Geohazard Evaluation of Bukit Merah/ Malaysia using Geospatial Information Technique

A'kif Al-Fugara (Corresponding author)
Department of Surveying Engineering, Faculty of Engineering, Al al-Bayt University, Mafraq, Jordan
Email: akifmohd@aabu.edu.jo

Rida Al-Adamat
Department of Surveying Engineering, Faculty of Engineering, Al al-Bayt University, Mafraq, Jordan

Omar Al-Kouri
Geographic Information Systems and Maps, Department of Human Sciences and Technology, Community College, Taibah University, Kingdom of Saudi Arabia P.O. Box: 2898

Saleh Taher
Geographic Information Systems and Maps, Department of Human Sciences and Technology, Community College, Taibah University, Kingdom of Saudi Arabia P.O. Box: 28981

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Abstract

Geospatial technology (that includes Remote Sensing and Geographical Information System GIS) has opened up opportunities for qualitative analyses of sinkholes distribution with multi thematic maps to define the relationship of GIS database. Kinta Valley have been deteriorating dramatically as a result of changes that had occurred in the past and continues due to the close relationship between the fast rate of lateral urbanization and extensive dimensional expansion of surface mining and quarrying activities, where sinkholes are the main crux of the geohazard in Kinta Valley. Geospatial information system for sinkholes had been established using pictorial, tabular and ancillary data to build a relational GIS database. The application is capable of analyzing an entire data set of sinkholes to create sinkholes distribution map. The objective of this paper is to highlight the value of Geospatial Information System as a tool to define sinkhole distribution and change detection for geohazard evaluation.

Keywords: Geospatial, Karst, Sinkholes distribution, Geohazard, Malaysia.

1. INTRODUCTION

The word ”karst” refers to a type of terrain, known for its distinctive topography in which the landscape is largely shaped by the dissolving action of meteoric water on carbonate bedrock. The late twentieth century had witnessed a substantial increase in the risk of natural disaster and awareness of environmental hazard that has never been greater (Alexander 1993 and Smith 1996). Hazard is a source of danger whose evaluation encompasses three elements; risk of personal harm (death, injury, disease, stress), risk of property (property damage, economic loss), and risk of environmental damage (loss of flora and fauna, pollution, loss of amenity) (Kovach 1995 and Smith 1996). Therefore, geohazard is an unavoidable element of life .

Consequently, many environmental problems occurred, especially concerning geohazards (Sinkholes, rock fall) along with technological advances in Geographical Information Systems (GIS). This has given rise to increase efforts by researchers, engineers, and planners to better understand the spatial distribution of karst features that characterize these regions. GIS applications enable researchers to objectively identify the conditions that trigger karst hazards and develops spatial database. However, karst formations develop in very specific ways that are influenced by the unique local conditions of the area. There are many researches that studied the effect of karst collapses and its environments (Laurance et al. 2000, Kaufmann. and Quinif 2002, Tralli et.al. 2005, Kovacic and Ravbar 2005, Bonacci et al. 2006, Myint and Wang 2006, Kucinshas and Seber 2007, Van Den Eeckhaut et al. 2007, Keqiang et al. 2007, and Galve et al. 2008)

Two major urban areas in Malaysia, Kuala Lumpur and Ipoh, are underlain extensively by carbonate rocks (Abu-Shariah 2002, Chow 2005, Tan 2005). Region of karst imposes some unique environmental hazards to humans, particularly in urban areas where heavy structures are built on cavernous limestone. Collapse of limestone occasionally occurs; damaging building with little warning, due to the rapid movement of groundwater from place to place in large cavern passageway. Pollution and contamination of water supplies are serious threats

(Strahler 1981).

Sinkholes are the main crux of the geohazard issue in Kinta Limestone Formation. Natural erosion processes, acting on the limestone bedrock could give rise to cavities which subsequently could lead to formation of sinkholes (North Carolina Geological Survey 2005). The formation or emergence of a sinkhole is usually very sudden and unpredictable, and its development can be catastrophic. Consequently, reporting and documentation of sinkholes swallowing parts of a road, a house, or entire civil structure are too common. Inherent karst features of the limestone bedrock (such as pinnacle profiles, cavities and linear trenches) all contribute or provide the geologic settings for the development of sinkholes. Man-made factors or activities such as dewatering of groundwater level by pumping, dewatering of deep excavations or basements and open-cast mining can trigger the formation or emergence of sinkholes occurrences, rockfall, and soil erosion.

The main objective of this paper is to highlight the usefulness of Geospatial Information System as a tool to define sinkhole distribution beside its ability for presentation the change detection in geohazard zones based on mining activities.

2. STUDY AREA

Kinta Valley is located in NW Peninsula Malaysia (Figure 1). It lies to the west of the Titiwangsa mountainous range “main range” and east of the Kledang range. Kinta Valley is drained by the Kinta River which runs from NE to Bota Town in the SE. Bukit Merah is located in Kinta Valley (Figure 1). It is an elongated piece of land stretching south from the Menglembu Township, about 1.6 Km along the Menglembu-Lahat and is bounded to the east by Menglembu-Lahat road and to the west by current tin mining land (Minerals and Geosciences Department 1998).

The topography of Perak is largely governed by its geology, comprising granite mountain ranges on its eastern side and flanked on the west side by a wide expanse of alluvium cover, low-lying land underlain by limestone and subordinate schist. The main mountain ranges consist of extensive masses of granite. The solubility of limestone has generally caused the topography to be lower than the surrounding country, but marked exceptions to this are the prominent limestone hills found chiefly in the Kinta Valley (Figure 2).

The karst mountains of tropical regions, such as Peninsular Malaysia, are distinguishable by their steep walled mountains separated by broad flat valleys or plains. These tower like mountains looming above, with rocky overhanging cliffs are riddled with caves and are only found in humid-tropical limestone regions. Kinta Valley limestone formation has gone through tropical karstification to form steep sided tower and cockpit towers protruding across the plain (Gobbett and Hutchison 1973, , Jennings 1982, and Fatihah 2002), (Figure 3)

