MANAGING LAND SUBSIDENCE AND SHINKHOLE IN HO CHI MINH CITY

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ABSTRACT

Ho Chi Minh city is increasingly facing serious land subsidence and sinkhole hazards. Land subsidence started in this city from the 1986s and was getting worse until now, and during the time between 2010 and 2011, more than 57 sinkholes appeared and created deep holes in the middle of roads of the central area.

This paper discusses the various causes of land subsidence and sinkhole in urban development activities and their impacts on the sustainable urban development. In addition, this study also introduces the Permanent Scatterer InSAR (PSInSAR) Technique in monitoring land subsidence and demonstrates solutions in the use of GIS for managing sinkhole in HCM city. The results show that the spatial and temporal variations of land subsidence depend on the corresponding variations of the urban development (average velocity > 6mm/year) and more than 90% of the sinkholes occurred in central portion of the city (almost of them created 1 – 2 m deep holes). Finally, application of GIS and Remote Sensing gained much positive impacts in managing sinkhole and land subsidence and satisfied the demands of urban managers.

Keywords*: PSInSAR Technique, Land subsidence, Sinkhole, GIS*

1. INTRODUCTION

Subsidence due to excessive withdrawal of groundwater has become a worldwide problem in, for example, Tokyo, Japan (Yamaguchi 1969), Bangkok, Thailand (Bergado et al., 1987), Venice, Italy (Carbognin et al., 2000),… In addition, the 1992 study of Florida sinkholes found that losses increased in both frequency and severity during the same period (Butler et al., 1992), a considerable number of people have died due to sinkholes formed beneath roads (Waltham *et al*., 2005),... However, the land subsidence in HCM city was discovered in 2003 and has resulted in tides moving into low-lying areas that were previously above high-tide levels. Each year, climate change could cause sea levels to rise by 3mm and in the mean high tide level, water level in rivers is higher than the ground level.

Flood prevention and traffic congestion mitigation has been problems of the biggest preoccupations of HCM City authorities. However, during the time between 2010 and 2011, more than 50 sinkholes appeared and created deep holes in the middle of roads of the central area. These phenomena affected the transportation activities and caused the situation traffic congestion of the city even worse.

Figure 1. Effect of subsidence at flooding areas

Figure 2. illustrates the deep holes

This paper discusses the various causes of land subsidence and its impacts that involved certain difficulties for flood prevention plan. What solutions should be taken for providing information on the distribution of sinkholes. Application of GIS and Remote Sensing for managing sinkhole and land subsidence are important tasks for risk mitigation that aims to achieve the sustainable urban management.

2. STUDY AREA AND METHOD

Ho Chi Minh City (former Sai Gon) is situated by the Sai Gon River and has population 8 mil. people, 2095 km2 area. This city consists of 24 districts and 60% of the city's area locates at the soft soil and the low elevation of the land, rivers and canals form a complex network that is affected by tide and its surrounding areas has grown very rapidly in the sectors of industry, transportation and many others from the year 1986 until now. This exponentially increase urban development introduce several environmental problems such as: extensive conversion of prime agricultural areas into residential and industrial areas; increase in groundwater extraction due to development of industrial activities and the high population increase. Especially, over 140km2 of the area has suffered the land subsidence that can be caused by the excessive groundwater extraction, load of buildings and constructions, and the combined effect of a large number of urbanized zones are situated at a very low elevation and along the canals with alluvium soil. The impact of land subsidence in HCM city could be seen in several forms, but almost subsidence are caused by human's activities, in which the groundwater large exploitation is the most important factor.

For monitoring land subsidence, Permanent Scatterer InSAR (PSInSAR) Technique is used that 14 ERS-1/2 and 8 ENVISAT images (from 1996 to 2010) are processed by Coherent Target Model (CTM). Figure 3 illustrates the land deformation map of the city is established by PSInSAR technique with the red colour where the subsidence rates up to about 15 mm/year was accumulated from 1996 to 2010. Maximum subsidence values is -319mm and some locations (yellow colour) where have the subsidence rates about 6 to 10 mm/year.

