FLOOD AND TSUNAMI FLOW IN RELATION TO THE LANDFORMS OF COASTAL AND ALLUVIAL LOWLANDS-CASE STUDY IN HAT YAI AND BANDA ACEH PLAINS

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ABSTRACT: *Flood control is a very important issue of the environmental management in the alluvial and coastal plains. For the detail management, it is necessary to know the behavior of the flooding on the plains.*

Micro landforms of these plains are closely related to the flow and inundation depth of floods. Landforms of an alluvial plain are roughly classified into three units: alluvial fan, floodplain and delta. Landforms of these units are further classified into micro landforms as natural levee, flood basin, paleo-river channel, beach ridges and so on. The places on a higher micro landforms are generally flood free places or the places where the flood depth is shallow. On the contrary, flood water concentrate on the place of the lower micro-landforms as flood basin or back swamp and inundation depth is deep in the areas. Coastal areas as coastal plain or delta plain are subjected to the inundation by tidal surge or tsunami. Regional differences of the landforms of the coastal plain are also related to the difference of flood condition in a plain. Hazard map or risk map for the flood disasters should be taken the characteristics of micro landforms into consideration.

Key words: *Flood, Tsunami, Coastal plain, Alluvial plain, Landforms*

1. INTRODUCTION

Flood occurs in many places of the world every year. Various efforts such as construction of dams and dikes have been done to prevent and control floods. However, remarkable damages still occur everywhere. Especially, the damages are rather large in the places where the infrastructures are not improved well.

As well as the controlling rivers for the flood prevention, it is necessary to consider where and how the damages or disaster occur in the flooding area. Recently, flood hazard map and a risk map were published in each local government, and it came to be conjugated in the local administration. Various flood models are used for the creation of these hazard maps. In general, flood condition has close relationship with the land condition, and it is necessary to examine the relationships between flood conditions and the landforms of the flooded areas in order to consider the countermeasure for flood disasters.

As inundation and damage caused by a tsunami have also good relationship with the landforms or topography of the ground, we can get important information about the relationship of the inundation and topography from the detail examination of the tsunami inundation.

In this report, I would like to examine the relations between the flood condition and landforms of a alluvial and coastal plains from the examples of flood and tsunami inundation in Thailand and Indonesia.

2. FLOOD IN THE HAT YAI PLAIN, SOUTHERN THAILAND

2.1. Regional setting

In November 2000, a very severe flood arose in the Hat Yai plain, southern Thailand. Maximum flood depth in the region was more than 4 meters, and great damages were caused in the city and the surrounding lowland.

The Hat Yai Plain is located in the downstream of the U-thaphao River basin, and faces to the southern coast of the Sap Songkhla Lake, which is the southern part of the Songkhla lakes. The plain extends about 20 km from north to south and 7-12km from east to west.

Landforms of the Hat Yai plain are characterized as natural levees, flood basins and coastal plains. The natural levees develop along the present and former river channels and the relative height from the flood basin (back marsh) is about 1-1.5 meters. Most of the flood basins are surrounded by natural levees. Landform of a crevass spray, which indicates a flood has flowed over a bank, is seen in several places. Most of the flood basins are used as paddy fields. The U-tapao River flows in the narrow valley plain in the south of the Hat Yai Plain and it enters the plain at about 5 km south of the Hat Yai city. The river system in the central part of the plain is extremely meandering, and the height of the riverbank is about 7-8 m. The U-tahao River changes its course from the west to east at the site near Kot Yang, eastern part of the plain. The extended part of the U-tapao River course in the western part of the plain is the river course of the Bang Klam River channel. The river system in the Hat Yai plain shows H character shape in the horizontal view.

A broad marshy area can be seen in the lower reaches of the right bank side of the U-tapao River. The lowland is considered as a part of the coastal plain, and the sediments are characterized as the peat or peaty sediments with 1-2 m thickness. The ages of the base of the peat layer are mostly 6000-7000 yrBP (Umitsu and Kawase, 1999), and rows of the beach ridges are located in the east of the lowland nearby the foot of Tha Nang Hom Mountain. These facts indicate that the coastal lowland was originally in a very shallow marine condition as tidal flat with mangrove forest.

