FLOOD HAZARD MAPPING BY SATELLITE IMAGES AND SRTM DEM IN THE VU GIA – THU BON ALLUVIAL PLAIN, CENTRAL VIETNAM

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ABSTRACT:

The objective of this study is to generate a flood hazard map based on geomorphologic approach employing Shuttle Radar Topographic Mission (SRTM) DEM and satellite image data (ASTER and LANDSAT). Supervised classification of satellite images is implemented to characterize land cover types. Moreover, the Modified Normalized Difference Water Index (MNDWI) is undertaken to identify moist surface or saturated areas to separate flood and non-flooded areas. SRTM DEM categorization of height range is incorporated with the results of surface analysis from unsupervised classification and MNDWI to delineate the flood affected areas in relation with geomorphologic features. The results are compared with landform classification map and flood hazard map generated by image visual interpretation, field survey, topographic maps and past flood inundation maps. A case study is conducted in the alluvial plain of the Vu Gia – Thu Bon River system, central Vietnam. The extraction of moist soil by MNDWI can help to detect flooded sites and this result is compared with the landform classification map, SRTM DEM elevation ranges and land cover classification. The comparison reveals close relationship between water saturated areas, elevation ranges, and flood condition that the areas with elevation lower than 4m and classified as flood basin and deltaic lowland are inundated deeply and for rather long duration. Higher areas such as terraces and sand dunes are not flooded and natural levees are less flood-affected. Moreover, this study proves the significance of MNDWI for separating moist soil for flood prediction.

1. INTRODUCTION

Flood is the most catastrophic disaster in Vietnam resulted from typical tropical monsoon climatic features, in addition to the intensifying topographic characters and recent climate change. Especially the coastal alluvial plains in central Vietnam are known as the most vulnerable to flooding because of distinctive geomorphologic features such as high rainfall, narrow coastal plain, short-steep rivers and densely populated due to advantageous livelihood conditions. Therefore, a flood hazard map is a very crucial tool for monitoring flood risk.

There are several methods for flood mapping based primarily on hydrologic, meteorologic and geomorphologic approaches. Particularly, in developing countries where hydro-meteorological data are commonly insufficient and inaccurate and restricted to generate flood models, the geomorphologic method demonstrated its effectiveness and appropriateness (Wolman, 1971; Lastra et al., 2008) because this method applies aerial photos interpretation and field investigation of flood evidences to study geomorphologic characteristics in relationship with historical flood events (Baker et al., 1988; Kingma, 2003). A geomorphologic map can help to study the extent of inundation area, direction of flood flows, and changes in river channel through remaining flood evidences, relief features and sediment deposits formed by repeated flood, hence understanding the nature of former flood and probable characteristics of flood occurring in the future (Oya, 2002). This approach of flood investigation has been verified significantly where the channel system and floodplain morphology of rivers change dynamically and have high erosive potential and substantial sediment supply (Lastra et al., 2008) that can be suitably adopted for the fluvial system of the Thu Bon alluvial plain. Moreover, as hydrological and meteorological data to develop a flood model is commonly restricted, a method for flood hazard zonation based on geomorphologic approach was considered.

Flood hazard mapping by data LANDSAT and SRTM DEM is known as an economical and efficient method for mapping flood hazard and deal with the problem of inadequate data source in developing countries (Wang et al., 2002). The combination of supervised land cover classification from LANDSAT and SRTM DEM classification could be employed for coastal flood risk analysis (Demirkesen et al. 2006; Willige, 2007). Umitsu et al. (2006) demonstrates the significance of SRTM incorporated with GIS in flood and micro-landform study. Ground surface height from SRTM contributes critically for investigating the relationship between flood-affected and flood height.

Shaikh et al. (1989) affirmed the efficient applicability of LANDSAT TM for coastal landform mapping by visual decipherment associated with field survey and aerial photos. And a variety of coastal landforms could be delineated such as shoreline, estuaries, mudflats, islands, mangroves, relict alluvium, cliffs, dunes, flood plains, paleo-channels, paleo-meanders, oxbow lake, and so on.

