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ABSTRACT

Floodplain in the alluvial lowland coastal area in the south of Danang City is a part of Vu Gia - Thu Bon river basin where is affected by serious and repetitive flood hazard. The topography and geomorphology which directly related to flood hazard but such relationship are still poorly understood. This study aims to measure flood inundation during a flood event in 2007 and estimate the potential flood hazard areas. ALOS PALSAR imageries were used for observing flood inundation dynamics. A 5m resolution DEM of study area were generated using field survey elevation points data and BS-Horizon interpolation method (Nonogaki et al., 2012). The generated DEM and flood inundation map were used as input data to extract the geomorphologic features of the study area and investigate relations on flood hazards. The flood potential mapping based on the investigation of ALOS PALSAR interpretation, topographical analysis and the land cover classification was carried out. As the result, flood inundation map shows good correlation to field survey flood map in 2007 and potential flood hazard map also coincides with flood scenario assessment by the Danang City government.

1. INTRODUCTION

Flooding is one of the most frequent and damage causing natural disaster in Vietnam and more so in Danang City. Several researchers have 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). However, in the previous studies, lack of high resolution digital elevation model (DEM) and near-flood events satellite data, the results may not be sufficient for reliable analysis.

This study aims to build potential flood hazard map for a lowland area in the south Danang City, Vietnam and estimate the change of flood hazard potential. ALOS PALSAR imageries before and during flood event in 2007 were used to characterize flood inundation. Land cover map in 2007 extracted from Landsat TM data was applied for the landform classification process. The potential flood hazard map was generated based on the probability of submergence of each landform unit. In addition, optical RapidEye remotely sensed data acquired in 2014 was used to evaluate the land cover change between 2007 to 2014. The potential impact of recent land cover change as a result of future flood event has been discussed. The result was compared with field survey flood pillar data, flood map of the past, flood scenario provided by Danang City government to assess future flood inundation potential in the study area.

2.   METHODOLOGY

2.1   Study area and data used

Study area comprises of 98 km^2 of lowland area located in the center of Vietnam, covered by Cam Le river in the north-west and Vinh Dien river in center (Figure 1). The study area includes semi-urban area in the south part of Danang City and a northern parts of Dien Ban district, Quang Nam province. This area currently undergoing rapid urbanization under the development policy of governments.
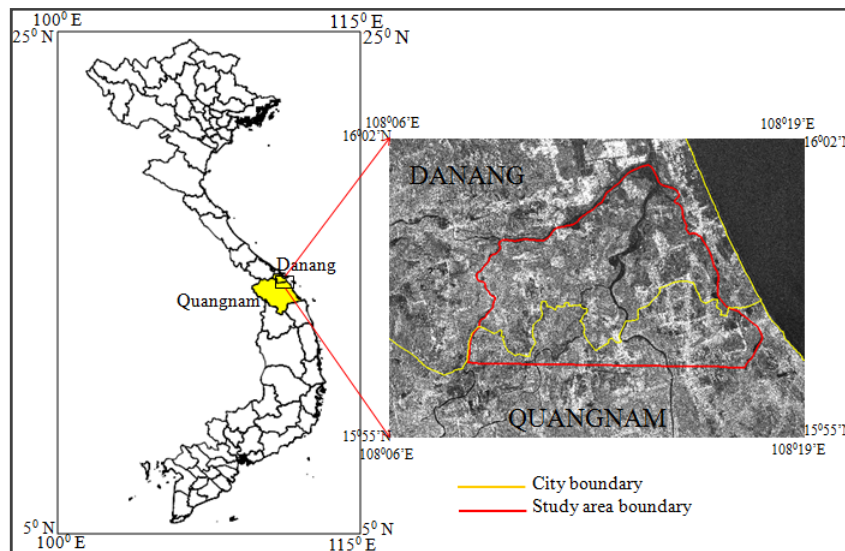

Figure 1. Location of study area in Vietnam. (PALSAR data on 15/09/2007).