2.2.Characteristic of the flood in the Hat Yai Plain

The flood in November 2000 was very severe, and almost whole area of the Hat Yai Plain was inundated. Depth of the inundation reached up to 2 m above the ground in many areas of the plain. It reached to 4 m in the area around Bang Klam Tai in the western part of the plain. Water depth about 2 m was also measured at Laem Ponear, the coast of the Sap Songkhla Lake. It indicates that the lake water rose according to the huge quantity of flooded water.

On the other hand, the flood level was very shallow on the natural levees, and the natural levees along Han-Khot Yang-Khu, Khlong Hae and Tha Sae were free from the flooded water.

Elevation of the flood basin in the Hat Yai plain gradually changes its height from the south to the north, but the depth of the flooded water shows distinct regional differences. These regional differences are caused to not only by the ground level but also by the water flow in the plain.

General direction of the flood flow was mostly from south to north, and there were also several flows from both sides of the plain. Relatively strong northward flood flows were observed in the northeastern part of the city and in the western part of the Hat Yai Plain. There was also a strong northwestward flood flow in the northwestern part of the city. This was due to the existence of the abandoned railway embankment. The flood flow was interrupted by the embankment and it was accumulated along the embankment to the northeastern direction.

At the time of the flood, strong stream flows were observed not only in the river channel but also in the western part of the Hat Yai Plain. Moreover, a strong flood flow crossed the natural levee at Ta Chan from south to north. These flows were clearly shown by the virtual drainage network drawn based on SRTM-dem data. On the other hand, a strong flood flow inundated from the main river in the southern part of the Hat Yai urban area, and the stream rushed to the northeastward along the abandoned railway embankment. The flows were also shown in the virtual drainage network. The actual flood flow data collected in the field has good concordance with the virtual flood flow conducted from the SRTM virtual drainage network.

2.3. Concluding Remarks

In this paper, the authors discussed on the relationships between landforms and flood flow of the Hat Yai Plain based on the SRTM-Dem data and GIS method. Landforms of the Hat Yai Plain are consisted of the flood plain and the coastal lowland, and the landforms of the flood plain are characterized by the distinct natural levees and back swamps. The river system of the lower reaches of the U-tapao River is characterized by the distinctly inflective river courses and several tributaries diverged from the main channel. As natural levees develop along those rivers, many flood basins are surrounded by the natural levees.

The ground level of the plain is generally higher in the south and lower in the north. Relatively broad depressions surrounded by natural levees are located in the western part of the plain. Lower eastern part is a part of the coastal lowland along the Tale Sap Songkhla Lake. The ground level of the flood basins, however, is not significantly lower than that of the central part.

However, the depth of flooded water in November 2000 shows a tendency to be deeper at the eastern marshy lowland and at the western flood basin along Bang Klam River. This is considered to be caused by the strong flood flow extended towards the western part and eastern part of the plain, and the strong flood flow was informed in the field survey.

Based on the analysis of virtual drainage networks of the plain, the fact that actual flood flow at the time of November 2000 corresponded with the virtual flood flow conducted from the network was discovered.

It is necessary to analyze the characteristics of micro-landforms and drainage conditions which are obtained from the survey of the landforms in order to predict future floods of the plain.

3. GIANT TSUNAMI AND GEO-ENVIRONMENT IN THE PLAIN OF BANDA ACEH, INDONESIA

3.1. Regional setting

The Band Aceh coastal plain is located along the lower reaches of the Aceh River. It is situated in a graben formed by movement of the Sumatra Fault (Fig. 2). The coastal plain is characterized by deltaic and tidal lowland in the central and western parts, and by distinct rows of beach ridges in the eastern part. Elevation of the plain is 1-3 meters high above sea level in the central and western parts, except the higher parts of natural levees along the present and abandoned channels. The eastern coastal area is also low-lying, but there is a small sand dune along the coast and rows of beach ridges, 1-2 m above the swales, exist in the inner area. Shrimp and fishponds are formed in tidal lowlands of the central and western parts of the plain. Deltaic lowland and beach ridges are occupied by houses, and the Banda Aceh urban area is located on the deltaic plain in the central part of the coastal plain (Fig.3). Calculated high and low tide levels of the Oleelheue near Banda Aceh on Dec. 26, 2004 are 172 cm and 42 cm, respectively, and the tidal range of the region is less than 1.5 m (based on the data by Tsuji et al, 2005).