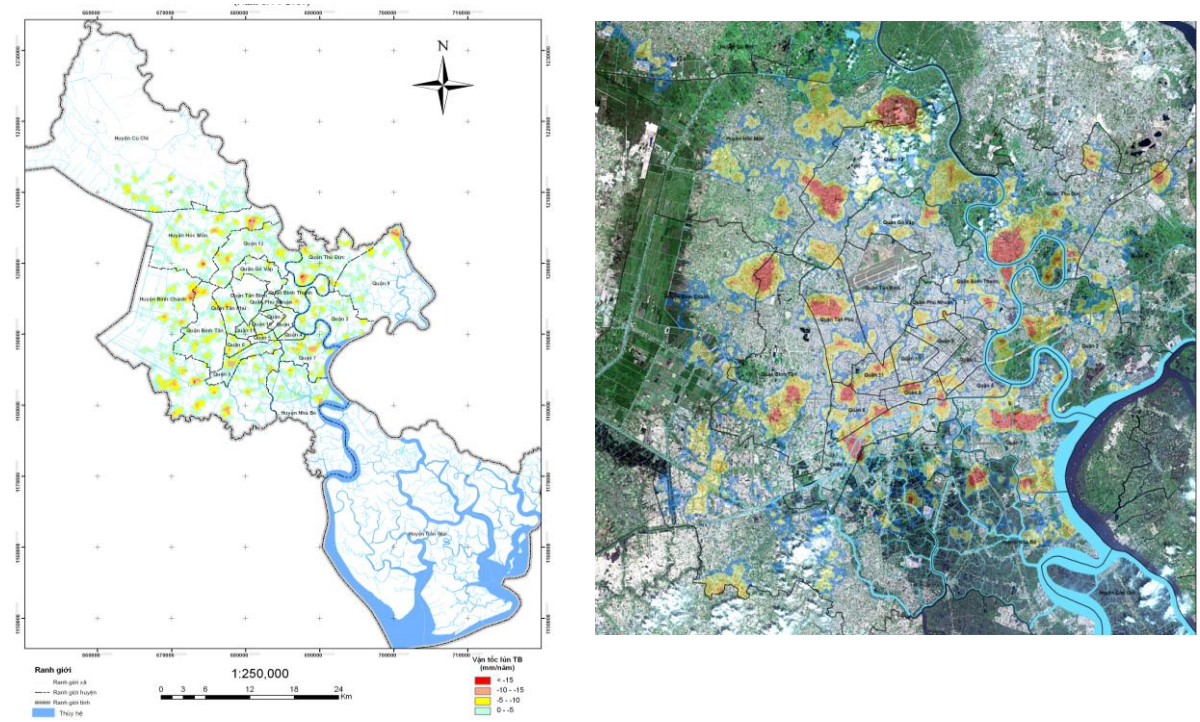


Figure 3. Land deformation map of the city

Since July 2010, 57 sinkholes have been found, some of them caused by poor-quality road surface restoration by contractors. In addition, the deteriorating facilities of the city's water supply and water drainage systems had also caused sinkholes between 2010 and 2011 and created deep holes in the middle of roads of the central area.

