

## 3D Topographical Analysis of Hanoi, Vietnam

YONEZAWA Go\*

### Abstract

Analyzing the relief of terrain and the micro-topography of Hanoi can play an important role in explaining its urban transformation. To analyze topographical changes, it is necessary to use elevation data to generate a digital elevation model (DEM), a digital representation of ground surface and the most important element of topographical analysis for urban transformation, providing evidence for the existence of features such as old rivers, lakes, fills and land subsidence. Consequently, the DEM of Hanoi in 2005 was generated with data collected for 8,015 points. Based on the surface estimation method using Cubic B-Spline Function, the DEM is generated at 2-meter resolution. The contour interval is 0.5 meter. The very subtle elevation gaps which can not be distinguished on the satellite image are significantly recognizable on this DEM. A second DEM was generated from the topographical map prepared by the French government in 1950, now held in the French library. This DEM at 2-meter resolution is also based on DEM generation using the method of STRIPE. By comparing the two patterns of DEM for 1950 and 2005, the areas of fills and land subsidence can be clarified.

**Keywords:** Hanoi, urban transformation, topographical map, dike, DEM, GIS

### Introduction

Hanoi, the capital of Vietnam, is one of the fastest-growing cities in Southeast Asia. Before the 19<sup>th</sup> century, the city contained many lakes and ponds which were relict lakes of Red River. In the early 20<sup>th</sup> century, however they disappeared almost completely from the map. The outline of this urban transition is explained by Sakurai and Shibayama [2007]. Practically, it is verified by Yonezawa and Shibayama [2007] and Duan and Shibayama [2008] using GIS (Geographic Information System) and remote sensing technology.

Two key points have influenced urban transformation in Hanoi. One is that Vietnam was under French rule in the late 19<sup>th</sup> century. Urban planning by the French government had a profound influence on the urban development of Hanoi. The second is the geography of Hanoi and its natural environment. Hanoi is located in a floodplain of Red River, the average elevation being less than 10 meters. It has faced repeated flooding for a long time. According to the map drawn by the French government, there was already a large-scale dike in the late 19<sup>th</sup>

---

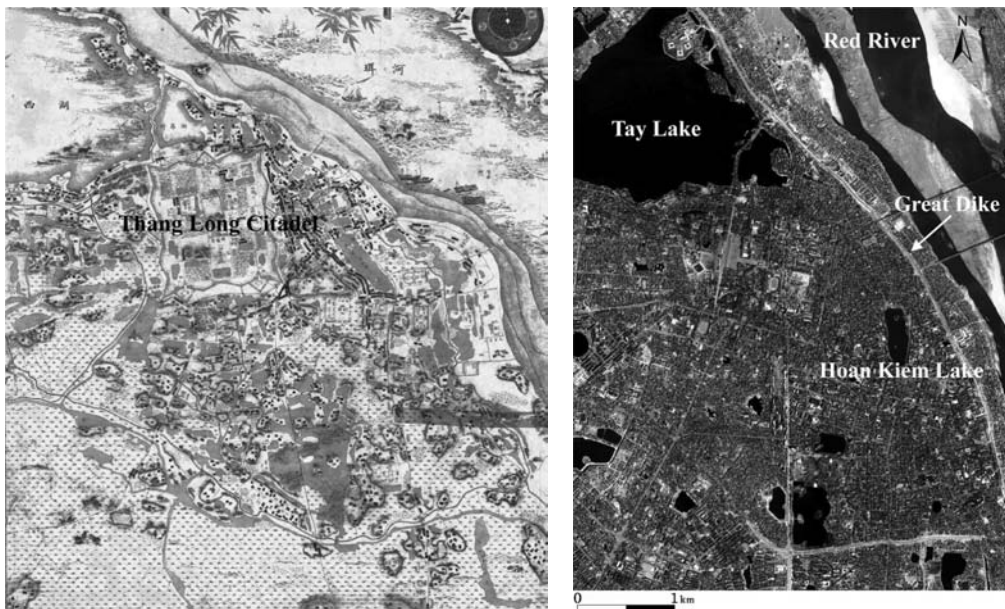
\* 米澤 剛, Institute of Sustainability Science, Kyoto University  
e-mail: go-yone@cseas.kyoto-u.ac.jp

century. This is one of the most important points to consider the topographical changes in Hanoi. However, it is difficult to describe the topographical changes using two-dimensional (2D) analyses only.

Yonezawa [2008] suggested a three-dimensional (3D) urban model consisting of three elements: aboveground data, topographical data, and subsurface data. Such a model can be expected to be the basis data of various area studies. The present study focuses on the topographical changes of Hanoi in the 19<sup>th</sup> and 20<sup>th</sup> centuries. To analyze the relief of terrain and micro-topography for such an urban transformation, we need to use elevation survey data to generate a digital elevation model (DEM), a digital representation of ground surface and the most important element of topographical analysis for urban transformation, providing evidence for old rivers, lakes, fills and land subsidence. Consequently, two patterns of DEM of Hanoi (2005 and 1950) were generated. By comparing them, the areas of fills and lands subsidence can be visualized. This will be useful for studying urban transformation, because it is difficult to estimate how many lakes and ponds disappeared by using only 2D spatial analysis.

