Science on Natural Resources and Environment 25 (2019) 21-29

Science on Natural Resources and Environment
Journal homepage: hunre.edu.vn/hre/d16216

THE RELATIONSHIP BETWEEN UNDERGROUND KARST AND GROUND COLLAPSE IN THE WESTERN AND SOUTHWESTERN AREA OF HANOI CITY

Nguyen Van Binh
Hanoi University of Natural Resources and Environment

Received 26 September 2018; Accepted 16 November 2018

Abstract

Recently, in the west and southwest of Hanoi city, ground collapse has been occurred and causing serious consequences. The locations of land subsidence occurred in Quoc Oai and My Duc districts including: Yen Noi village, Dong Quang commune (2007); Quoc Oai town (2009); village 16, Ang Ha hamlet, Le Thanh commune (2010), village 6, Xuy Xa commune (2011), Le Xa village, Le Thanh commune, My Duc district (2014); Yen Son commune, Liep Tuyet commune of Quoc Oai district (2014), Hoa Lac village, An Tien commune (2016). Land subsidence has damaged and destroyed infrastructures affecting the daily life and activities of local people. Many scientists have conducted a survey to find out the causes of ground collapse. Ground collapse occurs due to many closely related factors. The broken and highly fractured limestone and underground karst is one of the main causes.

This paper analyzes and evaluates the characteristics and distribution of limestone bedrock, the activity of the underground karst to identify the causes and mechanisms of land subsidence in the west and southwest of Hanoi city. It also provides warnings of the risk of ground subsidence for some areas.

Keywords: Land subsidence; Ground collapse; Underground karst

Corresponding author. Email: nvbinh@hunre.edu.vn

1. Introduction

Accoding to USGS, land subsidence is a gradual settling or sudden sinking of the Earth's surface owing to subsurface movement of earth materials.

The principal causes are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost. More than 80 percent of the identified subsidence in the US is a consequence of our exploitation of underground water, and the increasing development of land and water resources threatens to exacerbate existing land-subsidence problems and initiate new ones [9]

Land subsidence that results in settlement or collapse of the ground surface is grouped into four main categories: (1) subsidence due to man-made voids and natural voids relatively close to the surface (e.g., due to coal mining, stone mining, or karstic features), (2) subsidence due to the removal of fluids from depth (e.g., water/ oil extraction) and the consequential

change in effective stress conditions, (3) subsidence due to the removal of soluble minerals (salt, gypsum) in groundwater, and (4) subsidence due to the removal of fines in suspension (piping). In addition, subsidence may occur related to alluvial deposits, shrink/swell, volcanism, and thermokarst. The consequence of this phenomenon is the creation of sinkholes that destroy infrastructure and affect the lives of the population

In recent years, the frequency of occurrence of subsidence holes in the world in general and Vietnam, in particular, are increasing with different causes [3, 4, 7, 6].

2. Study area

The study area is located in the western, southwest of Hanoi city including Quoc Oai, Chuong My and My Duc districts, about 50 km western, southwest of Hanoi. Like all of North Vietnam, the western, southwestern area of Hanoi city is located in the tropical monsoon climate. There are two distinct seasons. The rainy season coincides with the hot season starting from April to the end of September, the average temperature is from 27°C to 31°C and the highest is 30°C - 39°C; The dry season starts from October to the end of March next year, the average temperature is 20°C - 22°C and the lowest is 6°C - 15°C. Topography feature includes lower mountain, hill and plain and geomorphology feature includes erode and accumulation terrains.

Quaternary sediments in the Western, Southwestern areas of Hanoi city includes four formations: Hanoi, Vinh Phuc, Hai Hung and Thai Binh

Hanoi formation (Q_1^{2-3} *hn*) included alluvial- proluvi sediment (apQ_1^{2-3} *hn*) characterized by pebbled, sandy, sandy and clayey deposits and river channel sediment (aQ_1^{2-3} *hn*) included gravel, sand with gravels. The Hanoi formation covers above older bed rock and is covered by younger sediments.

The Vinh Phuc formation (aQ_1^3 *vp*) is characterized by clay, sand with gravels and sandy clays of various colors of yellow, white, white and red. The Vinh Phuc formation covered above Hanoi formation or covered unconformity above older bed rock and was be covered by younger sediment.

