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Geospatial Information System for Karst: Morpho-Geological Study in Kinta Valley, Perak, Malaysia.

***Ros Fatihah Muhammad & Omar Alkouri**

Department of Geology, Faculty of Science, University of Malaya, 50603 Kuala Lumpur.
*rosfmuhammad@um.edu.my (*corresponding author*)

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ABSTRACT The Kinta Valley karst has gone through lengthy process of natural and human-induced degradation. The topography and lithology in this area has made it possible for accelerated limestone dissolution and the marble has been quarried for many years. The geospatial study to observe the changes on the karst for over 23 years has been carried out. A database of sinkhole distribution was created and the changes of limestone topography were analyzed as well as the other relatively important features. The intensification of natural denudation rate and human activities has given huge impact on the karst. It can be observed by spatial temporal data model that also has facilitated the delineation of the changes in the topography.

ABSTRAK Kars Kinta Valley mengalami proses degradsi secara semulajadi dan juga disebabkan oleh buatan manusia. Topografi serta litologi di kawasan ini membolehkan berlakunya kadar larutan batukapur yang cepat and pengkuarian batu marmar yang intensif. Kajian geospatial untuk melihat perubahan ke atas kars ini selama lebih 23 tahun telah dijalankan. Satu databes kejadian lubang benam telah dicipta dan perubahan topografi batukapur serta beberapa fitur penting yang lain dianalisa. Degradasi semulajadi serta aktiviti manusia yang intensif telah memberikan impak yang besar kepada kars tersebut. Ianya dapat diperhatikan dari model data spatial temporal yang juga memudahkan pengenalpastian perubahan yang berlaku ke atas topografi tersebut.

(**Keywords:** GIS, karst, Kinta Valley.)

INTRODUCTION

Geospatial information technique has been used to create a database of the karst geomorphological of Kinta Valley and also to evaluate its changes due to natural and human-induced activities. Karst landscape in this area has 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.

A Geographical Information System (GIS) that has been developed for defined purposes can handle large data sets, which makes it possible to analyse and visualise even complex spatial relationships. GIS applications have therefore been identified to be an important tool for geohazard studies. Among the relevant studies, an easily determined index of surface karstification, termed, sinkhole index, based on the main spacing of closed contours in a given area has been introduced.

RESEARCH MOTIVATIONS AND OBJECTIVES

Karst has a distinctive topographic landform resulting from geological weathering and erosion processes in rocks with high solubility and well developed secondary porosity [1]. The primary process is the dissolving action of water of soluble bedrock (usually limestone, dolomite, marble and to a lesser extent gypsum). Variety of karst landscapes are located in warm, tropical environments with lush vegetation and abundant rainfall, and are underlain by other soluble rock. The Kinta Valley karst is thought to be dissolved at a very fast rate, ranging from 224 to 369 mm/ka [2], compared to various other rates studied [3]. Growing environmental problems, especially concerning geo-hazards (sinkholes, rock full, quarry activity) along with technological advances in Geographic Information Systems (GIS), have given rise to increased efforts by researchers, engineers, and planners to better understand the spatial distribution of karst features that characterize these regions. GIS and remote sensing imagery applications enable researchers to objectively identify the conditions that trigger karst topography changes and hazards.

Limestone beneath the alluvium, which covers about 40% of Kuala Lumpur, shows highly irregular karst topography with pinnacles bedrocks, cutters or grikes, overhangs and limestone cliffs. These buried features have caused a variety of geotechnical problems and uncertainties in both design and construction of deep structural foundation in Kuala Lumpur as well as in Peninsular Malaysia [4].

In Draft Structure Plan (Ammendment) of Ipoh City Council 1998-2020, limestone hills have been recognized as a natural potential as heritage resource, certain species habitat, and also the presence of caves which can be exploited as tourism and research center. The current development of Ipoh and its surrounding shows that both the limestone hills and subsurface karst are further subjected to manipulation.

This paper presents ongoing research to develop a Kinta Valley Karst Feature Database (KFD) using Geographic Information System (GIS) and Database Management System (DBMS) technologies. In order to convert the digital format for use in the GIS environment, a relational, for example sinkhole database was created in Microsoft Access for structuring the large amount of data that includes the collapsed and subsidence sinkholes. The databases include important information collected for all incidents and thus were therefore useful for further investigation to better understand the sinkhole phenomenon.

The application is capable of analyzing an entire data set of karst features to create karst distribution map. The tabular database consisting of measurements on certain karst features that have been collected during various field surveys was developed with MS Access 2000. The working database provides guidelines and management tools for future studies of karst features in Kinta Valley and related environmental problems, especially concerning geohazards (eg. sinkholes, rock fall) along with technological advances in Geographical Information Systems (GIS).

Therefore, the overall objective of this study is to develop a database of karst with GIS applications that subsequently will enable researchers to objectively identify the conditions that trigger karst hazards and develops spatial database. This paper, however will present two examples of the features in the Kinta Valley karst: sinkholes and karst hills degradation.

METHODOLOGY

Geospatial database

A relational sinkhole database was created in Microsoft Access for structuring the large amount of data that includes the sinkholes occurrences, in order to be manipulated in digital format and to be used in the GIS. The database includes all the important information collected for each incident and thus can be used for further investigations.

The main interface screen in Microsoft Access application can be used to display and modify data records stored in the database. The view displays attributes for a sinkhole, for example and asks the user to enter some attributes for a specific sinkhole integrated with Arcview 3.2 to display the location. It can be used to display and modify data records stored in the database as well.