### Urban Transformation of Hanoi

Fig. 1 shows the urban transition of Hanoi. Fig. 1 (a) is a historical map of 1873, which shows many lakes and ponds all over the city. According to Haruyama [2004], the construction of a dike in Hanoi is the biggest reason for their presence. Hanoi is located in a floodplain of the



(a) Historical map of 1873

(b) Satellite (IKONOS) image of 2005

**Fig. 1** Urban Transition of Hanoi

Red River, the average elevation being less than 10 meters. Many floods have struck Hanoi from ancient times. Therefore, the construction of a dike was necessary to protect the capital city. When the mainstream of the Red River was cut by construction of the dike, some of the meander channels were left as oxbow lakes and channels in the floodplain. Tay Lake and Hoan Kiem Lake are typical examples. Although the dike was broken several times, it was rebuilt higher each time. Thus, infrastructure construction for flood-control can be found much earlier in Hanoi.

Fig. 1 (b) is a satellite (IKONOS) image of 2005. The lakes and ponds that existed in 1873 have disappeared. Thus, the apparent changes in the past 130 years are shown visually. Sakurai and Shibayama [2007] showed from historical materials (i.e., old maps and literature) that obvious urban transformation of Hanoi occurred during the Nguyen Dynasty period (1802-1945). This change would be related to French government planning. Because Vietnam was under French rule from 1887 to 1954, French army headquarters were strategically placed in the Thang Long Citadel (central Hanoi). At first, the French built many military facilities in the citadel. Urban development centered on the citadel continued until the 1930s. It was developed by the continuous land-filling of many lakes and ponds. This was verified by Yonezawa and Shibayama [2007] and Duan and Shibayama [2008], suggesting different approach to history or area studies using the methods of information technology and informatics such as GIS and remote sensing. However, it is difficult to understand two-dimensionally the problems of how lakes and ponds were filled and how the construction of the dike influenced the urban environment of Hanoi. It is necessary to analyze geomorphic change three-dimensionally to answer these questions. Consequently, using DEM can be an effective means to analyze urban transformation.

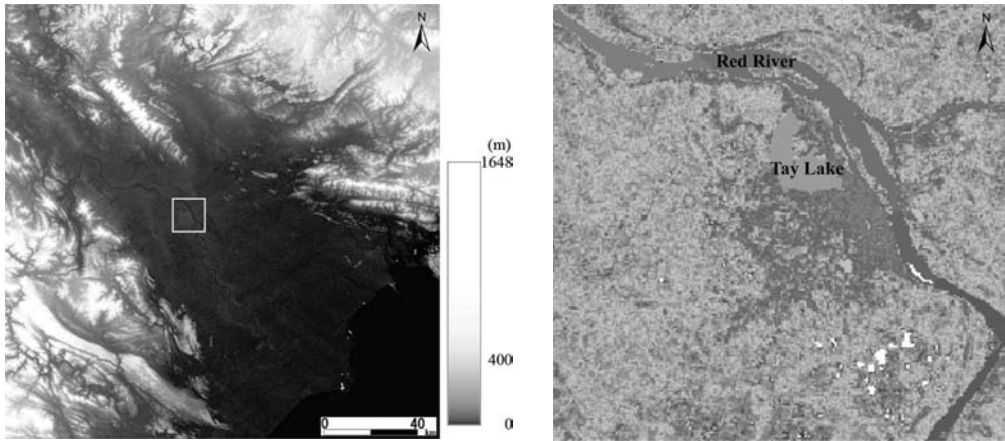
### **Generation of High Resolution DEM**

There are no high resolution DEM in Vietnam like "Digital Map 50 m Grid (Elevation)" published by Geographical Survey Institute in Japan. Therefore, we need to generate the high resolution DEM based on various data. In this study, the DEM of Hanoi is generated from SRTM, survey data and a topographical map.

#### *Utilization of SRTM*

The digital elevation data of SRTM (Shuttle Radar Topography Mission) is one of the most famous DEMs, covering the entire world. The SRTM is an international project produced by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The SRTM data has two patterns of resolution, the resolution of SRTM-3 is about 90 m, and that of SRTM-30 is about 900 m. SRTM-3 is the only DEM which covers all land area of the earth. Thus SRTM-3 is useful for natural environment analysis and development project work in areas where DEMs cannot easily be prepared.

SRTM-3 data for the area that contains Hanoi is shown in Fig. 2 (a). It is a mosaic image



(a) Elevation data of areas surrounding Hanoi from SRTM-3

(b) Elevation data in Hanoi from SRTM-3

**Fig. 2** Visualization of SRTM-3 Data (from NASA)

that connects four data (N20E105.hgt, N20E106.hgt, N21E105.hgt, N21E106.hgt) together. These data can be downloaded from NASA web page.<sup>1)</sup> The bottom-left corner of the downloaded file “N20E105.hgt” means latitude 20° N and longitude 105° E of WGS 84 as a geographic coordinate system. Fig. 2 (b) is the central area of Hanoi. However, we cannot see detailed changes in such a flat terrain. Because the resolution is too low for analyzing the urban transformation of Hanoi, it is necessary to generate a much higher resolution DEM.