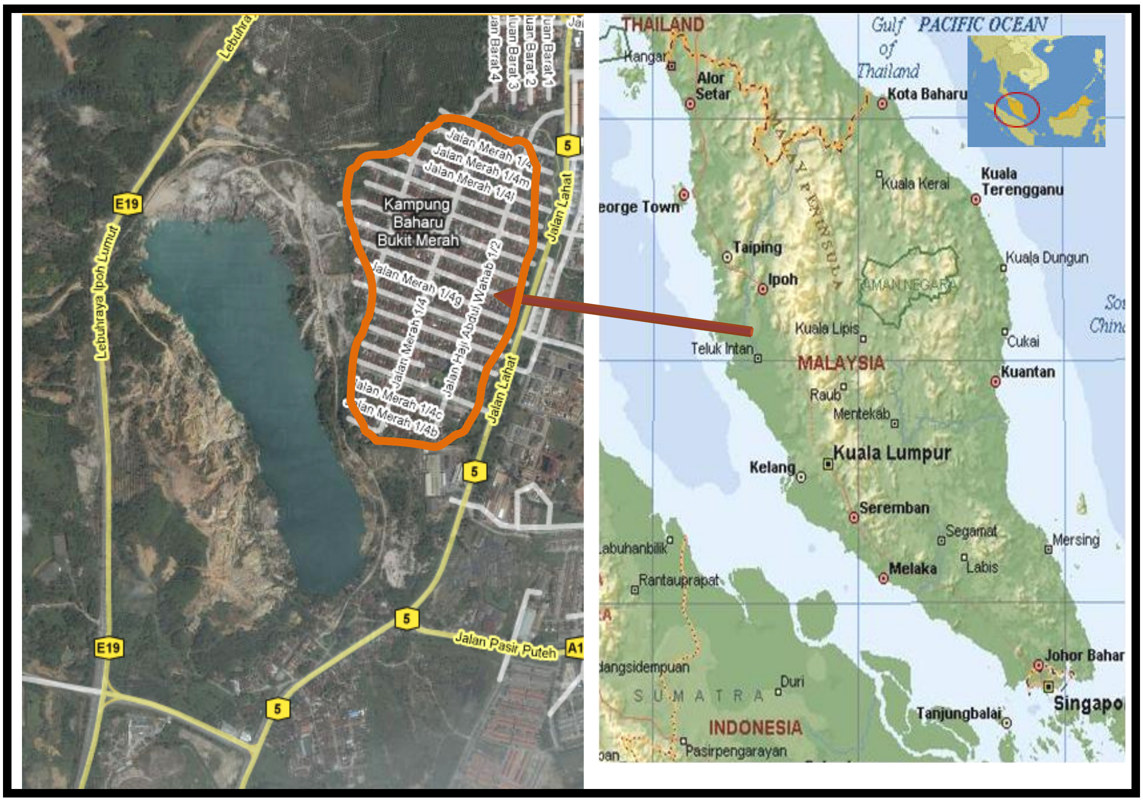


Figure 1: Bukit Merah, the location of study area.

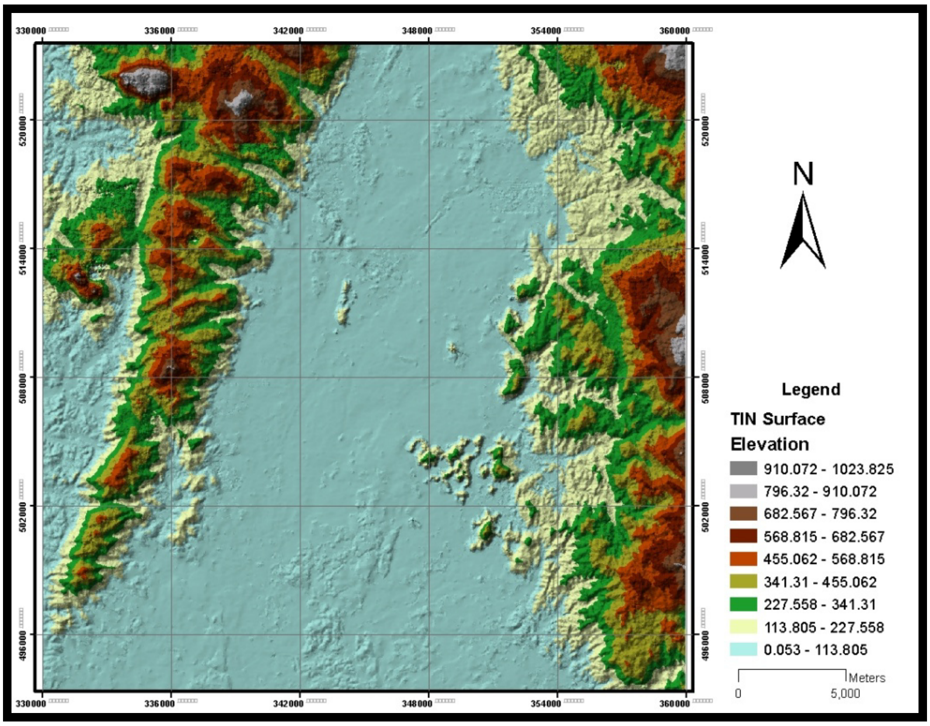


Figure 2: Digital terrain model (DTM) of Kinta Valley.

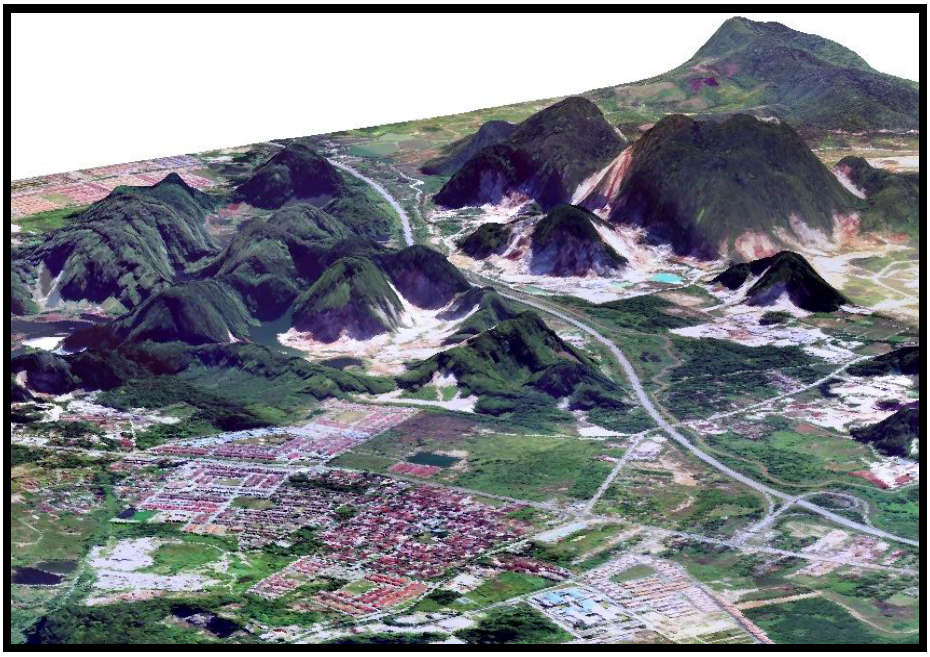


Figure 3: Karst tower separated by broad flat Kinta Valley.

Geologically, Kinta Valley is underlaind by the Kinta Valley limestone formation which has been dated from Devonian to Permian. Karst in the Kinta Valley takes the form of typical tropical karst. It is one of the most famous Karsted areas in Malaysia (Figure 4). The Kinta Valley is made up of four main types of lithologies, each producing a different landscape (Fatihah, 2002). Granite bodies of the Main Range and Kledang Range flank the plain in the east and west respectively forming rugged ranges of up to 1000 m above mean sea level (Figure 2). Schist makes up the rolling landscape of the valley, and Quaternary alluvial deposits had been deposited across the valley and formed a vast plain (Suntharalingam 1968 and Ingham and Braford 1960).