Hai Hung formation included alluvial-marine sediment (amQ_2^1 *hh*) is fine sand, gray-brown, gray, bog - marine sediment (bmQ_2^{1-2} *hh*) silty clay, sandy clay dark gray, contained organic, marine sediment (mQ_2^{1-2} *hh*) is green-grey clay, gray-yellow. The mineral composition of clay is kaolinite hydromica - monmoriolit or hydromica - kaolinite - chlorite and alluvial - bog sediment, narrow distribution, dispersed in coastal areas of the delta, thin thickness. The composition included: silt-clay, clay, silt, sand-clay with organics.

Thai Binh formation (aQ_2^3*tb*) is characterized by clay, silty clay, yellowish brown and fine sand, yellowish grey.

The main aquifers in the area included: sand of Thai Binh formation (qh), sand with gravel of Vinh Phuc formation (qp); gravel of Hanoi formation (qp) and fractured limestone of Đong Giao, Na Vang formations. The aquifers of Hanoi formation and Dong Giao, Na Vang formations are being heavily exploited. The limestone layer in western, southwest of Hanoi city is a large aquifer.

Survey results show that the groundwater in Quaternary aquifers is nearly depleted. At present, many water exploitation projects in this area are exploited in the fractured limestone aquifer. The groundwater level measured

in Quoc Oai town is 22 m, in Thach Than commune, Ngoc My area is 35.5 - 36.5 m, in Yen Son commune, the commune is 15 m. In Dai Nghia town the water level is 15 - 16 m, the areas of Le Thanh, Xuy Xa commune have a water level of 5 - 10 m.

3. Material and methods

This study used more than 431 drilling holes, depths of holes from 7 to 50 meters. Locations of drilling holes are shown in Fig.1. Some references of previous studies are listed bellows:

+ Tran Dang Tuyet et al., (1988). *Geological map of Ha Dong - Hoa Binh, scale 1:50,000* [10].

+ Nguyen Van Binh et al. (2013). *Report on the study of potential geological hazards related to urbanization in the western part of Hanoi* [1].

+ Nguyen Van Dung (2009). *Report on geological hazards of land subsidence and propose solutions at Km16, provincial road 419 in Quoc Oai town, Hanoi* [5].

+ Norwegian Geotechnical Institute-NGI (2008). *Subsidence estimation over the City of Hanoi using SAR Interferometry Mitigation of Geohazards in Vietnam* [8].

+ The reports on *"the survey results and determined the cause of ground collapse and execute fillings material for sinkholes in Hamlet 16, village Ang Ha, Le Thanh commune and Team 6, Thuong village, Xuy Xa commune, My Duc district"* by Northern Division for Water Resources Planning and Investigation, 2018.

The paper was completed based on research methods including: field survey method (survey of sinkholes, interviews with people in term of subsidence phenomena, exploitation status and use of groundwater); geophysical survey, exploration drilling, analysis of physical and mechanical properties of soil samples; Analytical methods for the spatial variation of limestone bed rock, kriging interpolation for underground karst distribution in the research area, mapping method for risk of the ground collapse.

4. Results

4.1. Characteristics of the limestone in the study area

Limestone in the western, southwestern area of Hanoi city are Na Vang formation ($P_2 nv$) (Quoc Oai district) and Dong Giao formation ($T_2 a\ dg$) (My Duc district) includes:

- Na Vang formation ($P_2\ nv$): distributed in Tram mountain (Chuong My district), Thay mountain (Quoc Oai district). The composition consists of siliceous limestone, limestone with thin clay layers, thickness limestone with dark gray, light gray, metamorphic or recrystallized. The thickness of the formation is about 250 m.

- Dong Giao formation: distribution in Ben market, Huong Tich (My Duc district) and Mieu Mon (Chuong My district) are divided into two layers as follows:

+ Layer 1: limestone, thin, gray, black clays with fine grained, brittle, easy to split by layer, above of layer is siliceous limestone, high fracture, fine grained with a thickness of from 10 cm to 40 cm, aged Anisi, with a thickness of layer 1 about 300 - 450 m.

+ Layer 2: limestone, gray, light gray, white gray, thick layer with silic, metamorphic or dolomitization, white, clean white, fine grained, thickness of layer 2 varies from 300 to 450 m thick. Total thickness of the Dong Giao formation is about 700 - 900 m.

