CHARACTERIZING TOPOGRAPHIC FEATURES AND FLOOD INUNDATION MAPPING IN ALLUVIAL LOWLAND AREA

An Tran Thi[1*], Venkatesh Raghavan[1], Shinji Masumoto[2]
Go Yonezawa[1] and Susumu Nonogaki[3]

[1] Graduate School for Creative Cities, Osaka City University
[2] Graduate School of Science, Osaka City University
[3]Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), Japan
[*]Faculty of Geography, Danang University, University of Education

ABSTRACT

This study aims to develop algorithm for generating high resolution DEM in an alluvial lowland area in the south of Danang city, Vietnam, where is suffering from high potential of flood hazard. An interpolation method using bi-cubic B-spline algorithm, namely BS-Horizon (Nonogaki et al., 2012), was used for generating high resolution DEM. BS_Horizon was evaluated as one of the highest accuracy method for generating DEM. This algorithm enables using elevation data as equality-inequality constraints on the surface. The optimal surface is the smoothest one that satisfied the given constraints (Nonogaki et al., 2012). This high resolution DEM was used as input data to determine the geomorphological features of the study area and the relations on flood hazards. The flood inundation mapping is based on the investigation of ALOS PALSAR interpretation, topographical analysis and the land-cover of study area that extracted from ASTER remote sensed data.

1. INTRODUCTION

Flooding is one of the most frequent and damage causing natural disaster in Vietnam as well as Danang city. Studying of flood hazard required understanding about hydrological, meteorological as well as topographical condition of study area. In case of hydrological and meteorological data is difficult to be obtained, topographical condition is an identify index to characterize the flood potential of an area.

Several methods for flood hazard mapping have developed using various hydrological, meteorological and geomorphological approaches. Some authors also tried to characterize the flood potential in Danang area, based on hydro-geomorphological methods integrated with remote sensed data (Ho *et al*., 2012; Do *et al*., 2014, etc.). However, in the previous studies, due to a lack of high resolution digital elevation model (DEM) and near-flood events satellite data, the results may not be sufficient for flood prevention plan.

In this study, a high resolution DEM was generated using BS-Horizon algorithm developed by Nonogaki *et al.* (2012) for an alluvial lowland area in the south of Danang city. This case study area is located in the flood prone region in Hoa Vang district, Danang city that used to experienced several flood events in several years, especially in 2007 and 2009.

2. METHODOLOGY

2.1 Study Area and data used

Study area is a lowland area located in the south of Danang city, characterized with an area about 75 km^2 and elevation range from 0m to 9.5m. Its area includes a south part of Hoa Vang district, Danang city and a north part of Dien Ban district, Quang Nam province.

Table 1. Data used in this study

Data	Type of data	Date	Resolution
DEM	Elevation point, contour	December 2009	5.0 m
Satellite data	ALOS PALSAR	2007/09/15	12.5 m
	ALOS PALSAR	2007/10/31	12.5 m
	ASTER	2009/03/29	15.0 m

The topography is relatively flat, crossing to Cau Do river and Vinh Dien river. Both of these two river canals are flowing to Han river, a part of Vu Gia-Thu Bon river basin in Central of Vietnam. This area is located in monsoon tropical climate with two seasons: a rainy season from August to December and a dry season from January to July, with rainfall mainly concentrated from September to December (70% - 80% of the total annual rainfall) (Do *et al*., 2014). On average, this area is directly or indirectly influenced by 1-2 typhoons and 1-2 great flooding spells each year.

The data used for DEM generation is elevation data extracted from 1/10000 topographic map given by Department of Natural Resource and Environment (DONRE), Danang city. This map included 10m interval contour lines and spot heights data measured and surveyed in 2009. For flood inundated mapping, a flood event from 28th Oct 2007 to 9th November 2007 was objected, therefore two PALSAR images close to this flood event were collected with respect to the time before and during flood. The PALSAR data is in level 4.1 with resolution of 12.5 and dual polarization that can support for various useful analysis for flood detection. In addition, an ASTER optical image in 2009 was used to classify the land-cover of study area that relate to flood hazard potential. The data used was showed in Table 1.

