Development of Flood Drain Direction using Mobile GIS and Spatial Interpolation Techniques in Municipality of Khon Kaen, Thailand

Chalermchai Pawattana[1]* and Phaisarn Jeefoo[2]

[1]Sustainable Infrastructure Research and Development Center, Department of Civil Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen, 40002, Thailand

[2]Geographic Information Science, School of Information and Communication Technology, University of Phayao, Phayao, 56000, Thailand

* Corresponding author. E-mail address: chapaw@kku.ac.th

Received: 10 February 2021; Revised: 24 June 2021; Accepted: 30 June 2021; Available online: 28 October 2021

Abstract

In this paper, techniques for interpolation of spatial elevation from elevation data by using mobile GIS field survey for flood drain direction mapping have been developed which can be served as a guideline for remote sensing and GIS operations to improve the efficiency of flood disaster monitoring and management in the municipality of Khon Kaen, Thailand. In order to estimate the interpolation of spatial elevation for flood direction, five GIS data were used such as satellite imagery, hydrology, road, boundary and elevation. The paper presents the flood drain direction mapping by using DEM data from IDW interpolation technique. The result was shown the flood water direction from Nong Khot lake and flow to Bueng Kaen Nakhon lake and the last flow to Bueng Thung Sang lake, respectively.

Keywords: Mobile GIS, Inverse distance weight, Ordinary Kriging, Flood drain direction, Municipality of Khon Kaen

Introduction

Floods are among the most devastating natural hazards in the world, wildly distributed leading to significant economic and social damages than any other natural phenomenon (DMSG, 2001; Haq, Akhtar, Muhammad, Paras, & Rahmatullah, 2012). Climate changes and human-induced land-use interventions are defined as important factors causing the flood hazard. There is a mutual trigger situation that the urban areas are the most influenced areas from the flood and also the urbanization is the most important reason of the formation of flood (Ozkan & Tarhan, 2015).

Remote Sensing has made substantial contribution in flood monitoring, mitigation and damage assessment that leads the disaster management authorities to contribute significantly. Geographic Information Systems (GIS) technology is ideally suited as a tool for the presentation of data derived from continuous monitoring of locations and used to support and deliver information to environmental managers and the public. GIS based spatial analysis and visual elements are used frequently in recent years for detection of flood hazard areas and for preparation of maps. GIS applications area based on database and which analysis tools have logical and mathematical relationships between the layers (Kourgiala & Karatzas, 2011).

Spatial interpolation methods have been widely used to reconstruct bathymetric surface, but different technologies, such as LiDAR (Light Detection and Ranging), aerial photogrammetry and multi-beam sonar, have been greatly improved and applied to map the swamp/canal/river bathymetry. Still, utilizing these techniques either cost expensively (such as multi-beam survey) or cannot detect the deeper parts (<2 m) of riverbed (such as LiDAR of aerial photogrammetry) (Kinzel, Wright, Nelson, & Burman, 2007; Hilldale & Raff, 2008)

Mobile GIS is a mature technology which takes geospatial technology beyond the walls of an office. Therefore, mobile applications have extended to field use which allows the user easy access, storage, updates, analysis and real time visualization of field data. Till recently, mobile GIS application were mainly used as a navigation or location-aware system. Mobile GIS technology nowadays offers a potential alternative to fill the gaps of traditional GIS systems. With mobile GIS technology, officers and many other field workers have the potential to access the enterprise geospatial data from the server-side to accomplish their tasks with high level of accuracy. More importantly, it is also possible to update these geospatial enterprise data in real time (Choosumrong, Raghavan, Jeefoo, & Vaddadi, 2016).

The main objective of this study was to develop the flood drain direction using mobile GIS and spatial interpolation in Khon Kaen municipality.

Methods and Materials

The study area

The study area was conducted at the municipality of Khon Kaen, the north east of Thailand. It covers an area of 58 square kilometers with Universal Transverse Mercator grid coordinate between 1,818,000 N to 1,824,000 N and 904,000 E to 914,000 E (Figure 1). The average yearly rainfall is 1,150 millimeters. The area always faces floods during heavy rainfall, normally in the rainy season. The officers try to solve this problem to mitigate flooding. The area has three main reservoirs namely Nong Khot, Bueng Kaen Nakhon, and Bueng Thung Sang. The floodwater from Nong Khot and Bueng Kaen Nakhon deliver water into Bueng Thung Sang reservoir and then release to the river, respectively.