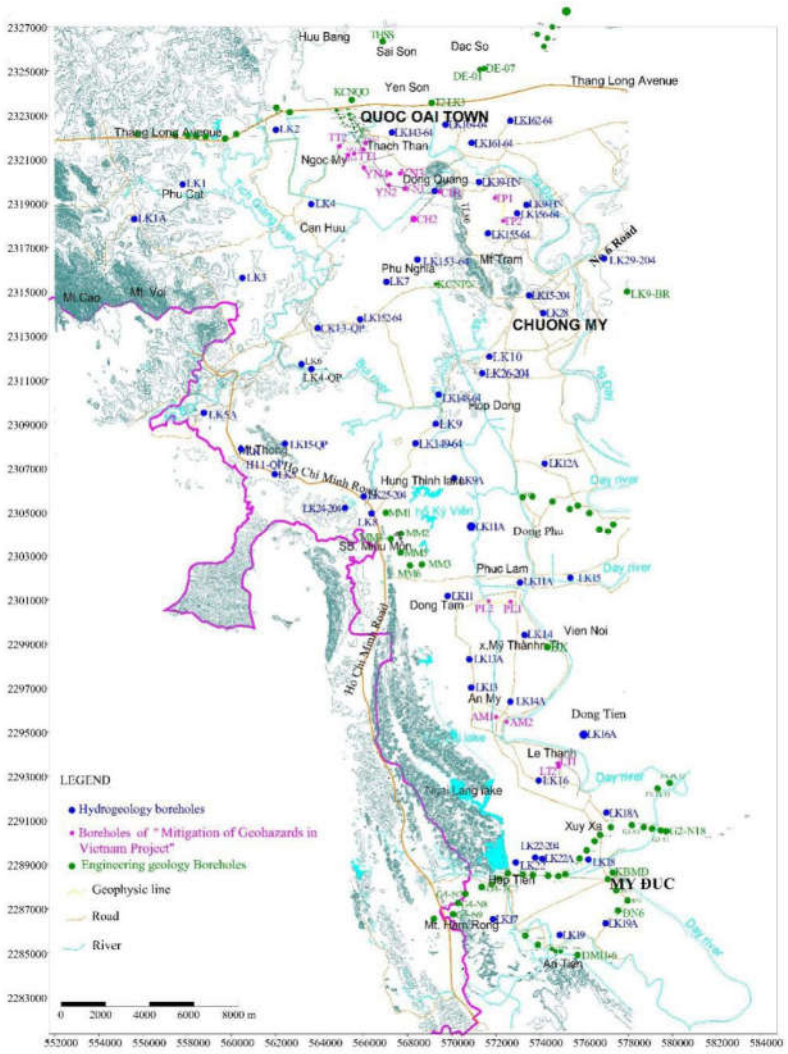


Figure 1: Locations of boreholes in the Western and Southwestern areas of Hanoi city [2]

In the plains, limestone is exposed in the form of remnants such as Hoang Xa limestone mountain, Thay mount (Quoc Oai district), Tram mount (Chuong My district). In addition, covered by Quaternary sediments and founded in boreholes. The elevation of the limestone surface in some places in Quoc Oai district as follows: Thay pagoda, Vuc Giang I, II bridge varies from -9 m to -13.07 m, Dinh To village (-12.7 m), Dong Quang commune varies from -26 m to -33.6 m, Thach Than commune (-33 m), Quoc Oai town (from -30.5 m to -41 m). Elevation of limestone surface in some places in Chuong My district as follows: in Phu Nghia industrial zone, Dong Phu commune is -33 m; Dong Son commune (from -11 m to -15 m). In other places such as Thuy Xuan Tien commune, Tan Tien commune, the elevation of the limestone surface varies from about -24 m to -27 m.

