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Environmental and geomatics assessment of the Ha Thanh basin to hydrological hazards in central Vietnam

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Abstract The Ha Thanh River (Binh Dinh Province-Central Vietnam) is poorly known. With a basin of 620 km^2 this fluvial system is very short (58 km) between the upper basins and delta floodplain (supplying the Thi Nai lagoon). This basin is affected by a typhoon season (October–November). The Ministry of Natural Resources and Environment of Vietnam (2009) reported that this delta will be affected by environmental changes by 2100: hydro-level rise the sea in central Vietnam; increased frequency and intensity of rainfall. In parallel, the urban projects in the Ha Thanh Basin could make human societies more vulnerable to hydrological risks. This paper presents the main concepts of the environmental assessment of the catchment using hydrological modelling and GIS. The entire process is carried out in a Geographic Information System, which could become a tool for the management and monitoring of the hydrology in Ha Thanh Basin.

Key words Vietnam; Ha Thanh River; hydrology; modelling; geomatics; environmental changes

INTRODUCTION

In Vietnam, almost half of the population is concentrated in the large deltas of the North and South (Red River and Mekong River): with an average density of 600 inhabitants/km^2. The deltas of large Vietnamese rivers have been the subject of many scientific studies about their formation and their hydrodynamics (Gupta, 1996; Meade, 1996). However, the fluvial hydrosystems in Central Vietnam have been relatively ignored. In the Annamite Cordillera (Truong Son) this small basin is inclined towards the South China Sea, (East Sea for Vietnamese). The Ministry of Natural Resources and Environment of Vietnam (Ministry of Natural Resources and Environment, 2009) reported that by 2100 the centre of the country may experience a rise in sea level of about 1 m and a temperature increase of about 3°C (with a general increase of the number of days >35°C, an increase in the frequency and the intensity of rainfall and increase of the temperature during the dry season). The basins in Central Vietnam are regularly exposed to typhoons that flood their deltaic plains.

This paper aims at improving knowledge of a deltaic area exposed to hydrological risks using environmental assessment and geomatics. The main purpose of this work is to provide acquisition and environmental data representation methods to: (i) identify the human and physical characteristics of the Ha Thanh basin, (ii) to understand flood hazards in the delta, and (iii) to develop GIS as a tool for a regional observational-hydrological modelling framework. Firstly the issues related to the deltaic environment in the Ha Thanh basin are identified. Anthropogenic and climatic disturbances may increase exposure to flood hazards. The historic flood of November 2009 is an important hydrological event to define the spatial distribution of issues in the delta. In the second part, we present the GIS solution to improve multi-thematic shapes. This could become a platform for environmental monitoring.

EXPOSURE TO FLOOD AND ENVIRONMENTAL CHANGE

Sources and methods

To implement an environmental assessment of the Ha Thanh River basin we need human and physical data. The work uses methods from environmental geography, in GIS (Kondolf & Piegay, 2003) and in cyndinic (Wisner *et al*., 2004). To analyse the risk of flood, we set up population surveys in delta. We recorded their experience of a hydrological event such as the flood of

November 2009 (water level in the houses, streamflows, management of the hazard). The study was performed by methods in fluvial geomorphology (Nanson & Croke, 1992; Nanson & Knighton, 1996; Knighton, 1998; Gautier *et al*., 2009): Digital Elevation Models, cross-section profiles, characterization and mapping of river beds (geometry, forms fluvial) using a Geographic Information System, remote sensing. Hydrological and meteorological data were provided by the Center Hydrometeorologic of Binh Dinh Province (Dieu Tri and Van Canh stations; rainfall data and water levels per hour).

