SINKHOLE RISK MODELING IN RESIDENTIAL AREA USING GIS TECHNIQUE

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Abstract

This study presents the development of an Integrated Geographical Information System (GIS), Geophysical Method and Global Positioning Systems (GPS) survey for sinkhole risk modeling in selected residential area. The sinkhole phenomena in residential area have been known to be related to geological factor, environmental and local activities. To determine the subsurface structure and also the location of sinkholes of the study area, the geophysical survey which is resistivity survey was carried out by using ABEM SAS 4000. From the resistivity survey, the area that was identified to have sinkhole was tagged using GPS coordinates through GPS survey using GPS Topcon HiPER. The above data were integrated as a GIS database. Spatial Analysis were carried out using the User Interface developed in this study from the components of ArcGIS Software which are ArcMap and ArcObjects in order to model the sinkhole occurrence risk for the selected residential area. The user interface developed in this study would be useful for those involved in planning and development of housing area and also the other land use activities so that the adverse effect of sinkhole collapse to them could be avoided.

Keywords: *Sinkhole Phenomena, GIS, sinkhole risk, resistivity.*

1.0 INTRODUCTION

This project describes the sinkhole risk modeling in residential area using GIS technique. The study involved data collection for GPS, Geophysical data as well as developing GIS database and development of sinkhole risk modeling using GIS technique. In Peninsular Malaysia, sinkhole occurrence mostly happened in Kinta Valley and Klang Valley. The sub-surface for both of this area is limestone bedrock.

The Study area covers Kinta Valley in Perak State, in which Bukit Merah New Village, Lahat has been identified as a data collection area. The Bukit Merah New Village was located on an elongated piece of relative flat tin tailing land stretching south from the Menglembu township which is 5 miles southwest of Ipoh. About 80 percent of the Kinta Valley is underlain by limestone bedrock of which some crop out as hills with spectacular, steep-sided cliffs. Natural erosional processes over time acting on the limestone bedrock give rise to cavities within the bedrock which subsequently could lead to the formation of sinkhole.

Sinkholes in urban areas or in areas of habitation have resulted in destruction or damages to property such as houses or buildings or in some cases, to loss of life. Therefore this study was conducted with the following objectives:

- To conduct surveying methods, which are Geophysical, GPS and GIS at selected sinkhole-prone area
- To develop GIS Database
- To develop spatial analysis and GIS modeling
- To develop GIS Application For Sinkhole Risk Modeling

2.0 BACKGROUND / THE SINKHOLE OCCURRENCE.

A sinkhole is formed as a result of a sudden collapse of the overlying soil into a depression with steep to sub vertical slides. Occasionally, a sinkhole may be a funnel-shaped or bowl-shaped depression an is circular. The size of a sinkhole may vary in diameter from as small as 0.5 meter to as large as 30 meter. The primary cause of sinkhole formation is the dissolution of limestone by acidic waters. Rainwater, which absorbs carbon dioxide in the air, forms a weak carbonic acid solution and on percolating through the natural fracture within the bedrock, slowly dissolves the limestone. Through geologic time, dissolution along these zones of weaknesses have resulted in the formation of cavities within the bedrock and the soil immediately above the cavity would fall into the cavity. If the groundwater table is high, the hydrostatic pressure on the roof of the void prevents the collapse of the soil into the cavities. However, if there is lowering of the groundwater table, there will be rapid collapse of the soil leading to the formation of the sinkhole.

According the report from Department of Mineral and Geoscience of Perak, sinkhole had been formed within the north-northeast trending zone along the western flank of the valley, stretching from Batu Gajah through Lahat, Bukit Merah, Menglembu, Manjoi, Jelapang and Tasek. While to the east, sinkhole had been formed near Gunung Lanno and in the Gunung Rapat and Gunung Panjang areas, within a zone trending in a north-northwest direction (Shu, 1995).

One of the methods for sinkhole investigation is Geophysical technique, such as microgravity, ground penetrating radar or electrical resistivity method or a combination of these methods. For this project, electrical resistivity had been applied to investigate underground structure. This technique measures directly the resistivity of the subsurface. The difference in resistivity between the limestone and the cavity such as air, water or sediment-filled, produces sufficient contrast for the technique to be applied in cavity detection (Chow, 1995).