In My Duc district, the elevation of the limestone surface varies from -16 m to -41 m. Along to Do Xa - Quan Son route passing through My Duc district, the limestone surface elevation from -17 m to -31 m. In other places such as An My commune (from -20 m to -27.8 m), in Phuc Lam commune from -33.6 m to 35.1 m; in Dai Nghia town the elevation of limestone surface varies from -20 m to -25 m, in Le Thanh commune (where has some ground collapse occurred) rock surface elevation from -29 m to -41 m

4.2. Characteristics of underground karst distribution in the Western, Southernwest areas of Hanoi city

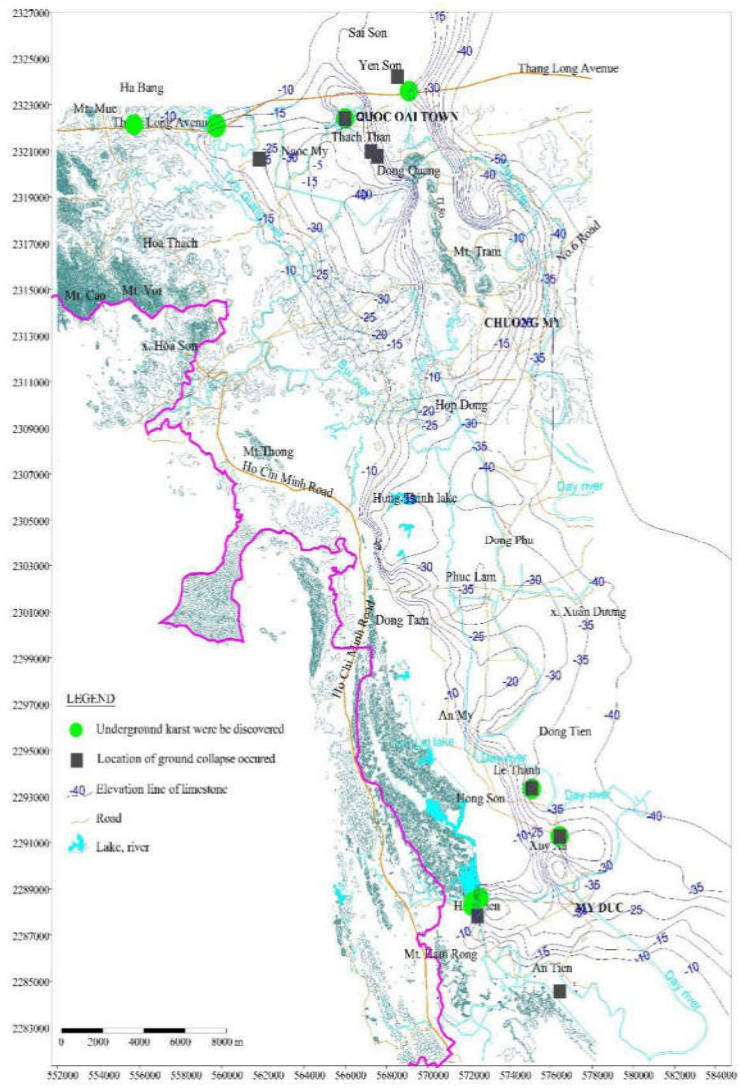


Figure 2: Elevation of limestone surface and location of underground karst, ground collapse in the Western, Southwestern areas of Hanoi city [2]

In the Western, Southwestern areas of Hanoi city, there are some places where karst caves are concentrated in the limestone mountain range, such as Cac Co cave in Thay pagoda, Hoang Xa cave in Quoc Oai town. In My Duc district, many big karst caves appeared in the Huong Son populations and are being used as well-known tourist destinations.

Underground karst was be founded in boreholes and geophysical documents. In the research area, underground karst was be founded in Quoc Oai and My Duc districts. In Chuong My district so far no findings of the existence of underground karst.

In Quoc Oai district, many underground karsts were discovered along Thang Long avenue and Quoc Oai town. The size of underground karst varies between 0.8 - 4.2 m. In other areas, although the limestone was highly fractured, however far no underground karst was be found.

In the My Duc district, many underground karsts were discovered in Le Thanh, Xuy Xa communes (ground collapse

occurred in 2010 and 2011) and Quan Son bridge (Hop Tien commune). The size of underground karst about from 0.8 to 3 m, in particular in Le Thanh commune, there is underground karst with the size from top to the bottom of about 7 m. The elevation of the limestone surface, the location of the underground karst was discovered in the boreholes and the locations of ground collapse occurred in the western, southwest of Hanoi city as shown in Fig. 2.