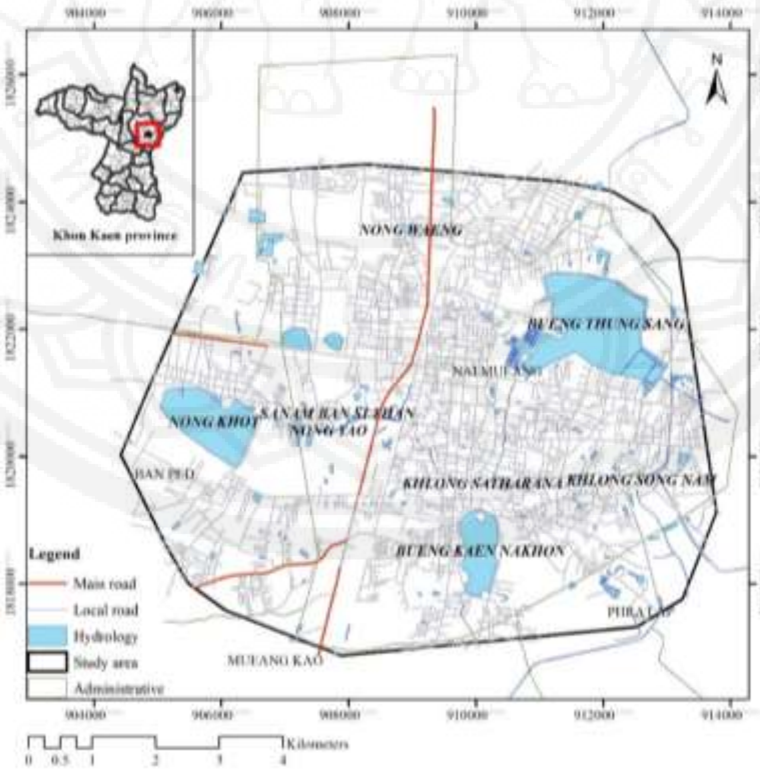


Figure 1 The map of the study area

Referring flowchart of methodology in Figure 2, three steps were involved in the study design such as collection of elevation points using mobile GIS, spatial interpolation to derive grid elevation and flood drain direction. Details of each step were described below.