The user interface is used to process karsts feature records from paper file formats. The geological map, soil map, photo-lithology map, wells usage, status location, hydro geological map and earthquake density map have been digitized, in order to be manipulated in digital format. Sinkholes location was converted from attribute map, so as to correlate, visualize and overlay on digital terrain model DTM. The entire converted digital format was stored as a geospatial database. Figure 1 shows the process of geospatial database sinkholes and thematic maps process.

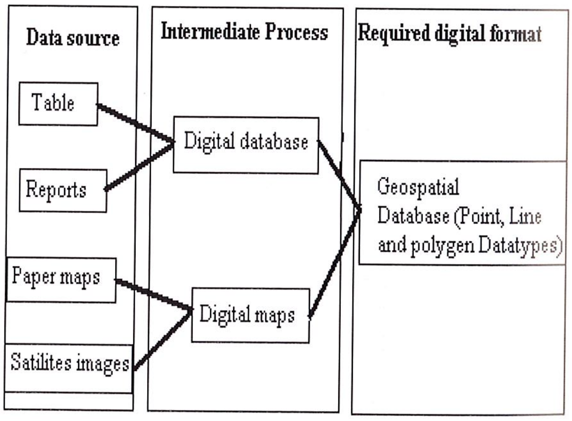

Figure 1. Geospatial database of sinkholes sources.

Karst feature was stored in a geodatabase to promote efficient viewing and editing of the data. This information can be extracted from the database to produce layers for the GIS environmental that dynamically respond to changes in the database. The attributes can then be stored for each karst feature using national projection RSO (Rectified Skew Orthomorphic System).

The Generation of Digital Terrain Model

Aerial photography from 2004 and 1981 from stereo pair and mosaic process are carried out. The black and white and color aerial photographs, stereo model images are generated by first resampling the original images along epipolar lines to aid stereo viewing by the operator and to assist in the image matching process during automatic DTM generation. The epipolar lines indicate where the epipolar plane intersects the two images and the images of the ground point will fall on the epipolar lines. Given two over-lapping images and a ground point, the epipolar plane is the plane containing the ground point and the two camera stations.

Ortho-images were then generated from the orientated black and white and colour images and the DTMs at a resample ground distance of 0.85 m and an-notated grid spacing of 30 m as shown in Figure 2. For 2004, the ortho-images and DTMs are mosaicked producing image maps that were annotated appropriately for use in the field. In georeferencing step, a total number of 225 ground control points (GCPs) are used throughout the study area for the purpose of exterior orientation. They are extracted from 1: 50000 scale digital vector maps of the area [5].