3.0 METHODOLOGY / STUDY DESIGN

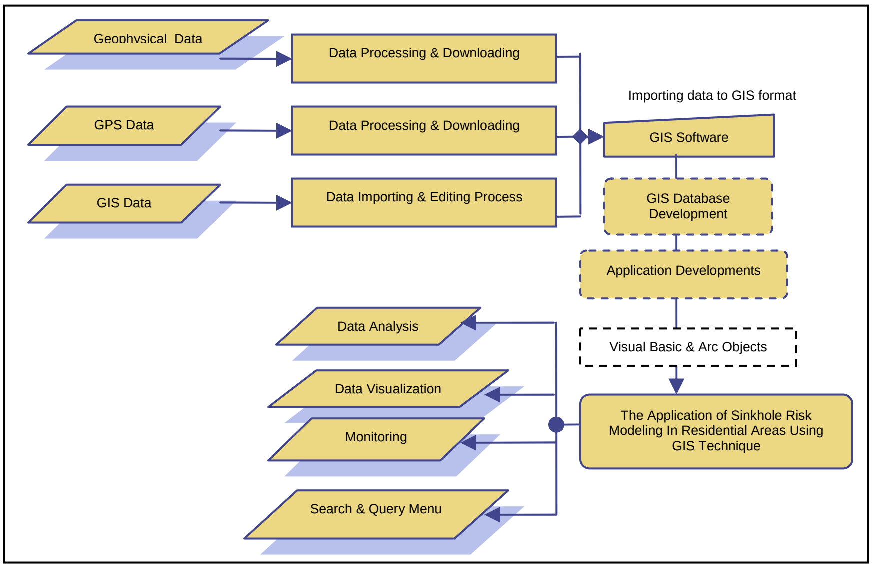


Figure 1: The Conceptual Process of Project

Broadly the methodology adopted in this study includes data collection, data editing and processing and development of GIS database and interface as depicted in Figure 1. The GIS Interface was developed using ArcGIS component which are ArcMap and ArcObjects.

3.1 Data Collection/Field Survey

This involves data collection in the form of resistivity data, GPS data and spatial data such as topographical and geological map of study area. The purpose of resistivity survey is to determine the subsurface profile of the study area. Different subsurface profile (such as limestone and cavity area) will have different resisitivity value (Crawford, Webster & Veni, 1999). Therefore the resistivity value could be an indicator whether or not sinkhole exists at a certain particular area. The resistivity survey was done using Terrameter SAS4000 and RES2DINV was used to interpret the data. Figure 2 indicates the location of the resistivity survey in the study area. An example of the output of the survey is shown in Figure 3, indicating the existence of cavity in sub-surface between 2 to 10 meter from surface. The locations of the sinkholes are tagged using GPS coordinates as indicated in Table 2. The instrumentations used in the data collection are summarized in Table 1.

Table 1: List of The Software and Hardware

Method/Technique	**Software**	**Hardware**
Geophysical Survey	SK2Win RES2DINV	Terrameter ABEM SAS4000
GPS	Topcon Pinnacle Version 1.0 Topcon PC-CDU 2.1.11	Topcon HiPER
GIS	ArcMap & ArcObjects 8.3 Visual Basic 6.5	-

Table 2: List of GPS Coordinate Points

Reference Coordinate Systems : RSO		
ID	**Northing (meter)**	**Easting (meter)**
01	503,521.4	338,731.1
03	503,534.5	338,660.8
04	503,295.9	338,783.7
Balai Polis Point	339,089.1	503,410.8

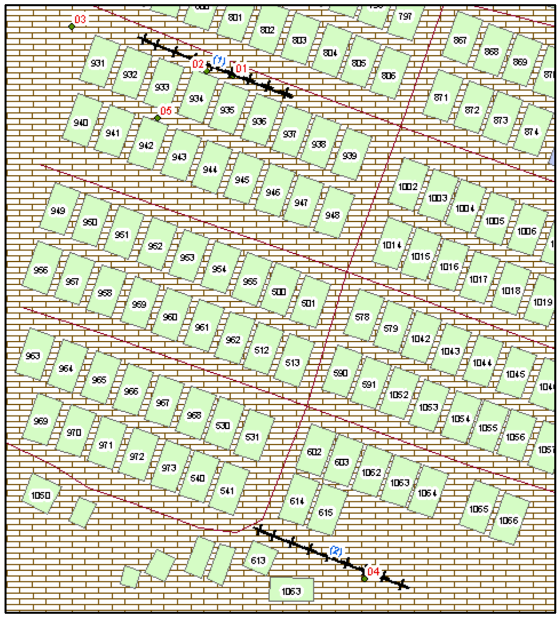


Figure 2: Location of Resistivity Survey Line (1) and (2)