Generally speaking, destruction of buildings in the Banda Aceh plain is related to the distance from the coast. Distinct regional difference of the destruction of buildings was also seen among the eastern and the central and western parts of the Banda Aceh coastal plain (Figs. 4-6).

3.2. Tsunami flow and landform change in the Banda Aceh Plain

Flow indicators on the Banda Aceh coastal plain generally show inundation from the northwest. However, some areas show different directions of the flow (Fig. 11). On the northeastern coast, flows spread out in a radial pattern from a gap in the sand dune along the coast. In the southwestern part of the plain, northeastward tsunami flow from the west coast penetrated the plain and the flow met in a gap of hills with the southward run-up tsunami flow of the Banda Aceh coastal plain. We also mapped indicators in the western part of the coastal plain that show southward flows deflected due to the existence of hills.

Tsunami flow extended inland in the central and western parts of the plain for about 4 km, and for about 3 km in the eastern part. Remarkable invasion of the run-up tsunami flow along the Aceh, the Aceh drainage and the Jreu rivers was recorded on the SPOT 2 image. The distances of the invasion of the flow from the coast into the rivers were 8 km, 8.5 km, and 6 km, respectively.

Inundation heights at similar distances from the coast were variable, with greater heights in the central and western part of the plain. The tsunami reached a height about 9 m on the ground near the port of the Banda Aceh and about 6-8 m in the western part of the plain about 2 km inland. In the eastern part of the plain about 2 km from the coast, however, tsunami heights were mostly lower than 3 m.

Severe coastal erosion occurred in the parts of the tidal plain used for shrimp or fishponds. The small narrow banks separating the ponds were easily eroded by the tsunami returning these areas to former tidal flat conditions. The conversion of these areas to tidal flats was due to erosion by the tsunami rather than tectonic subsidence. Interviews with local people confirmed that tidal areas are now exposed at low tide to the same extent as they were before the tsunami, and tide levels marked on several bridge are almost similar to levels before the tsunami. It was difficult to reconstruct the flows of the tsunami backwash flow in the Banda Ache plain because there are few indicators of backwash flow on the ground.

3.3. Effect of landforms on tsunami flow in the plain

Regional differences in tsunami flow patterns and tsunami height can be seen on the Banda Aceh coastal plain. The differences are related to the characteristics of the landforms of the plains. In the case of the Banda Aceh Plain, erosion of channels was not violent and the linear erosion is not observed on the plain. In some areas of the plain, however, coastal landforms were greatly modified. Shrimp and fish ponds on the tidal plain were extremely damaged and some of them disappeared after the tsunami. This indicates that the backwash flow was not concentrated linearly in the Banda Aceh plain, and sheet erosion of backwash flow dominated in the plain. This condition is shown on the SPOT image taken four hours after the tsunami intrusion.

The primary reason for the dominance of sheet erosion is that the ground level is related to the geo-environment of the Banda Aceh coastal plain. There is a broad tidal plain in the central and western coastal area of the Banda Aceh plain, and the ground surface is low and flat. This environment did not produce the concentration of backwash and linear-flow erosion was not remarkable.

The Tsunami heights in the central and western parts of the Banda Aceh coastal plain at similar distances from the coast were higher than in the eastern parts. It is suggested that the existence of low-lying tidal and deltaic plains in the western and central parts of the plain facilitated intrusion of tsunami flow inland. The tsunami inundation height also did not decrease in the regions of the plain. In the eastern coastal region, relatively higher landforms such as dunes and beach ridges prevented the tsunami flow from penetrating inland.

3.4. Concluding remarks

Tsunami flow and inundation in the Banda Aceh plain, Indonesia are related to its landforms. The landforms of the Banda Aceh coastal plain are characterized as deltaic lowlands with tidal plain in the west and central parts and the strand plain and beach ridges in the eastern part of the plain. Coastal erosion of the plains was caused by direct attack of tsunami wave in both the Banda Aceh plain, and the broad tidal flat of the Banda Aceh coastal plain was severely damaged by the tsunami flow. Sheet erosion dominated in the Band Aceh tidal plain. Micro-landforms such as beach ridges and natural levees prevented the flow of the tsunami from penetrating further inland in the area near the margin of tsunami inundation.