2.2 DEM generation using BS-Horizon method

For generating high resolution DEM of this study area, an interpolation method namely BS-Horizon (Nonogaki *et al.*, 2012) was applied utilizing equality-inequality constraint from topographic data. The inequality constraint was characterized by the elevation range from 0m to 10m of the study area. From the contour map, it is observed that this relatively flat area has no crossed contour, and the minimum contour elevation in the Danang city map is 10m. Therefore the values of 0m and 10m were used as lower and upper threshold to control the estimated elevation of the output DEM. In addition, a group of spot height data include 48010 elevation points was taken into account as equality constraint to generate the surface. In general, the possible constraint of an elevation z_i that is obtained at a point (x_i, y_i) can be expressed as follow:

$$f(x_i, y_i) - z_i = 0 \quad (1)$$
$$f(x_i, y_i) - z_i < 0 \quad (2a)$$
$$f(x_i, y_i) - z_i > 0 \quad (2b)$$

Equality (1) is used in case that the surface passes through the point. Inequality constraint (2a) is used in cases that the surface passes under the point, and the inequality constraint (2b) is used in cases that the surface passes above the point. In this case study, the inequality constraint mean that all the output elevation data must be greater than 0m and less than 10m. The equality constraint is that the DEM surface must pass through all elevation points given in input data.

This equality-inequality constraint was utilized as input data for BS-Horizon interpolation method. BS-Horizon is a bi-cubic B-spline approximation integrate with the exterior penalty function to determine the optimal surface. Exterior penalty function is a function that can control the balance between the smoothness and the violation of the constraint using a penalty parameter (α). The function can be showed in the equation 3:

$$Q(x, \alpha) = J(x) + \alpha R(x) \quad (3)$$

where, $R(x)$ is called an exterior penalty function, $J(x)$ evaluates the smoothness of the surface, $R(x)$ evaluates the degree of violation of constraints and α control a weight balance between $J(x)$ and $R(x)$.

BS-Horizon algorithm was coded in FORTRAN program (Nonogaki *et al.*, 2012). In order to run BS-Horizon the equality-inequality constraint need to be prepared. Firstly, we colored the inter-contour area in a certain color ramp. A color table was prepared include the color ramp and the elevation constraint in that area (0m to 10m). This colored map was save as bitmap 24 bit image and input to an application namely BMP2DAT. In this application the calculation region, the output cell size and the reference color table should be given. The output data is a text file of estimated elevation point with long/lat location and inequality elevation constraint. Next, the spot height data was converted to equality constraint in the same format as the inequality constraint data. Finally, both of these files were merged into an inequality-equality constraint data, which was used as an input for BS-Horizon. The process of running BS-Horizon for DEM generation in FORTRAN program can be described in Figure 3. As the result, the output DEM has elevation from 0-9.5m, the RMSE is only 0.4 m. Compare to other interpolation methods, Horizon-DEM has better smooth surface and the vertical error is also minimize (Figure 1).

2.3 Flood Inundation mapping

A pair of ALOS PALSAR images taken before and during flood event in 2007 was used for inundation mapping. These PALSAR data are in dual polarization with HH and HV bands. In flood monitoring application, HH polarization is more efficient (Twele and Martinis, 2009), therefore HH band in September 15th and October 31th were used for inundation mapping (Figure 2(a) and 2(b)). Firstly, PALSAR data was converted from Digital Number (*DN*) value to Normalized Backscattering Coefficient (NBC), expressed in decibels (dB). The calculation process flowed by this equation:

$$\gamma^0 = 10*\log_{10}(DN^2) - 83 \quad (4)$$

In which γ^0 is the Normalized Backscattering Coefficient, *DN* is the radar amplitude expressed as a digital number and –83 is the calibration coefficient for the PALSAR product.

This pair images are only 90 days of time difference, so the land-cover will do not have any significant affect on the change of SAR backscattering. If there is any severe change on the images, that should be because of sudden phenomenon. Also, the backscatter coefficient is reflected in response to the differences in brightness, where a water surface appears dark because the backscatter coefficient is weak on the smooth surface of water (PALSAR User Guide). Observing from two PALSAR images, there is a large area of water coverage appear as darker color in October 31th. This time is in the middle of flood event from 28th October to 09th November 2007. Using the difference in NBC between 15th Sept and 31th October images, integrate with threshold determining, the flood inundated area was detected properly. Compare to the original PALSAR image in 31th October, this flood area were almost match to the darker regions in SAR data (Figure 2(c)). The threshold was used is 10 dB, if the area has NBC's difference more than 10 dB, that should be inundated area. Using this method, flood inundated area not only be separated to non-water areas, but also be detected from permanent water such as river channel or lakes.