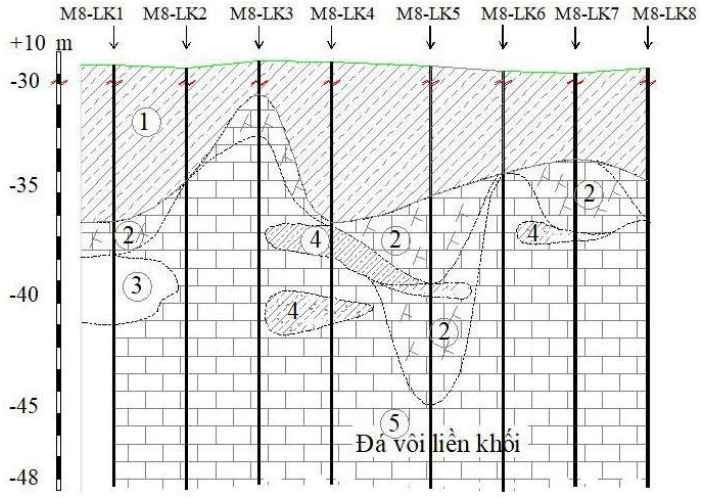
4.3. The relationship between underground karst and ground collapse in the Western, Southwestern areas of Hanoi city

Ground collapse hazard in limestone areas where karst activity occurs strongly is common in two forms: cover-subsidence and cover-collapse.

Cover-subsidence sinkholes tend to develop gradually where the covering sediments are permeable and contain sand.

Cover-collapse sinkholes will develop abruptly (over a period of hours) and cause catastrophic damages. They occur where the covering sediments contain a significant amount of clay [9].

The causes and mechanisms for the formation of ground collape associated with underground karst are considered to be extremely complex, depending on the surrounding conditions. To assess the relationship between underground karst activity and ground collape, some of the following transects were studied:



1: Clay with grit, 2 high fractured limestone, 3: Empty underground karst, 4: Underground karst filled by clay with grit, 5: Massive limestone

Figure 3: Geological section of Song Day Bridge (Km 15 + 358) Thang Long Avenue

Transect 1: Study areas along Thang Long avenue includes: Day river bridge (Km 15 + 358), North Phu Cat bridge, Dong Truc overpass. The typical geological section in these areas is shown in Fig. 3. At these sites during exploratory drilling, many underground karsts had been founded with dimensions varies from 1.2 m to 4.2 m. Some empty caves have no sedimentary material filled and some caves are filled by clay with grit. However, in this area, when drilling for geological investigation and construcstion piles driling with large diameter, there is no ground collape.

Transect 2: Study areas in Ang Xa hamlet, Le Thanh commune, Thuong hamlet, Xuy Xa commune, My Duc district, km 16, 419 road, Quoc Oai town, Son Trung village, Yen Son commune Quoc Oai). The soil layers of these areas is shown in Fig. 4.

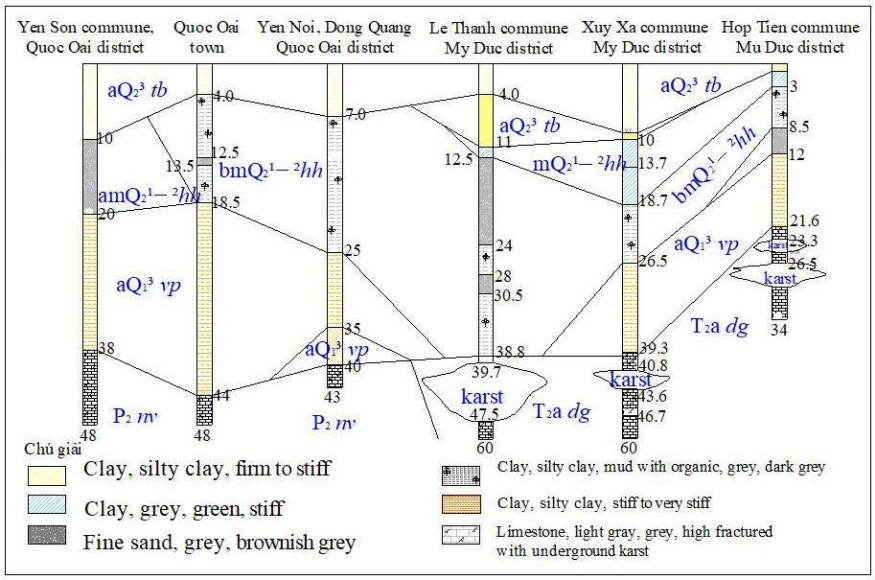


Figure 4: Combining succession of strata of ground collapse position in the Western, Southwestern areas of Hanoi city [2, 5]