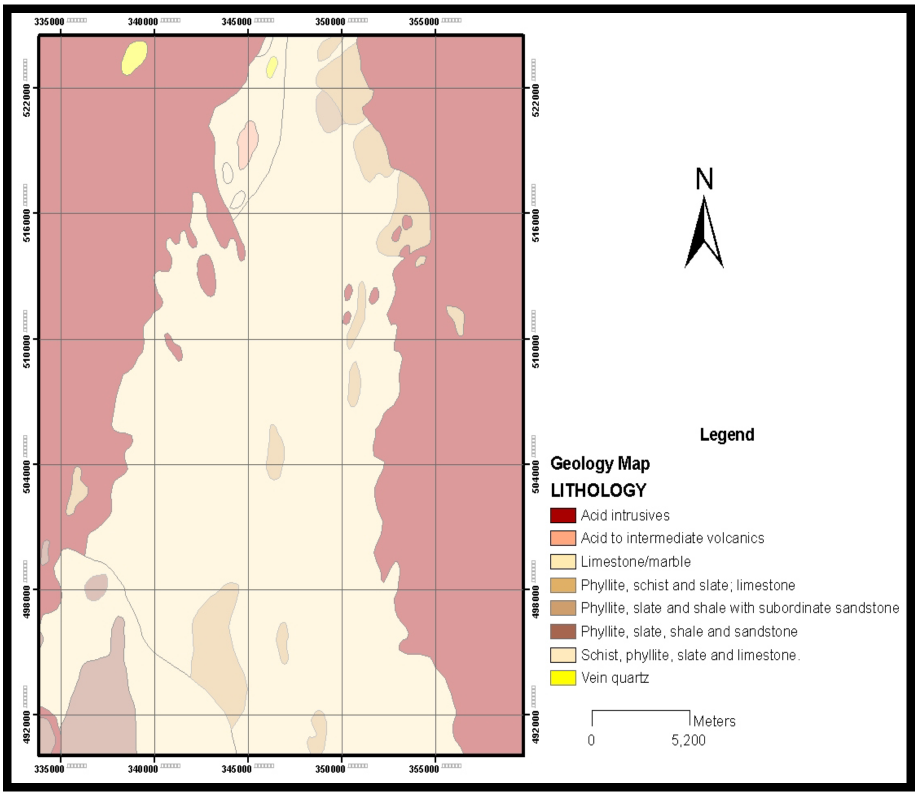


Figure 4: Geological map of Kinta Valley

3. METHODS

3.1. Geospatial Technique for Hazard Evaluation

Spatial technology makes it easier to explore the world and the neighbourhood we live in, share knowledge, find opportunities, and inform decisions. The development of spatial technologies had been driven by the need for better decision making. Early innovators were motivated by the belief that experts in a wide variety of fields could make better decisions if they had better tools for analyzing and visualizing geographic data (Harrison, 2004). Spatial information technology is useful in dealing with natural hazards to support increased coordination among multiple programs of risk management by examining the application of these technologies to the task of identifying, analyzing, assessing, treating and monitoring (Mansor et al. 2004). Many researches had been exploring the geological hazard (geohazard) by sharing knowledge, finding opportunities, and making informed decisions (Tan and Khoo 1981, Jennings 1982, Chong and Hong 1985, Tan 1987, Komoo 1995, Singh and Dhar 1997, Tan 1998, Li and Zhou 1999, Abu Shariah 2002, Fatihah, 2002, Mansor et al. 2004, Julie et al. 2004, Shang-Xian and Jincai 2005, Tralli et.al. 2005, Kucinshas and Seber 2007, Omar et al. 2007, Al Kouri et al. 2007, Rienzo et al. 2008).

Geographic information system (GIS) is a database system for storing, processing, manipulating, retrievaling and displaying digitally the spatial attributes. It is an integrated computerized approach of thinking, searching and studying tool for complicated phenomena and regional variables that are difficult to characterize, infer and deduce their interchangeable effects. Its ability to quantitatively analyze data of various types had won GIS the preferential position in research methodologies (DeMers 2000). Since it depends heavily on computer advances, it can handle thousands of volumes of data in short time, less effort and high level of accuracy.

GIS and remote sensing technologies are recognized worldwide as valuable tools in environmental applications, and they are particularly useful in monitoring environmental changes due to human activity (Zhang 2004). GIS and remote sensing techniques are critical components of any strategy to effectively protect and manage the natural resources in the Kinta Valley. The key features which differentiate GIS from other information systems are the general focus on spatial entities and relationships, together with specific attention to spatial analytical and modeling operations (Maguire et al. 1991). A Relational Database Management System (RDBMS) consists of a collection of tables, each of which is assigned a unique name with each row representing a relationship among a set of values (Silberschatz et al 2002).

3.2. Data Collection

The following remote sensing data were available for this research:

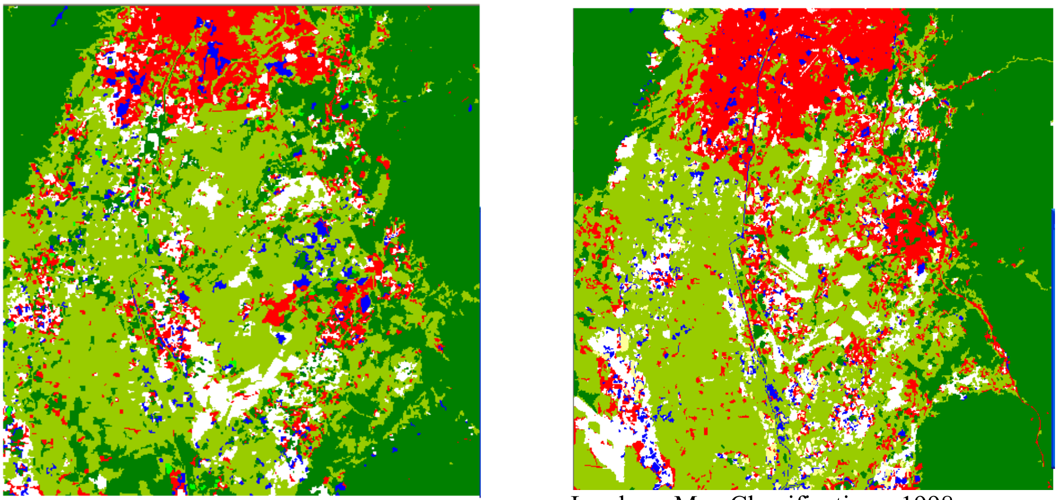
1. Landsat TM (land-observing satellites Thematic Mapper) that was acquired for 1991, 1998, and 2000,
2. SPOT5 (Satellite Pour l'Observation de la Terre) was acquired for 2005, and
3. satellite image acquired for 2007 (Google Earth) used for Bukit Merah.

3.3. Land Use Mapping

Land use areas were classified from Landsat TM images by using the combined object segmentation and fuzzy logic algorithm that is shown in Figure(5). Land use areas were classified into six categories: agriculture, water body, forest, mining, urban and grass. In 1991, and 2004 agriculture was found to be the highest of 26% and 33% respectively, while grass showed the least percentage of 0.41%. Land usage of 1998 forest was found to be the highest of 33%, while grass showed the least percentage of 1.5%. Results of land use areas of 1991, 1998 and 2004 were tabulated in (Table 1). It was found that the mining area had the highest percentage of land usage compared to the other categories, this was due to the human activities , such as surface mining (quarrying), and urban expansion.