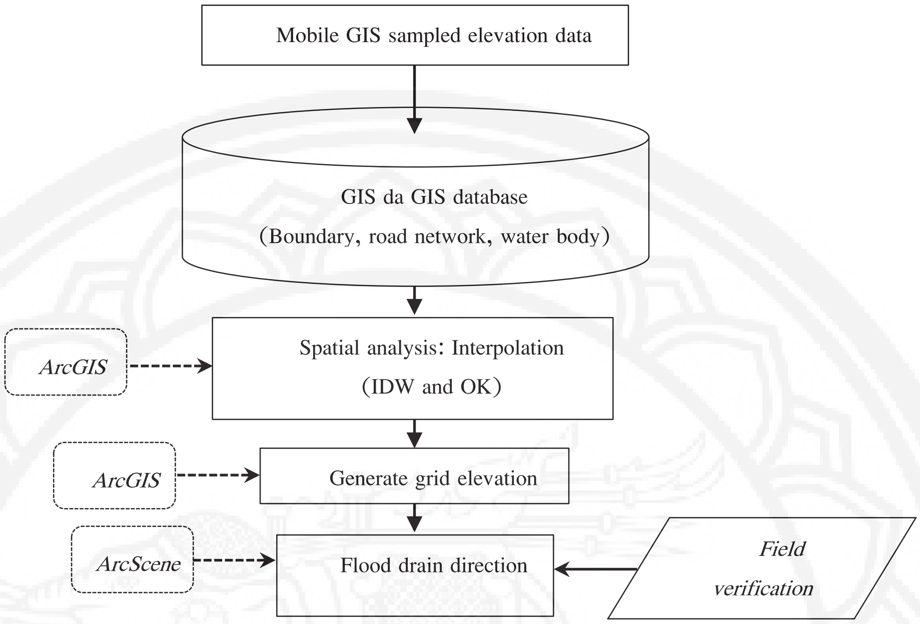
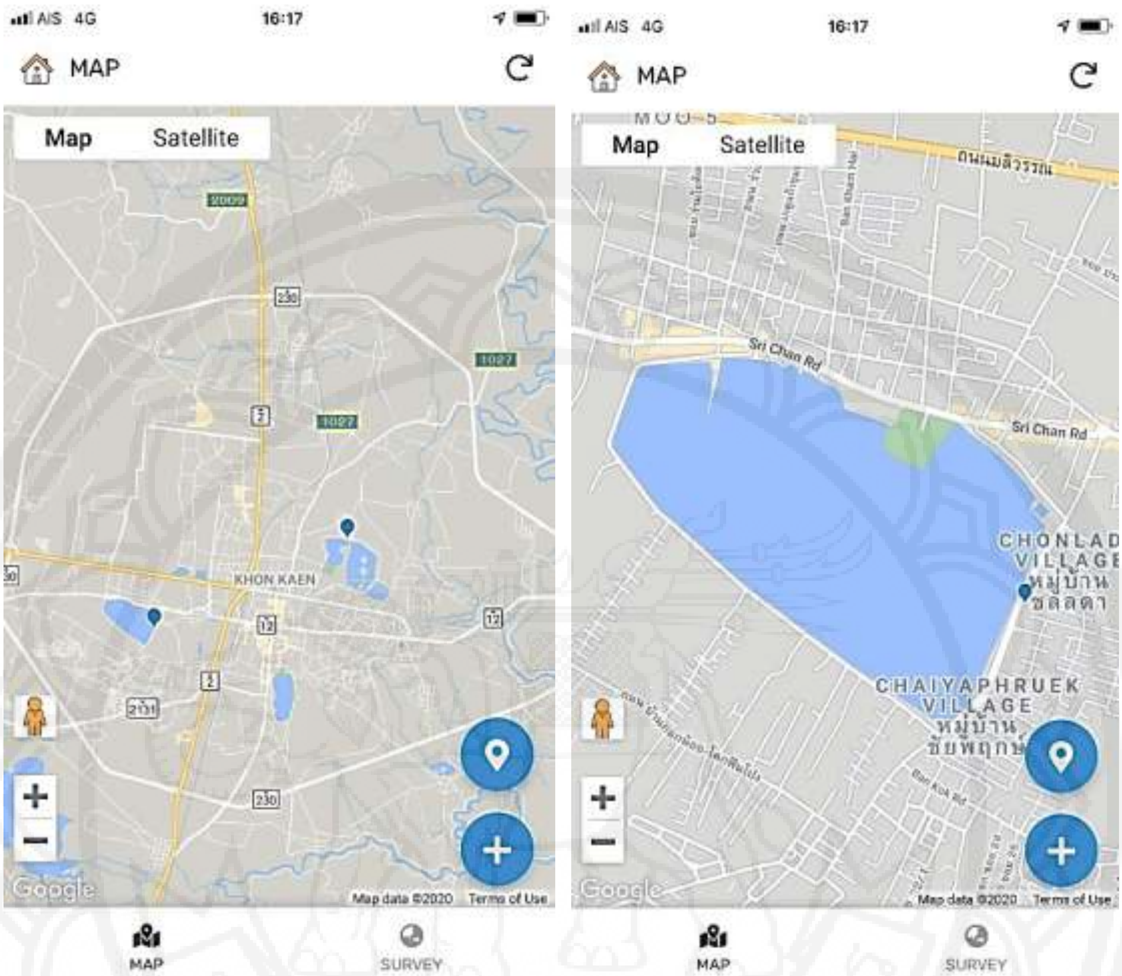