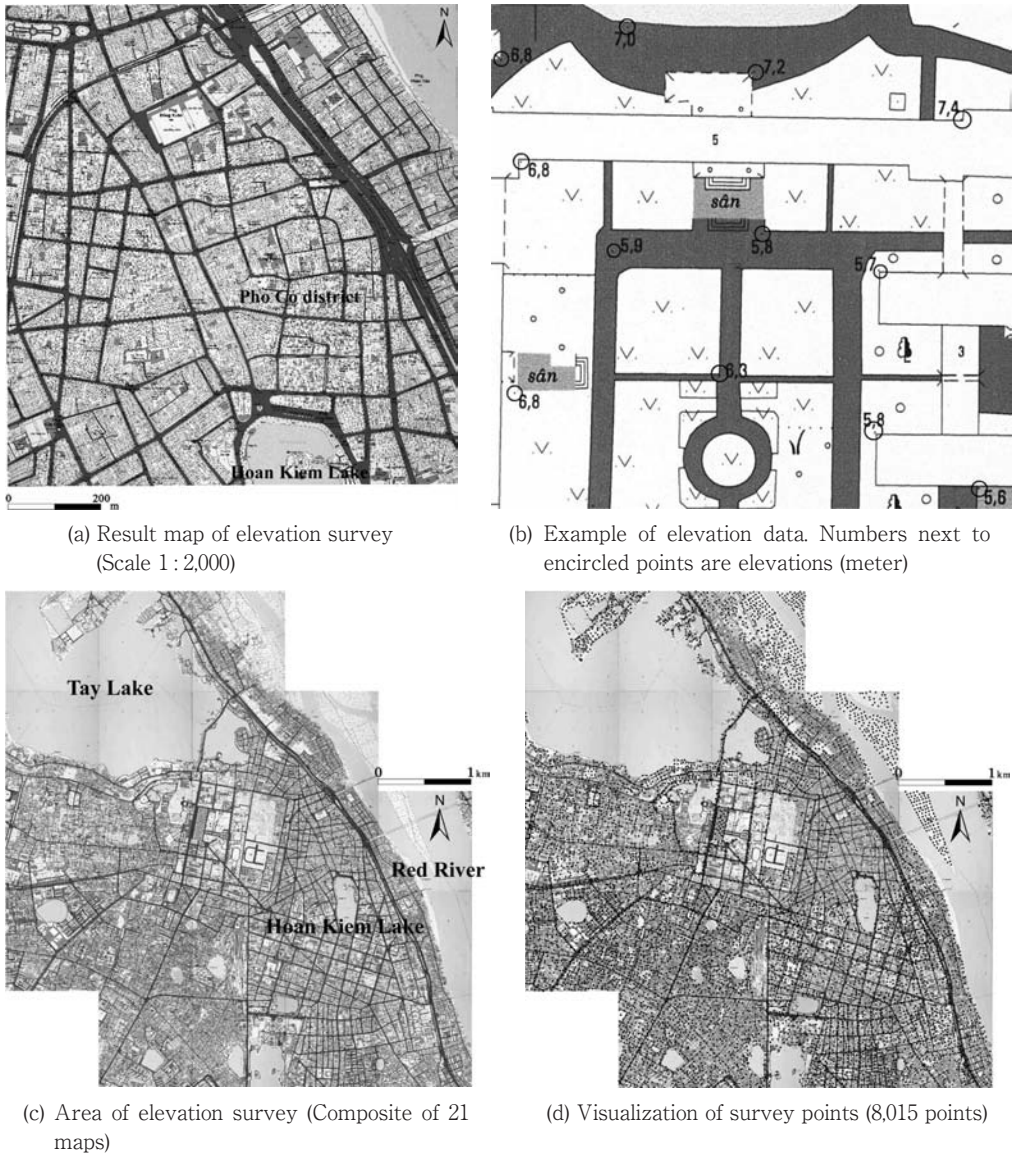
#### *Utilization of Survey Data*

Fig. 3 (a) shows a result map (paper map) of an elevation survey. The scale is 1: 2,000. Twenty-one such maps were collected through Hanoi University of Mining and Geology. An example of survey data is listed in Fig. 3 (b). The numbers next to the encircled points are elevation data (meter). Fig. 3 (c) shows the whole area of the elevation survey, being a composite of the 21 maps. The survey area is 5 km × 5 km, and the number of survey points is 8,015 (Fig. 3 (d)). First, a DEM was generated for the area of the old quarter (Pho Co district). The DEM was generated as follows:

(1) Input the point data ( $x, y, z$ )

First shows the paper map including the survey data was converted to digital data by scanning. Fig. 4 (a) shows the survey data on the map. The coordinates ( $x, y, z$ ) of each point can be read by using painting software (Adobe Photoshop, Corel Paint Shop Pro and so on). ( $x, y$ ) is a pixel position and  $z$  is its elevation (meter). This can be converted to latitude and longitude by an

1) SRTM; <http://www2.jpl.nasa.gov/srtm/>  
SRTM Data; <ftp://e0srp01u.ecs.nasa.gov/srtm/>



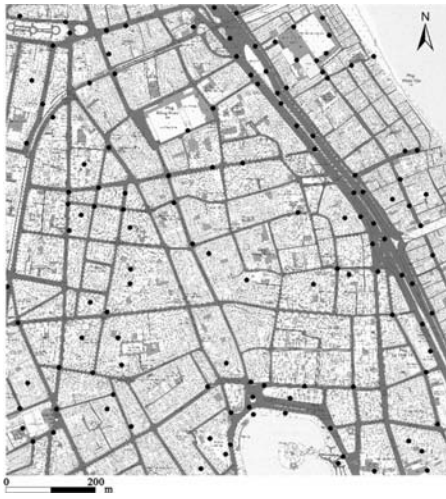
**Fig. 3** Elevation Survey Data of Hanoi

affine coordinate transformation.