Basin characteristics

With an area of 620 km^2, the Ha Thanh Basin represents approximately 10% of Binh Dinh Province. It has specific physical and human characteristics (Fig. 1). Ha Thanh River is a very short fluvial system: 58 km between the upper basins (900 m) and the delta plain (2 m on average). The flow gradient is very strong in the first 10 km (7%), and decreases rapidly in the delta (0.04%). At the contact with the Thi Nai lagoon, the delta is an anthroposystem between fluvial and oceanic environments. Covering an area of 85 km^2 the delta is inhabited by 60 500 people. They live on rice and aquaculture. Rural populations have developed a fluvial area based on the irrigation and the use of the intertidal zone. The riverbanks are stabilized. Dikes have been highly developed in the delta for 20 years. This containment sytem supports the economic and urban development of Binh Dinh province and Quy Nhon City. Development projects plan to increase the population and create an important port in Thi Nai lagoon. They strongly threaten the ecosystem and agrosystem in the delta. By 2020 nearly 50% of the mangrove will be destroyed and large areas of rice fields will be replaced by new buildings. New residents who are unaware of historical floods will move into the delta. These anthropogenic and environmental changes are worsening the vulnerability factors. The environmental assessment will detect these anthropogenic changes and establish the future changes of the delta. It is also important to understand how this area may be exposed to hydrological hazards by using a recent hydrological event: the Mirinae Typhoon and the flood of November 2009.

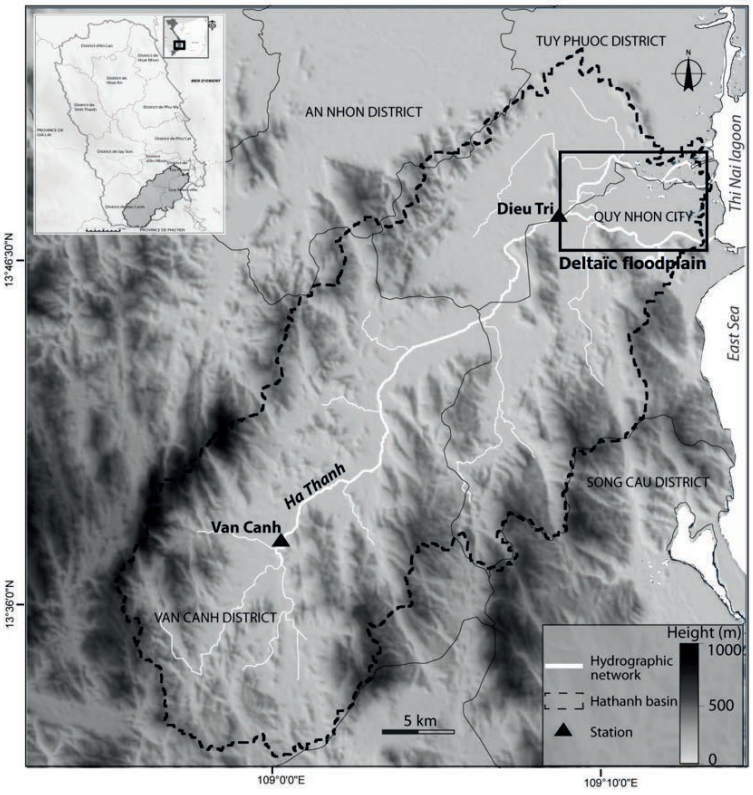

Fig. 1 Location map.

The experience of the flood of November 2009

Binh Dinh is subject to hydroclimatic tropical monsoon with a rainy season in June (100 mm on average) and a typhoon season in October–November (500 mm on average). The dry season record 15–60 mm average between January and April. In Vietnam, typhoons usually occur in the offshore area of the East Sea and move to Vietnam through the Philippine Sea. They generate heavy rainfall up to 1000 km inland and winds up to 300 km/h. They also cause sea surges and heavy rains towards the coast. These phenomena generate floods in the coastal rivers. From April the number of typhoons increases to October (more than 50 typhoons since 1945). Many provinces of Vietnam are regularly affected by these natural phenomena. The people, dependent on agriculture (70%), are placed in a vulnerable position.