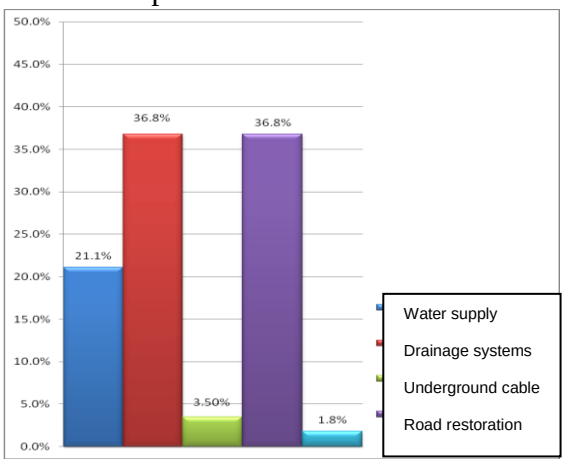


Figure 4. Causes of sinkhole and its ratio

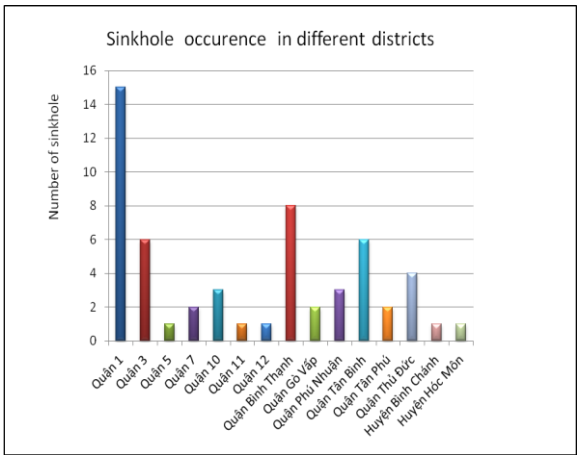


Figure 5. Sinkhole statistic for districts

The data for managing sinkhole is collected and entered into the database:
- Thematic maps: Land subsidence; Land use and Geological map;
- Topographical map (1:2000) with 7 basic layers and its attributes includes boundary ID of districts and wards. Cadastral map (1:500) represents all parcels of land and its attributes include: Parcel ID, Street ID,...
- *Street* attribute table consists of street ID, street name; date and location of the occurred sinkhole; the various causes;…
- Layers of underground water supply, drainage systems and underground cable is used to represent and analysis of the cause and to pinpoint a responsible party.

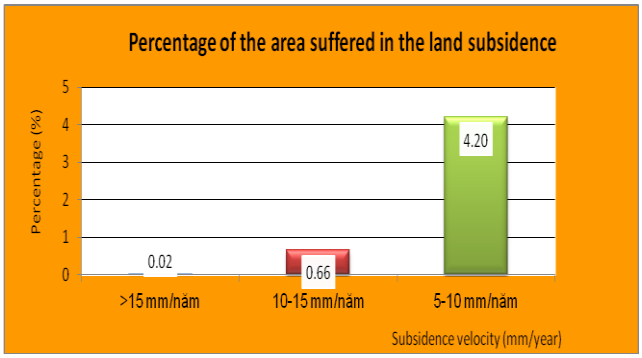
3. RESULTS AND DISCUSSION

3.1 Urban development and subsidence

The impact of land subsidence in HCM city could be seen in several forms, but almost subsidence are caused by human's activities, in which the groundwater large exploitation is the most important factor. Ground water level is decreasing (annual drawdown: 2m depth at the heavy ground water pumping stations) that may cause deform of soil due to ground water extraction. From 1996 until now, the ground level goes down at the rate of few 15mm per year that can be measured at the heavy ground water pumping stations. In addition, the increase in population and urban development activities in HCM city lead to increase in built-up areas, decrease in green areas and increase impervious surfaces that water cannot infiltrate. These surfaces are primarily associated with transportation (streets, highways, parking lots, sidewalks) and buildings,... In 1975, the green areas made up more than 40 percent of the HCM city's area and currently account for only 10 percent of the area (the inner city districts).

Over 140km2 of the area has suffered the land subsidence (0, 67% area of HCM city) with the maximum rate of subsidence is 10 - 15 mm/year. Five districts with subsidence greater than 15mm/year and the subsidence region coincides with a groundwater depression

cone. From 1997 to 2002, several subsidence areas have formed and widen, the total amount of subsidence had increased from 155mm in 2003 to 319mm by 2010