Prior to drilling water wells in these areas, ground surface in these area with no unusual sign. When drilling wells with a borehole diameter of 76 mm (most of the cases are drilling into limestone with cavity), ground collapse has occurred and damaging the constructions. Research on the sediment characteristics, the evolution of the ground collapse show that common characteristics of the subsidence are as follows:

- The phenomenon of ground collapse occurs when human impact (drilling for water wells);

- The cover soil layer are loose sand and soft soil layers;

- Limestone is highly cracked and underground karst distribution.

From above mentioned, it is possible to introduce the mechanism formation and development of the ground collapse in the Western, Southwestern areas of Hanoi as follows:

- When drilling into soft soil, loose sand layers has low bond, easy to wash away, driling liquid has washed out fine materials, soft soil and created a underground void.

- When drilling into highly fractured limestone with some underground karst, most of the drilling liquid with fine material and loose sand were attracted into the cracks and void. The rate of drilling liquid washed out the material increases rapidly, the void space in the underground is expanded, the roof of void extends towards to the ground surface.

When the voids have been expanded, the thickness of the overlay on the roof of karst gradually decreases, the cohesion, the strength of the overlying sediment layer fail because of their weight. Then the balance between strength and destructive force is broken and the collapse occurs at a rapid rate.

Thus, the nature of the ground collapse phenomenon is due to the run off of fine materials in the cover soil layers and destruction of the overlying above of voids. Cracks and underground karsts were served as paths and contain fine materials that has been washed away from the initial positions by the water. The ground collapse will not occur if there is no paths and move the fine materials out of the original positions.

In areas with soft soils, fine sand covered above the high fractured limestone if the groundwater level is lowered to the original rock surface, combination with the movement of water in the underground karst. The fine materials will be run into fractures, underground karst and that is the cause of land subsidence in sediment layers for long time without human activity (drill well). This is one of the causes of karst-slump if over-exploitation of groundwater and the water level lowered under the rock surface.

In the transect 1, overlayers above the limestones with 25 - 35 thick is clay with grit, very stiff, this layer as role of a stabilized roof, difficult to be washed away by water. In the case of collape underground karst in the deep from the any causes but does not have a movement fine materials into the fractures, underground karst, will be formed subsidence holes in a long time.

4.4. Mapping the warning of ground collapse in the Western, Southwest of Hanoi city

High-risk areas of ground collape in Quoc Oai district included Quoc Oai town and neighboring areas such as Yen Noi, Dong Quang, Thach Than, Yen Son, Liep Tuyet and Ngoc My communes, rest area less risk of ground collape. In Chuong My district, the weak soil layer is not much, narrow distribution, the limestone beded at high deep, the underground karst is not detected yet, so there is less risk of ground collapse.