Several bands combination method are also useful for detecting submerged areas. Figure 2(d) is a RGB composition from PALSAR of 31th Oct using both HH and HV bands as follow: Red: HH; G: HV; B: HH - HV. The RGB images also show the good correlation to flood inundated area.

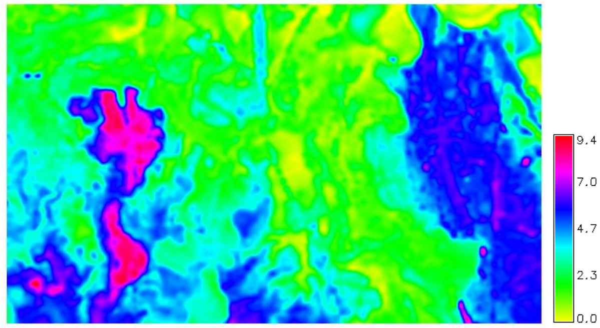

Figure 1. DEM 5m resolution generated by BS-Horizon algorithm

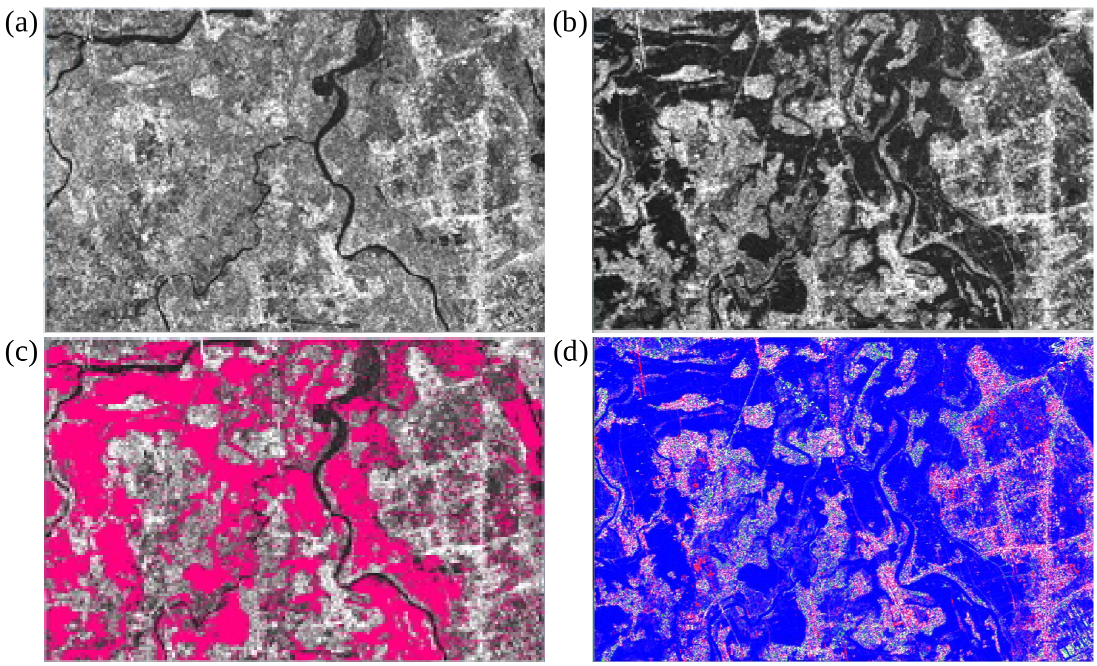

Figure 2. ALOS PALSAR data used to detect flood inundated area. (a) ALOS PALSAR 15th September 2007, (b) ALOS PALSAR 31th October 2007, (c) Flood Inundation areas overlay with PALSAR 31th October and (d) RGB composition.

2.4 Characterizing the topographic features and the relation to flood inundation

Topography is one of the leading elements to flood inundation. From 5m DEM, contour lines with 2m interval was extracted to detect the low-lying area (Figure 3(a)). The 2m contour line was matched perfectly with the flood inundation area boundary. It can be seen that the areas from 0m-2m is under the high vulnerability of submerging when flood occur. Also, it should be consider the land-cover to understand more about the geomorphology of this areas. A land-cover classification map was built from optical ASTER imagery in 2009 (Figure 3(b)).

