Analysis of urban expansion and flood risk change in Da Nang city in Central Vietnam

Do Thi Viet HUONG*, Ryota NAGASAWA** and Kazunobu TSUTSUI***
The United Graduate School of Agricultural Sciences, Tottori University, Japan*
Faculty of Agriculture, Tottori University, Japan**
Faculty of Regional Sciences, Tottori University, Japan***

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Summary

Flood is widely considered to be the most hazardous, frequent, and widespread source of disaster risk throughout the world. Urban expansion into flood zone areas and the possible effects of climate change are further elevating the risk of flooding. In Vietnam, Da Nang is one of the cities with the highest rate of urbanization. However, during the last 10 years, Da Nang has been faced with flood disasters that have caused loss of life and damaged livelihoods and infrastructure, as well as disrupted economic activities. This study analyses the urbanization process and flood risk, and their relationship, using remote sensing and geographic information system techniques. Time series Landsat TM/ETM images and multi-seasonal ALOS images were analyzed to generate temporal land use/cover maps (for 1990, 2001, 2007, and 2010), which were then utilized to analyze the urban expansion process. Flow direction characteristics derived from the Aster GDEM (30 m resolution) and the past flood experiences obtained from ALOS PALSAR image was integrated to analyze and rank the potential flood hazard zones. Flood risk was then obtained by evaluating the flood hazard and demographic vulnerability with a ranking matrix in two-dimensional multiplication model. The results show that Da Nang has experienced a high rate of urbanization over the past 20 years, the approximate rate of increased built-up in the area was 220%. The main directions of urbanization are seen in the West, Northwest, South, and Southeast and along the coastal line. The flood risk analysis represents that the most of the major high and moderate risk areas are located in the depression lowlands as well as along the banks of river channels. By overlaying expanded urban/settlements during 20 years (from 1990 to 2010) with those flood risk areas, we identified that some of urbanization have clearly invaded into the higher risk areas of flood. The potential risk revealed by such urban/settlement expansion into the relatively high flood risk areas increased from 1.9 to 3.5% (nearly twofold) in the urbanization periods of 1990-2001 and 2007-2010, respectively.

Key Words: Da Nang city, Flood hazard, Flood risk, Urban expansion, Vulnerability assessment

1. Introduction

Flood is widely seen as the most hazardous, frequent, and widespread source of disaster risk throughout the world (Wisner et al. 2003, Taubenböck et al. 2011). Located in the tropical monsoon, Vietnam is one of the most natural disaster-prone such as typhoon and floods in the Asia pacific Region in which floods are by far considered the most frequent and most devastating hazard causing significant economic, social and environmental damages, directly hindering the country from sustainable socio-economic development. Particularly, the Central Region of Vietnam which is narrow land strip along the coastline and has a complex terrain sloping towards the East Sea (commonly called in Vietnam), suffers the most frequent influence of typhoons, tropical storms and floods (counting for

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65 %) (Ministry of Agriculture and Rural Development of Vietnam - Managing Natural Hazard Project Mardvn 2012). As most of the population is living in low-lying river basin and coastal areas is estimated to be exposed to risk from flood hazards. What is more, there has been increasing urban population growth in these areas, causing high pressure on urban spaces. This results in the creation of settlements in inappropriate areas that are most likely to be exposed to natural hazards, especially flood hazards (Huong et al. 2011, Taubenböck et al. 2011).

In recent years, urbanization has taken place rapidly in Da Nang city, a coastal city located in central Vietnam. The growth of its commercial port, international airport, industrial zones, and new urban areas, as well as the expanding tourism sector along the coastal area, has resulted in huge developments in the socio-economic aspects and spatial structure of the city. On the other hand, the decline in agricultural and aquaculture lands, due to strategy investment as well as the sprawl of human settlements, industrial parks, and infrastructure in flood prone zones, has led to the congestion of storm water drainages that causes flooding. According to the report on the State of Coping with Natural disaster of the People’s Committee of Da Nang (2009), Da Nang city has suffered five great disasters (typhoons and floods) in the last decade, which killed nearly 200 people in the city and damaged houses, boats, infrastructure, transportation, irrigation canals, and agriculture products. The severity of the loss is estimated at approximately 5.902 billion VND (People's Committee Da Nang 2009).