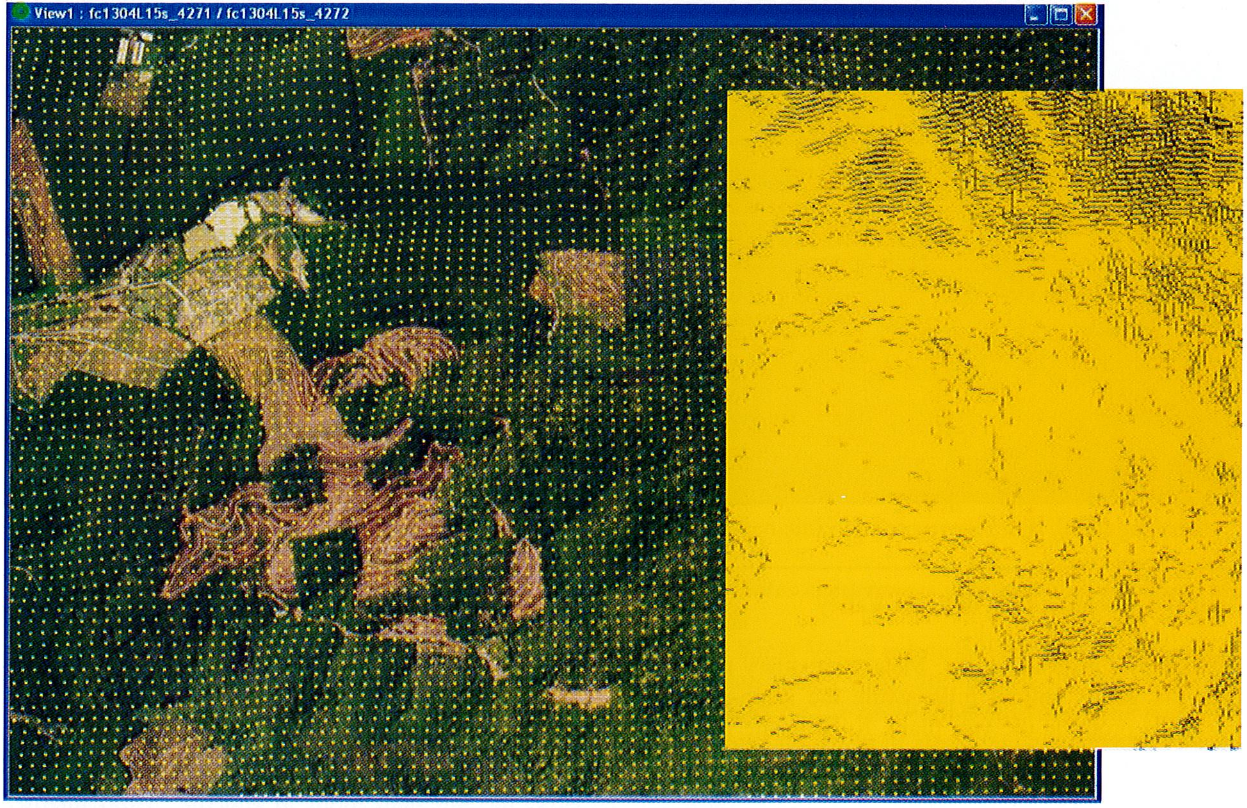

Figure 2. Typical example of grid point XYZ generated from stereo-photo pairs

DEM accuracy assessment

The accuracy of the DTMs has been assessed by comparing the GPS elevations at the GCPs with the elevation value recorded in the DTM at the same location. Errors are calculated as the difference between GPS and DTM elevations and summarized using mean error (ME), root mean squared error (RMSE), and mean absolute error (MAE). The RMSE and MAE are indications of the similarity between elevation values and the ME indicates the presence of any bias in the DTM. The final process is to assess the elevations generated from the geocoded DTM by comparing them with elevations produced by JUPEM using the photogrammetric technique.

General Description of Kinta Valley Karst

Kinta Valley lies within the west of the main range and east of the Kledang range (101°E, 4°N). Karst in the Kinta Valley takes the form of typical tropical karst in **Figure 3**. The Kinta Valley is made up of four main types of lithologies each producing a different landscape. Granite occupies the highland of the Main Range in the east and Kledang Range in the west, wide plain is covered by alluvial deposits, and

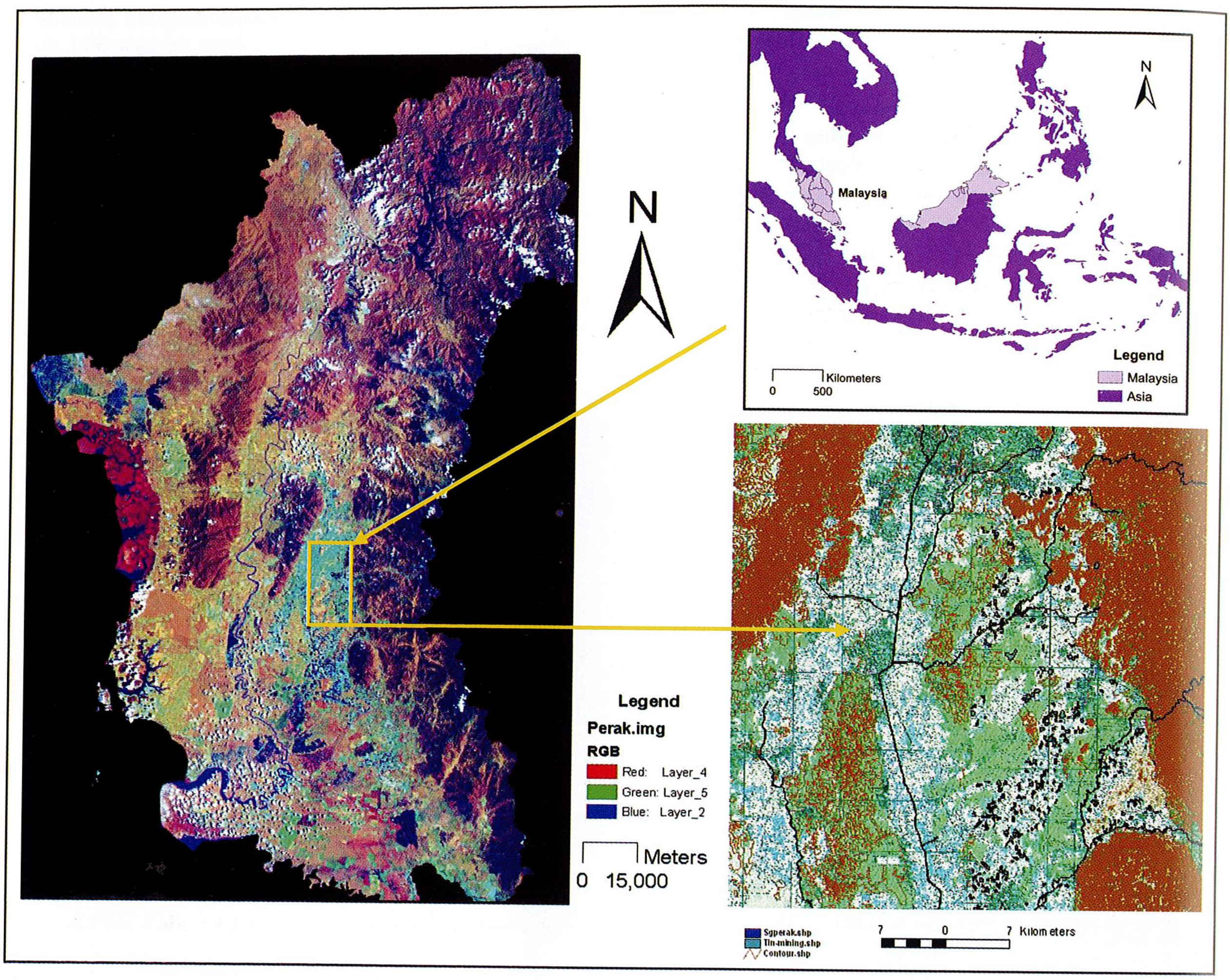

Figure 3. Location map of Kinta Valley

overlain by subsurface karst. Metasedimentary rocks form the gently rolling hills, while the steep-sided karst hills protrude the vast plain. Karst in the Kinta Valley takes the form of typical tropical karst. The subsurface karst is mostly overlain by tin-ore bearing alluvium with some are trapped in between dolines and pinnacles. This has made Kinta Valley renowned as the world's richest tin mines in early the 60's and 70's.