Figure 2 Flowchart of methodology

Mobile GIS for collection of sampled elevation data

In this research we have developed a mobile GIS field survey application for collecting the elevation data. The mobile GIS use the client/server architect that is common in internet-based applications. jQuery Mobile (jQM) provides a rich set of jQuery plug-ins, widgets and a cross-platform API for creating mobile applications. It is more or less similar to the jQuery User Interface (jUI) in terms of code implementation. The jQM is freely available as an Open Source codebase and provides a rich user experience on web browsers running on mobile devices (Ableson 2013). jQM uses HTML5, JavaScript, AJAX and CSS3 features to enhance basic HTML markup in order to create a consistent mobile experience across supported platforms. jQM based application work on mobile devices without JavaScript, even thought a lot of redundant HTML is transferred over the network. For users who have a browser that supports JavaScript, the server only generates HTML on the first request and then subsequent requests use JSON and client-side templates to dynamically render the page. JSON is the syntax for storing and swapping text data. JSON documents are typically smaller than XML, and faster and easier to parse (Choosumrong et al., 2016). The server-side provides access to geospatial data and performs online spatial requests such as find, spatial query, measure, and closeness analysis based on requests made by from client-side. On the other hand, the user at the client-side can navigate and display through separate GIS layers of the geospatial data hosted by the server-side.

Application of the mobile side of the system was concentrated on the mobile GIS application. The previous application was used for field survey report from the geospatial field survey. The GPS location in the smartphone is adept of pinpoint the current location with elevation value automatically. Once the existing location has been found, the user will be able to start inserting the data using the input form. Figure 3 shows some screenshots of the mobile filed survey application.



a) Main page (Nong Khot lake)

b) Database table with reporter, gender, address, phone, elevation

Figure 3 Screenshots of the mobile field survey

Spatial interpolation methods for calculating grid elevation

The methods for calculating grid elevation can be classified into two groups, deterministic and geostatistical methods. Spatial interpolation is generally estimated a regionalized value at unsampled points based on a weight of observed regionalized values. The most frequently used deterministic methods are Thiessen polygon (THI) and Inverse Distance Weight (IDW). Some advantages of IDW interpolation method are simple, intuitive and fast to compute interpolated values (Achilleos, 2011). The second group of spatial interpolation, geostatistical methods initiates a discipline connecting mathematics and earth sciences. Kriging is an example of geostatistical techniques used to interpolate of values of random variables. There are several types of kriging such as simple kriging (SK), ordinary kriging (OK) and universal kriging (UK). They are employed for different conditions as:

a) when it is assumed that the mean is constant and known, SK is applied;

b) where the mean is constant and unknown, OK is applied;

c) additionally, UK is applied where the mean is applied to show a polynomial function of spatial coordinates (Ly, Charles, Degre, 2013).

Pavlova (2017) studied various interpolation methods for creating digital elevation model (DEM) for plain areas. Results of study recommended IDW and OK methods due to less root mean square error. Additionally, IDW and OK methods were employed for this study.

IDW assumes that the sampled points closer to the predicted value than the sample points farther apart. Thus, IDW predicts the estimated value by averaging over all the known measurements, and assigning greater weight to nearer points (Phillip & Watson, 1982). The IDW is formulated as follows;

$$Z(x) = \frac{\sum_{i=1}^{n} W_i Z_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

$$W_i = \frac{1}{d_i^k} \quad (2)$$

Where Z(x) is the estimated value at a predicted point, and Z_i is the observed value at point i. W_i is the weight value assigned at point i, and d_i is the distance between point i and the predicted point; moreover, k is the power variable. The power variable decides how surrounding points affect the estimated value. A lower power results in higher influence from distant points. The regular IDW method assumed an isotropic surface and thus uses a circle as the search neighbourhood (Figure 4).