Delineating flood extent areas and water body in general is always the most crucial concern to deal with flood mapping operation. LANDSAT images are usually the first choice because of their convenient obtainment. There are numerous researches handling LANDSAT data to extract flooded areas in

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many approaches. The most common methods are single band density slicing to classify objects by determining thresholds, combination of relevant bands to highlight target features by maximizing or minimizing spectral characteristics, and the use of spectral indices and band ratios. Efficient methods for mapping flood extent using LANDSAT TM by distinguishing water and non-water areas based on reflectance characteristics using a pair of images before and after a flood event using TM7+TM4 formula (Wang et al., 2002) for extracting moist areas. Flood delineation could also be done by separating permanent water, flooded, and non-flooded from band 7 and 5 of a LANDSAT ETM image after a flood event in Mexico (Hudson et al., 2003; Wang, 2004). Isolation of water body can be conducted by using water ratio band 5/4 (Tewari et al., 2003) or band 2/4 and band 2/5 incorporated with threshold of band5 (Alesheikh et al., 2007). Particularly, an approach takes advantage of reflectance difference of water and non-water (land and terrestrial vegetated surface) of certain pair of bands in the equation (A-B)/(A+B) like the Normalized Difference Vegetation Index (NDVI) approach to create the contrast of digital value and facilitate their extraction, so-called the Normalized Difference Water Index.

This study aims to integrate both landform classification and spectral analysis for flooded area prediction by applying MNDWI and elevation range to assess flood inundation condition of the Vu Gia – Thu Bon alluvial plain, central Vietnam.

2. STUDY AREA

The Vu Gia and Thu Bon river originates from the Ngoc Linh Mountain (2,598 m) of the Truong Son range belonging to Kon Tum province, then, goes through a part of Quang Ngai province, almost whole Quang Nam province and Da Nang city in central Vietnam. The Thu Bon River runs in north-south direction, then, changes its course to flow southwest – northeast and finally west-east down to a plain, so-called the Thu Bon alluvial plain, and drains to South China Sea through the Dai River mouth; while the Vu Gia River flows in southwest-northeast direction, then west-east and returns southwest-northeast toward to Han River of Da Nang city. The Vu Gia – Thu Bon River lacks of distinct alluvial fan (Kubo, 2000). The channel of this river shows braided and/or anastomosing pattern indicated by meandering and anabranching. Sandy sediment supply dominates in river load and governs flow mechanism of the river and the drainage as well. Bed load of the Vu Gia-Thu Bon basin has increased many times than that of a century ago because of upstream deforestation and inherent unconsolidated soil as well as exploiting high slope land for settling and cultivating. Average volume of sediment supply measured at Thanh My gauge station of Vu Gia River is 460,000 tons per year. Consequently, the delta front is elevated and moved seawards by sediment deposition and flood levels trend to be more severe than that in previous (Nguyen H., 2007).

This alluvial plain is belonging to the central part of Vietnam which has the highest rainfall in the whole country. Rainy season is from September to December and the rest is dry season. Average annual rainfall in upland areas of the basin is approximately 3000-4000 mm that is much higher than annual rainfall in the coastal areas (approx 2000 mm per year). Maximum monthly rainfall concentrates in rainy season from September to December with 60 – 76% (75 – 76% at coastal areas) and resulted from storms and typhoons causing flooding.

Major flood events occurred in this area are in 1964, 1999, 2007 and 2009 induced by complex meteorological phenomena (storm, typhoon and tropical low pressure) causing torrential rain in most of the provinces in the central and southern parts of central Vietnam.

