Initial Investigation Of Land Subsidence Using GPS Data And Rigorous Analysis

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ABSTRACT

This research attempts to combine geophysical and Global Positioning System (GPS) data via Geographical Information System (GIS) to investigate the land subsidence phenomena. This paper discusses the land subsidence detection procedure using GPS via rigorous analysis, together with the initial results. For testing purpose, two epochs of GPS data (in RINEX format) were collected from 4 stations via static mode using dual frequency GPS receivers. Data for each epoch were imported into PINNACLE software for the computation of GPS baseline vectors (using precise ephemeris). The output from PINNACLE was exported into NGS Blue Book format, and used as input (via a special interface program CONVERT) for network adjustment using STARNET software. Consequently, the results from STARNET were used as input (via program CONVERT) for rigorous deformation analysis using our in-house developed software (GPSAD2000). The results show the practicality of the data processing procedure using PINNACLE, STARNET, CONVERT and GPSAD2000.

**KEYWORDS**: GPS, STARNET, GPSAD2000, Deformation Detections, GIS

1. INTRODUCTION

Land subsidence occurs when large amounts of ground water have been withdrawn from certain types of rocks, such as fine-grained sediments. The rocks compact because the water is

partly responsible for holding the ground up. When the water is withdrawn, the rocks fall in on it. Subsidence is simply the formation of depressions on the ground surface (USGS, 2004).

Land subsidence causes many problems including: (1) changes in elevation and slope of streams, canals, and drains; (2) damage to bridges, roads, railroads, storm drains, sanitary sewers, canals, and levees; (3) damage to private and public buildings; and (4) failure of well casings from forces generated by compaction of fine-grained materials in aquifer systems. In some coastal areas, subsidence has resulted in tides moving into low-lying areas that were previously above high-tide levels (USGS, 2004).

Sinkhole can be defined as a depression in the earth's surface caused by dissolving of underlying limestone, salt, or gypsum. Drainage is provided through underground channels that may be enlarged by the collapse of a cavern roof. Sinkholes are common where the rock below the land surface is limestone, carbonate rock, salt beds, or rocks that can naturally be dissolved by ground water circulating through them. As the rock dissolves, spaces and caverns develop underground. Sinkholes are dramatic because the land usually stays intact for a while until the underground spaces just get too big. If there is not enough support for the land above the spaces then a sudden collapse of the land surface can occur. These collapses can be small (Figure 1), or they can be huge and can occur where a house or road is on top (USGS, 2004).
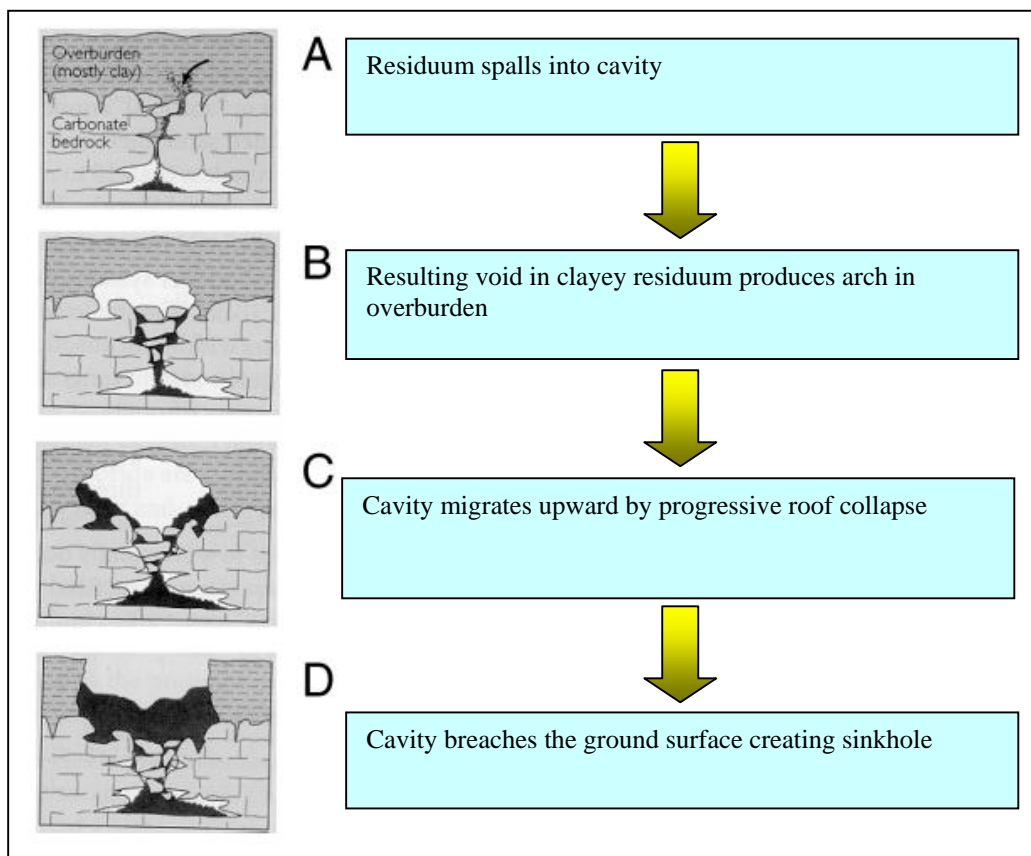
Figure 1. Diagrammatic evolution of a collapsed sinkhole (USGS, 2004)