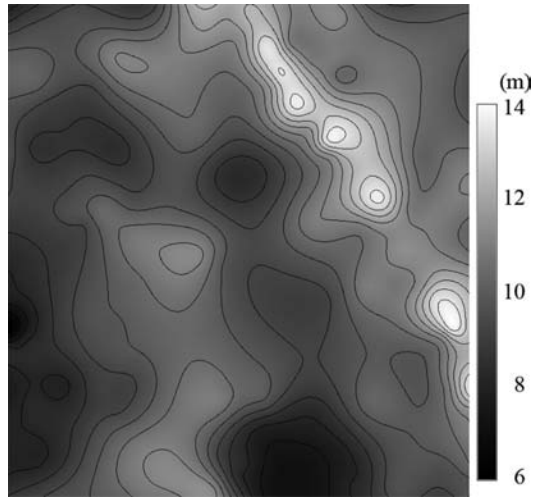
(2) Estimate the topographical surface using the developed program

The topographical surface is estimated from  $(x, y, z)$  based on the surface estimation method (we call it BS-Horizon) using the Cubic B-Spline Function [Nonogaki *et al.* 2008]. BS-Horizon is one of the surface estimation programs for geologic boundary surfaces and geomorphic surfaces. The data of Step 1 is input into this program.

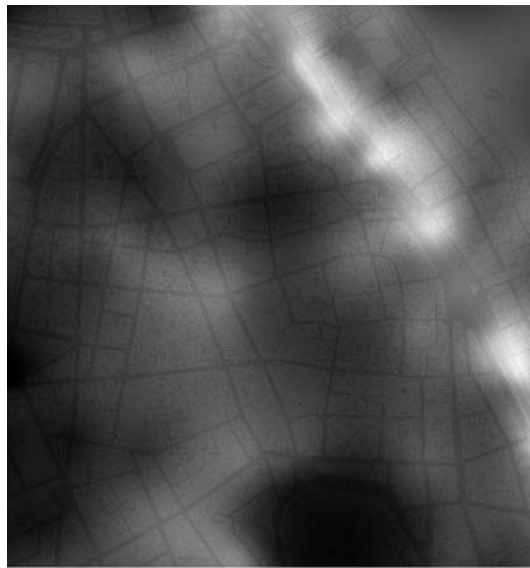
(3) Output the topographical surface (DEM)



(a) Survey points of old quarter (Pho Co district)



(b) Example of generated DEM with contours at intervals of 0.5 m

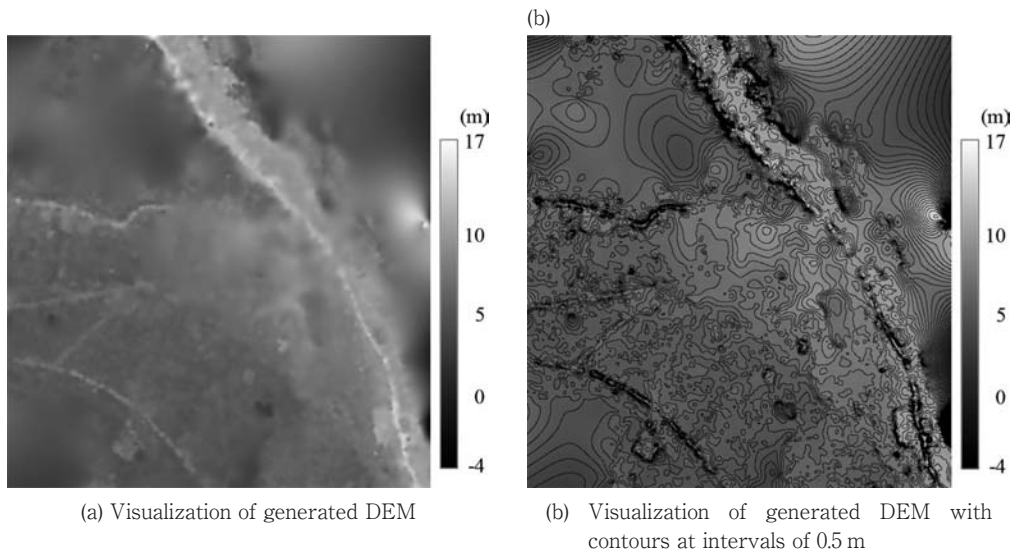


(c) Map (1 : 2,000) overlaid with generated DEM

**Fig. 4** DEM Generation of Old Quarter (Pho Co district)

The generated DEM of the old quarter of Hanoi is shown in Fig. 4 (b). The resolution is 2 meters and the contour interval is 0.5 meters. Hoan Kiem Lake and the Great Dike are visible in the generated DEM. The highlighted area has a high elevation. Fig. 4 (c) is an example of the generated DEM overlaid on the original map (1 : 2,000).

Fig. 5 (a) shows a DEM of the survey area (5 km × 5 km), which is defined as the 2005 DEM. It includes 8,015 points of survey data. All point data are shown in Fig. 3 (d). Fig. 5 (b) is a



**Fig. 5** DEM Generation of Hanoi

contour map with a contour interval of 0.5 meters. The very subtle elevation gaps which can not be distinguished on SRTM data or the satellite image are significantly recognizable on it.

An example of the visualization of 3-D DEM is shown in Fig. 6 (a) using the NVIZ visualization tool in GRASS GIS software.<sup>2)</sup> Fig. 6 (b) shows the generated DEM overlaid on the original map (1 : 2,000).