In November 2009, Mirinae Typhoon hit the coastal area of the centre of the country. The typhoon caused the death of 145 people, injured 123 people and caused nearly 5796 billion Vietnamese dong (214.66 million euros) of damage. The typhoon dumped 842 mm of rainfall in the Ha Thanh basin (2–3 November 2009). It caused the largest flood for 45 years (beyond the flood caused by Kyle Typhoon in 1993). In the delta, the river reached record water levels (7.33 m at 01:00 h on 3 November) (Fig. 2). The chronology of the flood has been restored thanks to the field investigation and the cooperation of local populations: measurements of water levels in houses, participatory mapping. The archives were used to complete the analysis of the management of the hydrological event. In our survey, 64% of people highlight the difficulty of living during the flood (2–4 days). The water level of the river just before the flood returned 12 days after the flood. The duration of the flood decline is a major factor in the level of adaptation of the inhabitants. The extent of flood in the province has not been anticipated there were no evacuation plans, no emergency scenarios. In addition, there is still no hazard maps and flood risk for the delta. There is therefore a need to strengthen the knowledge of the land subject to flooding, especially in the complex hydrological functioning of Vietnamese coastal basins. This complexity is enhanced by the regional particularity of being on the annual path of typhoons. Perfume River (Song Huong), in the province of Thua Thien Hue, has very similar features and often the subject of cyndinics programs and hydrological modelling (Tran & Shaw 2007; Oliver *et al.*, 2009). Kon River, the largest in the province of Binh Dinh, is better known than the Ha Thanh River.

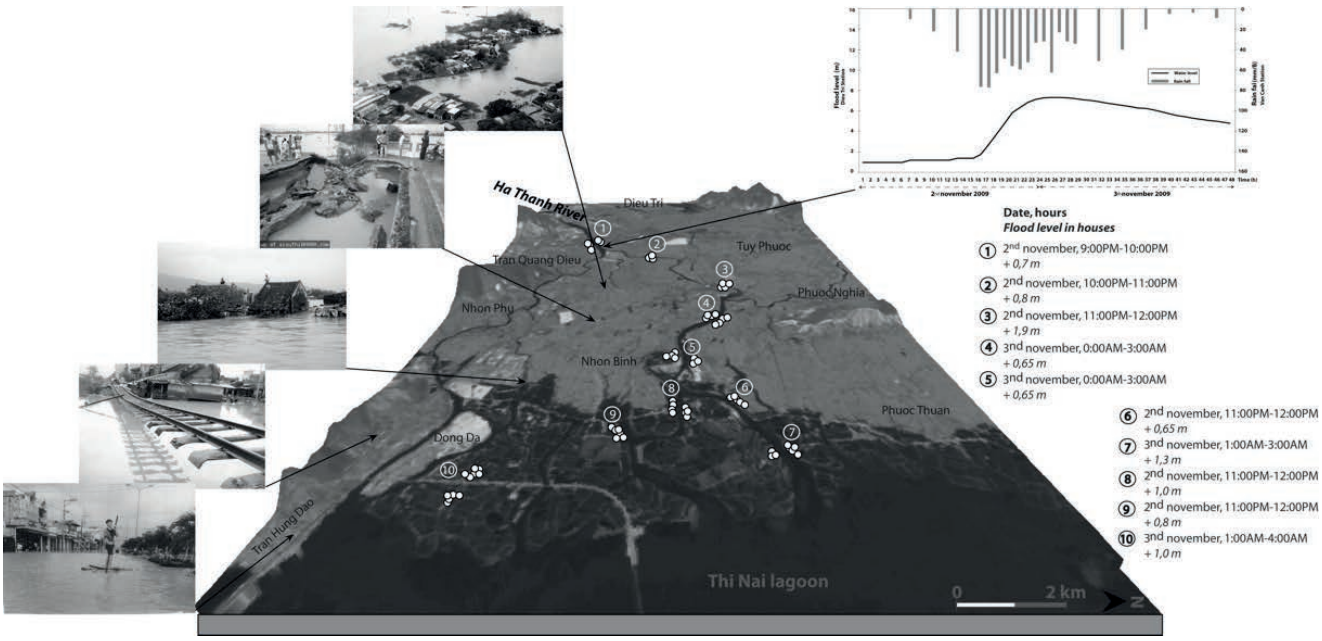

Fig. 2 Disasters in the deltaic floodplain (November 2009).