Several methods are available to monitor land subsidence and sinkhole. Examples of the methods are: repeated surveys with conventional leveling or GPS technique, geophysical

technique (such as surface resistivity, Ground Penetrating Radar (GPR)), and Interferometric Synthetic Aperture Radar (InSAR).

1.1 GPS Technique

GPS positional data is used for surface stability analysis, and GPS results provide interpretation of the movement (i.e. sinkhole) on the surface. In order to get high accuracy in the height component, several practical steps have to be followed. In this research, TRIMBLE 4000 and HiPer GPS receivers were used, together with PINNACLE software for data processing. HiPer GPS receiver (Topcon, 2004a) is an advanced and compact system (GPS and GLONASS) using HiPer antenna (GG 20 universal channel), which receive and process GPS/GLONASS and wide-area augmentation system (WAAS) signals from up to 20 satellites (Figure 2).

Figure 2. HiPer GPS Receiver (Topcon, 2004a)

The Malaysia Active GPS System (MASS) is a network of fifteen GPS Permanent Stations (Figure 3) established throughout the whole country (JUPEM, 2004). The stations automatically record and archive data from available GPS satellites for accurate position determination 24 hours a day. MASS provides code range and carrier phase data in support of post processing applications. Each permanent GPS station consists of a TRIMBLE 4000 series (SSI or SSE) dual frequency receiver, antenna and TRIMBLE Universal Reference Station (URS) software operating on the Windows NT system platform. All stations are tied to local geodetic survey networks to a high degree of accuracy. In this study, 3 MASS stations (Figure 3) were used as control stations.
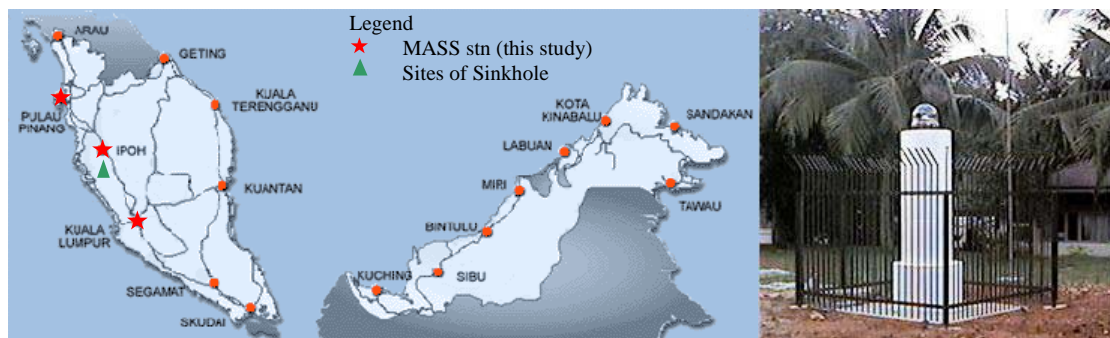

Figure 3. MASS station for Malaysia

1.2 Geophysical technique

Geophysical technique provides underground profile analysis. In this research, the equipment used for resistivity survey was Terrameter SAS 4000 (Figure 4). Resistivity software was used to produce a resistivity profile (Figure 5 and 6) for showing the locations of sinkholes