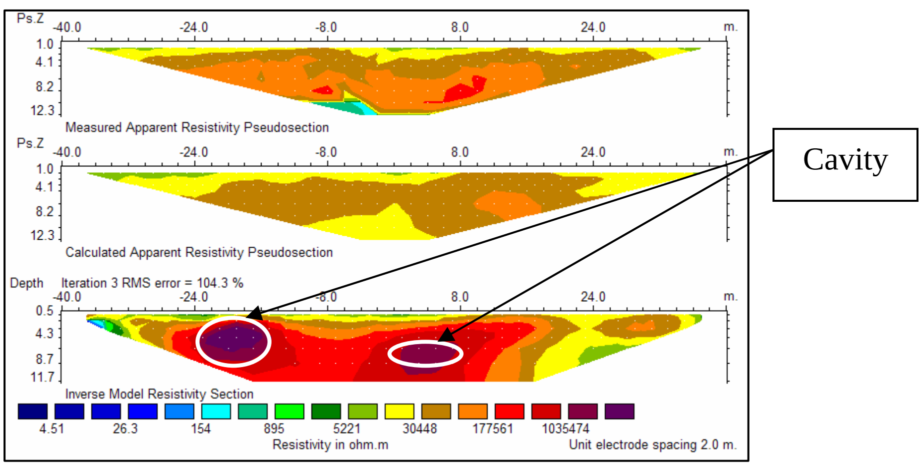


Figure 3: Image of Resistivity Model for Survey Line 1

3.2 GIS Database and User Interface Development

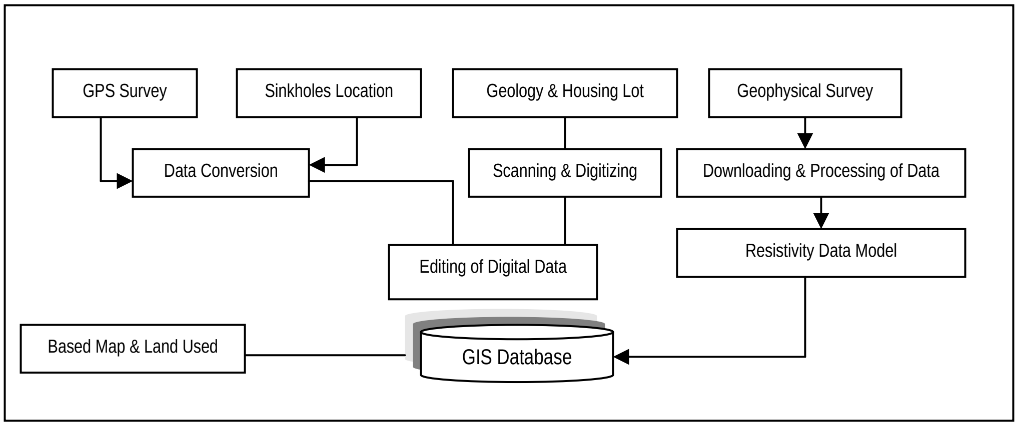


Figure 4: GIS Database Development Process

The detailed GIS database and user interface development flow is shown in Figure 4. The GIS database starts with four main data sources: GPS, Sinkhole Location, Geology and Housing Lot and Geophysical Survey. All the data sources are converted to GIS format through Data Conversion Process. The purpose of data conversion is to convert the typical data into digital data for the GIS software.