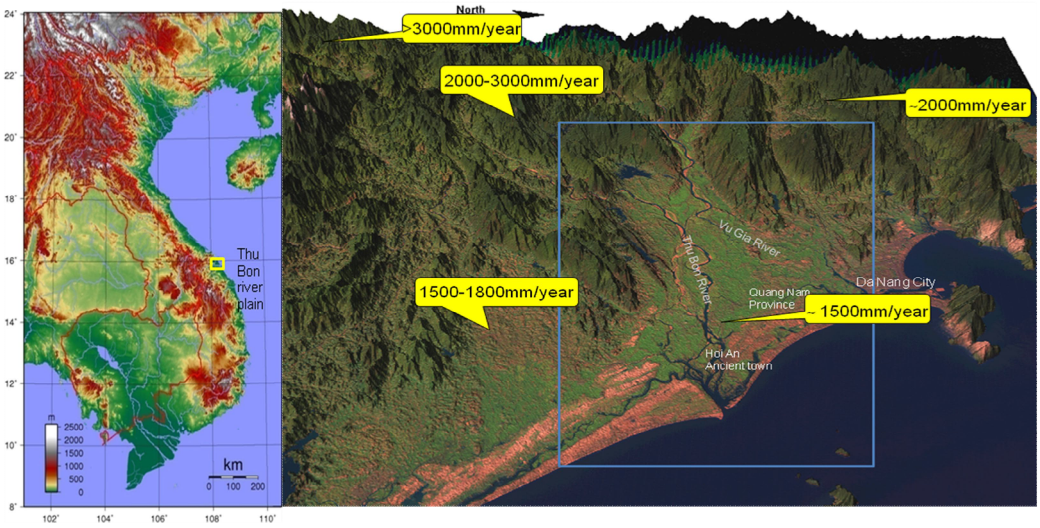

Figure 1. Study area and rainfall distribution

3. DATA USED

Data source	Resolution(m)	Path/row	Season	Crop
ASTER VNIR 2003/01/31	15	125/138	Dry	In crop time
ETM+ 2007/12/21 filled by ETM+ 2004/12/20	30	124/49	Rainy/flood	Non – crop
SRTM3 DEM	90	124/49		

Table 1. Data source characteristics

In the water and mountain areas LANDSAT and ASTER images were masked water and mountain areas in order to concentrate solely on terrestrial and low land.

4. METHODOLOGY

1.1 NDWI

The Normalized Difference Vegetation Index (NDWI) is employed to reach the goal of isolating water and non-water features. There are various definitions of NDWI that combine different pairs of bands (normally of TM or ETM), typically and originally including green and near infrared (NIR) (band2 and band4) (McFeeters, 1996), NIR and short wave infrared (SWIR) (band4 and band5) (Gao, 1996), and red band and middle infrared (MIR) (band3 and band5) band (Xiao et al., 2002). There are several studies employing those pairs of bands to delineate flood extent (Jain et al., 2005; Sakamoto et al., 2007; DeAlwis et al., 2007; Zheng, et al., 2008). However, in fact, the two latter definitions are to obtain water content in vegetation canopy, while the first one focuses more on water surface consisting of open water body and moist soil. $NDWI_{McFeeters}$ aims to 1) magnify the higher reflectance value of water in green band; 2) diminish the low reflectance value of water in NIR band and 3) make use of the distinguished contrast between water and land of NIR band. Therefore, water features have positive values, while soil and vegetation generally have negative values (McFeeters, 1996).

$$NDWI = \frac{Green - NIR}{Green + NIR} \qquad \text{(McFeeters, 1996)}$$

Nevertheless, $NDWI_{McFeeters}$ values of urban features are positive simultaneously as the reflectance pattern of urban areas is coincident with that of water in green band (band2) and NIR band (band4). Whereas, in MIR (band5) the reflectance of urban features is much higher than that of green band, thus use of band5 instead of band4 for NDWI calculation significantly avoids the confusion of water and urban extraction with positive values of water and negative value of other features including urban. The new NDWI is so-called Modified NDWI (MNDWI) (Xu, 2006) as follows:

$$MNDWI = \frac{Green - MIR}{Green + MIR} \qquad \text{(Xu, 2006)}$$

A graph expressing spectral reflectance of features: water, moist soil, urban, sand, forest, agriculture and cloud in 6 reflected bands (1, 2, 3, 4, 5, 7) of the study area reveals remarkable difference of reflectance patterns of water and moist soil from the other non-water features in band2 and band5 not only urban but also sand and vegetated surfaces. The only exception is cloud with reflectance pattern similar with water, however cloudy areas are usually in mountain and this problem can be solved by masking mountain. The graph indicates that the combination of band2 and band5 is the best to separate water and non-water features. The use of band4 and ban5 can separate water surface from urban, sand, agriculture but makes the misunderstanding of forest. Band2 and band7 indicate the highest contrast in water areas but cause the confusing extraction of other features. The pair of band3 and band5 is probably taken into account but the confusion between water and dry sandy area will likely occur. This finding suggests an effective method to isolate flooded areas of LANDSAT images obtained in flood season or water saturated areas in rainy season images with high potential condition of inundation.

Moreover, according to Figure 2, the reflectance difference of water between band2 and band5 is much bigger than that of moist soil features. Hence, it can be stated hereafter:

$$1 \geq MNDWI_{water} \geq threshold > MNDWI_{moist\ soil} > 0 \geq MNDWI_{non\text{-}water} \geq -1$$

Therefore, it is necessary to determine threshold to separate water from moist soil. The MNDWI threshold of this study area is 0.3. In summary, the ranges of MNDWI correspond with features (Fig. 5a) as following:

- $MNDWI < 0$: non-water
- $0 \leq MNDWI < 0.3$: moist soil
- $0.3 \leq MNDWI \leq 1$: water

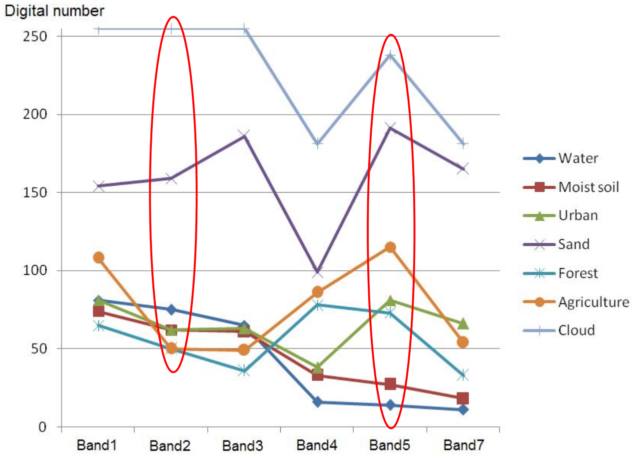

Figure 2. Spectral reflectance characteristics of main features of land cover in the LANDSAT ETM+ image 2007/12/21 of the Vu Gia- Thu Bon alluvial plain

1.2 Land cover classification

The ISODATA unsupervised classification of ASTER image was undertaken with 30 classes using. Then re-class process was performed to generate land cover categories: wet land, forest, agricultural land, sand, bare soil and urban (Fig. 5b).

1.3 SRTM DEM processing and classification

SRTM DEM processing

Filling voids

Prior to employ SRTM it is essential to apply some substantial pre-processing operations. The basic problem affecting to the quality of SRTM data is voids or missing data. Voids were resulted in two causes: shadow and layover effects, especially in mountainous areas that make poor signal return to the sensor, and smooth areas like water or sand which scattered too little energy back to the radar (Zandbergen, 2008). Therefore, voids commonly appear in high elevation areas and in areas such as water surface and sandy land.

The SRTM DEM used in this study is the finished SRTM DTED (Digital Terrain Elevation Data) Level 2. Although it is edited based on the SRTM Edit Rules following several processes such as defined water bodies and coastlines and filling voids (spikes and wells), some missing data still remain (JPL/NASA). In this study, 3DEM was adopted to patch spikes and wells.