underground (Abem, 2004).
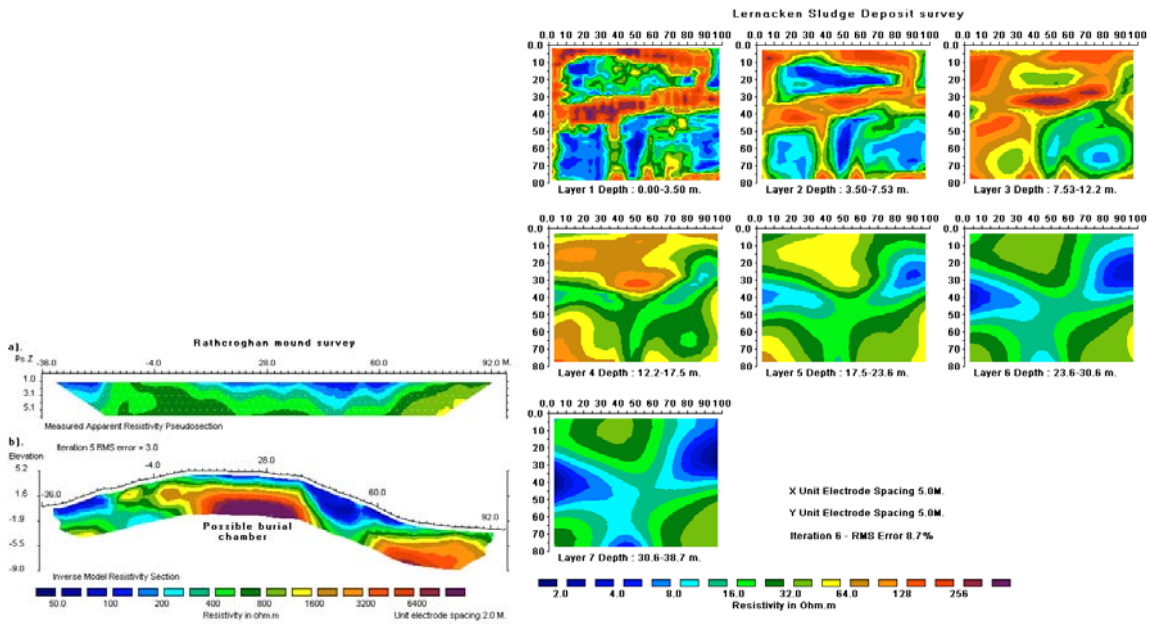

Figure 4. Terrameter SAS 400

Figure 5. 2D Resistivity

Figure 6. 3D Resistivity

This on-going research attempts to combine geophysical (i.e. resistivity survey) and Global Positioning System (GPS) data via Geographical Information System (GIS) to investigate the sinkhole phenomena (Figure 7).
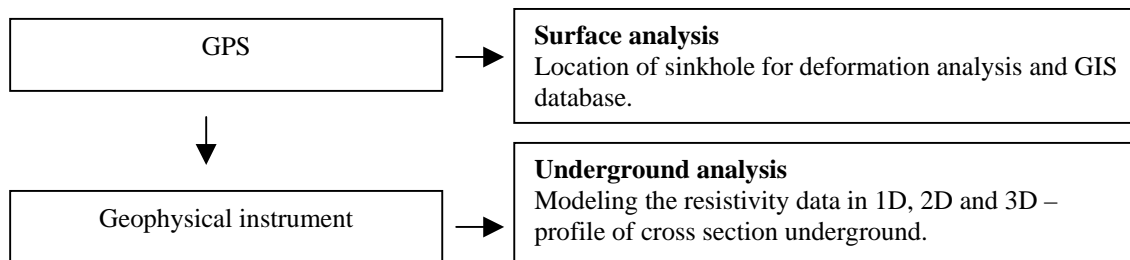

Figure 7. The research approach

However, this paper focuses on the land subsidence detection procedure via rigorous analysis of GPS data, together with the initial results.

2. METHOD

The procedure for subsidence analysis between 2 epochs is illustrated in Figure 8. Data for each epoch were imported into PINNACLE software for the computation of GPS baseline vectors (using precise ephemeris). The output from PINNACLE was exported into NGS Blue Book format, and used as input (via a special interface program CONVERT) for network adjustment using STARNET V6 commercial software. Consequently, the results from STARNET V6 were used as input (via program CONVERT) for rigorous deformation analysis using our in-house developed software (GPSAD2000). More details are discussed in Halim & Mohd Sharuddin (2002, 2003a, 2003b).
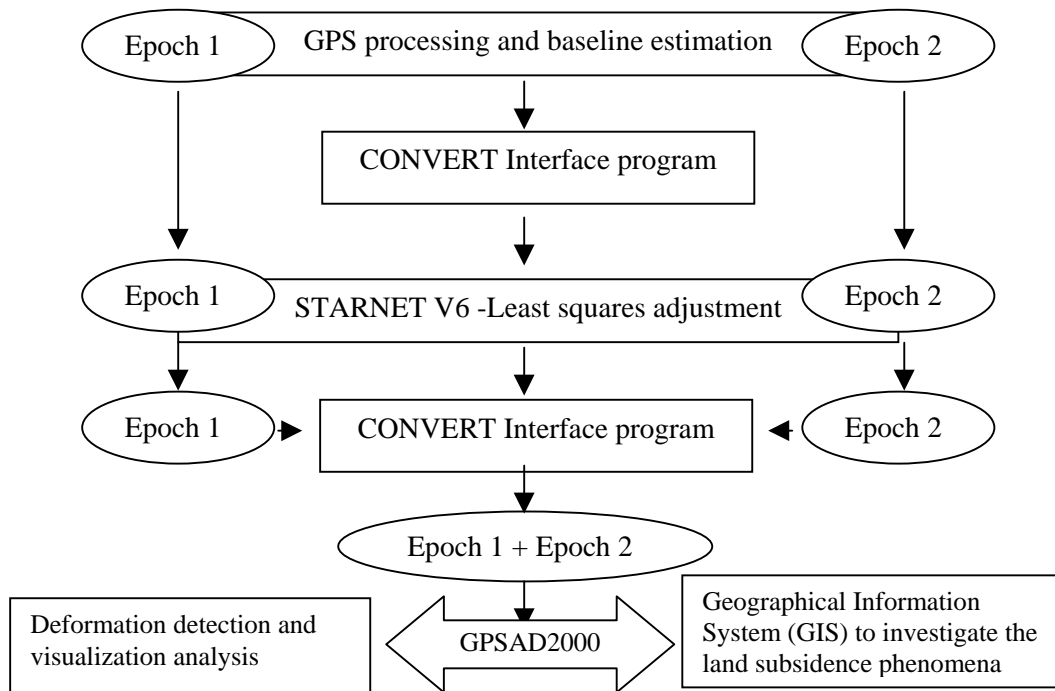
Figure 8. Data processing procedure