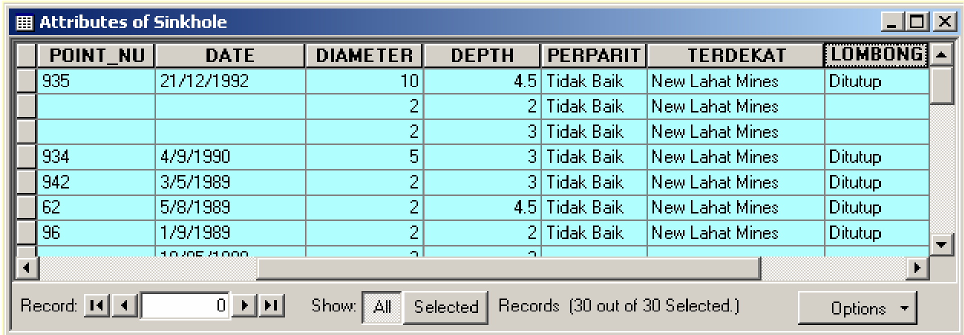
4.0 VISUALISATION AND ANALYSIS

Using the interface that has been developed as explained in section 3.0 and 3.2, spatial analysis of the data were carried out in order to determine the sinkhole risk index of the study area. The spatial analyses used were buffering, proximity, visualization and monitoring analysis.

4.1 Buffering Zone Analysis and Proximity Analysis

Buffering Zone Analysis is to produce ***equal distance zones*** in polygon shape of the study area from a sinkhole fault line. Using this analysis the area of potential sinkhole to occur could be forecasted, since normally sinkhole will occur at area where sinkhole fault line exists. Buffering Distance that was adopted is as follows:

Zone 1 = 0.0 – 2.0 km
Zone 2 = 2.0 – 4.0 km
Zone 3 = 4.0 – 6.0 km



POINT_NU	DATE	DIAMETER	DEPTH	PERPARIT	TERDEKAT	LOMBONG
935	21/12/1992	10	4.5	Tidak Baik	New Lahat Mines	Ditutup
		2	2	Tidak Baik	New Lahat Mines	
		2	3	Tidak Baik	New Lahat Mines	
934	4/9/1990	5	3	Tidak Baik	New Lahat Mines	Ditutup
942	3/5/1989	2	3	Tidak Baik	New Lahat Mines	Ditutup
62	5/8/1989	2	4.5	Tidak Baik	New Lahat Mines	Ditutup
96	1/9/1989	2	2	Tidak Baik	New Lahat Mines	Ditutup

Figure 5: Sinkhole Distribution In Buffering Area

The example of buffering analysis is shown in Figure 5. It shows the distribution of the sinkhole location of the study area. From the buffering analysis, the sinkhole risk could be divided into three indexes, which are:

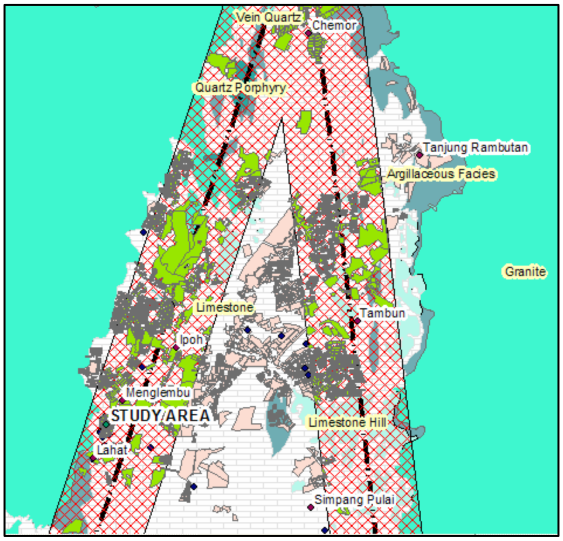
- Index 1 - High Critical Area (0.0 – 2.0 km from Fault Line)
- Index 2 - Medium Critical Area (2.1 – 4.0 km from Fault Line)
- Index 3 - Low Critical Area (4.1 – 6.0 km from Fault Line)

5.0 RESULT OF ANALYSIS

From this research the region that falls under certain category of sinkhole risk index of the study area are presented in Figure 6 to Figure 8, while the number of houses resides under the similar sinkhole risk index is presented in Table 3.

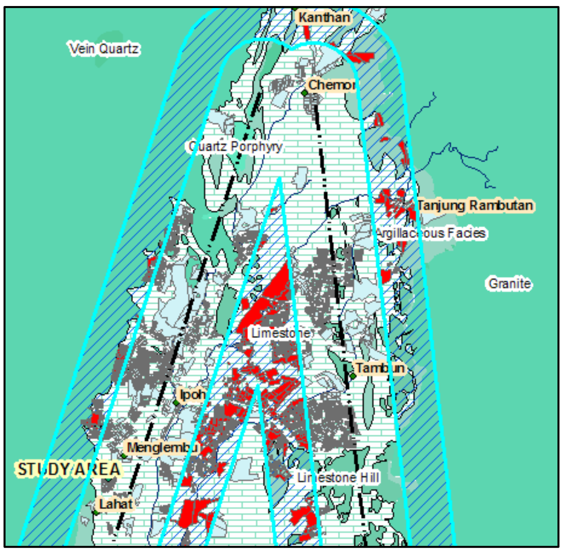
Table 3: List of The Total Residential Area In Sinkhole Index Category