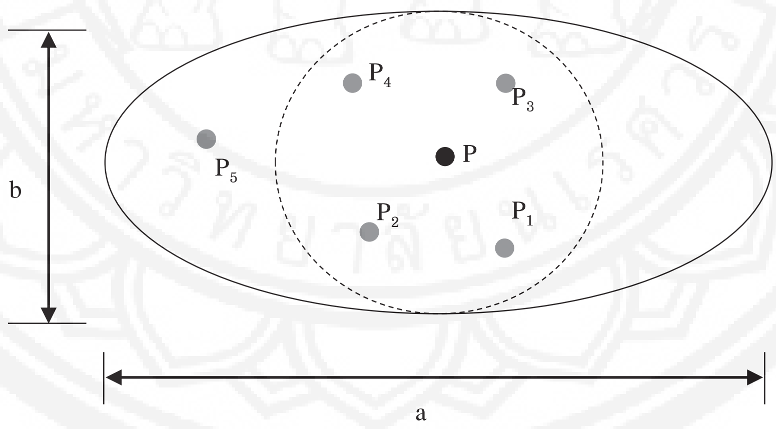


Figure 4 IDW interpolation methods (a) with sampled points P1 to P5 and unsampled point P in the centre, circular with dashed line represent its search neighbourhood, note that P5 is excluded in the search circle. Nevertheless, (b) shows elliptical search neighbourhood for EIDW algorithm (major axis = a, minor axis = b), and P5 is included in this case. (Modified from Merwade, Maidment, & Goff, 2006)

Ordinary Kriging is the fundamental method in the Kriging family. In general, the Ordinary Kriging interpolator assumes of random spatial process with stationarity, and goals to offer unbiased estimation with a minimized error variance (Goovaerts, 1997; Wu, Mossa, Mao, & Almulla, 2019). The basic formula for Ordinary Kriging is stated as:

$$Z(x) = \sum_{i=1}^{n} W_i Z_i \qquad (3)$$

Where Z(x) is the estimated value at a predicted point, and Z_i is the observed value at point i. W_i is the weight value assigned at point i. However, unlike the IDW method, the weighting coefficient (W_i) in the Ordinary Kriging system is assigned by not only considering the distance between unsampled and sampled points, but also the spatial correlation between these points. To ensure an unbiasedness results, the following condition must be maintained:

$$\sum_{i=1}^{n} W_i = 1 \qquad (4)$$

In addition, the error variance (σ^2) is stated as:

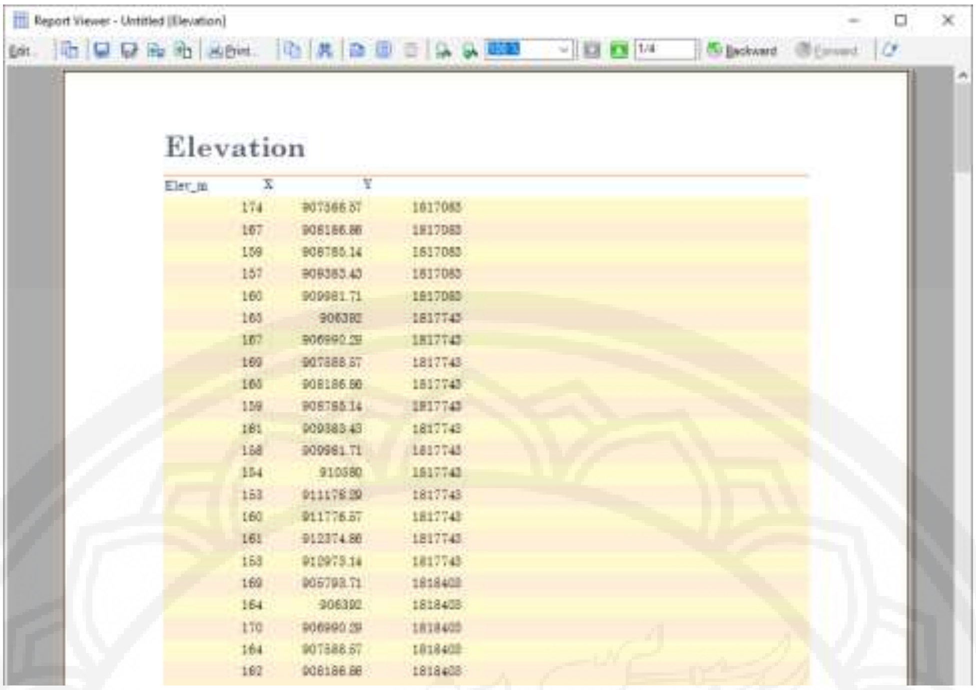
$$\sigma^2 = \frac{\sum_{i=1}^{n} (Z(x) - Z_i)^2}{n} \qquad (5)$$

Where n represents the total numbers of data points.