Remote Sensing and Geographic Information System (GIS) have become essential tools for monitoring urban expansion (Thy et al. 2010), as well as for mapping flood hazards and assessing flood risks (Suriya et al. 2012). In this paper, we focus on applying remote sensing and GIS, first to determine land use/cover changes, and then to assess hazard and flood risk. The aims of the study are to analyze the urbanization process and flood risk, and their relationship, using remote sensing and GIS techniques. The findings of this study will serve as a good reference, providing the local authorities with basic information for flood risk mitigation.

2. Study area

Da Nang city is located in the middle of Vietnam, between the range of 15°55'15” - 16°13'15” North latitude and 107°49'05”-108°20'18” East longitude. Da Nang is a dynamic city of the key economic zone in the central of Vietnam with its international airport, deep-water seaport and National Highway 1. The city has an area of 1,283.42 km² with a population of 926,018 people (2010). It consists of six urban districts, i.e., Hai Chau, Thanh Khe, Lien Chieu, Son Tra, Ngu Hanh Son, and Cam Le, one rural district (Hoa Vang) and one island district (Hoang Sa).

The topography is very diverse, combining mountains and a coastal plain, where the mountainous area dominates, with a high range between 700 and 1,500 m. The elevation of terrain gradually descends from west to east, with a narrow distance between hills and the plain. Da Nang city has two main rivers, the Han and the Cu De Rivers, as well as other smaller rivers, such as the Tuy Loan, Cau Do, Vinh Dien, Yen. Most of the local rivers spring from the mountainous area and they are short and sloping with a narrow riverbed, steep banks, and many cascades. With high temperatures and an equable tropical climate, Da Nang has two separate seasons; namely, the rainy season (from August to December) and the dry season (from January to July). According to the weather data of Da Nang Annual Statistics from 1995 to 2010, the mean annual precipitation is 2,504 mm, mainly concentrated in October and November (approximately 50 % of the total annual rainfall). In the rainy flood season, water from the upstream flows into the East Sea (commonly
called in Vietnam) through the mouths of only two small rivers, the Dai (at Hoi An city) and the Han (at Da Nang city), causing inundation. Da Nang is one of the coastal cities suffering from severe consequences of natural disasters. On average each year the city is directly or indirectly influenced by 2 - 3 typhoons and 2 - 3 great floods spells. Previous average 10 years, there appeared one serious flood, however from 10 years back many severe floods have occurred. The particular flood in 1999 with great intensity rainfall caused historical flash flood in Cu De and Tuy Loan River, killed 37 people, injured 61 people, and washed away thousands of houses and damaged agriculture, infrastructure. The total damaged was 611 billion VND. The serious flood in 2007 that killed 3 people, flooded 28,269 houses and damaged thousands ton of rice and agriculture crops, transport infrastructure and irrigation systems. The total damage was 1,524 billion VND. In 2009, the weather changed erratically and the severe typhoon Ketsana killed 8 people, damaged up to 495 billion to agriculture activities. From those evident figures, it can be seen that flood has caused serious damage to the life of residents in Da Nang city in recent years (People's Committee Da Nang 2009).

3. Materials and methods

3.1 Data Preparation

In this study, time series satellite images, demographic statistical data, and flood record data are collected for assessing the temporal and spatial characteristics of urban expansion from 1990 to 2010, as well as land use changes, and to determine a correlation between urbanization and flood risk.

The urban expansion process and land use/cover changes were investigated by image classification of Landsat TM (August 1990), Landsat ETM⁺ (March 2001), Landsat TM (March 2007), and multi-seasonal ALOS Avnir-2 images (March 2009 and May 2010). These created a temporal dataset that allowed analysis of the changes in urban expansion and land use/cover over a 20 year period. The ALOS/PALSAR image taken in December 2007 was applied in order to extract the inundated areas in the historical flood of 2007. The detailed specifications about satellite data are shown in Table 1.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Sensor</th>
<th>Date</th>
<th>Path/Row</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS</td>
<td>Avnir-2</td>
<td>2010/05/16</td>
<td>118/3275</td>
<td>10.0 m</td>
</tr>
<tr>
<td>ALOS</td>
<td>Avnir-2</td>
<td>2009/03/24</td>
<td>118/3280</td>
<td>10.0 m</td>
</tr>
<tr>
<td>ALOS</td>
<td>PALSAR</td>
<td>2007/12/16</td>
<td>472/300</td>
<td>6.5 m</td>
</tr>
<tr>
<td>Landsat</td>
<td>TM</td>
<td>2007/03/16</td>
<td>124/049</td>
<td>30.0 m</td>
</tr>
<tr>
<td>Landsat</td>
<td>ETM⁺</td>
<td>2001/03/23</td>
<td>124/049</td>
<td>30.0 m</td>
</tr>
<tr>
<td>Landsat</td>
<td>TM</td>
<td>1990/08/24</td>
<td>124/049</td>
<td>30.0 m</td>
</tr>
</tbody>
</table>