Kinta Valley is located in one of the more active and least understood karst region of the world due to lack of detail studies on it. This are is flanked between two major highlands, which supply continuous water to the floodplain. The wet, swampy conditions on the plain have promoted the formation of many ponds in wangs and around the foot of the limestone hills and subsequently forms foot notches. They are solution features that are extending laterally into the vertical walls of the limestone hills by water which had accumulated at the foot of the hills[3]. This has given rise to many flat roof overhangs that when intercepted with vertical joints or fault, forms rock falls and subsequently steep-sided limestone hills that can be seen scattered across the wide floodplain.

The floor of the Kinta Valley is in the form of corrosional karst plain with elaborate solutional sculpture and overall steeply dipping limestone that are horizontally truncated [6, 7, and 8]. Rapid urbanization gives direct impact on the karst landscape. As Kinta Valley moves toward redevelopment of lands [9], this database will hopefully be helpful to better understand the behaviour of the karst in this area and appropriate land use decisions can be made.

The Distribution of Sinkholes

According to Mineral and Geo-science Department [10], sinkholes occur in Kinta Valley in Perak state, where over 250 cases have been documented shows the number of sinkholes from 1955 to 2005. The number has been increased drastically after the devastating earthquake and tsunami on 26 of December 2004. However, there is no detail study on the relationship between the two events has been done to date. The occurrences are tabulated in Figure 4. The occurrences of the sinkholes are draped in a few maps to see their relationship with other features and controls. However, digital topographical map has been used as a georeference to clarify and overlie with the other maps.

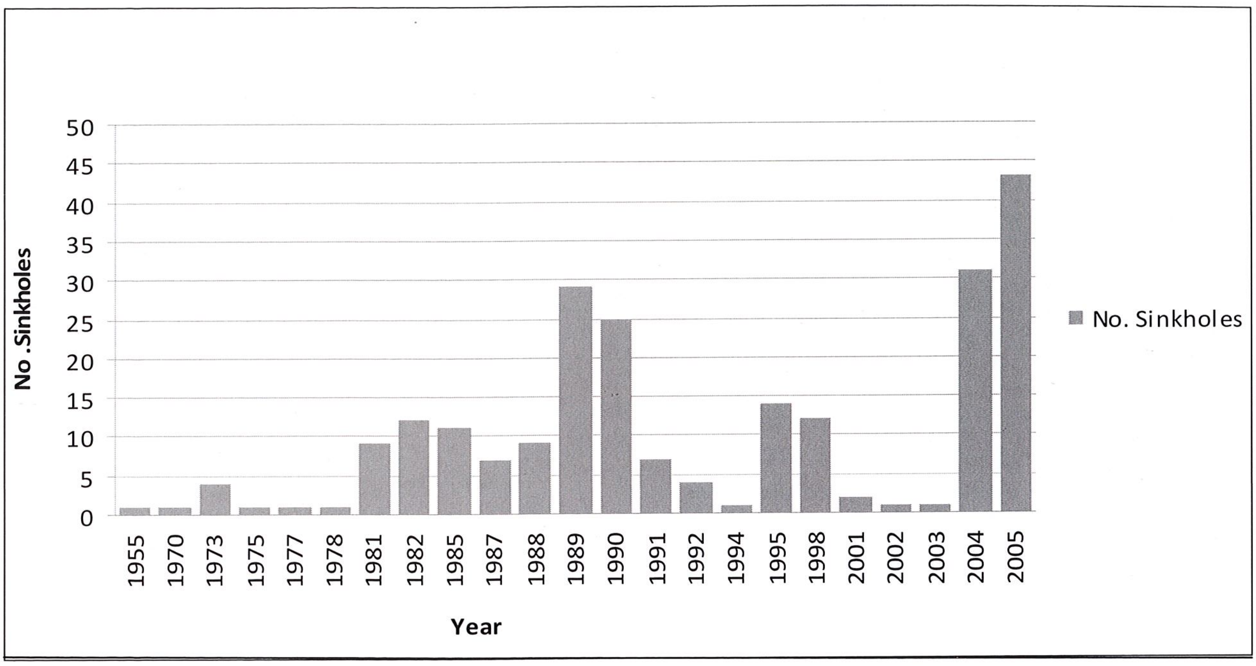

Figure 4. The documented occurrences of sinkholes from 1955 to 2005 in Kinta Valley.

Drainage Pattern and Sinkholes in the Kinta Valley

The erosion process at the foot of the river banks can destabilize the slope and leads to landslides. River terraces, composed of alluvium, sand and gravels, are also prone to collapse during heavy rainfall. The distance from rivers is therefore considered one important factor in characterizing vulnerable terrains. The drainage network of the study area was automatically extracted from the DTM and the drainage vectors were then categorized by their staler stream order. Streams of more than the 5th order, corresponding to main river channels, were selected for the generation of buffer zones, which were strictly prohibited for development.

The spatial analysis for the drainage system shows that there is a major trend ofNNE-SSW and a minor trend of NW-SE (Figure 5). Two major sinkhole clusters possess almost the same trend of the main drainage system. It is observed that drainage density of less than 1200 m/m2 indicates a recharge area (recharge area - area which supports the groundwater from subsurface water). If the density is more than 2400 m/m2, it indicates that the area is a discharge area (discharge area - area which supports the recharge area by surface water). Most sinkholes occurred in the recharge area showing a relation between sinkhole occurrence and drainage density.

