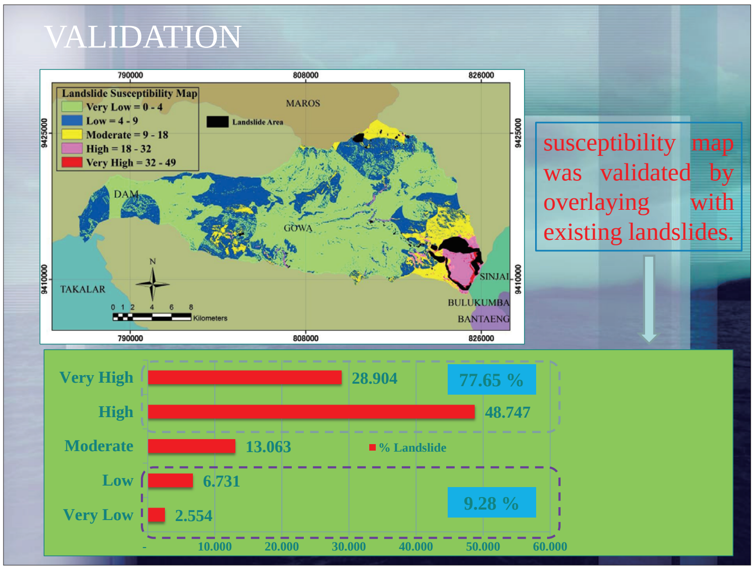


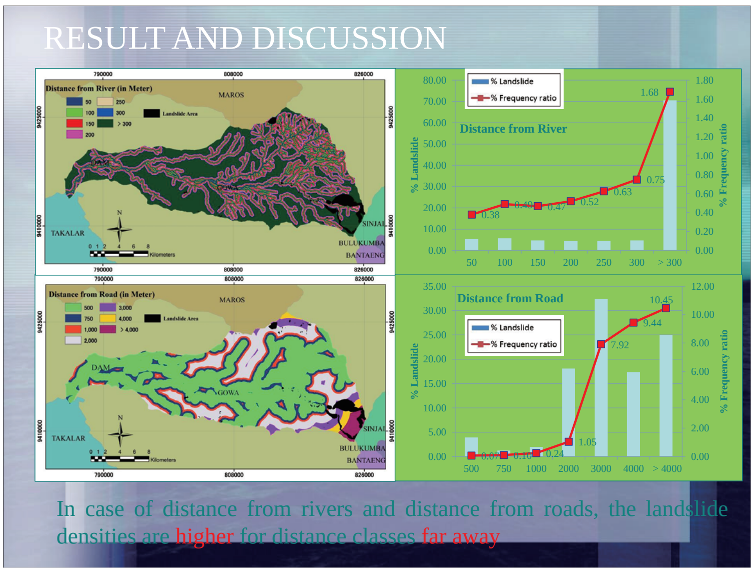
Open land/ground, bushes, grass land and forests, Fr >1, *tersier pliosen batu lava* (tpbl) and *quarter lompobattang volcanics* (qlv), Fr >1