All satellite images were geo-rectified with UTM map projection for zone 49 and the datum of WGS84, and then masked by the boundary of Da Nang city. ERDAS IMAGINE 2010 software was used for image processing. A Digital Elevation Model (DEM) of Da Nang, 30 m x 30 m, obtained from the ASTER Global Digital Elevation Model (GDEM), was applied for the topographic analysis for the flood hazards building progress. Existing GIS data were also collected as administrative and topography maps. The demographic data were integrated with GIS and remote sensed data for assessment.

3.2 Land use/cover classification

Land use/cover classification was firstly done by unsupervised classification (ISODATA) in order to discriminate the clouds and water bodies from other types of land use/cover. Then supervised classification got benefit from the result of unsupervised classification. This classification method uses the training sample data as a mean of estimating the average and variance of each land use/cover class, which is applied to estimate probabilities. The Maximum Likelihood algorithm was employed to detect the unique land use/cover type. Finally, the supervised classification was carried out using the training areas recognized in the statistical procedures (Xu et al. 2000).

The accuracy of the ALOS image classification was assessed using “ground truth” data and high resolution images from Google Earth at the same time as reference data. For an evaluation, a grid point with 500 m grid spacing was created and converted into a .kml file that included 3,901 points. Subsequently, each individual point was trained by visual interpretation of the Google Earth image. The coded grid points were then overlaid by the ALOS classification in order to compare the accuracy of the results.

3.3 Flood risk analysis

Risk is defined as the probability of harmful consequences, or expected loss (death, injury, disruption of property, livelihood, economic activity, or environmental damage) resulting from interaction between natural or human induced hazards and vulnerable conditions. The definition emphasizes the relationship between the hazard and vulnerability, in which risk is expressed by the notation: Risk = Hazard x Vulnerability (International Strategy for Disaster Reduction 2004). Hazard is referred to the physical events whereas vulnerability is referred to the social factors.

In this study, a flood risk map was developed using the basic ranking matrix in two-dimensional multiplication model of flood hazard and demographic vulnerability (Islam and Sado 2000). The extent of the area for risk analysis was set at less than 35 m in height and according to the administrative boundaries of 31 ward/commune levels. These areas correspond to the constantly flood-affected lowlands of the Hoa Vang, Cam Le, and Ngu Hanh Son districts and the wards along the Han River to the river mouth.

3.3.1 Flood hazard analysis

Hazard is defined as a potential damaging physical event, phenomenon, and/or human activity which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (International Strategy for Disaster Reduction 2004). In this study, hazard is concerned in flood events context in which flood hazard is defined as the acceleration probability of potentially damaging flood situation in a given area and within a specific period of time (Thieken et al. 2006). Flood hazard analysis in previous research has been performed by multiple approaches, such as hydrological-hydraulic (Karl et al. 2008), geomorphology, and hydro geomorphological methods (Loan and Umitsu 2011, Lastra et al. 2008). The conventional methods usually require large amounts of hydrological observation data, which are commonly inadequate or scarce in developing countries; this limits the generation of flood models (Loan and Umitsu 2011). The geomorphological landform classification method has been applied effectively in some research (Lastra et al. 2008) to analyze the geomorphology by examination of aerial photos and field work for flood evidence (Baker et al. 1988). However, this method is relatively complicated and previous research on geomorphology characteristics of a study area can be scarce and appropriate aerial photo data can be lacking. Thus, a simple method is needed for these cases. Our approach is to identify the areas that are prone to flood hazard. Flow direction analysis reveals the effectiveness of extracting these areas. In this study, flow direction characteristics and the past flood inundation experiences obtained from ALOS/PALSAR images were integrated to analyze and rank the potential flood hazard zones. Flood records for the 2007 historical event, obtained from field surveys, were then integrated to check the accuracy of these putatively identified flood affected areas.