DÒNG LŨ VÀ SÓNG THẦN LIÊN QUAN TỚI CÁC DẠNG ĐỊA HÌNH VÙNG ĐẤT THẤP ALUVI VÀ VEN BIỂN

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TÓM TẮT: *Kiểm soát lũ lụt là vấn đề quan trọng trong quản lý môi trường ở các đồng bằng aluvi và ven biển. Để quản lý chi tiết, cần phải biết quá trình lũ lụt trên các đồng bằng.*

Các dạng vi địa hình của các đồng bằng này liên quan chặt chẽ với dòng và độ sâu ngập lũ. Các dạng của đồng bằng aluvi được phân chia sơ bộ thành ba đơn vị: quạt aluvi, đồng bằng ngập lụt và delta. Các đơn vị này lại được phân chia thành các dạng nhỏ hơn như đê thiên nhiên, lưu vực ngập lụt, kênh sông cổ, các gờ bãi biển ...Các vị trí trên các dạng vi địa hình cao hơn thường không ngập lụt hoặc chỉ ngập nông. Ngược lại, nước lũ tập trung vào những nơi phân bố dạng vi địa hình thấp hơn như lưu vực ngập lụt hoặc đầm lầy sau và mức độ ngập sâu hơn ở những khu vực này. Các khu vực ven biển như đồng bằng ven biển hoặc đồng bằng delta thuộc về các diện ngập do sóng triều và sóng thần. Những phân dị theo vùng của những dạng địa hình ở đồng bằng ven biển cũng liên quan tới sự phân dị điều kiện lũ trong đồng bằng.

Từ khóa: *Lũ, Sóng thần, Đồng bằng ven biển, đồng bằng aluvi, dạng địa hình*

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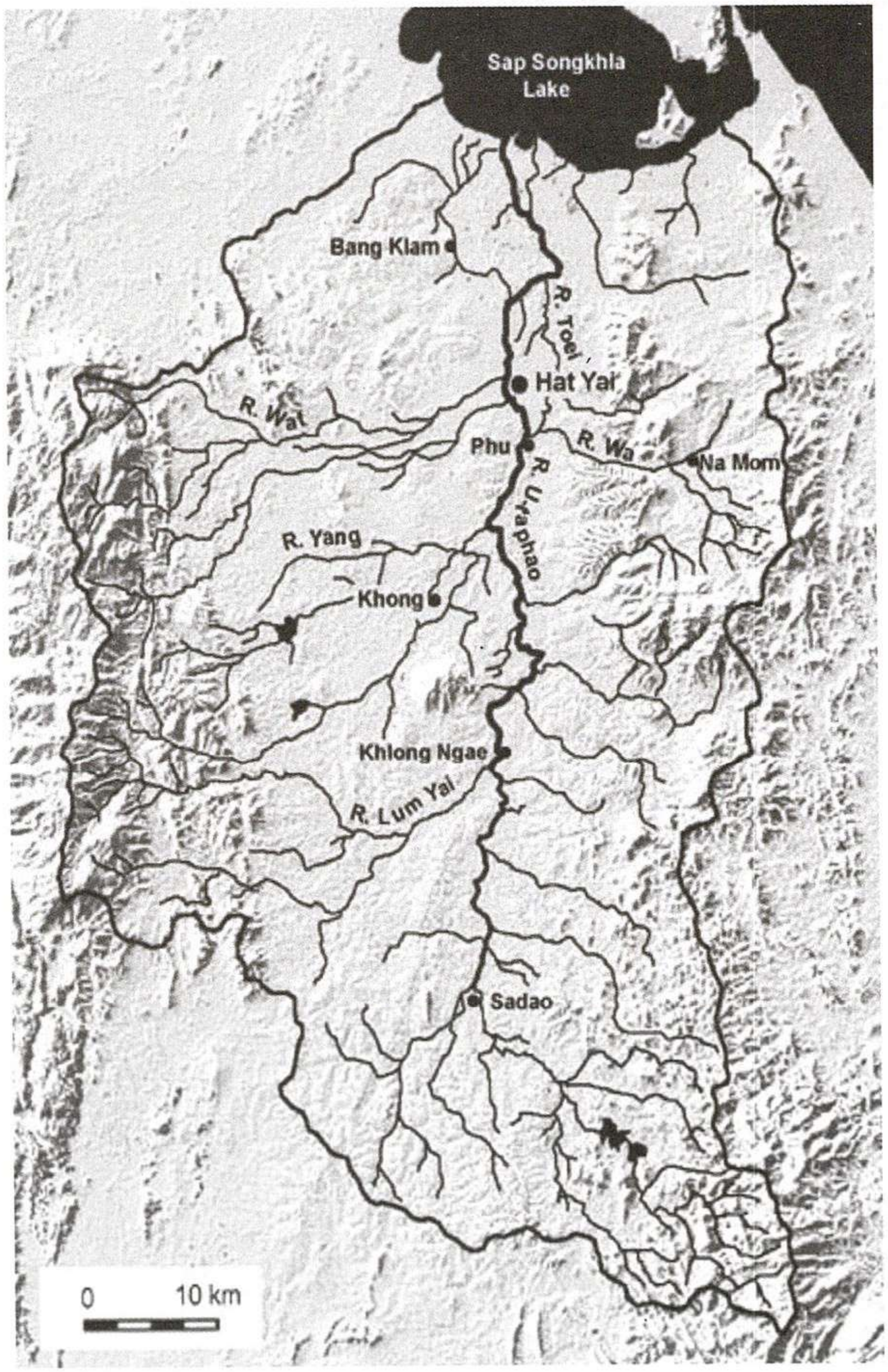