3. LAND SUBSIDENCE DETECTION

Two epochs of GPS data were collected from 4 stations (3 MASS stations (Figure 3, Figure 20) and 1 object station (with HiPer GPS receiver) via static mode for 1-2 hours (Figure 9). The procedure for data processing is summarised in Figure 8. Table 1 shows the baseline distances between stations.

Baseline (from to)		Distance
From	To	
KTPK	5720930A_L9MO	157390.668m
USMP	5720930A_L9MO	131005.833m
IPOH	KTPK	169952.874m
IPOH	USMP	124701.065m
KTPK	USMP	288249.700m

Table 1. Baseline distance

3.1 GPS baseline processing

PINNACLE software (Figure 9) was used for GPS processing and baseline vectors estimation only. The processing engine supports Stop-and-Go, Rapid Static, and Kinematic (with On-The-Fly ambiguity resolution) as well as classical Static survey. It can process any combination of single and dual frequency GPS and GLONASS data. The least-square processing of both static and kinematic data allows short occupation time and renders the processing insensitive to cycle slips because they are repaired very effectively. The program automatically chooses the processing parameters for each session. This allows it to handle arbitrarily long occupations and long baselines (up to 1000 km and longer). PINNACLE has the capability to export the data in NGS Blue Book format. This format contains values of GPS baseline vectors and covariances of each baseline (Topcon, 2004b).
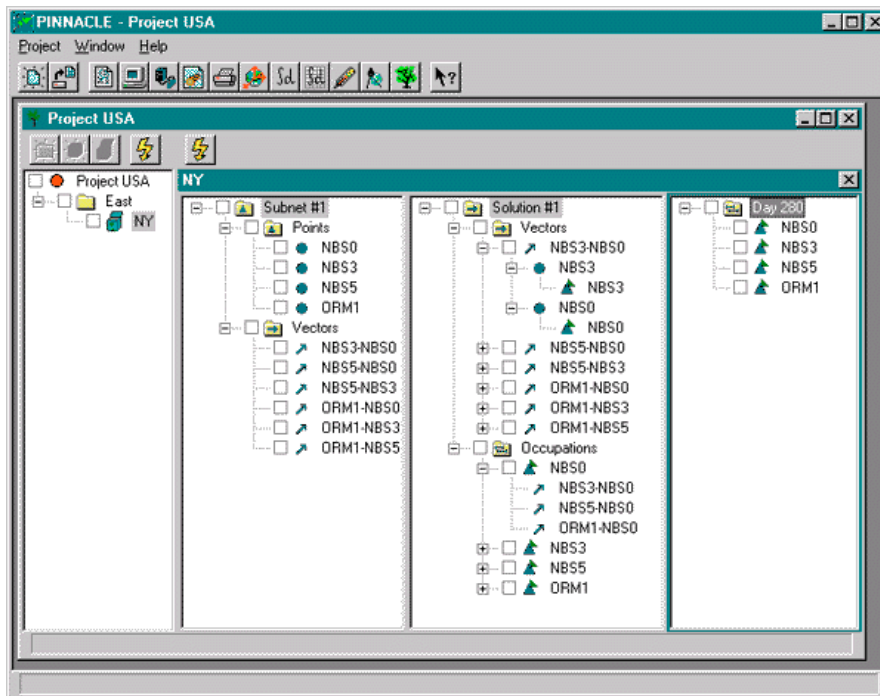

Figure 9. PINNACLE software

3.2 CONVERT NGS Blue Book Format into STARNET format

PINNACLE exports the data in NGS Blue Book format. Unfortunately, this format is not supported by STARNET software (Table 2). In this research, we developed a special interface program called CONVERT. Program CONVERT has two tasks (Figure 10 and Figure 21), conversion of input data (from NGS Blue Book format to STARNET format *.gps) and output data (from STARNET output *.dmp to GPSAD2000 format *.def).