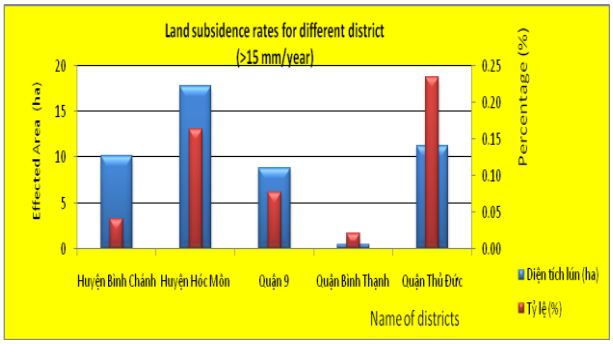


Figure 5. Affected rate of land subsidence **Figure 6. Five districts with maximum rate**

HCM city dominantly consists of plains of which the percentages are 60 % is that ground elevation level is below +1.5m while current max tide level: +1.58 m. The effect of land subsidence and sea level rise have caused residents in many wards suffered water-logging of between 0.4-0.5m. In addition, land subsidence leads to the permanent lower down of the ground elevation and caused substantial damage including the increase of flood hazards, cracking of buildings, failure of underground water supply and sewage pipelines,... This damage results in huge economic loss.

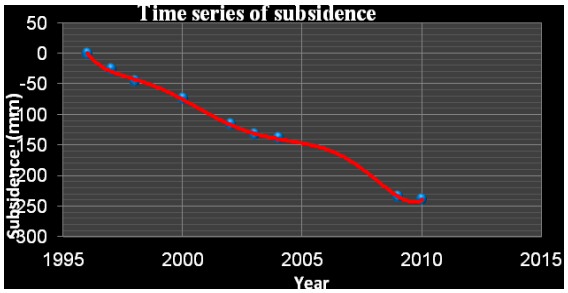


Figure 7. The substantial damage and time series of subsidence at PS (1996 – 2010)

Monitoring of land subsidence in HCM city aims to provide some management actions such as prohibition of groundwater use in the subsidence region, artificial recharge by pumping water back into ground to mitigate the situation as well as predicting potential geological hazards and designing compensation strategies.

3.2 Managing sinkhole

In order to define the causes and to support the adequate prevention measures for managing sinkhole emergencies, a software based on ArcGIS for managing and monitoring sinkholes in HCM city has been developed. This program can be incorporated in early warning system by using Ground Penetrating Radar (GPR) for the detection of sinkhole location over roadways indicating the upcoming occurrence of sinkhole.

Since July 2010, sinkholes occurred in central area of HCM city due to water supply pipelines breaks or sewer collapses and some sinkholes form when the land surface is

changed, such as when poor post-construction restoration, the substantial weight of the new material can trigger an underground collapse of supporting material, thus, causing a sinkhole. In general the sinkhole exhibit spatial and temporal variations, the developed software to support the efficient tools for managing to reduce that repeated accidents due to sinkholes have made the people feel unsafe when going out into the street.

- **Module for supporting information:** includes functions used to determine the sinkhole location based on street information and indicating the upcoming occurrence of sinkhole that is necessary to define adequate prevention measures for the mitigation of loss of human life and of assets.
- **Module for statistics on sinkhole:** includes functions used for quantitatively assessing sinkhole, statistics on the most significant causes for each sinkhole type and tools that help to create automatic reports and export list of sinkhole for different districts.
- **Module for updating data:** consists of basic tools for updating new sinkhole location, attribute information and images of the new appeared sinkholes as well as thematic maps such as underground water supply, drainage systems and underground cable is used to represent and analysis of the cause of sinkhole