Fig. 1 Drainage system of the U-taphao river.

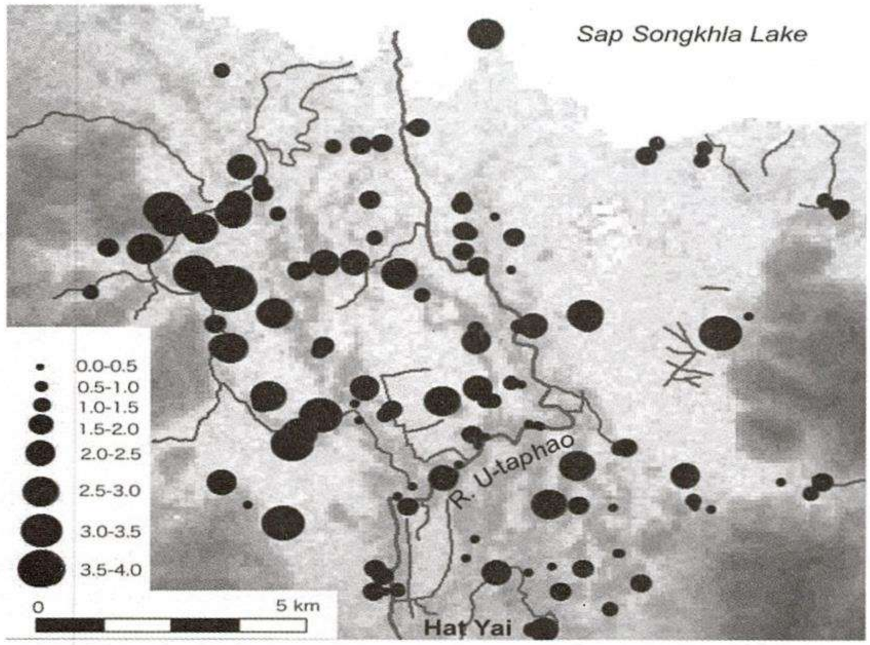

Fig. 2 Inundation depth in the Hat Yai Plain at the flood of November 2000.