3.3 Least Squares Adjustment with STARNET V6

STARNET V6 is a windows-based software package for rigorous simultaneous least squares adjustment of 2D and 3D survey networks (Starplus, 2000). STARNET comes with the following options: STARNET standard edition for 2D and 3D adjustments, STARNET Professional edition for GPS adjustment processing using baseline vector, and STARNET Level edition for 1D. In processing GPS baseline vectors, STARNET has the capability to import several formats (Table 2). It is possible to process baseline using any GPS software which has the capability to export into the supported formats in Table 2.
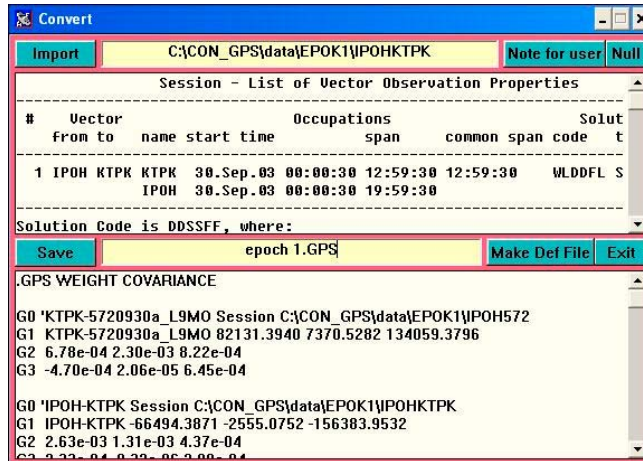
Figure 10. CONVERT: NGS Blue Book to STARNET format

No	Base line format	Extension
1	Astech	0*.*
2	Blue Book GFile	*.ngs
3	Geo Genius	*.txt
4	Leica	*.asc
5	NovAtel	*.job
6	Sercel	*.phs
7	Sokkia	*.sgl
8	Topcon	*.ts
9	Trimble Geomatic Office	*.asc
10	Trimble GPSurvey	*.ssf, *.ssk
11	Trimble TSC1	*.dc
12	Waypoint	*.exp

Table 2. GPS base line format for STARNET

When using STARNET V6 for deformation detection purposes, special setting is required in order to extract the variance covariance and other relevant information in the dump file *.dmp (Halim & Mohd Sharuddin, 2003b).

The procedure for adjustment with STARNET is shown in Figure 11 to Figure 19. Initially, select **Input > Data Files**, and input 2 data files (i.e. provisional coordinates and GPS format *.gps that has been rearranged using CONVERT earlier) (Figure 11). Next, determine setting using **Options > Project**: Adjustment (Figure 12), General (Figure 13), Instrument (Figure 14), Listing file (Figure 15), Other file (Figure 16), Special (Figure 17) and GPS (Figure 18).
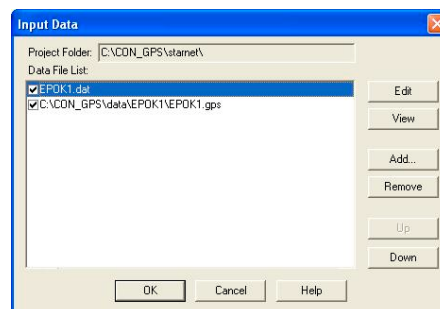

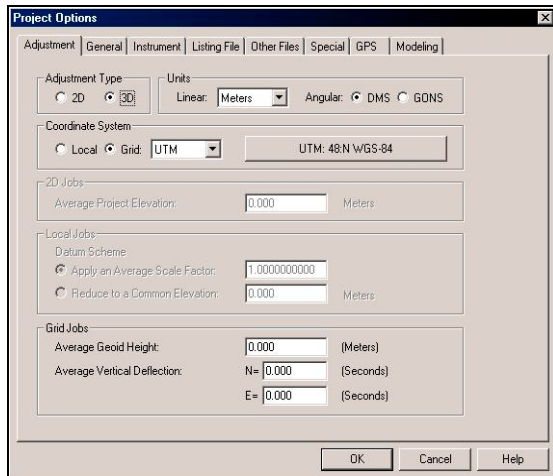**Figure 11.** Input of GPS baseline vector and provisional coordinates