Adjusting the overestimated elevations of SRTM DEM

DEM obtained from SRTM data did not indicate “bare-earth” surface or Digital Terrain Model (DTM) but is identified as Digital Surface Model (DSM) where land covered by tree canopy and/or buildings known as noise, thus actual height can only be reflected at areas which are not covered with high vegetated and spread over by houses and other constructions (Zandbergen, 2008). On the other hand, the typical trend of elevation value of SRTM can be expressed as rather higher than real elevation at low elevation (less than 2000m) and lower than that at higher elevation (Berthier et al., 2006). Therefore, SRTM DEM must be subtracted a certain interval of elevation to match with the real elevation of terrain because this study area is located in the low part of the Thu Bon basin.

To figure out the different elevation interval between height value of SRTM and actual height, topographic maps (1/25,000) was selected for examining. Due to the fact mentioned above, the areas covered by trees and buildings do not show actual height. Thus, places used for elevation collaboration must have bare surface or existing sparse and low trees like paddy field, bare soil. To find out the height deviation between SRTM DEM and real elevation, 55 points were selected in random to examine the elevation value of SRTM DEM and topographic maps (Fig. 3). The mean deviation value calculated for all of the values of 55 selected points is 3.5 (m). Therefore, value of SRTM is subtracted with 3.5 (m) by using the command r.mapcalc in GRASS6.3.

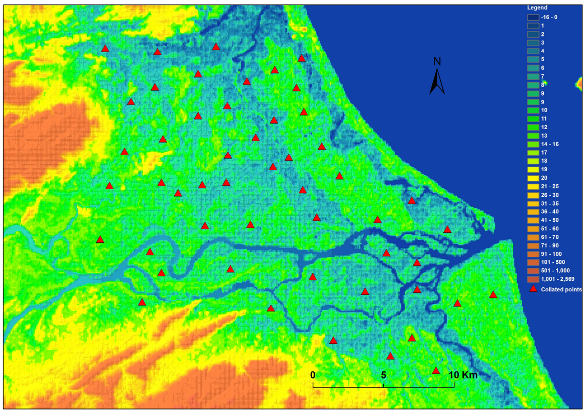

Figure 3. 55 points selected to calculate a mean deviation of elevation between SRTM DEM and topographic maps

SRTM DEM classification

SRTM3 DEM was classified into elevation ranges: < 3m, 3m-4m, 4m-6m, 6m-20m, > 20m. The reason of selecting such ranges is that each range has specific features of landform and flood condition according to the result of manual landform classification. The elevation range > 20m was used to mask the area higher than 20m and corresponding to mountain and hill based on visual interpretation and field survey (Fig. 5c).

1.4 Landform classification

A landform classification map (LCM) was produced by visual interpretation of LANDSAT ETM+ images interpretation and SRTM DEM elevation. The result was verified by aerial photos, topographic maps (1/25,000) and field investigation. The landform of an alluvial plain consists of categories: deltaic lowland, dry river bed, flood basin, former river course, valley plain, sand dune, lower sand dune, inter-dune marsh, terraces (higher, middle, lower), mountain and hill, water (Fig. 5d).
Field work was also done including navigating and observing in field surrounding the study area to examine the geomorphologic features and sedimentary characteristics. Flood condition was obtained by investigating in field. Interviews of local people were also carried out to obtain flood level, and flood evidences were found and measured as well.

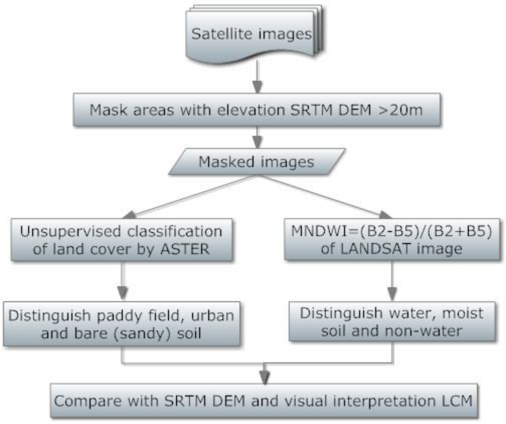

Figure 4. The flow chart of the process

5. RESULTS AND DISCUSSION

The comparison of MNDWI, land cover, elevation range and landform classification was implemented to find out their relationship with flood condition (Fig. 5).