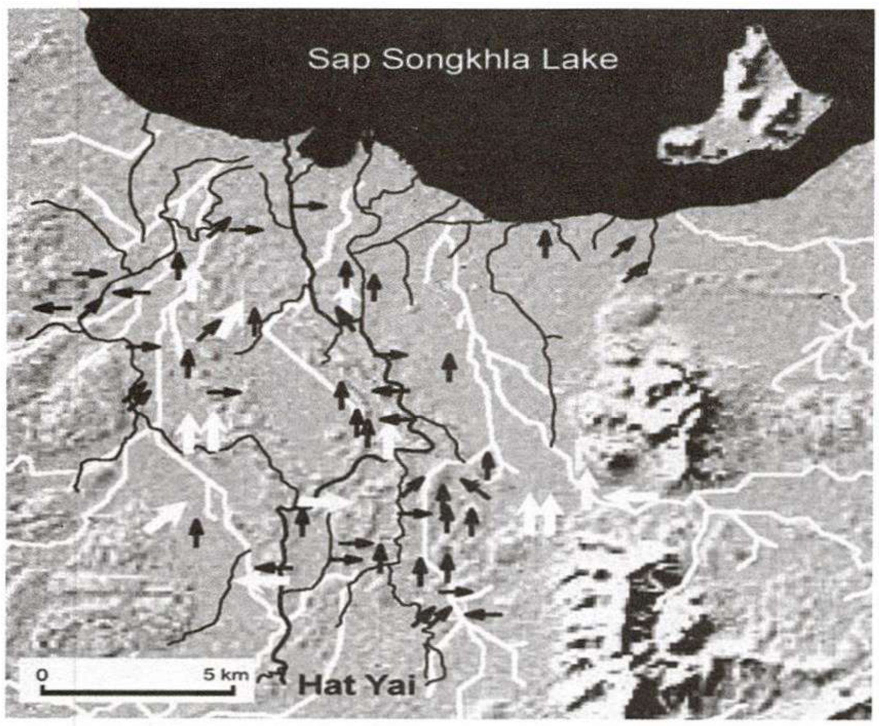

Fig. 3 Flood water direction and DDM (Draiage Direction Matrix). Black line: rivers,

White line: Draiage Direction Matrix, Large white arrow: fast flood flow, small black arrow: slow flood flow

Fig. 4 Prediction of flood flow based on the research in the 3D diagram of the ASTER satellite image.