The flow direction was derived from the ASTER GDEM (30 m resolution) using the Hydrology tool in ArcGIS ver.10. The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. The depressed surfaces into which water can accumulate at the time of flooding also need to be identified. From the flow direction grid, if the adjacent pixels have different values, it means that water cannot accumulate and will pour in many directions. In contrast, if the adjacent pixels have the same direction value, water will concentrate and that area will be prone to flood hazard. From this point of view, extraction of the depressed surfaces from the large and smooth areas in flow direction grid is relatively easy.

ALOS PALSAR image taken on December 16, 2007 (about 1 month after the big flood) was used to extract the flood water inundated area. First, geometric correction was carried out using a geo-referenced ALOS Avnir-2 image of the same area, until the Root Mean Square Errors (RMSE) were less than 1 pixel. A second order polynomial fit was applied and resampled with the Nearest Neighbor method. Flood inundation mapping was based on water appearing darker in the image because the backscatter coefficient is weak on the
smoothness of water (Earth Remote Sensing Data Analysis Center 2006). The Synthetic Aperture Radar (SAR) image in Digital Number (DN) value was converted to a decibel image (dB) in order to determine the dynamic threshold. The speckle noise in the SAR image was also reduced using the Lee filter with 3 x 3 window sizes. Based on that threshold, the image was classified into two classes: inundated and non-inundated areas. This flood inundation map was then derived by masking with the permanent water bodies.

Suppose that one month after a flood, water partially poured but no SAR images taken close to that flood time are available to check for this. To overcome this deficiency, a flow direction element was carried out to ascertain the flood hazard in this area. Those areas were then overlaid with the flood inundation map from the ALOS PALSAR image interpretation. A flow direction polygon with a high proportion of inundated sections indicated a more flood more prone and hazardous area.

### 3.3.2 Vulnerability analysis

The concept of vulnerability has been defined using

<table>
<thead>
<tr>
<th>No</th>
<th>Vulnerability group variable (Pi)</th>
<th>Weights (Wi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Percentage of children &lt;5 years</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Percentage of elder &gt;65 years</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Percentage of poverty household</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Percentage of female</td>
<td>1</td>
</tr>
</tbody>
</table>

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**Table 2: Weight assignment for each vulnerable group**

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**Fig. 2** Land use/cover maps in 1990, 2001, 2007, and 2010

**Fig. 4** Urban expansions in Da Nang city
many different approaches by many researchers in various fields (Wisner et al. 2003, Füssel and Klein 2006). Vulnerability is understood as the characteristics of a person or group and their situation that influences their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard (Wisner et al. 2003). In this study, the degree of vulnerability can be defined by several indicators of socio-economic status, such as poverty, ethnicity, gender, disability, age, occupation, and immigration status. The vulnerable groups, which included children, the elderly, impoverished households, and females, were utilized for analysis. Based on the degree of susceptibility to flood hazard, a particular vulnerable group is managed by the weighting (W\textsubscript{i}), in which the high value of the percentage of people who are under 5 years old and above 65 years old corresponds to a higher weight, as showed on Table 2. The Demographic Vulnerability Index (DVI) score was calculated for each ward/commune level by the following formula:

\[
DVI = \sum_{i=1}^{n} P_i W_i
\]

Where: DVI: Demographic Vulnerability Index  
\(P_i\): Value of vulnerable group variable  
\(W_i\): Weighting of each vulnerable group

The demographic census data in 2009 was used for assessment of the demographic vulnerability of flood hazard prone areas.

4. Results and discussion

4.1 Land use/cover mapping and accuracy assessment

The time series land use/cover classification maps over the past 20 years are shown in Figure 2 and the area statistics of major land use/cover are shown on Table 3.