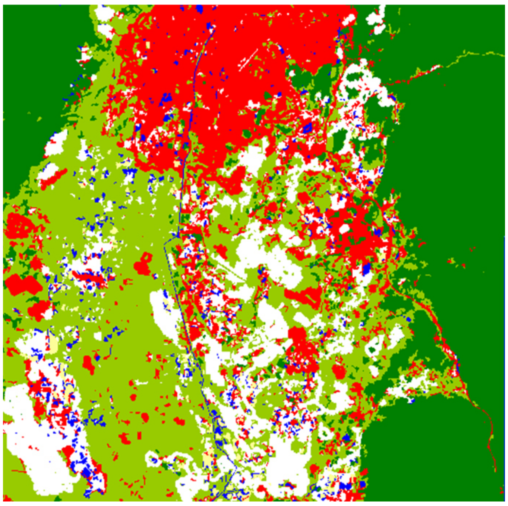
Table 1: Percentage of land use in Kinat Valley

Land use	1991	1998	2004	Difference in Percentage
Agriculture	20.1856	21.166	23.434	16.38
Water Body	5.37324	3.1362	3.72	-44.44
Forest	39.5248	33.102	27.51	-43.67
Mining	8.60248	13.1662	15.762	83.23
Urban	25.90038	27.81	28.14	7.96
Grass	0.4135	1.5403	1.434	71.16

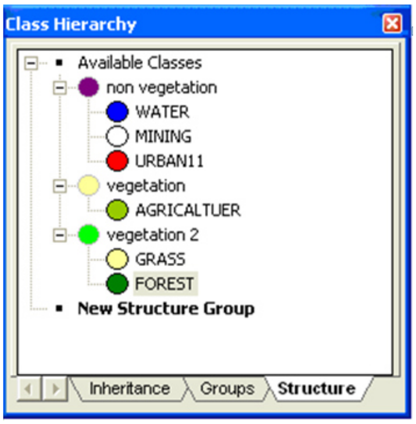


Land use Map Classifications, 1991

Land use Map Classifications, 1998



Land use Map Classifications, 2004



Class Hierarchy

- Available Classes
  - non vegetation
    - WATER
    - MINING
    - URBAN11
  - vegetation
    - AGRICALTUER
  - vegetation 2
    - GRASS
    - FOREST
- **New Structure Group**

Figure 5: Land use Classifications map of the Kinta Valley

Bukit Merah land use map shows six classes of land use which are: the agriculture, mining, forest, infrastructure, water body, field and grass, and swamp (Figure 6).

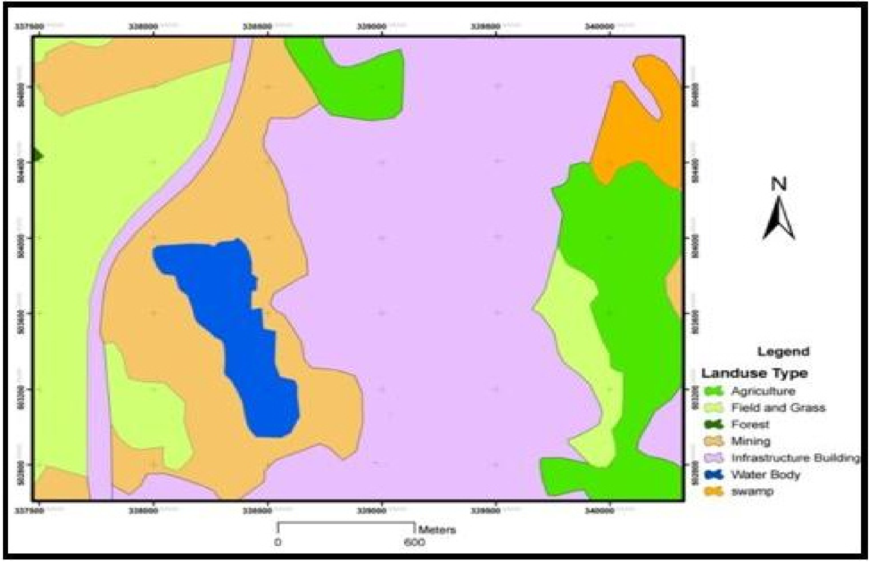


Figure 6: Land use of Bukit Merah, 2005

4. DATA ANALYSIS AND RESULTS

4.1. Geohazard Evaluation of Bukit Merah

4.1.1 Relational Sinkhole Database

A relational sinkhole database was developed in Microsoft Access for structuring the large amount of data that includes the collapsed and subsidence sinkholes, in order to be manipulated in digital format and to be used in the GIS environment format, (Figure 7). The database includes all the important information collected for each incident and thus can be used for further investigating and understanding the phenomenon. The developed database included collapsed and subsidence sinkhole information gathered from several sinkholes incidents, some of which caused losses in human lives, others that were very large in size causing a great amount of damage to structures and life lines.

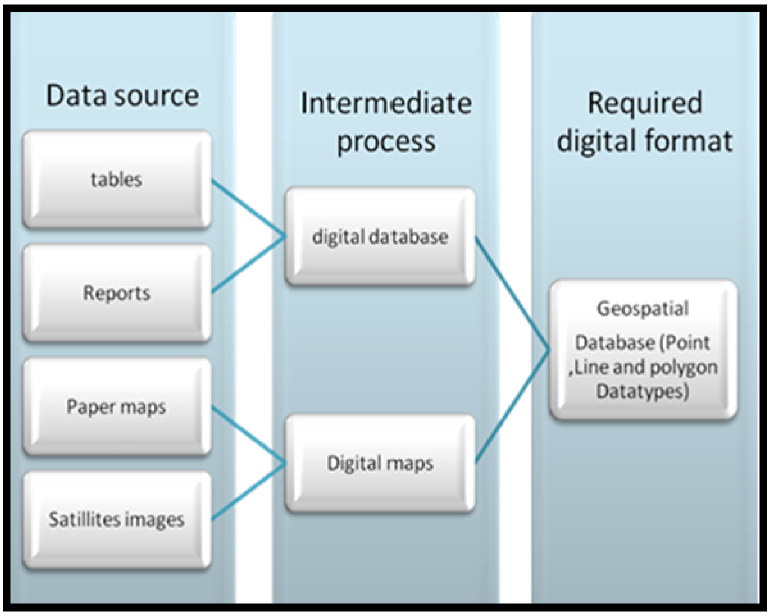


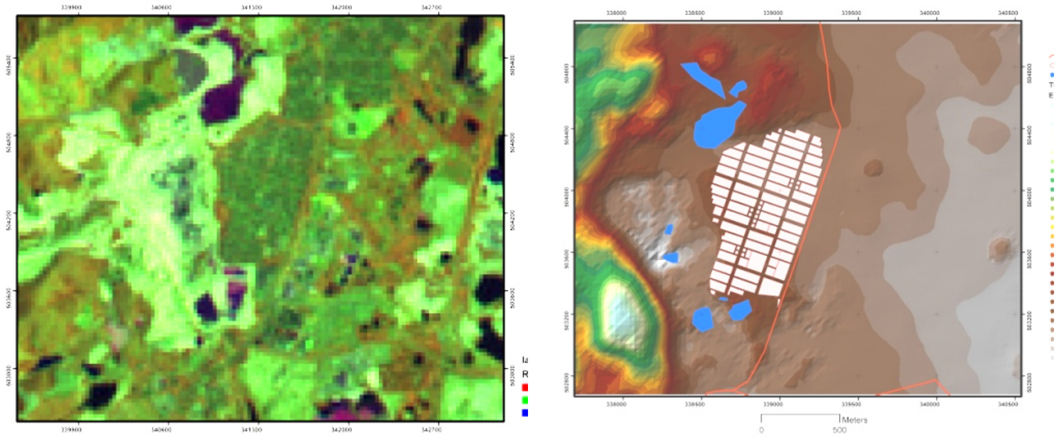
Figure 7: The flowchart of the geospatial sinkholes database system that was developed under three phases for Kinta Valley

4.1.2 Land Use and Change Detection

The study focuses on the use of spatial technology techniques for the detection of changes and the effects of mining on geomorphology, especially the use of sequential satellite images that allow the detection of changes taken place from time to time, to provide efficient tools to extract information/knowledge for logical decision making. For this purpose, a mining site at Bukit Merah was selected as shown in Figures (8 and 9). This area lies at a distance of few hundred meters from Bukit Merah town and remained the main supplier of limestone and marble for the constructions materials to the surrounding areas.