Sinkholes occurrences with alluvium thickness and roads

The Kinta Valley subsurface karst is characterized as a flat plain with the buried limestone bedrock covered by the tin-bearing alluvium. The map of the average thickness of alluvium with sinkholes location is shown in Figure 6 shows the thickness of the alluvium in Kinta Valley ranges between around 0.0 —21.34 m (0.0 to over 70 ft) [8].

The area with the least alluvium is overlain mostly by the limestone hills and the highland. Sinkhole occurrences are clustered at areas where the thickness of the alluvial deposits is ranging from 3.05 to 9.14 m (10 to 30 ft), with few scattering in the zone of 9.14 to 15.24 m (30 to 50 ft) thickness. This could indicate the presence of subsurface cavities or channels in these areas and other existing triggering factor to cause the failure. This also indicates that sinkholes may not necessarily occur in the areas with the heaviest overburden as no occurrences are observed in the areas with the thickest alluvium.

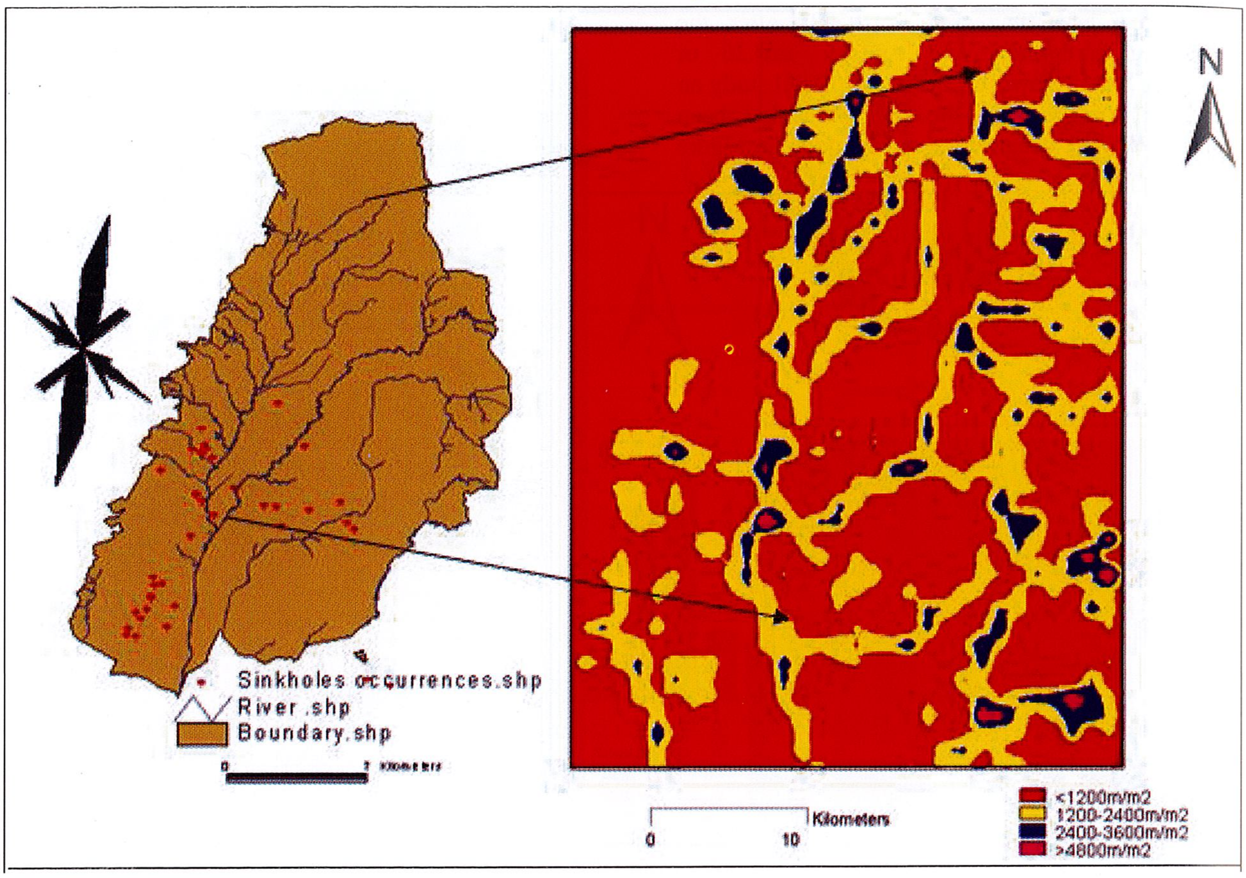

Figure 5. The distribution of sinkholes and drainage.