The *in-situ* spot height data surveyed by Department of Natural Resource and Environment (DONRE), Danang City in 2009 was used for DEM generation process. In order to characterize flood inundation pattern, major flood event from 28/10/2007 to 09/11/2007 was investigated. A pair of ALOS PALSAR image before and close to this flood event were acquired and analyzed. In addition, optical remote sensed data include Landsat TM in 16/03/2007 and high resolution RapidEye satellite image in 02/03/2014 were used to classify the land cover of study area that relate to flood hazard potential. Flood pillars data collected by a field survey in March 2015 was used as reference data to assess the accuracy of flood map and potential flood hazard map.

Firstly, 5m resolution DEM was generated from field survey elevation point data using BS-Horizon method (Nonogaki *et al.,* 2012). BS-Horizon is a bi-cubic spline interpolation method implemented as Fortran program which takes advantage of equality-inequality elevation constraints. The DEM generation methodology was already mentioned in previous study of Tran *et al.* (2015). This DEM was used as input data for flood inundation mapping and assessment of the flood hazard potential.

2.2. Flood inundation mapping

A pair of ALOS PALSAR HH polarized image (Figure 2a and 2b) for time before and during flood event in 2007 were used for flood inundation mapping. Firstly, Lee filter was applied to reduce speckles in PALSAR data. Subsequently these data were converted from Digital Number (*DN*) value to Normalized Backscattering Coefficient (σ^0), expressed in decibels (dB) as shown in equation (1) below;

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$$\sigma^0 = 10 * \log_{10}(DN^2) + \text{CF} \qquad (1)$$

Where σ^0 is the Normalized Backscattering Coefficient, DN is the radar amplitude expressed as a digital number and CF is the calibration coefficient for PALSAR standard products, and equals -83 dB.
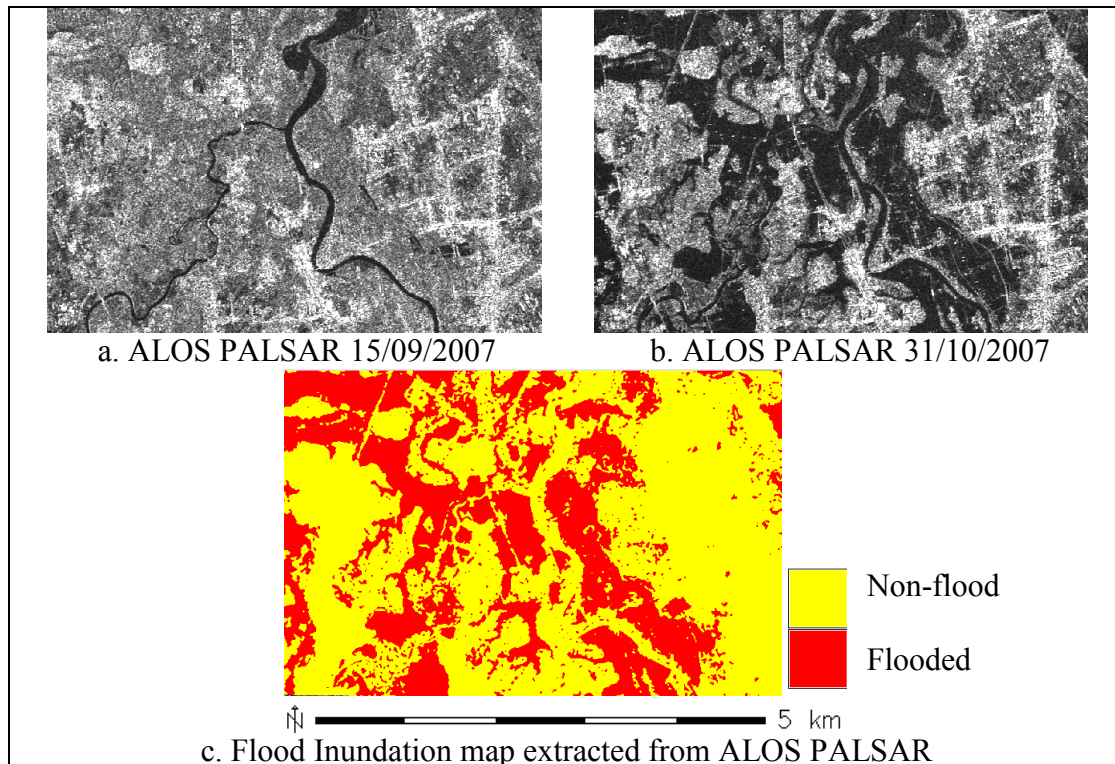

a. ALOS PALSAR 15/09/2007   b. ALOS PALSAR 31/10/2007

Non-flood

Flooded

5 km

c. Flood Inundation map extracted from ALOS PALSAR

Figure 2. ALOS PALSAR HH Polarization (a, b) and flood inundation map (c).