GIS AND MODELLING FOR ENVIRONMENTAL ASSESSMENT OF DELTA

Development of GIS and modelling (Fig. 3)

The GIS solution is developed under the UTM projection system, ellipsoidal WGS84 (World Geodetic System 1984) 49N area. The original coordinates are from the Institute of Geography of Vietnam (Decision no. 83, 2000), National VN-2000 projection.

The development of GIS was based on several steps: (a) conceptualization of database (INTER); (b) Raster data collection: topographic maps (1976, 1999, 2009), satellite images (1988, 2002, 2009 and 2011); (c) geo-referenced topographic maps; and (d) integration and creation of vector data (thematic layers): land use, human activities, river engineering, drainage system, identification of river bed, topographic profiles.

Some vector layers are integrated for hydrological modelling of the basin and the deltaic plain (MH-GIS project (HYD)). Using GIS, we can conduct longitudinal developments, especially in the delta between several dates to: (i) determine the population growth and urban development (1976–1999 and 1999–2009), (ii) define the type and the evolution of the land cover, and (iii) analyse the morphology of the river and its floodplain (1988–2002, 2002–2009 and 2009–2011).

For hydrological modelling, we use the HEC-HMS (Hydrologic Modeling System) model developed by the US Army Corps of Engineers (USACE). This model uses vector data GIS project (INTER): DEM (slope, flow directions, topography of the floodplain), drainage system, cross-sections profiles (geometry of the river bed), land (roughness, soil sealing) (Fig. 4). The purpose of hydrological modelling was to examine restoring the flow conditions in the basin and to develop scenarios of flooding in the delta. It was thus possible to reconstruct flood flows: the flood of November 2009, for example, reached 2560 $m^3.s^{-1}$; the discharge 19 $m^3.s^{-1}$ and the specific discharge 30 L/s /km^2. Modelling is a very useful tool for reproducing the hydrological behaviour in the basin. The relatively short distance between mountains and the deltaic plain generates very fast flow conditions and a very short response of hydrological processes. Cyclonic events scheduled in Central Vietnam, accelerate this process. They increase the vulnerability of exposed populations in the delta. According to the operation of hydrological data, it was estimated that it took 4 h for the flood wave to reach the delta (DieuTri station) from the upper basin (Van Canh station) (Fig. 4). The period was relatively short, especially as the main event took place at night.