MNDWI values can help significantly to isolate water and moist soil from non-water including dry land and vegetated surface. Then non-water areas can be integrated with SRTM DEM and depending on their shape and pattern to be assigned as different landform units. For instance, sand dunes are witnessed with elongated shape and located parallel to the coastline with elevation ranging mostly from 4m-6m. Natural levees are areas distributing along the river side, with long shape and rather higher than adjacent low land (about 3m-6m). Terraces have higher elevation than levees (approximate 6m-19m) and commonly flat surface. Such high and dry areas are fairly ideal for human settlement and urban development and considerably prevented from flood or less severe flood condition (Table 2).
Valley plain areas are usually formed on the way of water flow from upstream to downstream. Thus, they can be located among either mountains or terraces with land cover similar with other low land areas. Flood basin areas (back swamp) cover most moist areas extracted by NDWI and usually are agricultural land (paddy field). They spread over different elevation ranges but have relatively lower elevation than natural levees and sand dune terraces. Deltaic lowland is known as lower flood basin because of young deposition near the river mouth with height <3m. The height range < 3m is the most vulnerable to flood inundation with flood height 2-4m in the region of flood basin and deltaic low land (paddy field or back swamp) (Table 2).

As in the north of Da Nang city near the mouth of Han River moist soil is also observed (Fig. 5a) this area in the filling image (ETM+ 2004/12/20) is cloudy. As a result the NDWI values are also positive. And this problem can be dealt with adopting SRTM DEM and land cover as this area have high elevation in DEM and classified as urban (Fig. 5b,c).