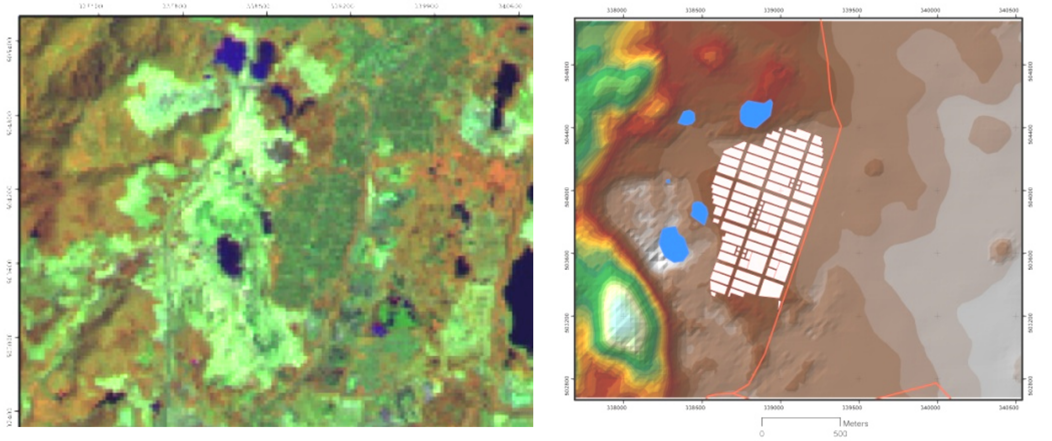
The Kinta Valley was the largest producer of tin ore in the world in the first half of the 20th century. Most of the mechanisms were open cast, and the remains of these sites can still be seen until today. This series of remote sensing data shows 15 years of mining growth in Bukit Merah. The available remote sensing data shows the condition of the mining site from 1991 to 2007 (Figures 8 and 9). Landsat TM false colour composites (FCC) of bands 4, 5, and 2 (Figure 8) shows open pits mining for tin-ores at the south and northeast, and the absence of the first layer of alluvial deposits for quarrying activities (light green). The condition after 7- years (1998), Landsat TM false colour composites (FCC) of bands 1, 2, and 3 (Figures 8c and 8d) shows two locations of open pits in north and in the middle of the site, and limestone bedrock exposure at the surface due to mine the alluvium (Omar et al. 2008) . It is expected that in the coming years the eastern side of the mining lake may be increased furthermore due to continuous quarrying,

The quarrying activities by large surface open pit at the site increased since 1998 (Tables 2 and 3). In 2000, Landsat TM false colour composites (FCC) of bands 4, 5, and 2 shows the mining site being consumed by the quarrying activities and that rapid opencast mining was going on continuously. The increased number of pits increased in size and took the shape of a single elongated mining lake. There was a lightly noticeable change in the mining lake landscape after 2000 (Figures 8e, 8f, and 9) (Tables 2 and 3). The mining site near the lake was changing mostly due to the expansion of the quarry activities towards the limestone hill.



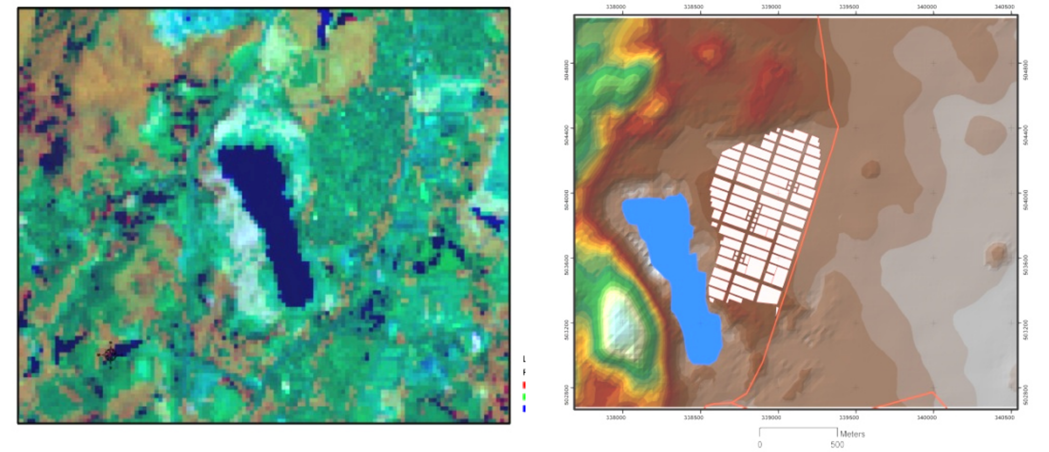
a- Landsat TM, 1991

b- Water body at 1991



c- Landsat TM, 1998

d- Water body at 1998

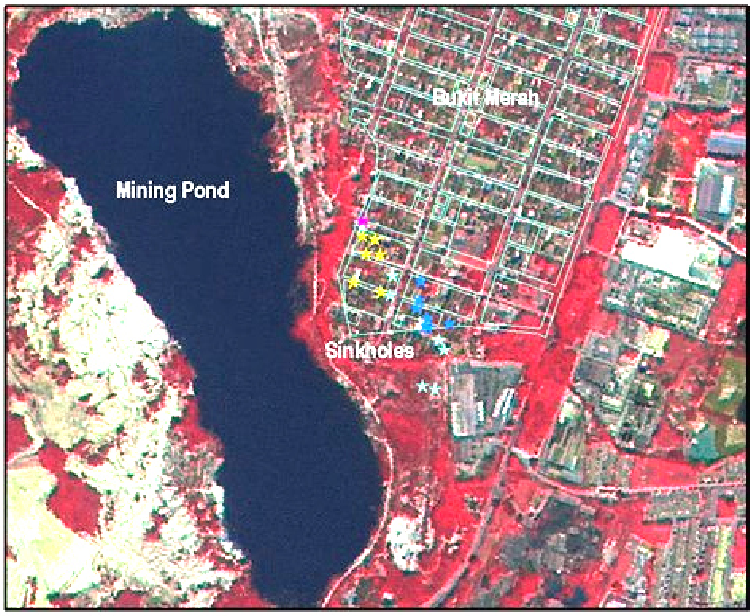


e- Landsat TM, 2000

f- Water body at 2000

Figure 8: Time-series Landsat TM satellite images of Bukit Merah show Open pit tin mines in Bukit Merah between 1991 to 2000