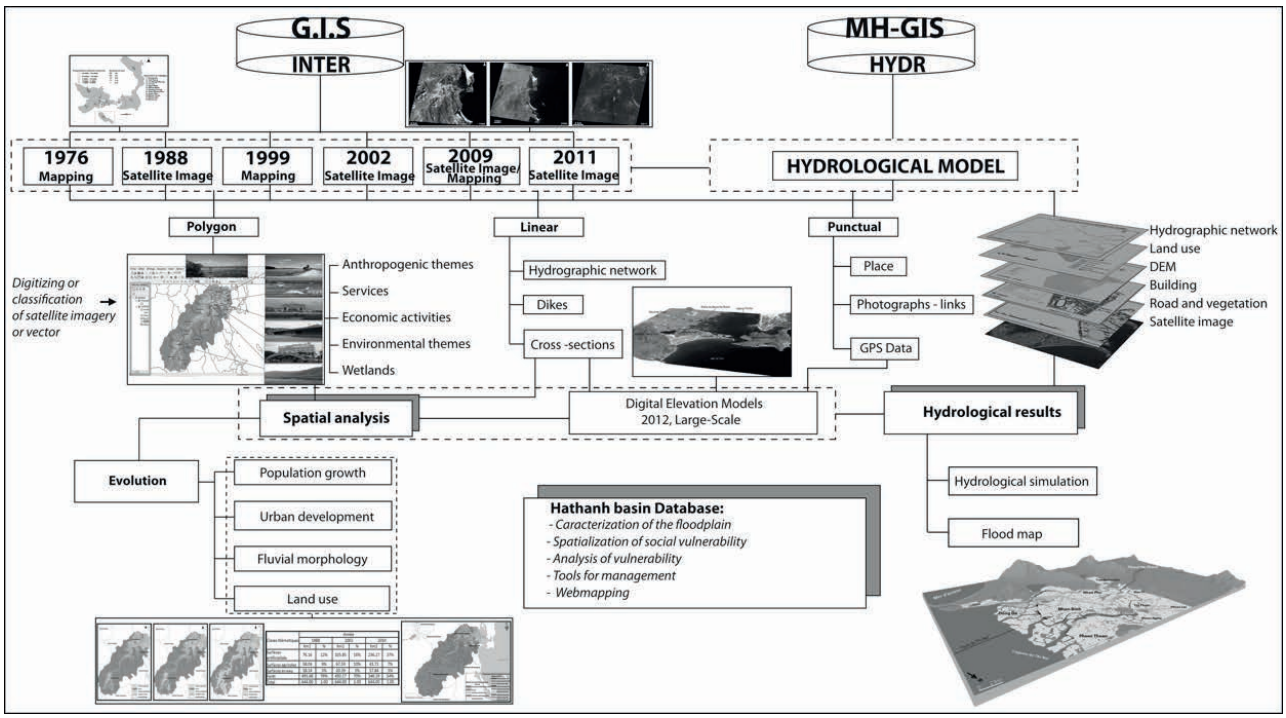

Fig. 3 Development of a GIS focus on Ha Thanh basin data.

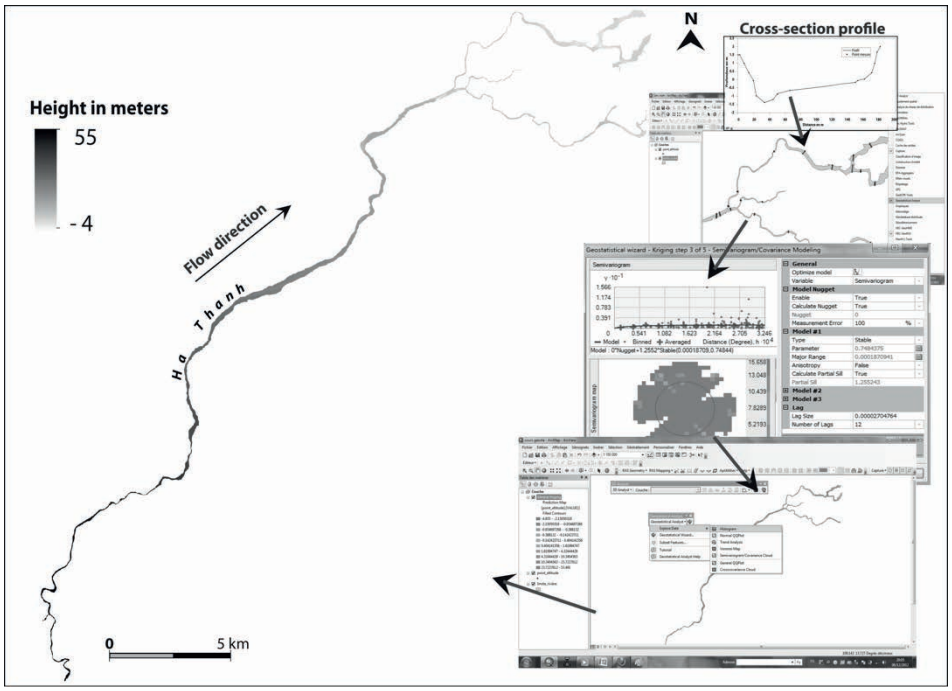

Fig. 4 Stages of hydrological modelling within GIS.