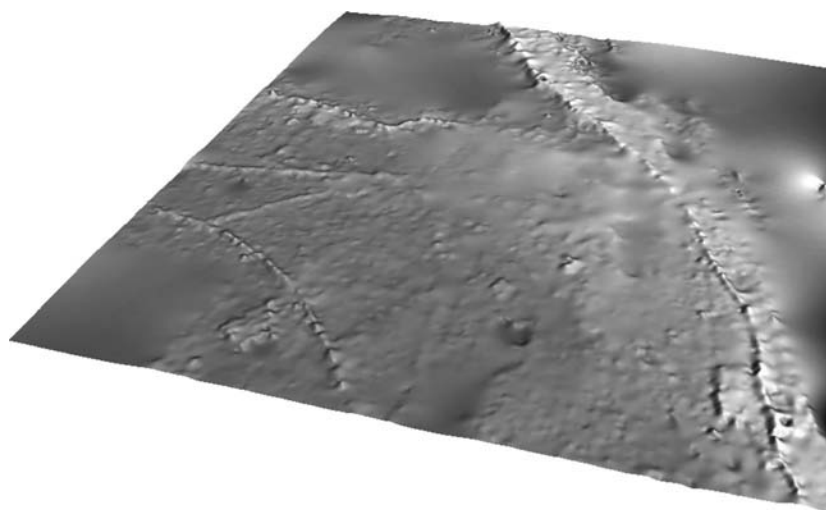
#### *Utilization of Topographical Maps*

The topographical map used was generated by the French government in 1950 and comes from the French National Library (Bibliothèque nationale de France) as paper map (Fig. 7 (a)) with a scale of 1 : 4,000. Fig. 7 (b) is an example of contours at intervals of 0.5 meters. The DEM at 2 m resolution is generated based on the STRIPE method (Fig. 8) [Noumi 2003]. The STRIPE method is an efficient means to generate a DEM from a topographic map. The elevation  $f(x_p, y_p)$  at a point  $(x_p, y_p)$  in a space between two successive contour lines  $h$  and  $H$  must be

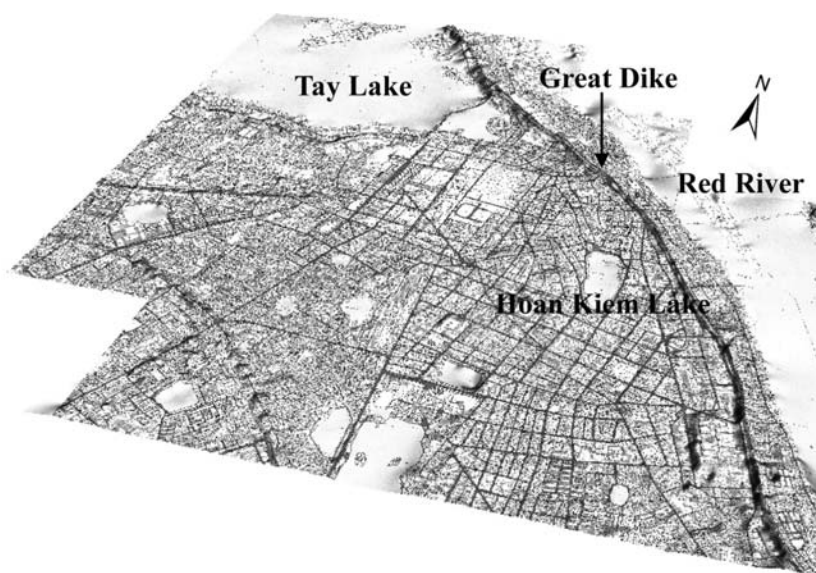
$$h < f(x_p, y_p) < H.$$

Based on this idea, we can quickly generate a DEM by assigning the inequality constraints to each point in a space between contour lines after scanning a topographic map. This result is shown in Fig. 9 (a), which is defined as the 1950 DEM. The contour interval is 0.5 meters.

2) GRASS (Geographic Resources Analysis Support System) is a software for performing spatial analysis. It consists of more than 350 modules for processing vector (2D/3D), raster and voxel data. Many interfaces to other programs in related domains like geostatistics, databases, mapserver and even other GIS software exist. Nviz is a visualization tool of GRASS. It is used for dynamic visualization of geologic cross-sections and generation of animated image sequences. URL; <http://wgrass.media.osaka-cu.ac.jp/grassh/>



(a) 3D visualization of generated DEM of Hanoi



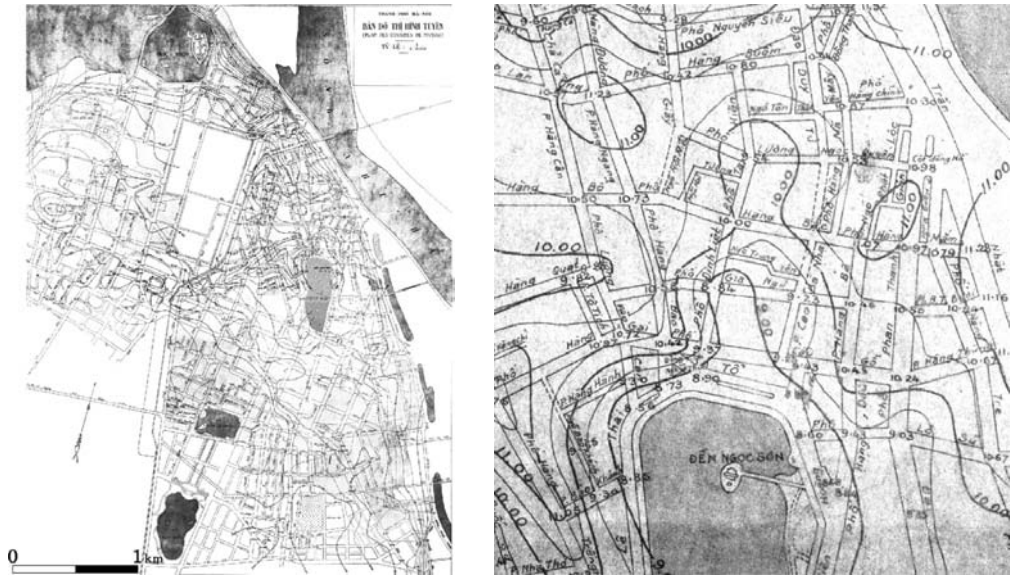
(b) 3D visualization of map overlaid with generated DEM