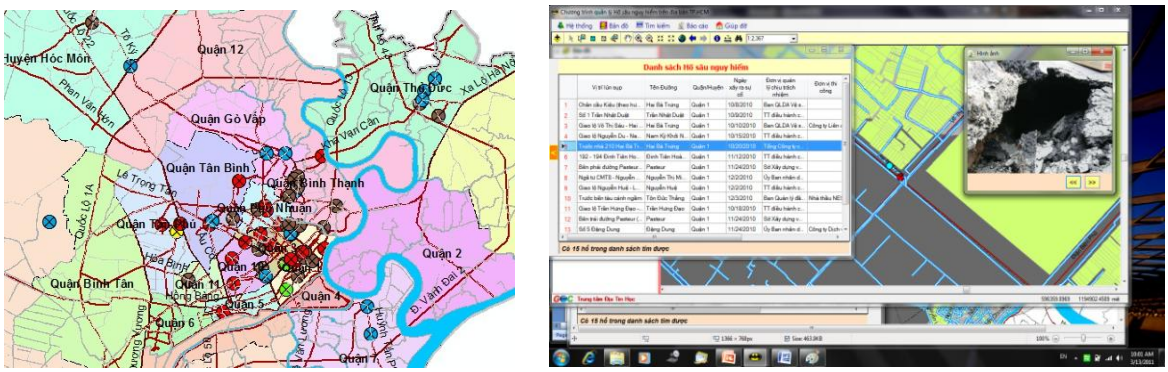


Figure 8. The spatial and temporal variations of sinkholes

The results obtained indicate that the proposed software is a suitable solution for administrative tasks. The production of a complete sinkhole database of GIS can automatically determine sinkhole location for each street and create automatic reports about the list of sinkhole for a particular ward/district. In addition, this is a flexible and efficient way for developing the thematic maps that provide information on the distribution of preexisting sinkholes and the prediction of occurrence of new sinkholes. Finally, an important task for sinkhole risk mitigation is statistics and analysis of the causal factors that are related to the topography, hydrogeology, subsidence processes and human activities.

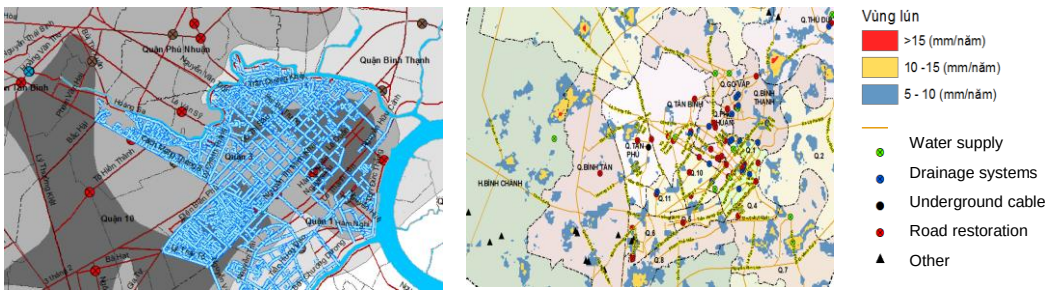


Figure 9. Analysis in determining significant causes for each sinkhole type

There is not the correlation between land subsidence and the occurrence of sinkholes that can be illustrated in Figure 9. Therefore, the proposed solution provided an understanding of the major causes and sinkhole mechanisms in HCM city and created a suitable plan for sinkhole risk mitigation.

4. CONCLUSIONS

The HCM City locates at the soft soil and the low elevation of the land, rivers and canals form a complex network that is affected by tide. This paper showed that impacts of the land subsidence and sinkhole on sustainable urban development and the following conclusions are deduced from this study:

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- The subsidence velocity over HCM city is derived with the rates of about 6 to 15 mm/year and reached a remarkable value of 319 mm accumulated from 1996 to 2010.
- Land subsidence in HCM city can be caused by the excessive groundwater extraction, load of buildings and constructions, and the combined effect of a large number of urbanized zones are situated at a very low elevation and along the canals with alluvium soil.
- Land subsidence combined with a global sea level rise has been increased frequency of flooding, that residents in many wards suffered water-logging of between 0.4-0.5m.
- Since July 2010, 57 sinkholes have been found and their locations exhibit spatial and temporal variations. The complete sinkhole database of GIS is established and the proposed software is showed an efficient solution for administrative tasks
- Almost sinkholes occurred in central area of city (created 1 – 2 m deep holes) due to water supply pipelines breaks or sewer collapses and poor post-construction restoration.
- Sinkholes affected the transportation activities and caused the situation traffic congestion of the city even worse. GIS for managing sinkhole is applied to create suitable measures in sinkhole risk mitigation and assessment their impacts that aims to achieve the sustainable urban development.

5. REFERENCES

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