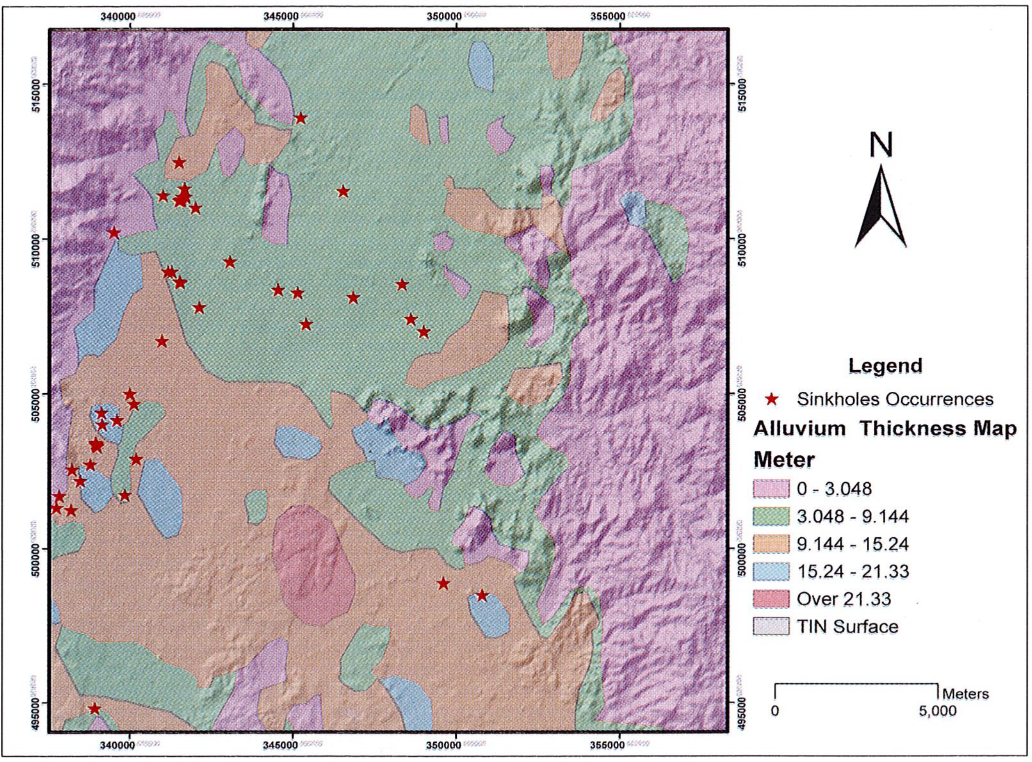

Figure 6. The occurrences of sinkholes draped on alluvium thickness map.

The occurrences of sinkholes are also concentrated along the major roads. We can deduce that by relating the sinkholes occurrences to the human activities in the study area, it could be assumed that two triggering factors which may have enhanced the sinkhole formation are the surcharge resulted from the construction activities and the vibrations induced. Reactivation by natural or artificial changes of karst water levels by excessive water pumping for water supply, mine dewatering etc., also lowers the buoyant support of karst cover [11].

Karst Hills Degradation

Stereo aerial photography of Kinta Valley that has been generated from 1983 and 2004 is shown in Figure 7. The comparison of karst extent revealed a substantial movement over the period of twenty three years; this is due to response to either natural geological changes or human-induced activities. Changes in the height of karst area is observed from the profile from DEM 1981 and 2004 in the Kinta Valley limestone hills as shown in Figure 8 a, b, and c respectively. The study demonstrated the viability of using time-series of aerial photography for monitoring and understanding the long-term response of geological and environmental changes. These changes in limestone hills elevation and morphologies in the three study sites were found to be directly affected by erosion arising from natural dissolution and mining activities operations.

DEM analysis also was carried out to assess the accuracy of the digital elevation model data. This will help to evaluate topographic parameters for karst surface movement modelling and analyses of the variation. The quantity assessment was checked against existing digital vector map with 20 meter interval, spot height points, and GCPs provided in digital topographical map. The heights of 1023 points were extracted from the topographical map after converting the contour lines into xyz data, and compared with their corresponding points in the DEM as shown in Figure 8.

The change of the volumetric movement on Gunung Terendum from 1981 to 2004 was also generated and shown in 3-D images in Figure 9. It shows the rapid degradation caused by quarrying in the area. Similar method can also be used to study the natural degradation on other hills and subsequently the rate of degradation can be estimated.

CONCLUSIONS

Geographic Information System (GIS) and Database Management System (DBMS) have been proven to be useful tools in developing the Kinta Valley KFD. Studies are ongoing to study all the impact of natural and man-made activities to other hills and area in the Kinta Valley and other geohazard such as rockfalls, etc. We hope to be able to use the similar application for other parameters that exist in this area such as the effect on the water chemistry in the drainage on the karst system, landuse etc. Subsequently, the finding will hopefully be helpful in managing this sensitive area for the betterment of the environment and the public.