**Fig. 6** Example of 3D Visualization

Fig. 9 (b) shows the generated DEM overlaid the topographical map (1 : 4,000). Fig. 9 (c) shows the accuracy of STRIPE method, which closely reproduces the original contours.

Unfortunately, the only topographical maps available were the survey data in 2005 and the French topographical map of 1950. However, comparison of the two DEMs can be expected to show the urban transformation of Hanoi from a topographical perspective.

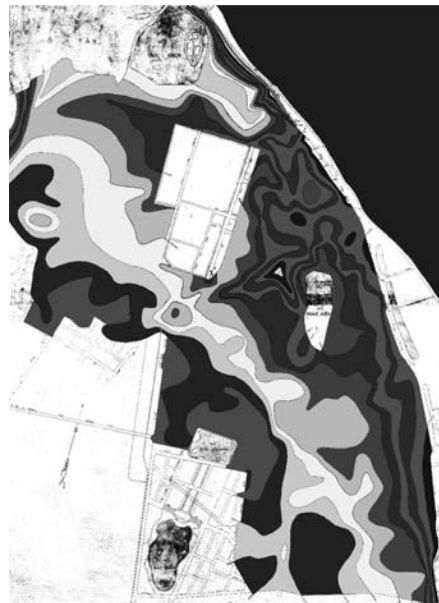




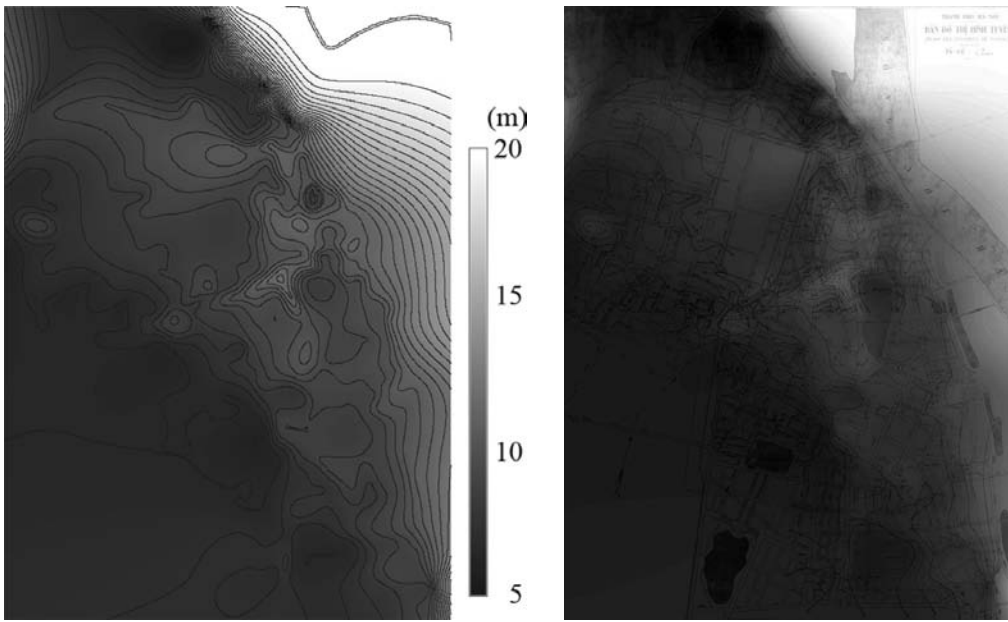
(a) Topographical map from French government (Scale 1 : 4,000)