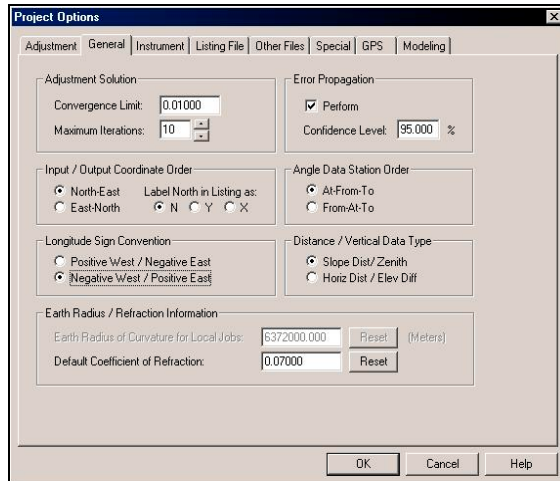**Figure 12.** Adjustment setting

Figure 13. General setting

Adjustment configuration (Figure 12) includes choosing 3D grid coordinate system (WGS84 and for Malaysia using zone 48 for latitude between 102 and 108 degrees north).
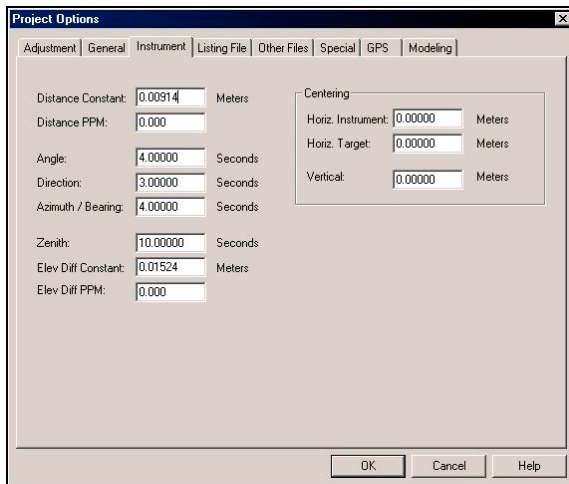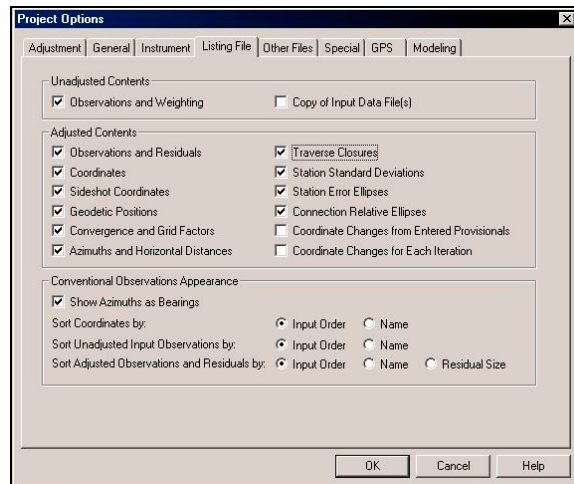

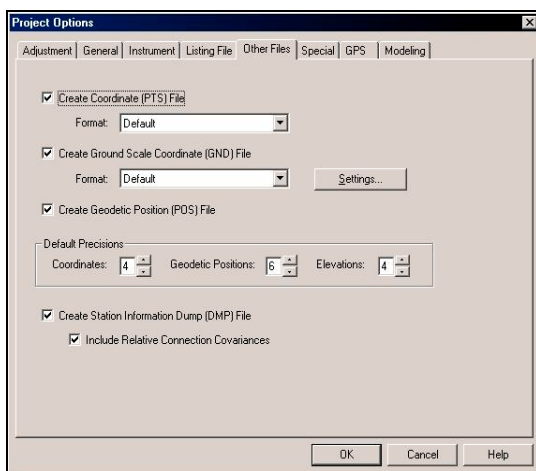**Figure 14.** Instrument setting

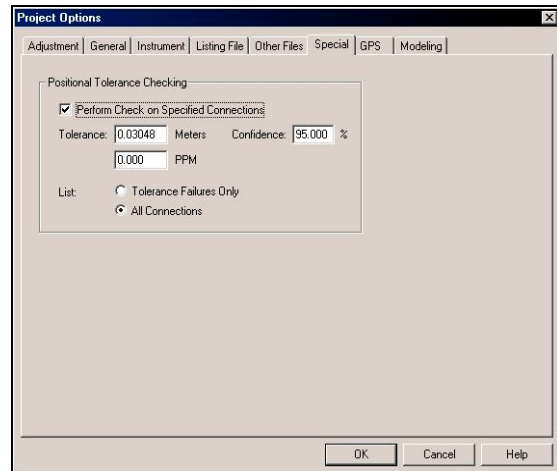
Figure 15. Listing file setting

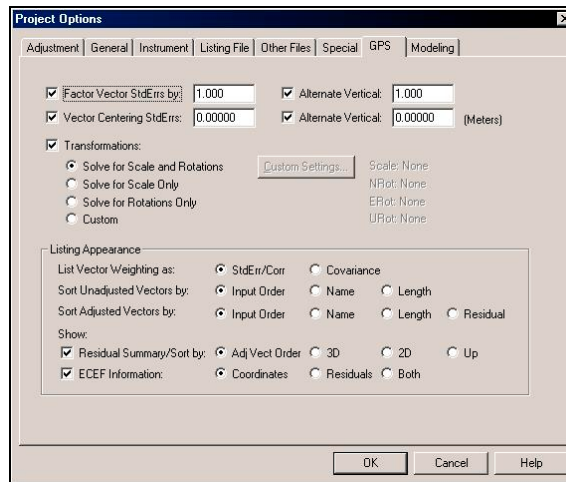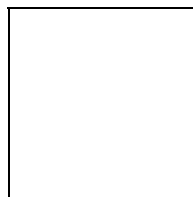**Figure 16.** Other files setting

Figure 17. Special setting

Figure 18. GPS setting

Figure 19. Dump file

In **Other file** setting (Figure 16), choose **Create station information dump (DMP) file** and **Include relative connection covariance**. In **Special** setting (Figure 17), choose **Perform check on specified connections** and **All connections**. Finally, perform the adjustment via **Run** > **Adjust Network**.