The general structure of the land use/cover in this study area was agglomerated significantly for four major land use/cover types: built-up area, agricultural field, bare land, and shrubs/grass. The proportion of built-up areas increased steadily from 1990 to 2001, 2007, and 2010, at 5.2, 7.3, 9.7, and 11.5 %, respectively. Since 1990, the built-up area has expanded beyond the Hai Chau and Thanh Khe districts to the districts along the coastal line. In contrast, the proportion of agricultural fields from 1990 to 2001, 2007, and 2010 has continuously decreased from 8.4 % to 6.5, 4.9, and 4.1 %, respectively. The decline in agricultural fields during this period agrees with the development strategy of Da Nang city, which follows “Service, Industry and Agriculture”, in which the density of service and industry is increasing and

![Table 3 Land use/cover changes from 1990 to 2010](chart.png)
therefore ha area built. The tendency was and 7 has 2 16. 339 Da ha per year on average. - and Jusoff, 2000 ha in 1990 and 2010 (Table 4) determin Accuracy 85.29% 79.2 76 2 22 160 0.64 76 5 92.0 36. as 18 ha between 1990 and 2010, - s Google Earth the slight decline 0.7 of the land the 75. changes, 7 was 13 21 area grew by 6 0 0.90 2 2006 0.69 Occupancy of built - area 0.69 The rate of 10, 6 = 22 which showed : 1994 7 4 2631 2004 which showed Urban expansion and flood risk change in Da Nang city 22 98.1 8 3 82. The populations from 1990 to 2010 5 extracted with good 1996 s/ 53 3 49 8 f available = 67.8 0 11, Urban expansion process in Da Nang city 4 4 0.41 or good agreement 2008 s 67.8 0 11, Land use/cover 4 1998 4 8 41.5 0.53 built 55.2 4 0 2002 15 135 34.6, 13 2003, from the dramatic economic development decrease 7. strong industrialization, modernization actively in building Da Nang into a modern city agriculture is decreasing. The city authorities invested actively in building Da Nang into a modern city, with strong industrialization, modernization, and high services. Therefore, most bare land was reclaimed and covered with industrial zone, infrastructure, and newly built-up areas, which showed a rate of decline from 7.3 % to 3.2 % in 1990 and 2010, respectively (Fig.3).

In particular, a total of 2,853 ha of bare land disappeared during the period of 2001-2007. The sharp decrease observed over these 6 years may have resulted from the dramatic economic development beginning in 2003, when more infrastructure, industrial real estate, and residential structures were built. The tendency was also marked in forests, which showed a slight decline in area. The forest area decreased gradually from 69,773 ha to 67,931 ha in 1990 and 2010, respectively. During this time, shrubs/grass increased, probably due to this deforestation. However, from 2001 to 2007, the increase in shrubs/grass area accelerated to cover 3,343 ha, which showed a high disparity compared with the 120 ha area of deforestation. This is because of the limits of reflectance spectra during the classification. The difference between young offshoot forests and shrubs sometimes was not discriminated; therefore, there was some interconversion between the forest and the shrubs/grass categories.

Accuracy assessment is an important step in the classification as it permits quantitative determination of how correctly the pixels were grouped into the feature classes in the area under investigation (Ismail and Jusoff 2008). The overall classification accuracy of the land use/cover map for 2010 was determined as 85.29 %, with an overall Kappa coefficient of 0.69, which was considered to indicate acceptable or good agreement with the optical data (Table 4). For the built-up areas, the Kappa coefficient was extracted with good agreement, at 0.64. Therefore, these data were available for continuous study.

4.2 Urban expansion process in Da Nang city

Da Nang is recognized as a new economic hub in Vietnam; i.e., a rapidly developing city in recent years. From our analysis of its land use/cover changes, Da Nang city has clearly undergone a rapid urban expansion. Tremendous urban development has taken place over the past two decades, amounting to 11,208 ha in 2010 as compared to only 5,091 ha in 1990. The built-up area grew by 6,117 ha between 1990 and 2010, or nearly 300 ha per year on average. The rate of

<table>
<thead>
<tr>
<th>ALOS Classified data</th>
<th>Reference data - Google Earth</th>
<th>Accuracy Assessment for ALOS image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-up</td>
<td>Water body</td>
<td>Paddy field</td>
</tr>
<tr>
<td>Built-up</td>
<td>339</td>
<td>15</td>
</tr>
<tr>
<td>Water body</td>
<td>2</td>
<td>76</td>
</tr>
<tr>
<td>Paddy</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Upland field</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Bare land</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Forest</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Shrubs/Grass</td>
<td>28</td>
<td>2</td>
</tr>
</tbody>
</table>
increase in built-up area was 140.3 % between 1990 and 2001, 132.9 % between 2001 and 2007, and 118 % between 2007 and 2010. Visual examination of the four land use/cover maps shows vast differences in built-up areas.