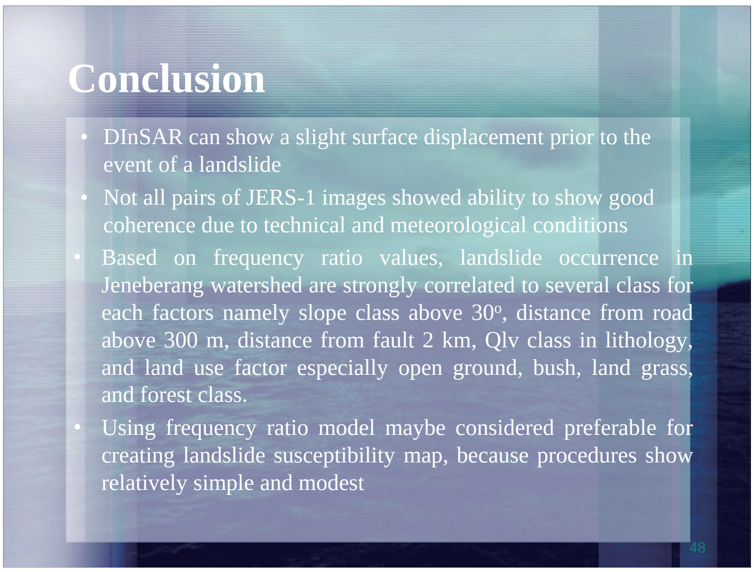

RESULT AND DISCUSSION
Aspect
% Landslide
% Frequency Ratio
Flat
North
Northwest
East
Southeast
South
Southwest
West
Northwest
0.02
0.69
0.97
0.72
0.96
1.54
1.65
1.16
0.50
Curvature
0.10
0.43
1.05
2.11
1.71
0.58
0.13
% Landslide
% Frequency ratio
MAROS
TAKALAR
SINJAI
BULUKUMBA
BANTAENG
The frequency ratio values exhibit a slight difference, which concentrate around 0 to 1


Landslide Susceptibility Map
790000
808000
826000
9425000
9410000
Legend
Value
High : 49
Low : 0
MAROS
DAM
GOWA
TAKALAR
SINJAI
BULUKUMBA
BANTAENG
0 1 2 4 6 8
Kilometers
Landslide susceptibility map was created by summation of each factor's ratio values using LSI = $\sum Fr(ij)$, where ***FR= (Rating for each factor's class)***


RESULT AND DISCUSSION
Slope in Degree
% of Landslide
% Frequency Ratio
0-5
5-10
10-20
20-30
30-40
40-50
> 50
18.42
4.99
1.09
Distance from Fault
% Landslide
% Frequency ratio
3.08
0.90
0.09
0.12
2
4
6
8
10
> 12
MAROS
DAM
GOWA
TAKALAR
SINJAI
BULUKUMBA
BANTAENG
If slope angle is high, the landslide susceptibility will be high, otherwise in the case of distance from the fault decrease, the probability of landslide occurrence increase.


VALIDATION
Landslide Susceptibility Map
Very Low = 0 - 4
Low = 4 - 9
Moderate = 9 - 18
High = 18 - 32
Very High = 32 - 49
Landslide Area
MAROS
DAM
GOWA
TAKALAR
SINJAI
BULUKUMBA
BANTAENG
susceptibility map was validated by overlaying with existing landslides.
Very High
28.904
77.65 %
High
48.747
Moderate
13.063
% Landslide
Low
6.731
Very Low
2.554
9.28 %
10.000
20.000
30.000
40.000
50.000
60.000


RESULT AND DISCUSSION
Distance from River (in Meter)
Distance from River
% Landslide
% Frequency ratio
50
100
150
200
250
300
> 300
0.38
0.47
0.52
0.63
0.75
1.68
Distance from Road (in Meter)
Distance from Road
500
750
1000
2000
3000
4000
> 4000
0.24
1.05
7.92
9.44
10.45
MAROS
DAM
GOWA
TAKALAR
SINJAI
BULUKUMBA
BANTAENG
In case of distance from rivers and distance from roads, the landslide densities are higher for distance classes far away


Conclusion
DInSAR can show a slight surface displacement prior to the event of a landslide
Not all pairs of JERS-1 images showed ability to show good coherence due to technical and meteorological conditions
Based on frequency ratio values, landslide occurrence in Jeneberang watershed are strongly correlated to several class for each factors namely slope class above 30°, distance from road above 300 m, distance from fault 2 km, Qlv class in lithology, and land use factor especially open ground, bush, land grass, and forest class.
Using frequency ratio model maybe considered preferable for creating landslide susceptibility map, because procedures show relatively simple and modest
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Future Research

- Using detail geology map of the prone to disaster area
- Integrating the DInSAR image map as one input parameter to model
- Comparing other statistics model and possible combination of the models to create a better landslide susceptibility map
- Developing monitoring techniques of GIS-based landslide inventory database which enable real time and cost effective method.

Acknowledgement

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