Nu.	Number of Houses	Sinkhole Index
1.	3,369	*High Critical Area* (1)
2.	1,648	*Medium Critical Area* (2)
3.	91	*Low Critical Area* (3)



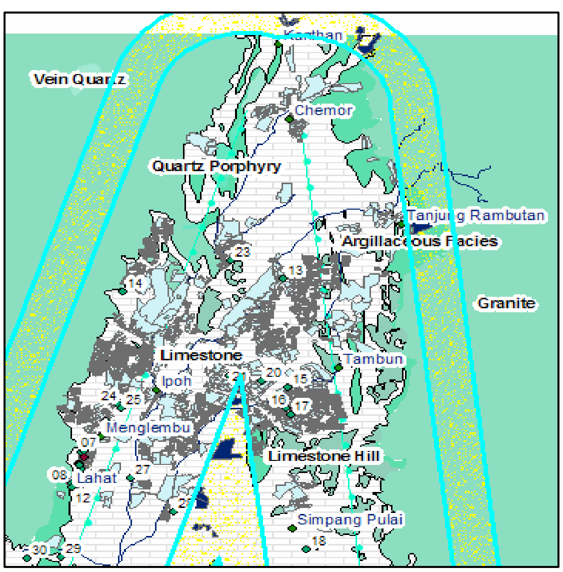
- Housing areas with sinkhole risk are shown in green
- *High Critical Area* is the overlay *Sinkhole Index 1* and *Residential Area*. *Data*
- Residential Area is 0 –2.0 km from sinkhole *Fault Line*
- *Total of Houses affected are 3,369.*

Figure 6: Residential Area In Index 1 – Highly Critical to Sinkhole Occurrence



- Residential areas with sinkhole risk are shown in red
- *Medium Critical Area* is the overlay *Sinkhole Index 2* and *Residential Area*. *Data*
- Residential area is 2.1–4.0 km from the sinkhole *Fault Line*
- *Total of houses affected are 1,648.*

Figure 7: Residential Area In Index 2



- Residential areas with sinkhole risk are shown in red
- *Low Critical Area* is the overlay *Sinkhole Index 3* and *Residential Area*. *Data*
- .
- Residential Area is 4.1–6.0 km from the Sinkhole *Fault Line*
- *The total of houses affected is 91.*

Figure 8: Residential Area In Index 3

6.0 RECOMMENDATION

Using the available data this research has produced a risk index of sinkhole occurrence for a selected residential area. However the outcome of this research could be further enhanced with the following additional data:

- Underground Water Table

This is due to the fact that sinkhole phenomena are closely related to underground water table. Low underground water table will potentially accelerate the sinkhole formation and collapse due to less hydrostatic pressure to support the already existing ready to collapse sinkhole.

- Improved Sinkhole Data

  The sinkhole data obtained from the relevant authority is in the form of event report. The individual sinkhole case was not properly tagged/indexed and accurately coordinated. Therefore it is recommended that the sinkhole data be upgraded by the relevant authority in order to facilitate further research on sinkhole risk effect to residential area as well as other land area to be developed for other purposes.

- Other Additional Data

  The authors would like also to suggest additional data to be included in the GIS interface developed in this study, so that its capability to model the sinkhole risk could be enhanced. The data includes sub surface gravity data and seismic survey data.

- To conduct Deformation Survey using GPS

  At the identified high sinkhole risk area, it is recommended that high precision deformation survey to be conducted using GPS. This is to monitor the ground movement prior to any sinkhole collapse. The survey could be done in six months interval or less especially if there is factor that could accelerate sinkhole collapse such as Earthquake.

- To extend study area coverage

  It is also recommended that this study is extended to the whole Peninsular Malaysia so that the overall risk effect of sinkhole phenomena for the whole country could be obtained. This is particularly important for the future development planning so that the adverse effect of sinkhole phenomena to property and life could be avoided.

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