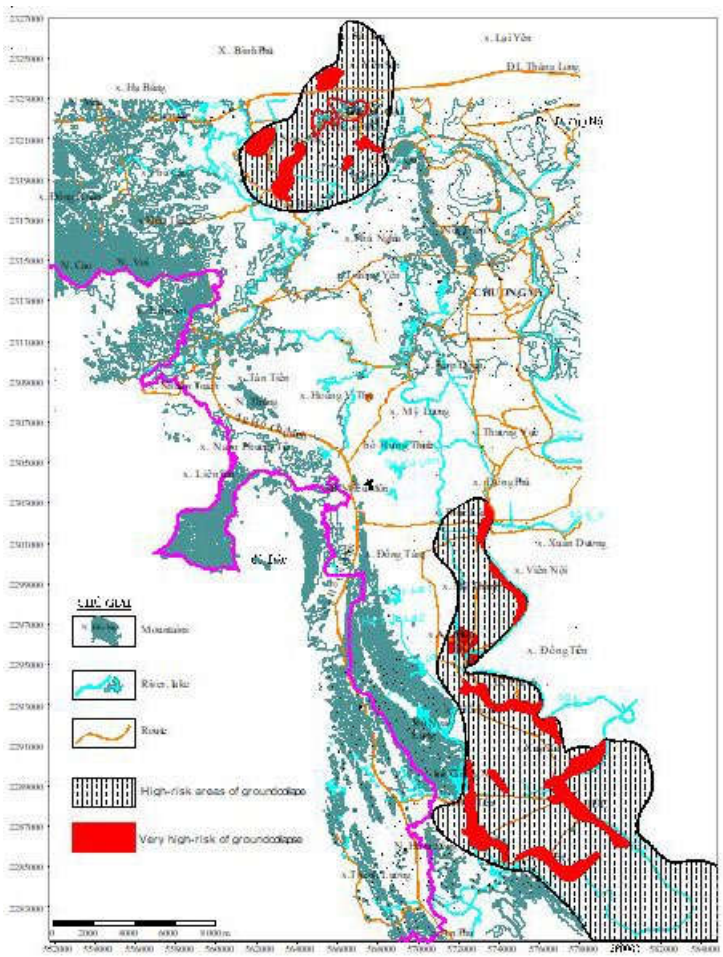


Figure 5: The warning map of risk on ground collapse in the Western, Southwestern areas of Hanoi city [2]

In My Duc district, many very high-risk of ground collapse areas such as Le Thanh, Xuy Xa, Hop Tien communes whereas in Ung Hoa district Hoa Xa, Van Thai communes are high - risk of ground collapse (Fig. 5).

5. Conclusions

The ground collapse phenomenon in the Western, Southwestern areas of Hanoi city occurred in places where the limestone was high cracked and there was underground karst with the presence of fine sand layer and soft soil layer. The ground collapse phenomenon was initiated from the cover layer with soft soil layer. Fine sand layer removed by flushing water and transport of fine materials (fine sand, soft soil) into the cracks, underground karst. Underground karst is a pathway, where fine material is deposited by the water flowing down in drilled borehole before being transported further by groundwater in the karst cavern.

The very high risk areas of ground collapse in the Western, Southwestern areas of Hanoi city are Quoc Oai town and surrounding areas such as Yen Noi village (Dong Quang commune), Thach Than commune, Ngoc My commune, Yen Son commune. In Chuong My district, research results show that this area is less likely to occur ground collapse. In My Duc district there exists many very high risk of ground collapse such as Le Thanh commune, Xuy Xa commune, Hop Tien commne. In the rest of district area high level of ground collapse could happen.

REFERENCES

[1]. Nguyen Van Binh (2013). *Final Report on Research on Potential Geological Hazards Related to Urbanization in the West of Hanoi*. Hanoi.

[2]. Nguyen Van Binh (2015). *Research on characteristics of Quaternary sediments and the relations to land subsidence in the West area of Hanoi*. PhD, Graduate University of Science and Technology, Vietnam Academy of Science and Technology, Hanoi.

[3]. Cui Z. D (2012). *Land subsidence Disaster caused by natural factors and human activities.* Disater advanced, Vol 5(2).

[4]. Dang Quang Khang, Do Minh Duc, Nguyen Van Binh, Vu Van Loi, Pham Truong Sinh, Pham Hong Duc, Nguyen Ngoc Truc (2012). *Mechanism of sink hole formation in underground limestone karstics area (A case study of Natum area, Backan province.* Scientific - Technical Journal of Mining and geology No 38/4 - 2012. , 16-24.

[5]. Nguyen Van Dung (2009). *Report on geological hazards of land subsidence and propose solutions at Km16, provincial road 419 in Quoc Oai town, Hanoi.*

[6]. Dương Thi Toan, Vu Cao Minh, Doan Van Tuyen (2010). *Land subsidence hazard due to karst in Vietnam and mitigation measures*. Proceeding of the Inter. Simposium Hanoi Geoengineering 2010, pp. 267 - 274.

[7]. Bui Van Thom, Nguyen Dang Tuc, Nguyen Huy Thinh (2011). *Study results on ground subsidence in Ha Trung - Hau Loc, Thanh Hoa*. Vietnam Journal of Earth sciences, 493 - 500.

[8]. Norwegian Geotechnical Institute-NGI (2008). *Subsidence estimation over the City of Hanoi using SAR Interferometry Mitigation of Geohazards in Vietnam*. Hanoi.

[9]. Robert M. Hirsch (2000). *Subsidence in the United State.* 176.

[10]. Tran Dang Tuyet (1988). *Geological report of Ha Dong - Hoa Binh, scale 1:50,000*. Division of the Geological Mapping of the North.