a- SPOT5, 2005



b- SPOT, Google Earth 2007

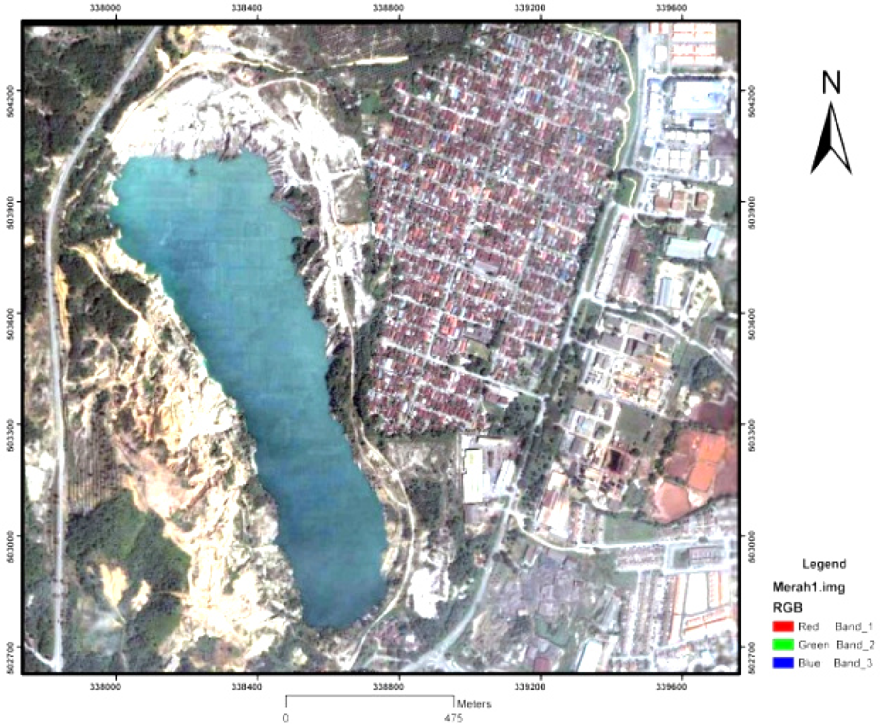


Figure 9: Time-series SPOT satellite images of Bukit Merah

4.2. Geohazard Evaluation

In general, the conflicting issues associated with the quarrying operations can be clustered into the following subjects: Conservation of unique natural habitats and ecology associated with a specific geological formation, economic impacts linked directly to the infrastructure and commercial development of the State and country, and social impacts relating to direct employment and spin off occupation as well as quality of life.

Kinta valley have been deteriorating dramatically as a result of changes that have occurred in the past and continues due to the close relationship between the fast rate of lateral urbanization and extensive dimensional expansion of surface mining and quarrying activities. Sizes of sinkholes in Malaysia vary from as small as 0.5 m to more than 30 m across (Table 4).

In Kinta Valley, the sinkholes were formed within north-northeast trending zone along the western flank of the valley from Batu Gajah through Lahat, Bukit Merah, Menglembu, Manjoi, Jelapang and Tasek. Other sinkholes had formed near Gunung Lanno, Gunung Rapat and Gunung Panjang in a north-northwest trending zone to the east of the valley based on the data gathered. Distributions of sinkholes are mostly located in the southern part of the western belt of limestone hills and an east-west line across Ipoh. Therefore, sinkhole development is more common in pure limestone with over 95% CaCO3 content while the more dolomatized karst areas with about 40% MgCO3 content are less prone to sinkhole development (Teh et al. 1998).

Table 2: The area of the water body was increased since 1991 due to quarries and open pit tin mines.

Year	No. of ponds	Area (km2)	No. of pixels
1991	1	0.477	529
	2	0.290	323
	3	0.205	228
	Total	0.972	1080
2000	1	2.975	3306
2005	1	3.726	4140

Table 3: The increasing percentage of water body was dramatically large in Big Foot Lake since 1991.

	Area (km2)	No. of pixels	% of change
1991-2002	2.003	2226	306.1
1991-2007	2.754	3060	383.3

Occurrences of sinkholes in Bukit Merah site had been documented since 1981, based on the Geological Survey Department that began recording the occurrences of sinkholes; Table (4) shows their proprieties. There are factors that played its role in the increasing number of sinkholes occurrences and can be summarized as follow: type of bedrock, the presence of fractures, quarry and mining activities, the climate (the annual rainfall between 1983 and 2006, Figure 10), topography, shape of lake, mine water drainage, the possibility of major water inflow from karst aquifers, lake floor, and erosion. Three geological hazards are associated with karst in this site. Two common karst-related geologic hazards; collapse sinkhole and sinkhole flooding cause the most damage to the buildings. Finally, the hydrology of the karst aquifer makes the groundwater vulnerable to pollution.

Table 4: Occurrences of sinkholes in Bukit Merah (Minerals and Geosciences Department 1998).

No.	Date of Occurrence	Diameter (m)	Depth (m)
1	28-September-1998	3.0	4.5
2	09-October-1998	4.5	3.0
3	09-October-1998	2.7	4.5
4	09-October-1998	4.5	9.0
5	10-October-1998	1.5	4.2
6	30-October-1998	1.8	2.6
7	Unknown	2.5	2.0

Collapse sinkholes occur suddenly when the soil collapses into an underlying grike, a fissure will be created. Larger it grows when resides in and water dissolves limestone. Heavy rains or extended droughts can bring on collapse sinkhole. Each weakens the soil over a grike, either by saturating the soil with water or robbing it of cohesion. Eroded soil falls into the grike and water moves the soil to an underlying cave, forming cavity in the mantling soil. In high- flow events, water in the cave may back flood into the overlying soil. As the water recedes, the cave and grike drain faster than the soil, which means that saturated soil spans the void in the grike. The overloaded soil arch falls into the soil cavity and the cover collapses (Cobb and Currens 2001).

Mining activities in karst areas had been closely associated with sinkholes in Bukit Merah (Figures 8, 9, 11, and Table 4). Surface collapse causes an increase in mine water drainage and the possibility of major water inflow from karst aquifers, which threatens the environment in the mining areas, and endangers mine and infrastructures safety. The study area shows that the present quarrying rate remains active (Figures 8, 9, and 12).