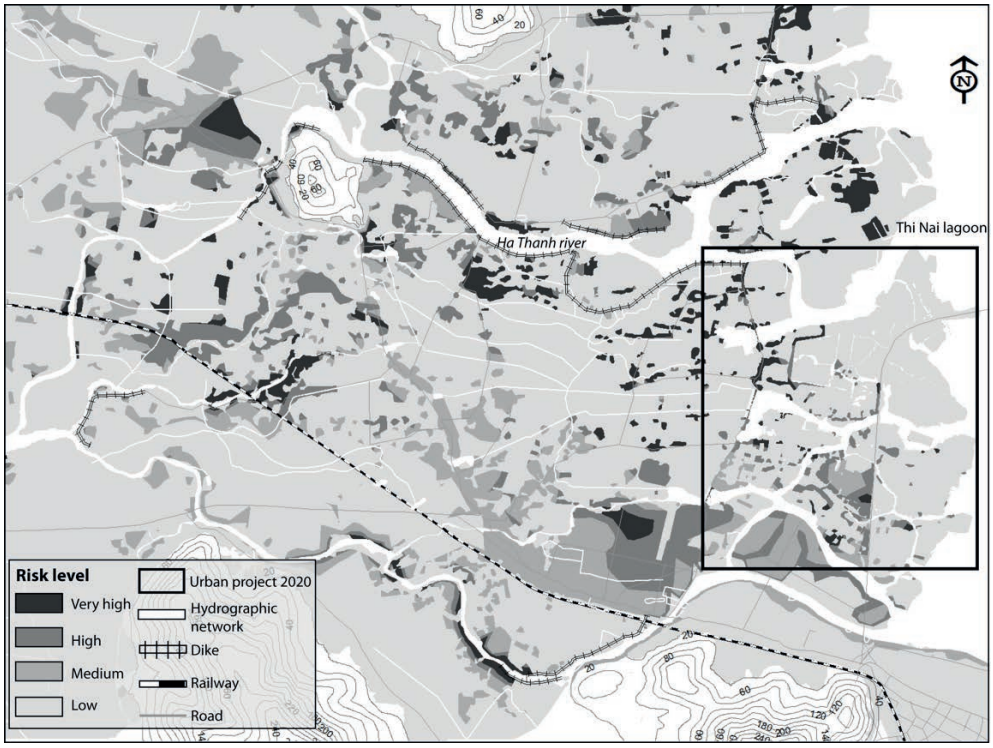

Fig. 5 Risks of flood in the delta river.

Spatial flood risk

GIS, field surveys and *in situ* measurements are used to acquire and to connect the physical and human data: geomorphological and topographical data (altitude, fluvial forms, height of dikes), human data (type of habitat, number of people), census 2009, field data (measurements of water levels in the houses). The combination of these different human and physical parameters is summarized in a current mapping of the flood risk in the delta with different risk classes (Fig. 5):

– Low risk: sparsely populated areas (50 inhabitants / km^2.), medium altitude (>2.5 m);
– Medium risk: density (100 inhabitants / km^2), low to medium altitudes (1–2 m).
– High risk: high density (340 inhabitants / km^2), low altitude (about 1 m); and
– Very high risk: > 480 inhabitants / km^2, low altitude (<0.5 m).

It is estimated that 35% of the rural population lives in high to very high risk areas. For 2020, the most ambitious urban project plans concern about 3.6 km^2 of land in the delta (Nhon Binh & Dong Da districts). They are already at a high growth rate (3%. year^{-1}) (Fig. 5). This is currently an area of medium to very high risk where there are still mangroves to protect the intertidal zone. Geomatics results show perfectly the level of exposure of future residents. This fact reinforces the disseminating and using knowledge of the basin and delta.

Development of a data network for basin management

The difficulty of obtaining data, or their absence, has involved developing a first level of analysis of the territory exposed within a GIS (human data and environmental data). To develop a regional data framework, you will need to install a network of hydrological stations more powerful and better distributed.

For example, this network would provide an early warning and give reaction time to act in crisis management in the delta system. This approach would allow the most vulnerable populations to reach shelter areas during the flood. During the Mirinae typhoon many people were taken by surprise.

CONCLUSION

The study of the flood of November 2009 and spatial analysis in GIS show elements of vulnerabilities in the delta plain and in the basin. The vulnerability of human societies relates strongly to their alluvial environments, which are sensitive to anthropogenic changes (containment, dam, urbanization) and natural changes (global climate change, typhoon events). In a context of rising sea levels, these environmental changes are of concern. Adaptation to climate change can be progressed through better management of hydrological risk, with a good knowledge of the physical environment and human exposure issues. The approach with GIS is an effective way to achieve this by examining all human and physical parameters of the basin: a prerequisite for any rational management of hydrological risks.

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