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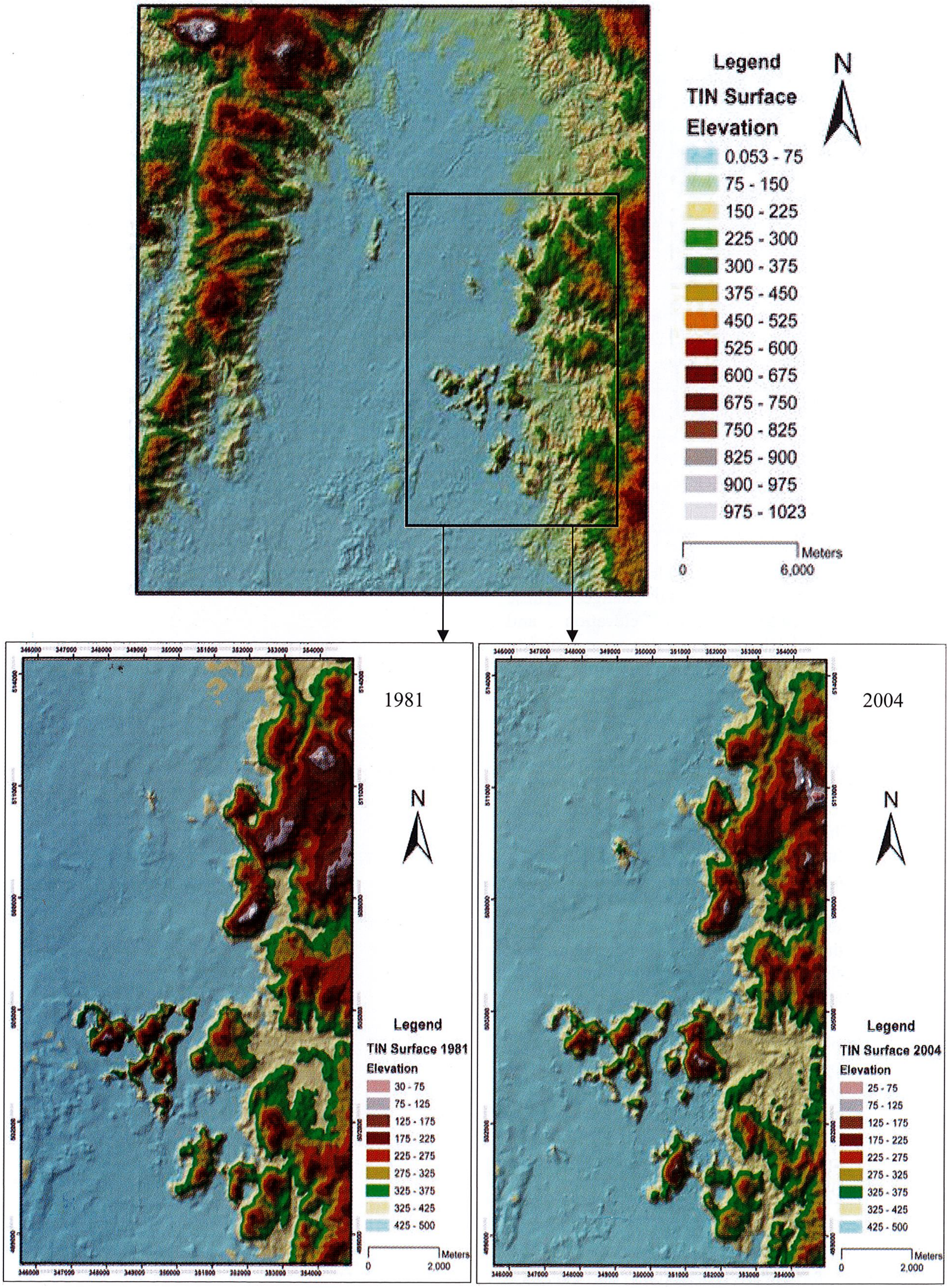


Figure 7. TIN Surface Results generated from Aerial photography stereo-pairs from 2004 and 1983