It is observed that the land-cover also have closed relation on flood hazard. The areas of paddy field are also belong to submerged areas during flood time, and also corresponding to 2m contour lines. Paddy is characterized with the low-lying and good irrigated areas. From this detection, it is easy to determine the flood basin base on contour elevation and land-cover classification. Figure 4 is a cross session to flood plain that can express the geomorphological features of each landform unit clearly.

(a) (b)

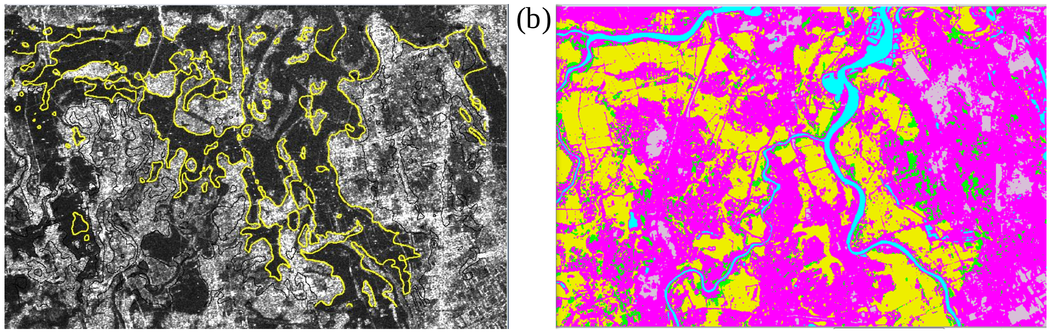

Figure 3. Contour data and land-cover classification used to determine geomorphological features. (a) 2m contour lines overlay with PALSAR in 31th October, during flood event and (b) Land-cover classification: Yellow: paddy; Pink: Built-up; Gray: Bare soil; Green: dry vegetation, Cyan: water.

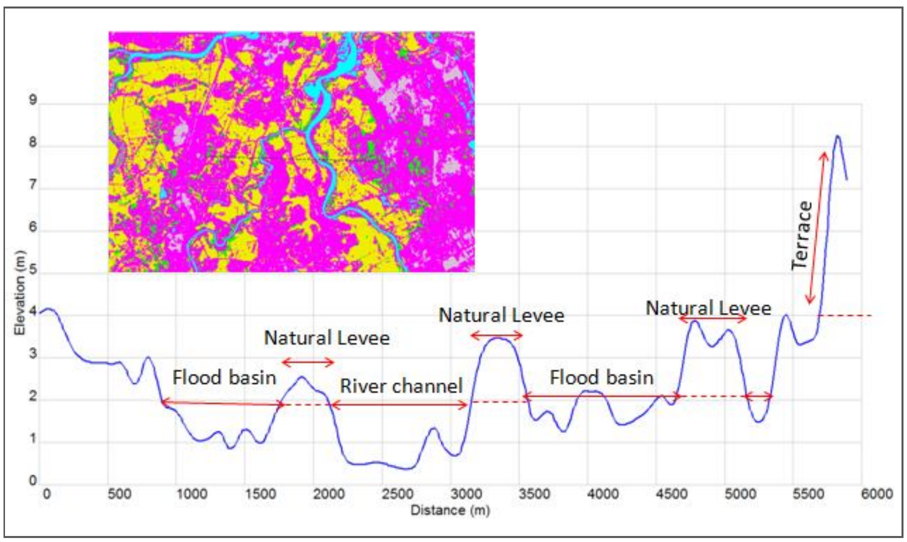

Figure 4. The geomorphological features from a cross session in a flood plain.

A landform (*LF*) classification map was built based on land-cover (*LC*) classification and elevation information from DEM. Figure 4 shows a cross session to flood plain with different landform units. The elevation of 2m and 4m were used as threshold to separate some landform types. The rule for landform classification in this study can be expressed as below:

If (*LC* = paddy), *LF* = flood plain,
If (*LC* = built-up or *LC* = dry vegetation or *LC* = bare land and 3 < DEM ≤ 4),
LF = lower terrace,
If (*LC* = built-up or *LC* = dry vegetation or *LC* = bare land and DEM > 4),
LF = higher terrace,
If (*LC* = built-up or *LC* = dry vegetation or *LC* = bare land and DEM ≤ 3),
LF=natural levee,
If (*LC* = water), *LF*=permanent water.