The contents of dump file are illustrated in Figure 19. The minimum constraint (MASS station IPOH as fixed) was used as datum definition for the adjustment. Figure 20 shows the configuration of the GPS network.

### 3.4 CONVERT STARNET output into GPSAD2000 format

Program CONVERT also provide interfaces between least square adjustments using STARNET V6 and deformation detections using GPSAD2000 (3D) (Figure 21). This program extracts and converts variance covariance (and other information about the epoch) in Dump file (*.dmp from STARNET) into a suitable (*.def) format (Figure 22) for deformations detection using GPSAD2000 (in house software).

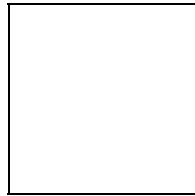### 3.5 Deformation Detection via GPSAD2000

GPSAD2000 (Figure 23) is a windows-based software system specially developed for GPS baseline adjustment via LSE, deformation detection (Figure 24) and graphical visualization (Figure 25). GPSAD2000 employs 3 types of LSE solutions (i.e. minimum constraint, minimum trace (free network) and partial minimum trace), based on the selected datum, for deformation analysis purposes. GPSAD2000 uses the method of congruency testing, S-transformation and single point test (Halim & Bong, 2000). During deformation analysis, all 3 MASS stations were used as preliminary datum definition, i.e. partial minimum trace.
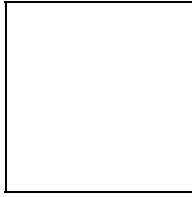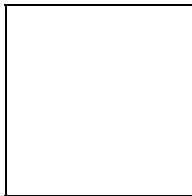
Figure 20. Network configuration
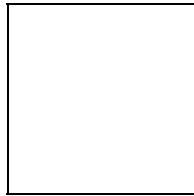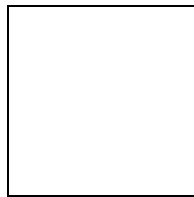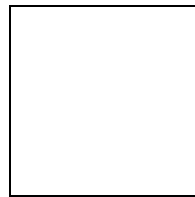

Figure 21. CONVERT program

Figure 22. Def file

Figure 23. GPSAD2000 program

Figure 24. Deformation analysis

Figure 25. Graphic presentation

3.6 Results of deformation detection

The provisional coordinates and positions for all 4 GPS points are shown in Table 3. The summary of results of deformation analysis is shown in numerical (Table 4) and graphical forms (Figure 26), indicating all stations are stable. Graphical analysis (Figure 26) indicates small subsidence (via XZ and YZ axes) at station 5720930a_L9MO (3), i.e. (0.022, -0.008, 0.179) m.

Provisional Coordinates			
Stn	Easting	Nothing	Height
IPOH	485500.000	332111.000	26.000
KTPK	328555.000	397057.000	3315.000
5720930a_L9MO	463192.000	315736.000	-589.000
USMP	571182.000	241512.000	-4025.000

Table 3. Provisional coordinates (in meter)

3D data analysis for single point test							
Stn	Dx	Dy	Dz	Displacement Vector	FCOM	FTAB	INFO
IPOH (1)	0.000	0.002	-0.048	0.048	1.06	5.98	stable [1]
KTPK (2)	-0.004	0.016	0.013	0.021	0.34	5.98	stable [1]

5720930a_L9MO (3)	-0.022	0.008	-0.179	0.181	4.59	5.98	stable [0]
USMP (4)	0.004	-0.018	0.035	0.039	1.04	5.98	stable [1]