The extent of expansion of built-up areas indicates that the core of the city (Hai Chau, Thanh Khe district) has been well developed since 1990. With the substantial development of the emerging industry parks and major infrastructure as well as roads and bridge networks from 2003, this has led to connection with other districts (Lien Chieu, Son Tra, and Cam Le). After 2007, the city authority has accelerated the development of sea park and tourism zones/resorts along the Son Tra - Dien Ngoc coastal road that connects Hoi An city in the Southeast. The urban area has largely expanded beyond the central city to connect Ngu Hanh Son and Cam Le, demonstrating a complete interconnection of urban areas. These developments resulted in the pattern of spatial expansion observed in this study area. Thus, the main direction of urbanization was to the West, Northwest, South, and Southeast, and along the coastal line (Fig.4).

During the 20 year period covered by this study, urbanization appeared highest in the Lien Chieu urban district, followed by the Ngu Hanh Son and Cam Le urban districts. In contrast, the center of Da Nang city, Hai Chau, and Thanh Khe showed a lower rate of expansion because they were already completely urbanized by 1997 (Fig.5). During this time, most of built-up areas were reclaimed from paddy fields and bare lands for the construction, industrial park, and tourism sectors. This can be seen especially in the areas West, Northwest, and Southeast areas of the city, where a large area of bare land was transformed into residential sectors between 1990 and 2010.

Together with the high rate of urbanization and industrialization, Da Nang city is further faced with the pressure of a greatly increasing population. According to the results of a population census, just within 20 years, the population of the city has increased by 1.7 fold, from 537,509 to 926,018 in 1990 and 2010, respectively. Lien Chieu is the leading district, with an annual average population growth rate of 7.4 %, followed by the Cam Le and Ngu Hanh Son districts, which are the urban fringes. In contrast, Hai Chau, which is the center district, has the lowest rate of average population growth, at only 0.7 % per year (Da Nang Statistical Office 2010). These facts clearly demonstrate that rapid urbanization has occurred, together with increases in population in the urban districts.

4.3 Flood risk assessment

4.3.1 Flood hazard map

The inundated areas extracted from ALOS/PALSAR showed that even one month after the flood, the inundated areas still remained, and the percentage of the inundated areas for some land use types still remained relatively high, such as paddy fields (58 %), bare land (36 %), upland fields (29 %), and built-up areas (19 %), so these could be used for further analysis. The potential flood hazard was mapped by evaluating the percentage of inundated area per flow direction with respect to the flood depth point records for the 2007 historical flood. Almost all of the flood depth points less than 1 m (5/5 points) fall within 4-23 % of the inundated flow direction, 77.3 % (17/23 points) of the flood depth points from 1-2 m fall in the range of 26-49 %, while 90 % (18/19 points) of the flood depth points above 2 m fall in the range of 50-70 %. Therefore, a threshold value was set for classifying the hazard rankings shown in Table 5. A smaller hazard rank index was used to assign a low flood depth or low percentage of flow direction (P), while a larger hazard rank index was used to express a high hazard.

Most of the flood hazard areas were clearly concentrated around the Cau Do and Tuy Loan Rivers.

<table>
<thead>
<tr>
<th>Table 5 Flood hazard rank index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of inundated per flow direction (P%)</td>
</tr>
<tr>
<td>No flood</td>
</tr>
<tr>
<td>0&lt;P≤25</td>
</tr>
<tr>
<td>25&lt;P≤50</td>
</tr>
<tr>
<td>P&gt;50</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Table 6 Demographic vulnerability rank index</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
</tbody>
</table>
The highest flood hazard was in the Hoa Xuan ward, followed by the Hoa Phong, Hoa Hai, Hoa Quy, Hoa Chau, and Hoa Khuong wards (Fig.7). These areas are located in a sunken region and along the Tuy Loan, Cau Do, and Vinh Dien Rivers, which are frequently inundated in flood times. In contrast, most of the wards along the Han River to river mouth area are under low flood hazard due to relatively high elevations and water can easily pour out from them to the sea.