(b) Example of contours at intervals of 0.5 m

**Fig. 7** Topographical Map of 1950

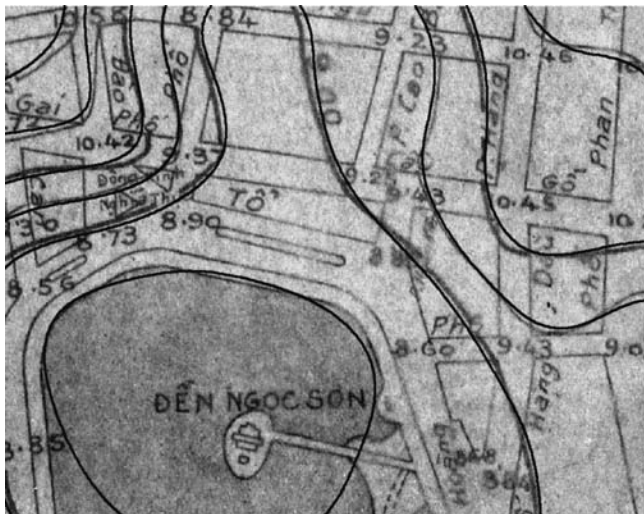


**Fig. 8** Generation of DEM Using the STRIPE Method



(a) Visualization of generated DEM with contours at intervals of 0.5 m

(b) Map (1 : 4,000) overlaid with generated DEM

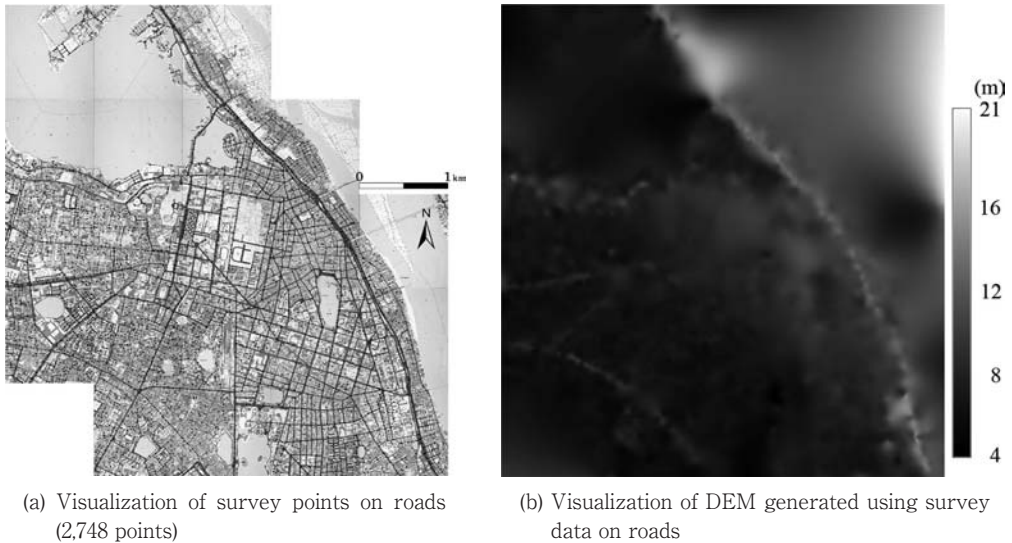


(c) Accuracy of STRIPE method

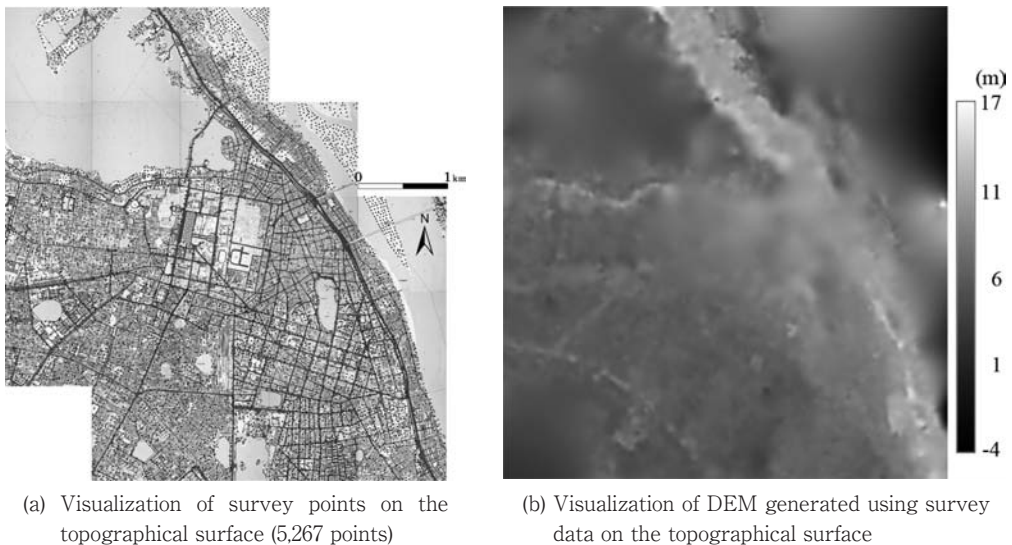
Fig. 9 Generation of DEM from Topographical Map

### DEM Analysis

The DEM of Hanoi was generated using the random survey data of 8,015 points in the city. The survey data can be sorted into data on roads and data on the topographical surface. This

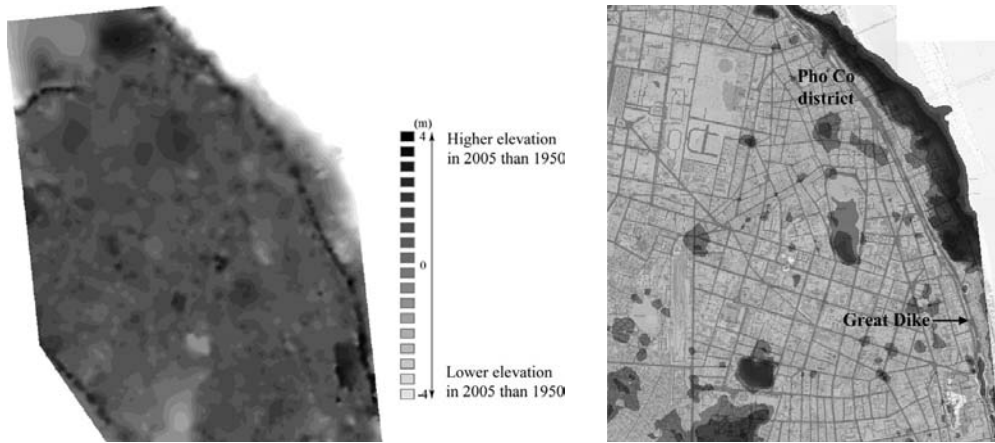


**Fig. 10** Generation of DEM Using Survey Data on Roads



**Fig. 11** Generation of DEM Using Survey Data on the Topographical Surface

enables two kinds of DEM to be generated. The distribution of the elevation data of survey on the roads is shown in Fig. 10 (a). The number of data points is 2,748. Fig. 10 (b) is an example of visualization of the DEM generated using the survey data on roads. The roads and the dike on this DEM are clearer than on the DEM generated from all survey points. The distribution of the elevation data of the survey on the topographical surface is shown in Fig. 11 (a). The number of data points is 5,267. Fig. 11 (b) is an example of visualization of the DEM generated



(a) Result map of difference between 2005 DEM and 1950 DEM

Note: The darker-shaded area is higher in 2005 than 1950.