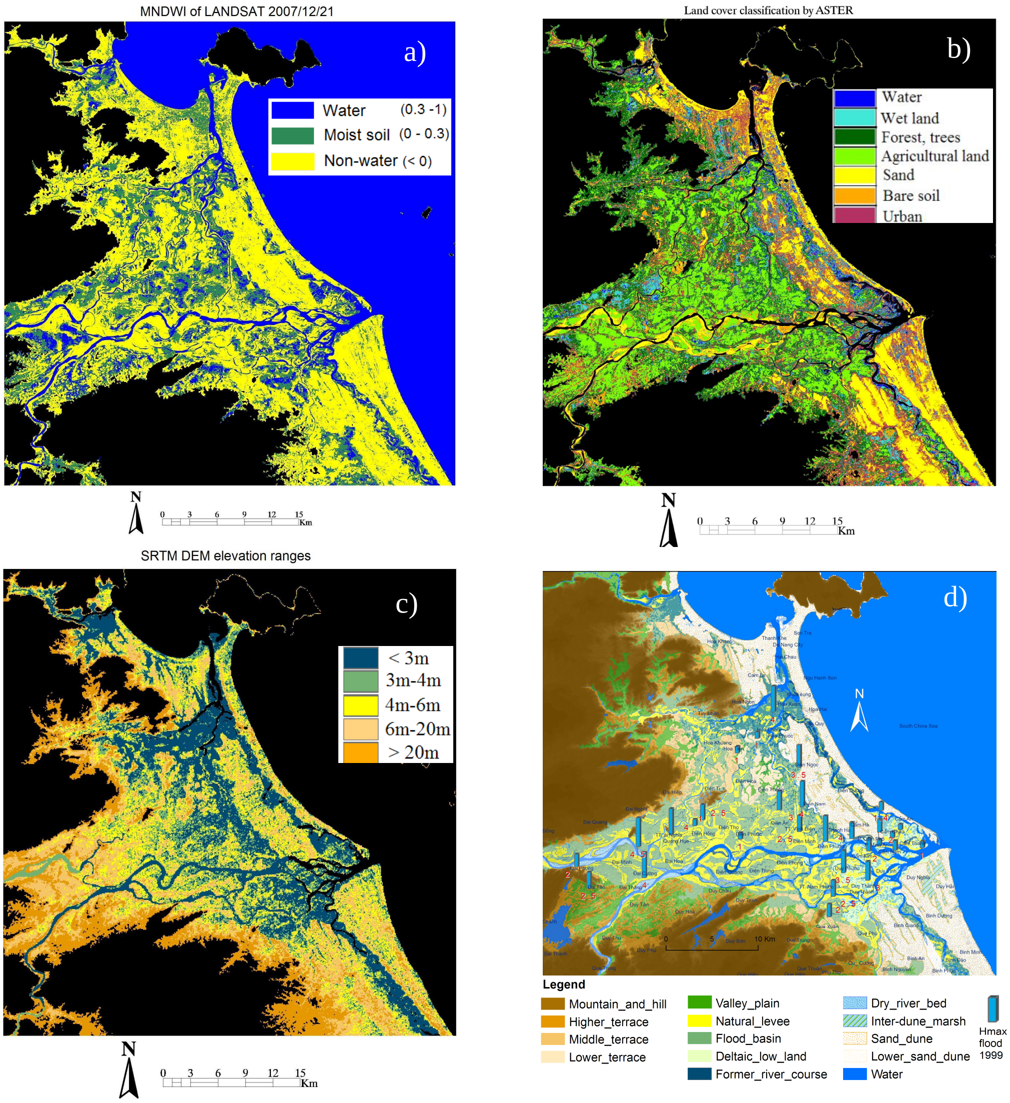

Figure 5. The corresponding patterns between a) MNDWI of LANDSAT 2007/12/21, b) land cover classification by ASTER, c) SRTM DEM elevation range and d) landform classification map

Landform	NDWI range and characteristic ETM 2007/12/21	Land cover of ASTER 2003/01/31	SRTM DEM	Flood status
Mountain & hill		Forest	> 20m	Permanent water
Water	0.3 – 1	Water		Non-flood
Terrace	<0	Urban, bare soil trees	6 – 19m	Flood with long duration
Natural levee	<0	Urban, trees	3m – 6 m	Non-flood
Sand dune	<0	Urban, bare soil trees	4m – 6m	Flood, good drainage
Valley plain	0 – 0.3	Agriculture		Shallow flood, good drainage
Flood basin	0 – 0.3	Agriculture		Deep flood
Deltaic lowland	0 – 0.3	Agriculture	< 3m	Permanent water

Table 2. Classify landforms and flood status

6. CONCLUSION

The analyses of this study revealed pretty good fitness between non-water areas with the areas of terraces, sand dunes and natural levees; and moist soil (water saturated) areas with flood basin, deltaic lowland and valley plain areas in manual landform classification map. Particularly, the moist soil areas spread from the river mouth to farther inner part and these areas are indicated classified as flood basin and have quite high flood level (about 2.5-4m), while SRTM DEM indicates the low land area distributing around coastal zone and the inner part has higher elevation. This can be explained by the mechanism of micro-landform. It means though the flood basin of the inner part has higher elevation, relative elevation is lower than adjoining levees, dunes and terraces. Therefore, flood basin formed in any absolute elevation has deep flood condition.

This study proposed an effective method for flood hazard assessment based on geomorphologic approach by applying Modified NDWI, SRTM DEM and land cover classification of satellite data through their correlation. Solely application of SRTM DEM restricts the analyses due to low spatial resolution. If MNDWI itself is utilized apart from DEM to evaluate flooding, various flood statuses are hardly determined. The land cover classification was undertaken to affirm NDWI and SRTM interpretation as well as initiate further flood risk discussion.

On the other hand, this study proves the significance of modified MNDWI for extracting not only flooded areas but also open water body due to the distinguished reflectance pattern of water and moist soil from non-water features.

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