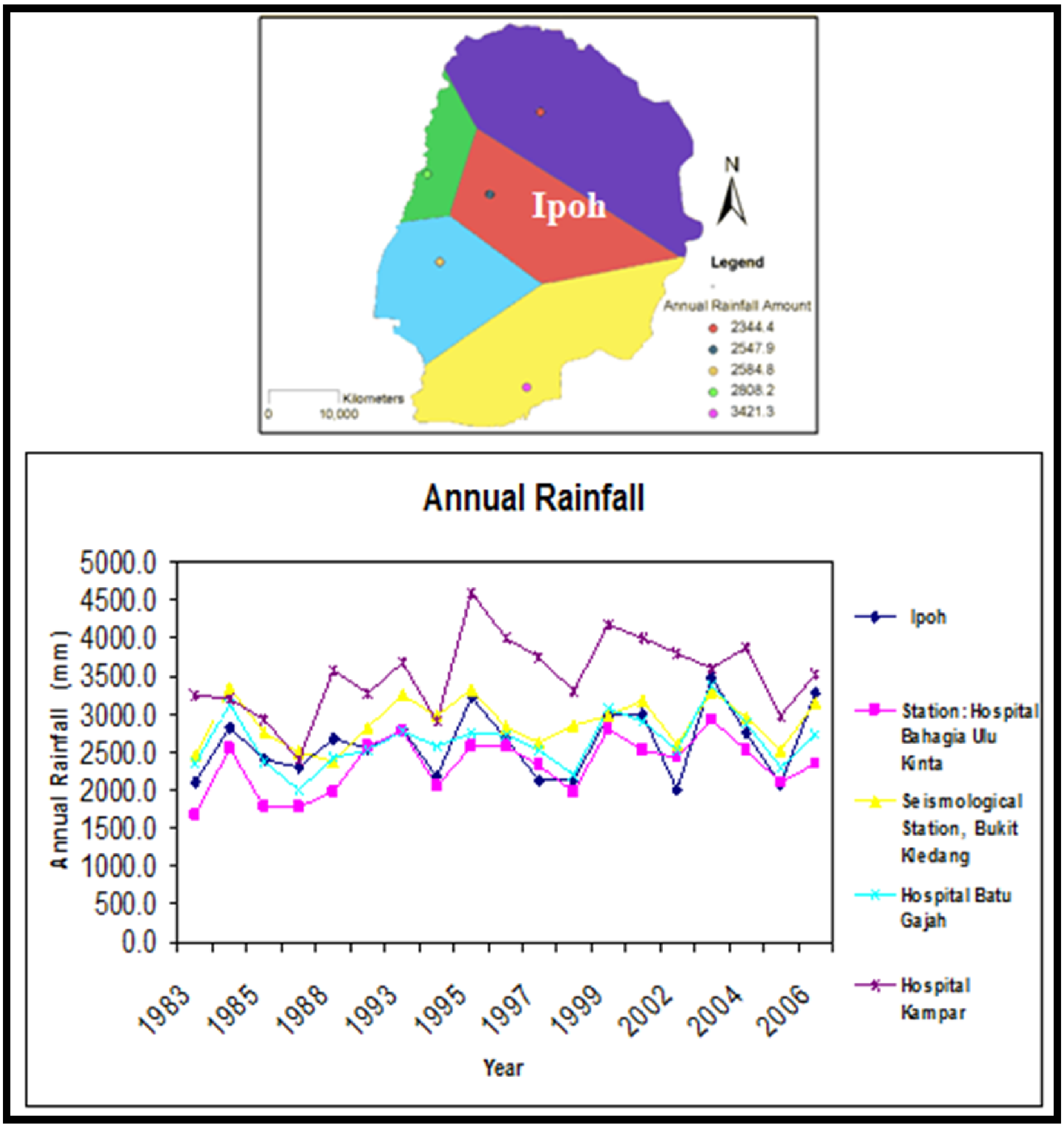


Figure 10: Rainfall map of Kinta district and its annual mean rainfall between 1983 and 2006

Lower-elevation areas within a compound sinkhole and karst valley may be affected by flooding (Figures 11 and 12). Most sinkhole flooding occurs when the rate of inflow of runoff from rain or lake/river exceeds the rate of water flow that the conduits and cave passages can transmit. When the lake fills during wet periods and water storm, it drains from the east and south side into the surrounding area causing flooding of Bukit Merah. Therefore, cross-sectional area of the conduit walls will be enlarged based on the increasing water pressure that will increase the rate of dissolution of limestone. There is a backwater effect on groundwater flow from sinkholes with bottoms lower than the level of surface streams at flood stage. Particularly in urban areas, structures are often built within sinkhole flood plains (Waltham 1989 and 1994). Flooding problems may be greatly aggravated in the site by: Increased rates of runoff caused by land use changes, especially from impervious roofed or paved areas, decreased storage due to sinkhole grading and filling, and clogging of sinkhole drains by debris, silt, and mining materials. These human and mining activities conditions increase the chance of sinkhole flooding.

The solubility of limestone and mining activities has generally caused land built of the lake to be lower than the surrounding. Mining lake is catching runoff especially from highland at the west and the north sides due to the elevation lake that is lower than the surrounding, where its elevation is around 30 meters above the main sea level and the elevation of tower karst is greater than 130 meters above the main sea level (Figures 8, 9, 11 , and 12). Moreover, the regional climate is tropical and major changes in the precipitation of the surrounding basin have large impacts on the water level and the area of the lake, beside changes by the mining activities which in

addition to the destruction of the natural landscape are causing large scale environmental degradation.
Solution sinkholes, form more slowly and gradually as a result of enlargement of conduits by solution. Eventually the rocks may settle and the cover material washes into the cavern in a process called ravelling. Most commonly, it suspends in the hydraulic conditions in the aquifer, either natural or man-induced such as mining activities that lead to ravelling and solution sinkhole activation, groundwater pollution increases the possibility of this type.