Table 4. Deformation analysis (in meter): numerical

4. GIS AND SINKHOLE MODELING

Figure 27 shows the integration of various data via GIS for sinkhole modelling, using ArcViewGIS and VISUAL BASIC. The geophysical and GPS data provide the stability status of the sinkhole. The GIS (or topographical) data provides information in several layers (e.g. such as contour, land use, residential area, etc). All these data are imported into GIS database for further analysis (i.e. Buffering, Proximity, Visualization of DTM, Cross section, and Monitoring the movement of sinkhole) (Figure 28).
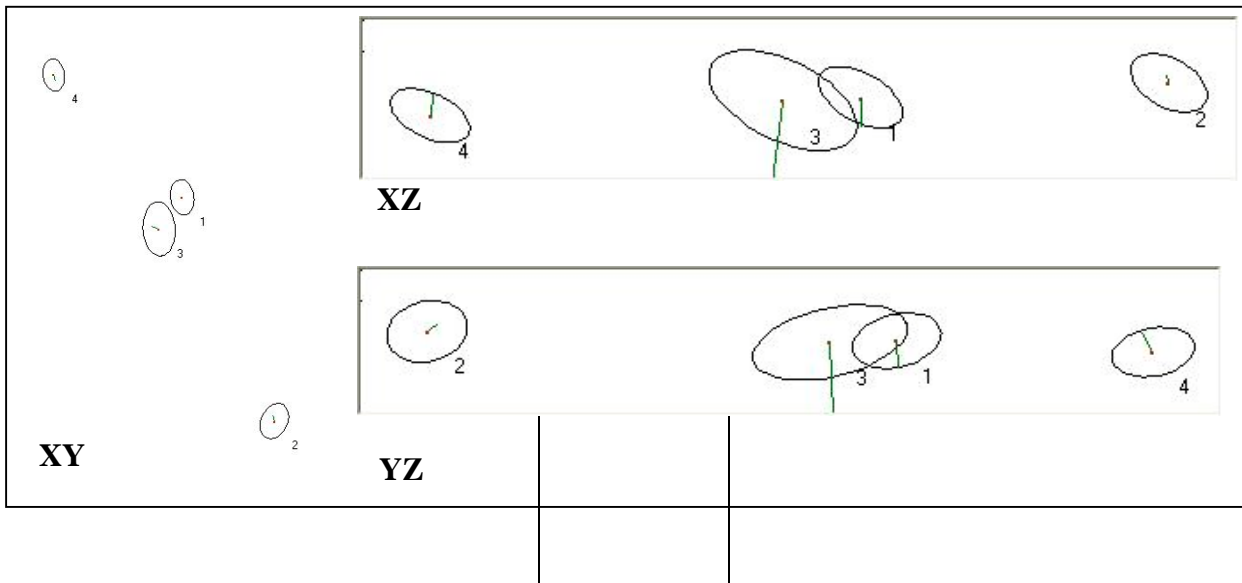

Figure 27. GIS integration for sinkhole modelling

5. CONCLUSIONS

This research attempts to combine geophysical and Global Positioning System (GPS) data via Geographical Information System (GIS) to investigate the land subsidence phenomena. This paper discusses the land subsidence detection procedure via rigorous analysis. The results show the practicality of the data processing procedure using PINNACLE, STARNET, CONVERT and GPSAD2000. Integration of various data via GIS provides a practical tool to investigate the land subsidence phenomena.
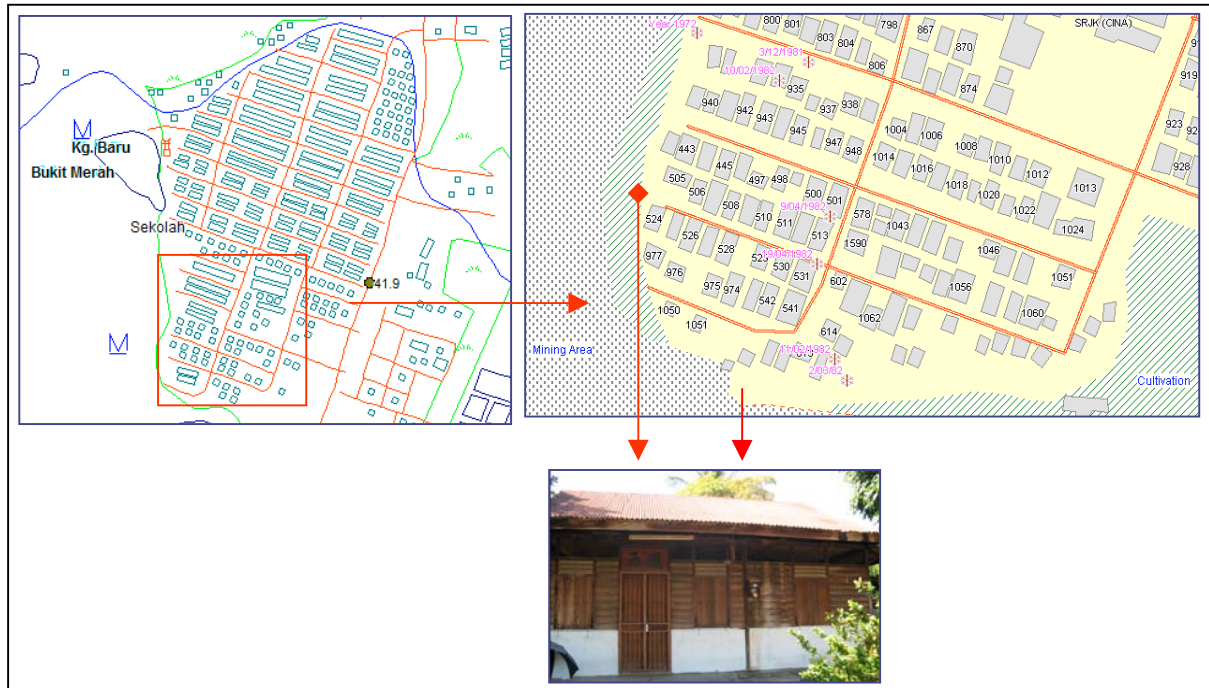
Figure 28. GIS database

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