Flood inundated areas were extracted using the difference in σ^0 between 15/09/2007 and 31/10/2007 images and DEM data. Firstly, the difference in σ^0 between two PALSAR data was calculated, then a threshold of 7dB was used to separate water and non-water objects. The resulting flood inundation map still have too many noisy pixels which were filtered using the 5m DEM. Comparing with field survey data, all of flood pillar points have elevation lower than 5m. Therefore a threshold of 5m elevation was used to remove all the noisy pixels in the higher elevation area. Subsequently a 5*5 smoothing filter was applied. All of the data analysis was carried out using GRASS GIS.

As a result, comparing to the original PALSAR image in 31/10/2007, this extracted flood inundation map matched well with the flooded regions in SAR data (Figure 2(c)). Using this method, flood inundated areas were not only separated from non-water areas, but also demarcated from permanent water such as river channels and lakes.

2.3. Characterizing the topographic features and the relation to flood inundation

Geomorphological analysis is recognized as an essential part of understanding of floodplains, based on a simple principle: the floodplain boundaries of a stream correspond to the envelope curve of its past flood. Firstly, contour lines with 2m interval were extracted from 5m DEM to detect the low-lying area (Figure 3a). The 2m contour line was also corresponded to the flood inundation boundary. It can be seen that the areas from 0m-2m is under the high vulnerability of submerging when floods occur. Also, it is observed that land cover has significant effect on flood hazard. Land cover map extracted from Landsat TM in

2007 reveals that agricultures are submerged areas during flood time. As a result, it is easy to determine the flood areas based on surface elevation and land cover class.

Statistical evaluation of DEM and land cover shows that the average elevation of each land cover is related to flood condition. Table 1 shows the calculation of mean elevation based on land cover classification. It is observed that water and agriculture usually locate in the lowland area where can be easily submerged if flood occurs. Built-up and bare land are generally located in the upper area. Based on this average elevation, integrated with flood inundation map and land cover classification, a method for landform classification of this study area was proposed.

Table 1. Average elevation of each land cover (Calculate from 5m DEM).

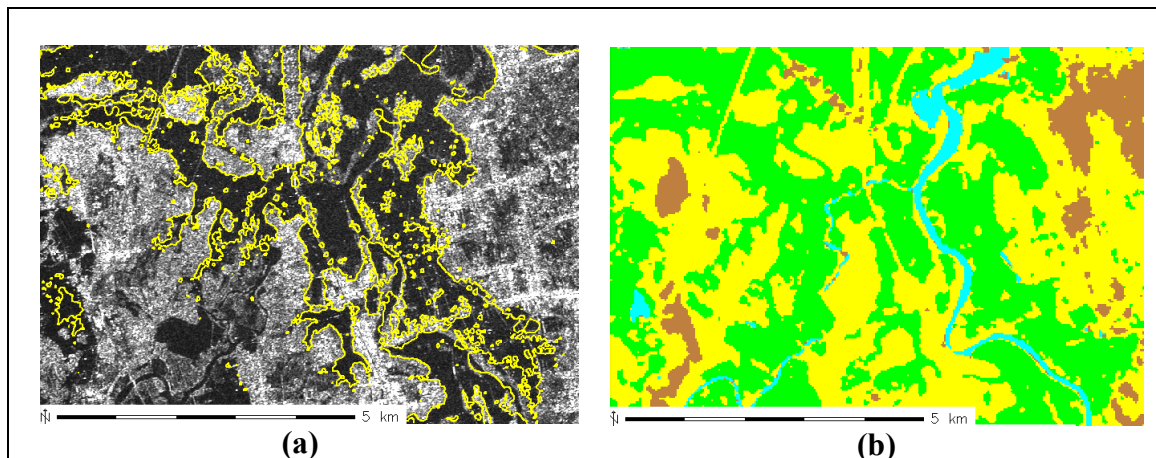| Land cover	Average Elevation
Agriculture	1.97
Built-up	3.67
Water	1.42
Bare land	5.06

Figure 3. Contour data and land cover classification map.
(a) 2m contour lines overlay with PALSAR in 31th October. (b) Land cover classification: Green: Agriculture; Yellow: Built-up; Cyan: water; Brown: Bare land.