Results and Discussion

Collection of sampled elevation data using mobile GIS

The officers can visualize the reporting points of real time field survey that send data, and then can make use of that data for recording and analyzing purposes. By clicking on pinpoint of the map, the information related with the image such as reporter, address, mobile number, email, coordinate (X,Y), elevation (m), and date separately. The elevation data was reported with coordinate (X,Y) totally 156 points over the study area (Figure 5). This report is generated automatically from the mobile application and convert to Microsoft Excel and PDF format correspondingly.



Elevation

Elev_m	X	Y
174	907366.57	1817083
167	908186.86	1817083
159	908785.14	1817083
157	909383.43	1817083
160	909981.71	1817083
165	906392	1817743
167	906990.29	1817743
169	907588.57	1817743
165	908186.86	1817743
159	908785.14	1817743
161	909383.43	1817743
158	909981.71	1817743
154	910580	1817743
153	911178.29	1817743
160	911776.57	1817743
161	912374.86	1817743
153	912973.14	1817743
169	905793.71	1818403
164	906392	1818403
170	906990.29	1818403
164	907588.57	1818403
162	908186.86	1818403

Figure 5 Shown the report of elevation location data

Figure 6 shows the graph of elevation data of 156 points. The average of elevation is 166.35 m. The highest is 190 m over the mean sea level and the lowest is 0 m over the mean sea level because this value located the unknown elevation level from the equipment in the lake and have only two points of the total.

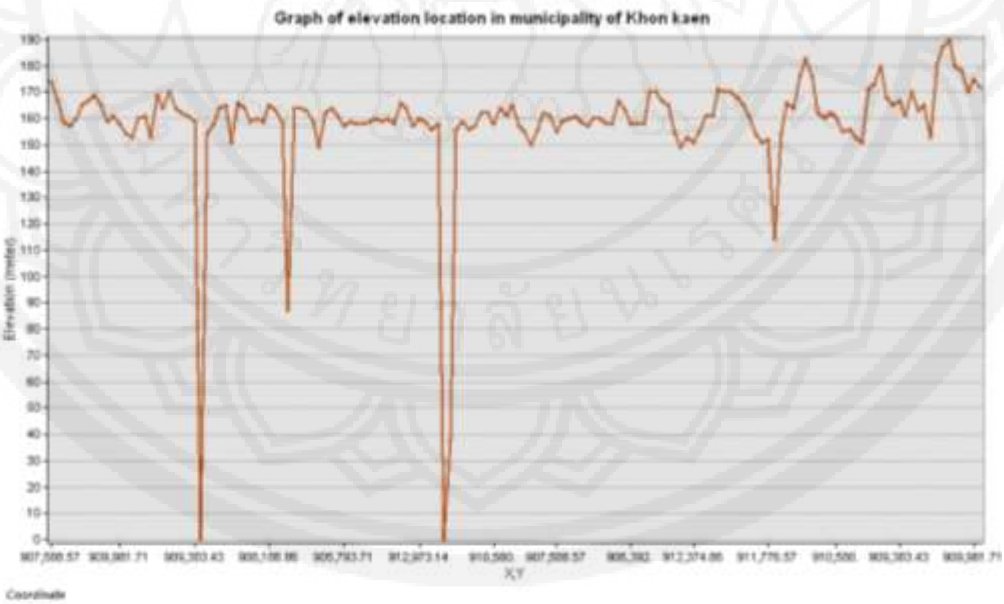


Figure 6 Shown the graph of elevation location in municipality of Khon Kaen

Spatial interpolation

To adjust the elevation accuracy, field survey was managed of validity the elevation data set by inquiries from the engineer of the Khon Kaen municipality. Moreover, ground recheck is necessary to confirm elevation accuracy using Garmin GPS hand help. The various thematic layers were prepared using a spatial interpolation technique through IDW. This method uses a defined or a selected set of sample points for estimating the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points; and, it controls the significance of known points upon the interpolated values based upon their distance from the output point, generating thereby a surface grid as well as thematic isolines. Figures 7 and 8 present results of spatial interpolation using IDW and OK methods.