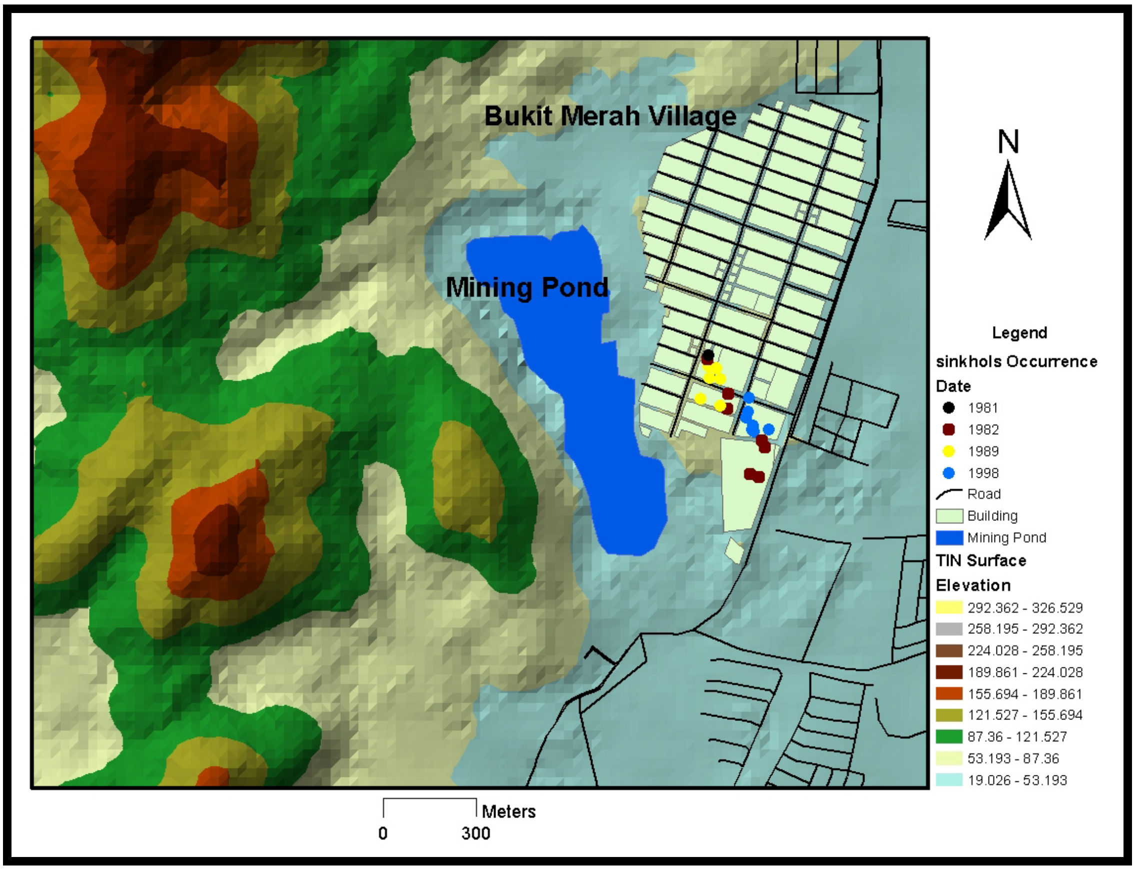


Figure 11: Bukit Merah, sinkholes distribution

Furthermore, Figures (11 and 12) show the area that has high risk where the formation of the sinkholes is highly developing in this zone. The increasing numbers of sinkholes in this zone depends on the following factors quarry activities, topography, the shape of the lake, lake floor, mine water drainage, and location of urban area.
Open pit tin mines had been close to Bukit Merah town (Figure 12a) and (Tables 2 and 3). They were associated with sinkholes and the nearest area to the lake is now located in the middle of the lake (Figure 11). The distance between the Bukit Merah town and this point is around 85 m. The narrowest part of the lake is located in its middle (around 218 m width), and takes the shape of big foot (Figure 12a). Surface collapse sinkholes have a high chance to develop in this zone caused by the mine water drainage and major water inflow in the lake causes flow velocities in this area to increase compared to the velocities in other part allowing little time to warn downstream with high degree of erosion and weathering. Groundwater flows through conduits so that there is great opportunity for groundwater to move rapidly through conduits and fractures especially through rainstorm. The lake floor might increase the velocity of the water and groundwater flow because the deepest depth is located in the middle of the lake (Figure 12a-e). Factors that increase the potential of sinkholes due to the increasing weathering are the presence and density of fractures, the possibility of major water inflow from karst aquifers, and the erosion caused by limestone dissolution rates that are highest in this area. Moreover, “the formation of the cavities in the limestone bedrock is related to the fluctuations of the groundwater level. Cavities are developed mostly within the zone of the ground-water level fluctuation. Therefore, this zone has increased the potential of sinkholes occurrences. Quarry activities in the karst areas had been closely associated with sinkholes in Bukit Merah (Figure 12), (Tables 2 and 3). Surface collapse causes an increase in mine water drainage and the possibility of major water inflow from karst aquifers, as mentioned previously which threatens the environment in mining areas and cause danger to the area safety. Another factor that also plays its role in adding threat to the area is the vibrations caused by quarry activities where it may cause the plug to fail by

erosion and upward piping failure.

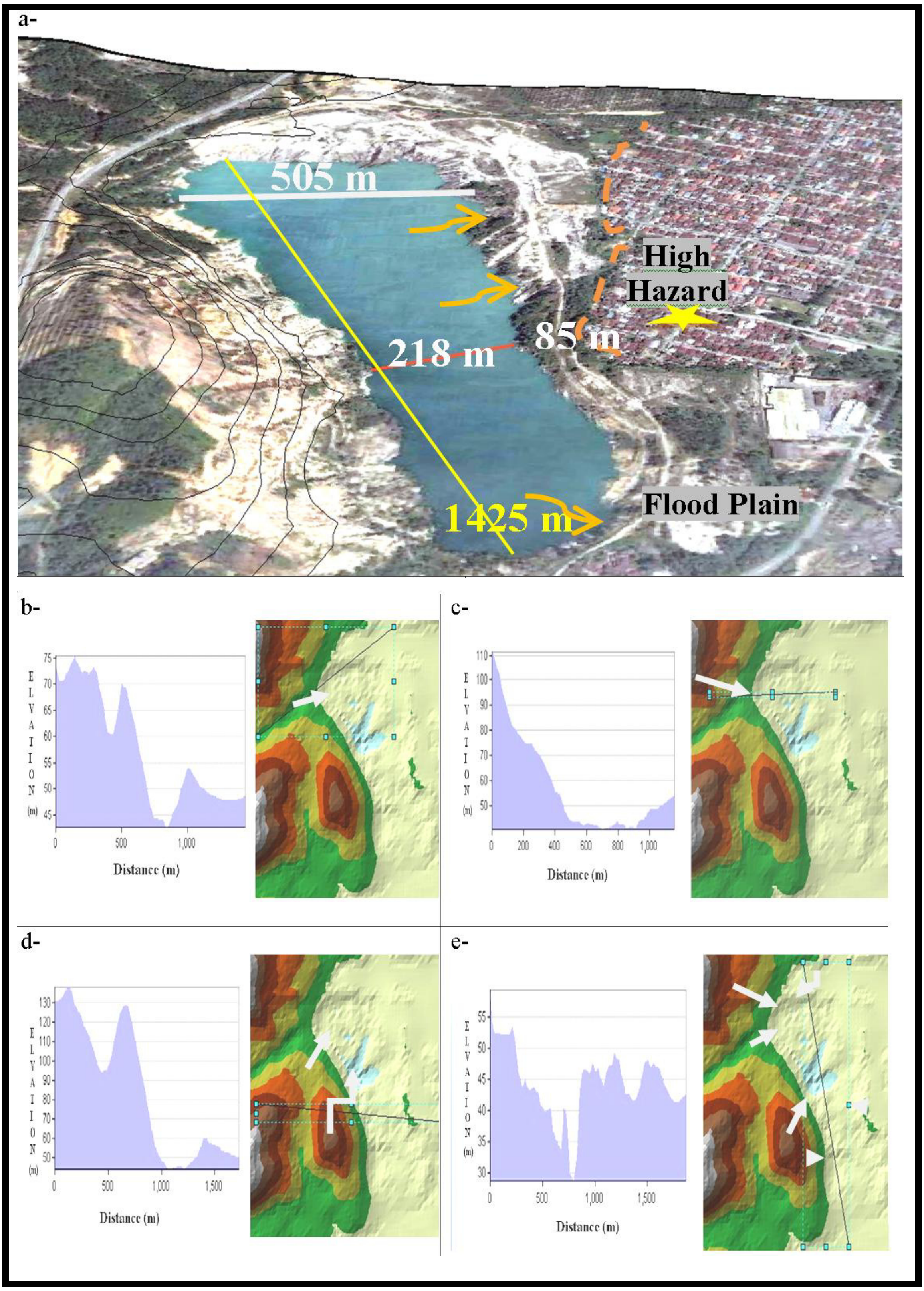


Figure 12: Geohazard evaluation.

Karst region imposes serious unique engineering and environmental hazards to humans and their properties which can be influenced by land-use modification and mining activities in Bukit Merah. The quarries and open pit tin mines need more planning that involves geotechnical hill slope stability studies, pit optimisations, hydrological modelling, pit designs, reserve estimation , site layout plan , equipment selection and operating plan, production scheduling, metallurgical processing and recoveries and risk assessment and mitigation. Therefore, These results will assist the local authorities, urban planners, and citizens to provide planning and studies to avoid hazardous areas, and to predict the future trend of sinkholes distribution in order to reduce the number of sinkholes at the high risk area by controlling the amount of mine drainage, reducing water-level fluctuation, sealing off karst conduits and subsurface cavities in the overlying soil, preventing water inflow, improving drainage systems in the developing area, and improving the leakage in quality and techniques used in quarries and open pit tin mines.

5. CONCLUSION

Karst features represents one of the most widespread and often under evaluated geologic hazards in Kinta Valley Limestone Formation. Geospatial information system for sinkholes was established for building a relational GIS database and creating sinkholes distribution maps. Geospatial technology, that includes Remote Sensing and GIS were consisdered successful for qualitative analyses of sinkholes distribution associated with multi thematic maps, to define degree of the risk in this study. Landsat TM, moderate resolution, false colour composites (FCC) and SPOT5, high resolution image, provide very useful information for land-use mapping and change detection water bodies in the mining site. The research in the mining area in Kinta Valley Limestone Formation have shown that remote sensing data offers effective methods for remote identification hazard and change detection in mining environments. Finally, geohazard caused by sinkholes cannot be completely prevented but the study can be provided to the policy makers and the public to develop strategies for minimizing or avoiding loss and improving the leakage in quality and techniques that can be used in quarries and open pit tin mines.

6. REFERENCES

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