Figure 4 shows a cross section across the floodplain with different landform units. The elevation and distance to river channel are criteria to separate landform types. Based on the rule-based landform classification proposed by Ho *et al.* (2012), integrated with land cover (LC) map in 2007, 5m resolution DEM and flood inundation map extracted from ALOS PALSAR data, a new landform classification method was implemented as below:
 - Permanent water: if LC = water
 - Flood basin: if LC = agriculture or Flood map = flood or DEM <= 2m
 - Natural Levee: if LC = non-water and Distance from channels <= 500m and DEM <= 3m
 - Lower terrace: if LC = non-water and DEM <= 4m
 - Middle terrace: if LC = non-water and 4m < DEM <= 5m
 - Higher terrace: if LC = non-water and DEM > 5m.

Using the landform map, potential flood hazard was analyzed based on the potential of submergence of each landform unit. Geomorphological landform classification map is intended to estimate the nature and extent of flood. The potential flood hazard map that reflects relationship between the landforms and flood condition in this alluvial lowland area is shown in Figure 5 and summarized in Table 2.
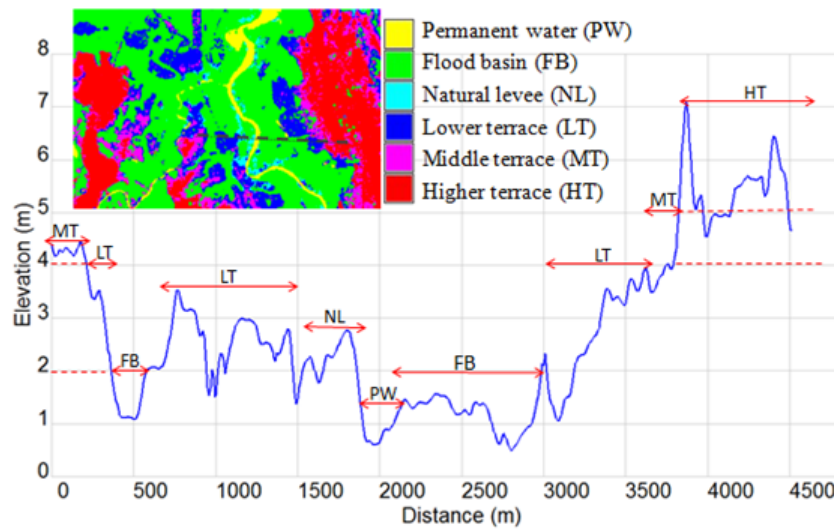
Figure 4. The geomorphological features from a cross session in a floodplain.

Table 2. Flood condition and potential of flood base on landform types.

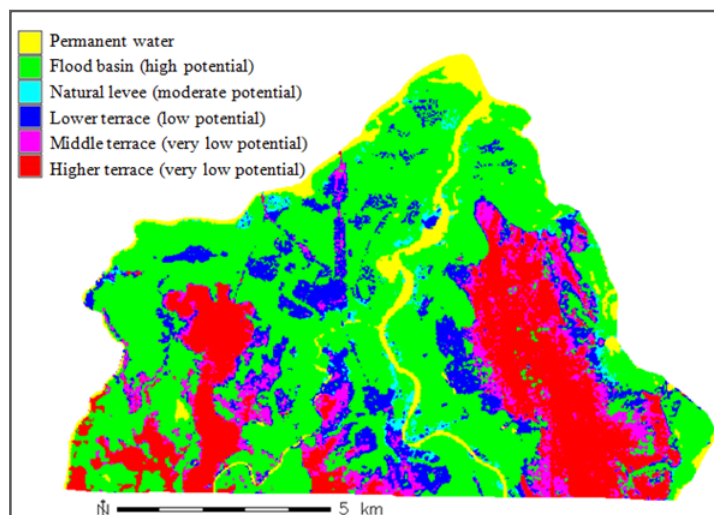| Landform type	Flood condition	Potential of flood
Permanent water	Water level rise, but no damage	Non-flood hazard
Flood basin	Submerged for long time with deep water	High
Natural levee	Submerged in an extra-ordinary flood but drain well	Moderate
Lower terrace	Submerged in major flood	Low
Middle terrace Higher terrace	Never submerged	Very low

Figure 5. Landform map and the reflected potential of flood hazard in 2007.