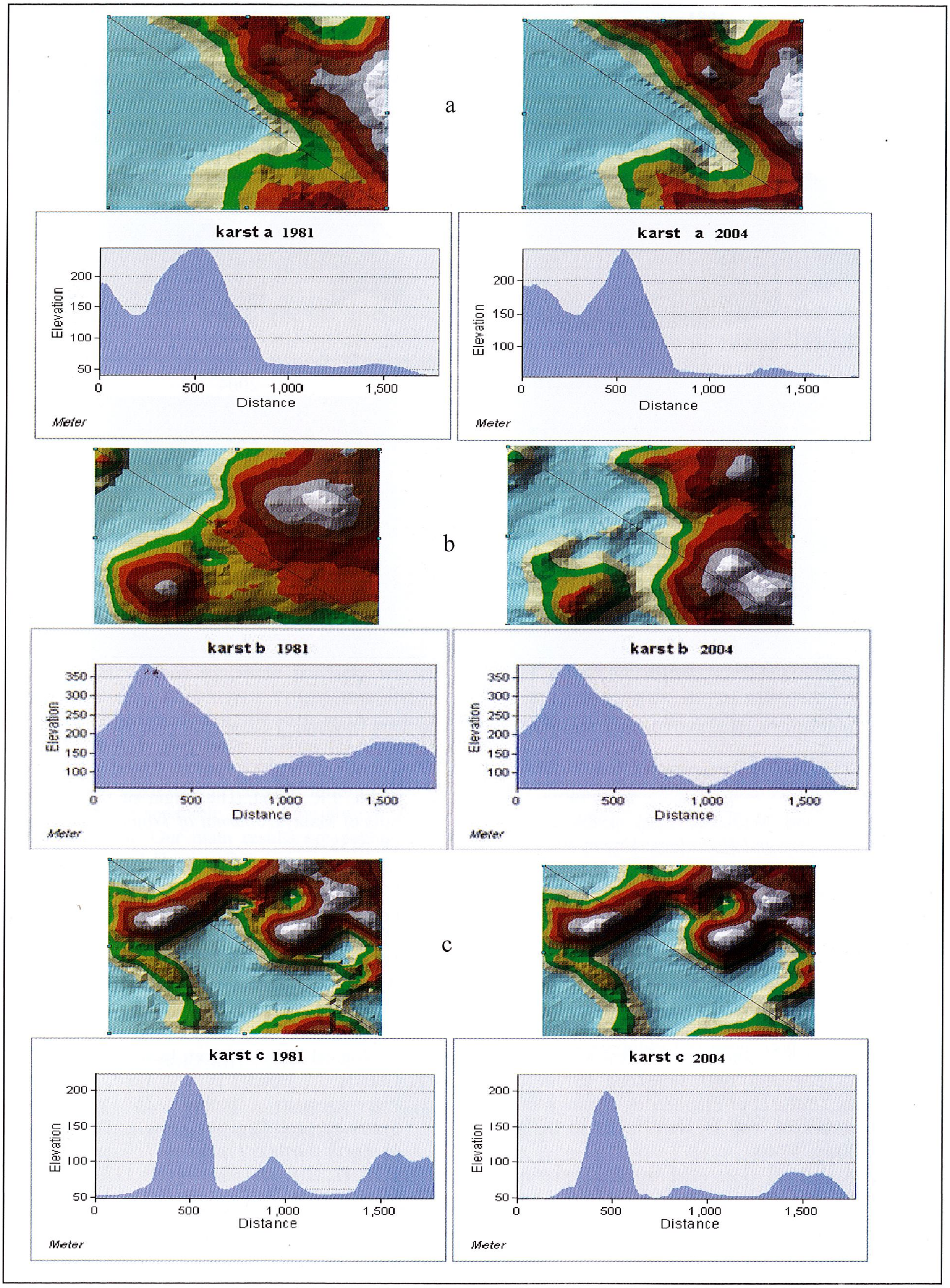
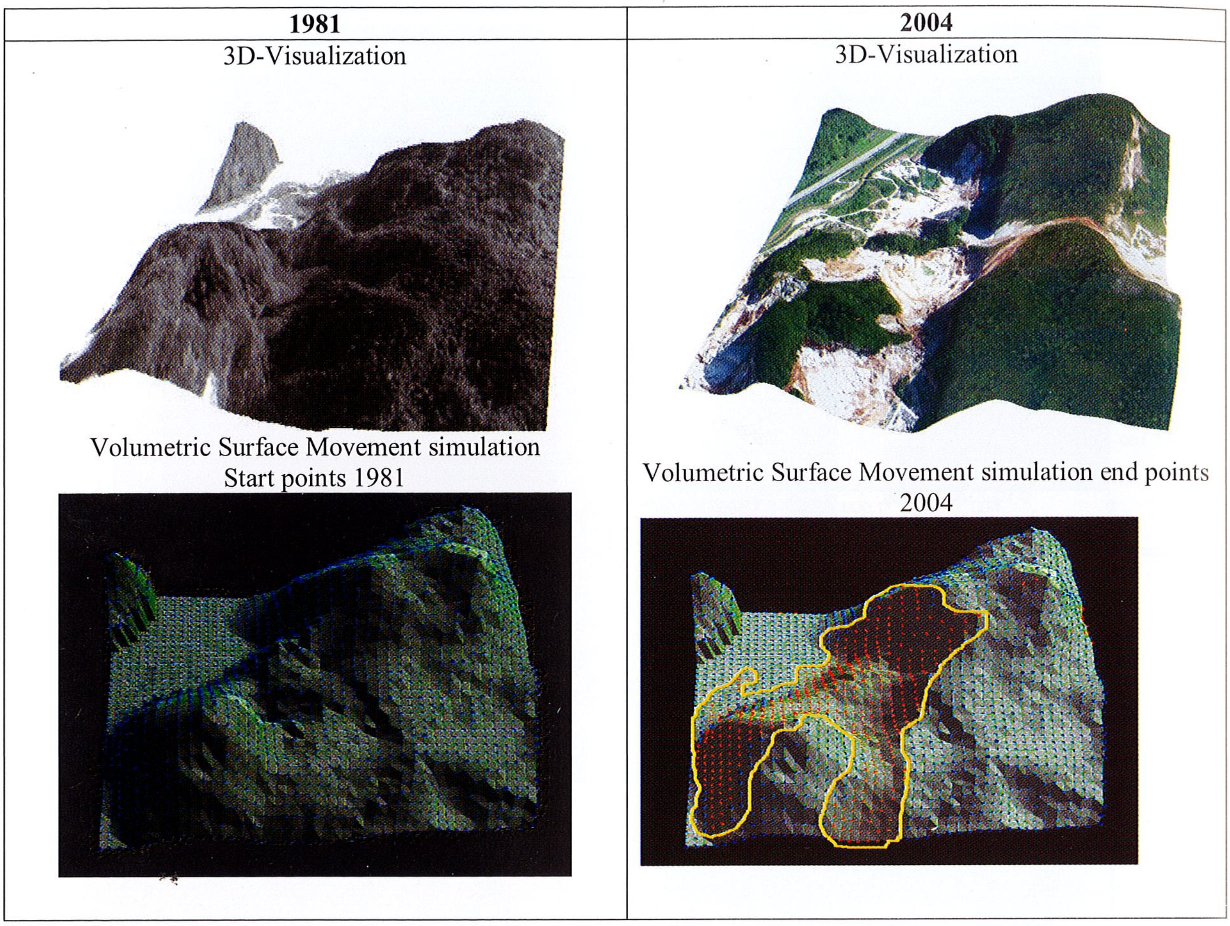


Figure 8. Limestone hills profiles from DEM from 1981 to 2004



1981

3D-Visualization

Volumetric Surface Movement simulation Start points 1981

2004

3D-Visualization

Volumetric Surface Movement simulation end points 2004

Figure 9. Volumetric surface movement simulation from 1981 to 2004 on Gunung Terendum.

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