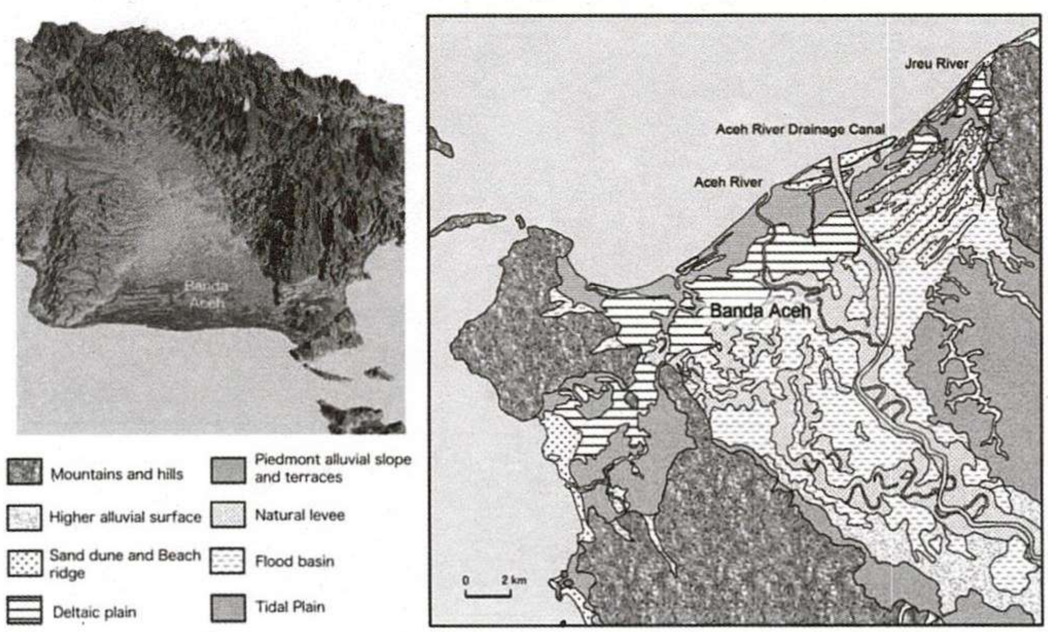

Fig. 5. 3D view and landform classification map of the Banda Aceh coastal plain

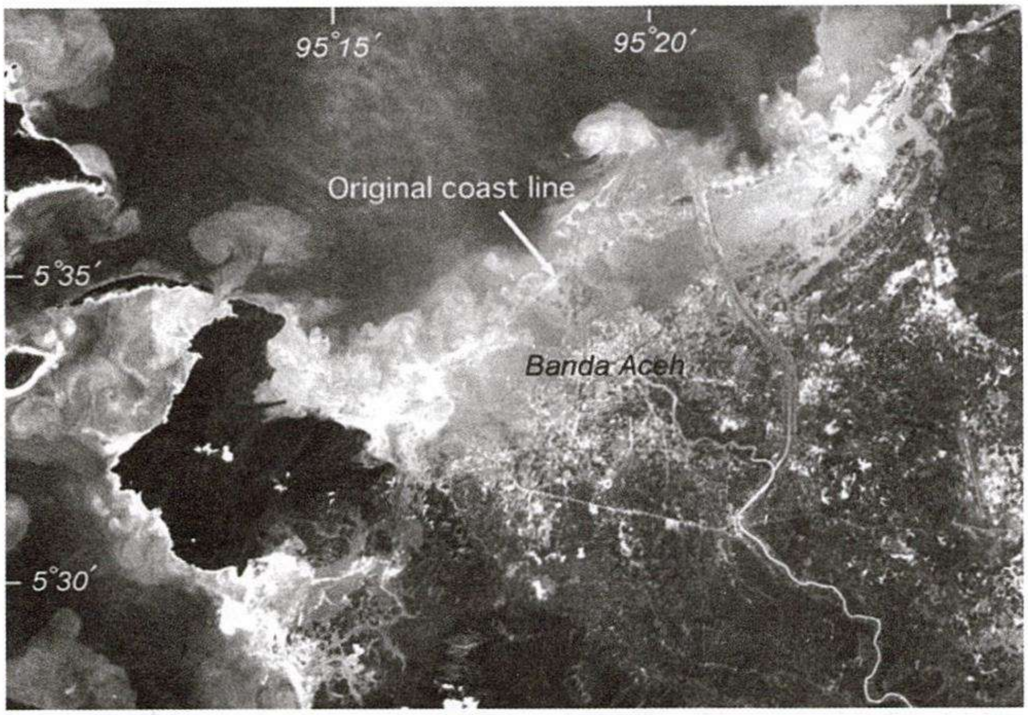

Fig.6. SPOT-2 image of the Banda Aceh coastal plain about 3.5 hours after the tsunami inundation. The image was taken at 11:23:40 (local time) on December 26, 2004. (Includes material from CNES2005, Distribution Spot Image S.A., France, all rights reserved). (Umitsu et al, 2007)

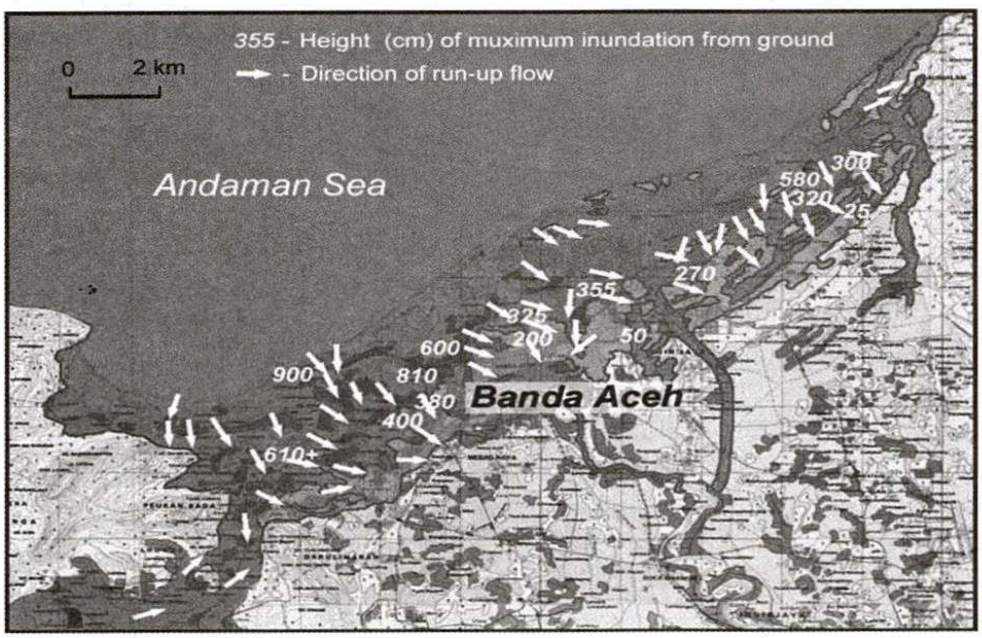

Fig. 7 Direction and height of tsunami flow in the Banda Aceh coastal plain (Umitsu et al, 2007)