2.4. Estimating the change of flood hazard potential based on land cover change

The study area is currently undergoing the rapid change of land cover. Landsat TM image in 2007 and high resolution RapidEye data in 2014 were applied for land cover classification of study area. Both data were acquired in March, so it is more reliable to detect
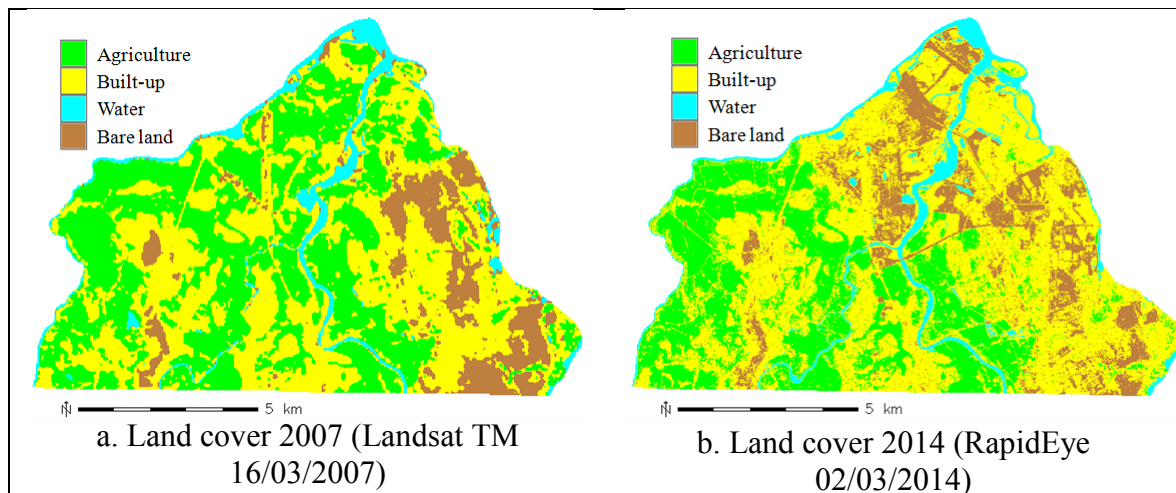
the land cover changes.

<table>
<tr><td>a. Land cover 2007 (Landsat TM 16/03/2007)</td><td>b. Land cover 2014 (RapidEye 02/03/2014)</td></tr>
</table>

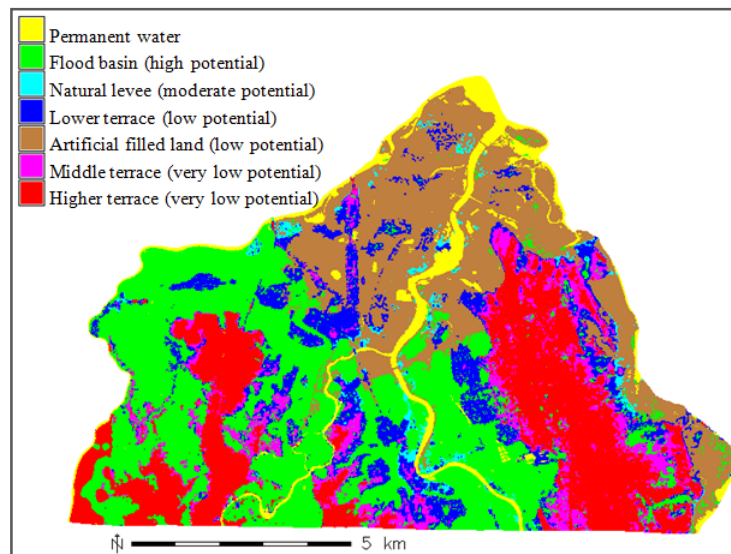**Figure 6 : Land cover maps of study area in 2007 and 2014.**