(b) Map (1:2,000) overlaid with difference of DEM

Note: The darker-shaded area is lower in 2005 than 1950.

**Fig. 12** Difference of DEM (2005 and 1950)

using the survey data on topographical surface. The detail of the topographical surface can be observed in this DEM.

The difference between the 2005 DEM and the 1950 DEM is shown in the result map in Fig. 12 (a). The darker-shaded area is higher in 2005 than 1950. Two remarkable points emerge from Fig. 12 (a). One is that the elevation of the Great Dike is about 2 meters higher in 2005 than 1950. The average height of the dike in 2005 is about 12 meters, compared with about 10 meters in 1950. This difference shows that the dike has been raised since 1950. Haruyama [2004] showed the height of the dike in 1809 was 3.5 meters from several historical materials. Therefore, the height of dike has been increasing with the passage of time.

The second point that emerges from Fig. 12 (a) is land subsidence in Pho Co district. Fig. 12 (b) shows the 2005 map overlaid with the difference map of Fig. 12 (a). The darker-shaded areas have lower elevation than in 1950. The average elevation of Pho Co district is about 9 meters in 2005, which is 0.5 meters lower than the elevation in 1950. Therefore, land subsidence has occurred.

## Conclusion

In this study, the DEM of Hanoi in Vietnam was generated from the elevation survey data and a topographic map. The very subtle elevation gaps which cannot be distinguished on the satellite images are significantly recognizable on the DEM. These high resolution DEMs are useful not only for analyzing the urban transformation of Hanoi, but also for the urban sustainability of Hanoi, as in improvement of urban infrastructure and disaster prevention.

The generated DEMs give us not only detailed information about the terrain of Hanoi, but also information on landform changes over approximately 50 years. There are two notable changes: (1) construction to raise the dike, (2) the change of terrain around Pho Co district. In future, the relation between flooding and the construction of dikes would be the most important element to study in this area. Hanoi will celebrate its 1,000<sup>th</sup> anniversary in 2010. Through dikes this city has been protected from flooding by the Red River for a long time. It is necessary to consider the effects of dikes on the urbanization and the life of residents. Additionally, it is necessary to search for traces of ancient rivers and landfills from the generated DEM. These signs can be more practical indicators when we consider the relation between urban transformation and topographical changes.

#### Acknowledgement

This research is based on "Development of system for spatiotemporal mapping with emphasis on urban area in Southeast Asia" supported by a Grant-in-Aid for Young Scientists (B) (Issue No. 19710208, Go Yonezawa, Kyoto University); "Development of Area Informatics: With Emphasis on Southeast Asia" in Scientific Research (S) (Issue No. 17101008, Mamoru Shibayama, Kyoto University); and "Impacts of Development Programs on Sustainable Use of Ecological Resources of Southeast Asia" (Yasuyuki Kono, Kyoto University) in the Integrated Research of Institute of Sustainability Science, Kyoto University.

#### References

- Haruyama, S. 2004. *Natural Environmental Study Applied for Agriculture in Northern Vietnam: Natural Hazard and Their Defense Policy against Disaster, the Red River Delta*, p. 131. Tokyo: Kokon Shoin.
- Ho Dinh Duan; and Shibayama, M. 2008. *Studies on Hanoi Urban Transition in 20<sup>th</sup> Century Based on GIS/RS*. Kyoto Working Papers on Area Studies No. 3 (G-COE Series 1), p. 20.
- Nonogaki, S.; Masumoto, S.; and Shiono, K. 2008. Optimal Determination of Geologic Boundary Surface Using Cubic B-Spline. *Geoinformatics* 19(2): 61-77.
- Noumi, Y. 2003. Generation of DEM Using Inter-Contour Height Information on Topographic Map. *Journal of Geosciences* 46(14): 217-230. Osaka City University.
- Sakurai, Y.; and Shibayama, M. 2007. GIS4D Analysis of the Distribution of Thang Long-Hanoi Relics and Inscriptions. *Symposium "Area Studies and Informatics: Opening a New Horizon" Lecture Series*, pp. 37-53. Center for Southeast Asian Studies, Kyoto University.
- Shibayama, M. 2005. Area Informatics Approach for Exploring Thang Long-Hanoi Historical Heritage. In *Proceedings of International Symposium on Area Informatics and Historical Studies in Thang Long-Hanoi*, pp. 1-9.
- Yonezawa, G. 2008. Developing of 3D Urban Modeling of Hanoi. *Intriguing ASIA* 113: 168-174. Tokyo: Bensei Shuppan.
- Yonezawa, G.; and Shibayama, M. 2007. Clarification of Historical Changes and Urban Transfiguration in Hanoi, Vietnam Using GIS. *IPSJ Symposium Series* 2007(15): 139-146.