From this landform map, a flood risk map was built based on the probability of submerging of each landform unit. Geomorphological land classification map is intended to enable to estimate the nature and extent of flood (Haruyama *et al.*, 1996). Figure 5(b) shows relationship between the feature of the flooding and the micro-topography in this alluvial lowland area.

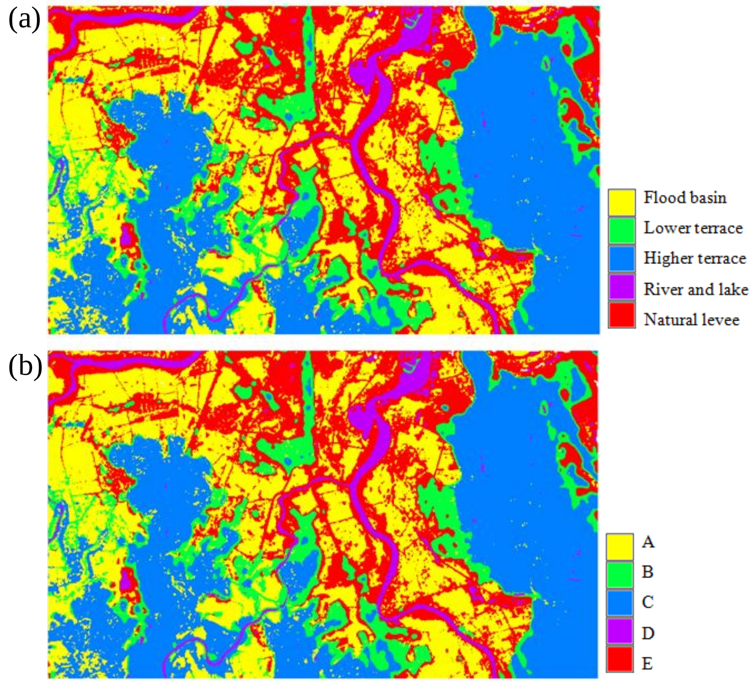

Figure 5. Landform classification and flood susceptibility map of study area.
(a) Landform classification map and (b) Flood risk for probability of exceedance:
A: Submerged for long time with deep depth of flood water; B: Submerged in major flood;
C: Never submerged; D: Permanent water; E: submerged in an extraordinary flood time.

3. CONCLUSIONS

DEM generation for an alluvial lowland area has to face to many problems. BS-Horizon interpolation method is an effective solution that can satisfy the requirement of smoothening surface and agreement with the given elevation constraints. ALOS PALSAR satellite imagery support good data for observing flood inundation dynamics, especially the HH polarization band is enable for flood detection. Landforms classification and land use map from study area integrate with high resolution DEM data is a effective approach for estimating the nature of flood as well as flood risk zoning.

REFERENCES

Haruyama, S., Ohkura, H., Simking, T. and Ramphin, 1996. *Geomorphological zoning for flood inundation using satellite data.*, GeoJournal, 38, 273-278.

Do, T.V.H. and Nagasawa, R., 2014., *Potential flood hazard assessment by integration of ALOS PALSAR and ASTER GDEM: a case study for the Hoa Chau commune, Hoa Vang district, in central Vietnam*, Journal of Applied Remote Sensing,8, 1-12.

Ho, L.T.K., Yamaguchi, Y. and Umitsu, M., 2012. *Rule-based landform classification by combining multi-spectral/temporal satellite data and the SRTM DEM*, Int. J. of Geoinformatics, 8, p27-38.

Nonogaki, S., Masumoto, S. and Shiono, K., 2012. *Gridding of geological surfaces based on equality-inequality constraints from elevation data and trend data*, Int. J. of Geoinformatics, 8, p49 - 60.

Twele, A. and Martinis, S., 2009. *Flood classification using TerraSAR-X data.* Hands-on training and tutorial, Center for Satellite Based Crisis Information (ZKI), German Aerospace Center (DLR), p54.