Figure 7. Landform map and the reflected potential of flood hazard in 2014

Comparison of land cover maps for 2007 to 2014 indicates that there is a significant change especially in built-up area and agriculture. The agriculture area in the northern was totally replaced by built-up and bare land. These bare land areas are mainly under construction for developing of new township. The urban development policy of Danang City has planned the conversion of these areas from rural communes to urban areas. A large area of bare land observed in the eastern of study area in 2007 was also replaced by built-up. The changes in this eastern included new residential areas in Ngu Hanh Son district (Danang city) and Dien Ban district (Quang Nam province), the development of series of universities (Danang Universities Zone - Ngu Hanh Son district) and Dien Nam-Dien Ngoc urbanized zone in Dien Ban district.

The change in land cover leads to the change in topography (valley-fills) as well as flood hazard potential. In this consideration, it is difficult to obtain DEM data in 2014 and also there is no flood event in this year, hence flood inundation map in 2014 is also not available. Land cover in 2014 and the previous landform map were used to estimate potential flood hazard in future. Agriculture was considered as flood basin in 2014, due to the close relation between this land cover type and flood inundation. Permanent water was extracted

from water class in land cover map in 2014. Natural levee usually does not change in several years, therefore it was kept as same in landform map 2007. The significant areas of land cover change are the new residential areas and areas under construction that were filled-up. These areas were named as artificial filled land in landform map 2014. These areas usually are not easily affected by annual floods except in some major floods, so they are in low potential of flood hazard. Other landform units include, middle terraces and higher terrace were maintained from landform map 2007. The estimated landform map and potential flood hazard map for the year of 2014 can be seen in Figure 7.

4. RESULTS AND DISCUSSION

4.1 Flood inundation mapping and landform classification

Field work was conducted in March 2015 to collect 36 flood pillar data which contains all of the historical flood depth during past flood events. This survey point data then was imported to flood inundation map extracted from ALOS PALSAR and landform map in 2007 to evaluate the accuracy of these maps. There are 23 flood pillar points belongs to inundated area in flood map 2007 and the remaining 13 points are non-flood. This is because of flood map extracted from ALOS PALSAR on 31/10/2007 that was only in the first stage of flood event from 28/10/2007 to 09/11/2007. Therefore, the water level still has not reached to maximum flood level.

Comparing to flood inundation map in 2007 given by Danang City government (Phong Tran *et al.,* 2013), it is observed that the flood basin or high potential flood areas in 2007 extracted from this study are mostly coincided with flood map in 2007 given by Danang City government (Figure 8).