4.3.2 Vulnerability map

The demographic vulnerability formulation was used to obtain the weighted scores of Demographic Vulnerability Index (DVI), which ranged from 99.07 to 187.01. These were subsequently standardized on a scale from zero to one, in which a higher rank index value indicated a higher demographic vulnerability (Table 6).

Many wards/communes were vulnerable to flood hazard within the demographic vulnerability context. In total, 6 and 10 wards/communes fell into the high and moderate demographic vulnerability classes, respectively. As shown in Fig.8, almost all of the high demographic vulnerability areas fell within the communes located in the upstream areas. Those communes located in the rural areas and having a high percentage of children and elderly, as well as high rates of poverty, have a greater susceptibility to flood hazards. In contrast, most of the wards in the center urban district are under low and moderate demographic vulnerability. It seems that the probability of exposure to the demographic vulnerability is higher in rural areas.
than in the urban centers.

4.3.3 Flood risk map

A risk map was derived by a 2D Multiplication Model of the flood hazard and the demographic vulnerability component shown in Table 7.

The flood risk map has a rank of index order from 1 to 9, in which the rank 1-3 was set as low risk, 4-6 as medium risk, and 7-9 as high risk. The flood risk analysis revealed that an area of approximately 933 ha is under high risk, while 2,958 ha and 3,588 ha areas are under moderate and low risk, respectively. The high risk area is represented by a combination of both high flood hazard and high demographic vulnerability. Three wards/communes, namely Hoa Quy, Hoa Phong, and Hoa Khuong, fall into the high risk category, while 6 wards/communes, namely Hoa Xuan, Hoa Hai, Hoa Nhon, Hoa Tien, Hoa Chau, and Hoa Phuoc, fall into the moderate risk category. Most of the major high and moderate risk areas are situated in the lowlands of the Hoa Vang and Ngu Hanh Son districts, as well as along the banks of the Tuy Loan, Cau Do, and Vinh Dien River systems and other small rivers. These areas are the urban fringes, situated in the low-lying areas that are particularly exposed to extensive riverine floods. Although the result shows that the ratio of the relatively highest risk is not particularly large, it is necessary to identify and address this by providing strategies for mitigation because the damage to the lives and livelihoods of local people here have been relatively high in previous historical floods.

4.4 Urbanization and flood risk changes

Da Nang city showed a high rate of urbanization during the 20 years from 1990 to 2010. By overlaying expanded settlements during 20 years with the flood risk map, we identified that some urbanized areas have clearly invaded into flood risk areas. The settlement areas exposed to flood risk increased from 31.6 % to 31.8 % and 36.7 % in the urbanization periods of 1990-2001, 2001-2007, and 2007-2010, respectively (Fig.10).

The occupation of settlements in areas with no or low flood risk decreased slightly, while the occupation of settlements in areas with moderate and high flood risk increased nearly twofold from the 1990-2001 to the 2007-2010 urbanization periods. The settlement expansion into the moderate flood risk areas increased from 8.3 % in 1990 to 15 % in 2010 (312 ha) and expansion into the high flood risk areas increased from 1.9 % to 3.5 % in 2010 (74 ha). In contrast, the settlement expansion into the no flood areas decreased from 68.4 % in 1990 to 63.3 % in 2010 and expansion to the low flood areas decreased from 21.3 % to 18.2 % in 2010. In essence, the urbanization process increases population density, with the result that space for resettlement becomes rare and expensive. Consequently, the urban poor people or migrants from rural areas tend to settle in the outskirts of the city, which are prone to floods or other hazards and where the wealthier do not want to live (Associated Programe on Flood Management 2008). Urban expansion has been increasing in the present study area into regions where settlements are subject to significant flood risk.

5. Conclusion

In this study, remote sensing and GIS have been applied to analyze the urbanization process and flood risk changes in Da Nang city. The time series Landsat and multi-seasonal ALOS images were interpreted to create temporal land use/cover maps (for 1990, 2001, 2007, and 2010), which were then used to analyze the urban expansion process. The proposed methodology was successfully applied to produce a flood risk map by combining the flood hazard and demographic vulnerability maps. Flow direction extracted from GDEM was integrated with ALOS PALSAR images to produce the flood hazard map. This method is effective when hydrological and meteorological data are inadequate and remote sensing images taken during flood times are not available or are insufficient. The flood risk map was developed using a ranking matrix of flood hazard index and the demographic vulnerability index. This was then overlaid with the urbanization map for three periods to identify the rate of settlement exposure to flood risk.