4.2. Evaluating future flood hazard potential

The land cover change as well as land filling has made change in flood condition in the corresponding areas. The estimated potential flood hazard map in 2014 shows the replacement of flood basin in the north and east parts of study area by artificial filled land, therefore the flood potential has changed from high to low potential. Comparing to flood scenario given by Danang City government, the flood inundation areas are coincide to high potential flood areas in estimated map 2014, and the new residential areas becomes non-flood areas (Figure 9).
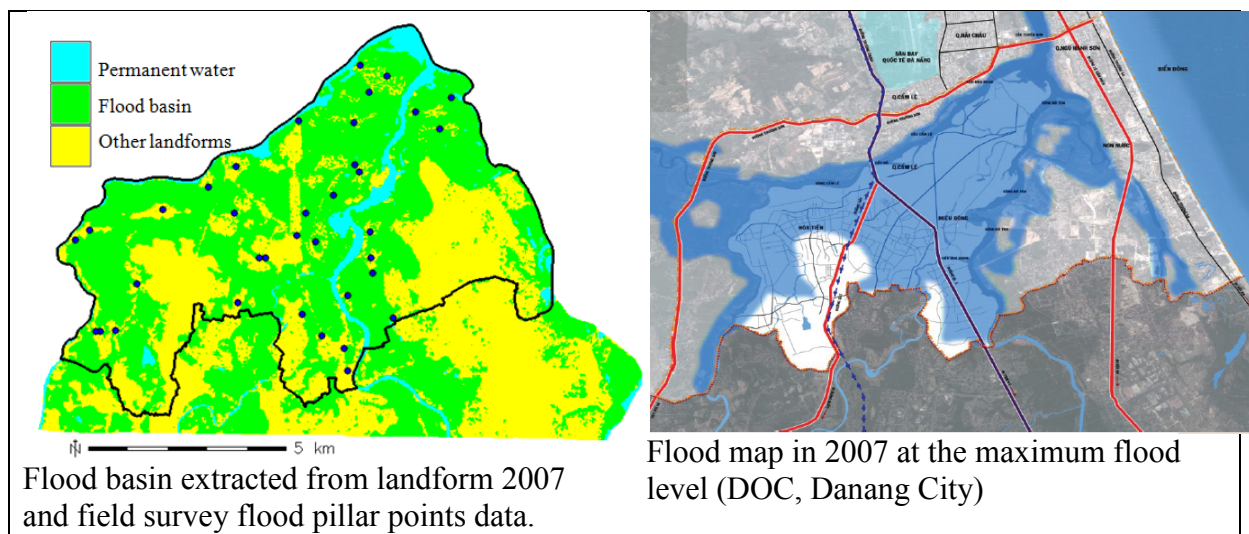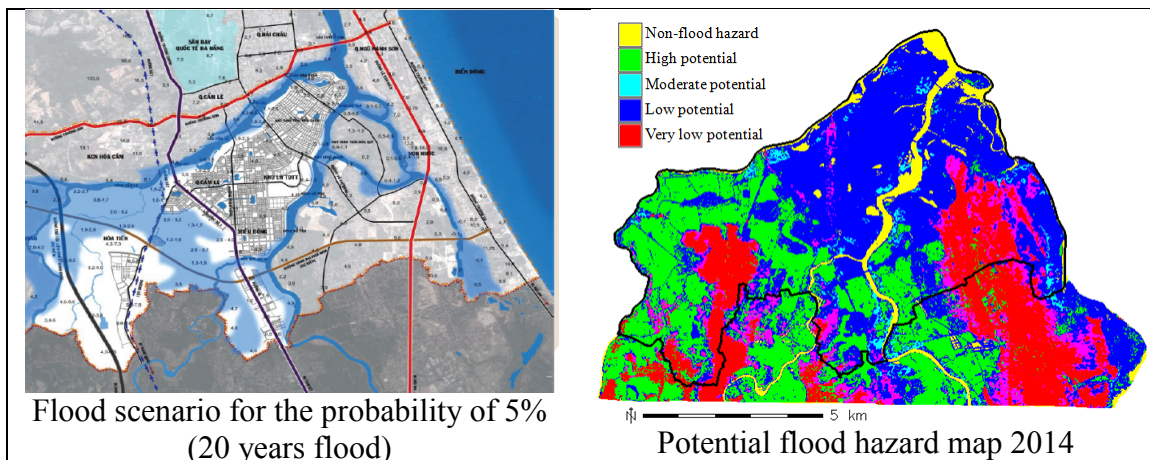

Flood basin extracted from landform 2007 and field survey flood pillar points data.

Flood map in 2007 at the maximum flood level (DOC, Danang City)

Figure 8. Accuracy assessment for flood inundation mapping

Flood scenario for the probability of 5%
(20 years flood)

Potential flood hazard map 2014

Figure 9. Accuracy assessment for potential flood hazard mapping.

CONSCLUSION

ALOS PALSAR data supports for creating flood inundation map rapidly and accurately. The availability of PALSAR data taken during flood time is effective for characterizing flood inundation in this study. Moreover, high resolution DEM integrated with flood pillar data have contributed to evaluate the accuracy of flood map.

In this study flood basins are the lowland agriculture areas situated along either side of Cam Le river and Vinh Dien river. The land cover as well as topography has significantly changed from 2007 to 2014. The flood basin in 2007 were replaced by artificial filled land in 2014 in a large area in north and east parts of study area. The potential flood hazard in these areas also change accordingly from high potential to low potential.

Landforms units derived from rule-based classification of land cover map, 5m DEM data and flood inundation map not only facilitates the understanding of the nature of flood but also in flood hazard potential evaluation. The methodology developed in this study would be useful in coastal lowlands in Vietnam and other parts of the world.

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