The study revealed a high rate of urbanization during the 20 year period (the approximate rate of increase in built-up areas was 220 %). Analysis of the detected land use/cover changes showed that the built-up area increased at a rate of 140.3 % between 1990 and 2001,
and at 132.9 % and 118 % between 2001 and 2007, and 2007 and 2010, respectively. The flood risk analysis represents that approximately 933 ha is classified as high risk, while 2,958 ha and 3,588 ha are classified as moderate and low flood risk, respectively.

The urban/settlements exposed to flood risk show a tendency toward a relative increase in moderate and high risk areas and a slight decrease in the low and no flood risk areas. However, the degree of risk to flood hazard does not only depend on the susceptibility to exposure to flood and demographic vulnerability, but also depends on social factors like the susceptibility and resilience of the community. In further studies, the response of the community to flood hazards, as well as the urban landscape changes before and after a flood disaster, must be considered in detail at the village level.

References
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◊✲ㄽᩥ䞂䜵䝖䝘䝮୰㒊䚸䝎䝘䞁صنع(cx)꼈Isl)䛚䛡䜛㒔(cx)꼈Isl)䛸وكالةรม䝸䝇䜽䛾ቑ኱䛿䚸௒ᚓो㧗䜢 diện$acyj)_멕كرة") học ảnh theo thời gian (multi-temporal satellite images) để thực hiện phân tích rủi ro và tác động của biến đổi khí hậu. Các phương pháp phân tích rủi ro lũ ở thành phố được nghiên cứu trong một hội thảo quốc tế tại Muscat, Oman, từ ngày 4 đến 6 tháng 9 năm 2006.


研究論文

**ヴェトナム中部、ダナン市における都市化と洪水リスクの変遷に関する検討**

鳥取大学大学院連合農学研究科* Do Thi Viet HUONG

鳥取大学農学部** 長澤良太

鳥取大学地域学部*** 筒井一伸

要旨

洪水は、世界的に各地において頻繁に発生し、かつ広域に及んで災害リスクをもたらす現象である。洪水危険地域への都市の拡大や気候変動による洪水のリスクの増大は、今後一層高まることが予測される。ヴェトナム中部に位置するダナン市は、近年同国において最も都市化が著しい地域のひとつである。ダナン市では過去10年間に数回洪水災害を経験し、人命、農業生産、社会基盤が甚大な被害を受け経済活動は混乱するものとなった。そこで、本研究ではリモートセンシングと地理情報システムの手法を用いて、都市の拡大と洪水リスクの関係について検討を行った。まず、時系列のLandsat TM/ETM画像と多季節で取得したALOS画像の解析によって1990年、2001年、2007年および2010年という地域利用特性の変化を示す都市の拡大過程を明らかにした。次に、ASTER GDEM (30 m解像度) を用いて流域特性を図示するとともに、ALOS PALSAR画像から過去の洪水氾濫の範囲を復元し、それらを統合することで潜在的な洪水ハザードの度合いを解析した。最終的な洪水リスクは、こうして得られた洪水ハザード危険度と人口データに基づいた洪水脆弱性との重ね合わせによって解析した。その結果、ダナン市では過去20年間に都市域が約220％の割合で増加し、その拡大方向は特に既成市街地から西部、北部、海岸線に沿って顕著であった。洪水リスク危険度の相対的に高い地域は、河川の堤防沿いや低地のなかに存在する回地地形に多く見られた。過去20年間（1990年～2010年）に拡大した都市域と洪水リスク地域域を重ね合わせた結果、より危険度の高い箇所に都市化が進行している個所が確認された。こうした洪水リスクの高い地域への都市の拡大は1990年～2001年間の1.9％から2007年～2010年間の3.5％へと2倍近く増加していることが明らかにされた。

キーワード：洪水ハザード、洪水リスク、ダナン市、都市化、脆弱

*,**,*** 〒680-8553 鳥取県鳥取市湖山町南4-101

(Correspondence: nagasawa@muses.tottori-ui.ac.jp)