Accuracy assessment including statistical measures, Root Mean Square Error (RMSE) was reported by using ArcGIS software. The IDW and OK interpolation techniques revealed RMSE of 0.6524 and 0.5311, respectively. So, the OK technique appropriates for represent the flood drain direction in the study area. The flood drain direction from Nong Khot lake and flow to the east to Bueng Kaen Nakhon lake and flow to the north to Bueng Thung Sang lake, respectively with elevation level of 110 to 120.18 m. Additionally, elevation surface classification maps have been created for the study area.

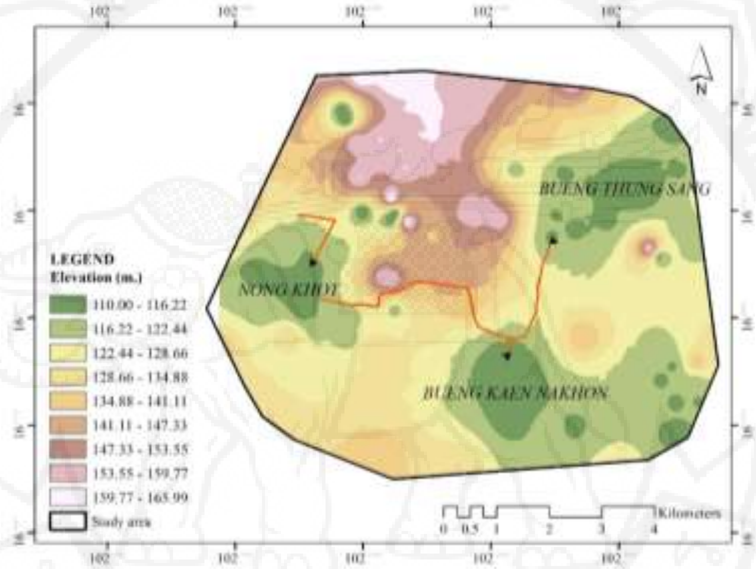


Figure 7 IDW interpolation

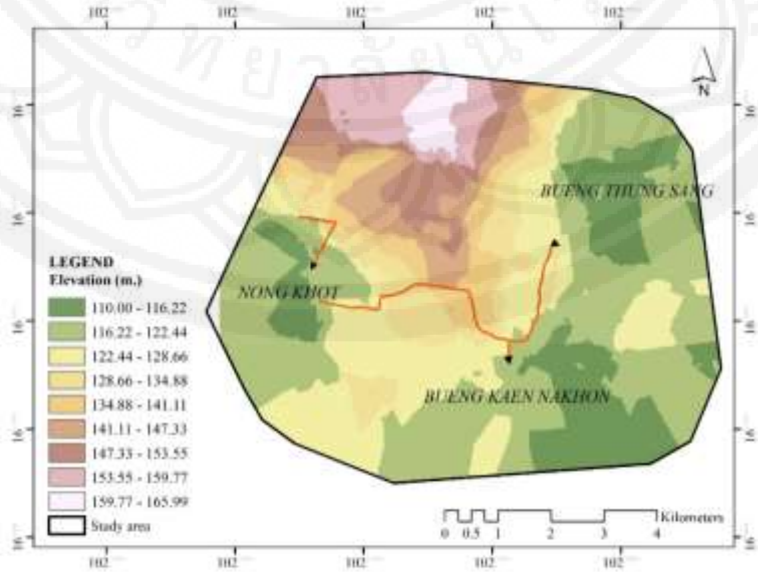


Figure 8 Ordinary Kriging interpolation

Flood drain direction

Spatial and temporal simulation of the flood flow in the study area were revealed, calculated and analysed using interpolated DEM data and processing by ArcScene software with input the water depth of 1m level from mean sea level started from 110 m until 190 m. Newer data and displays for the same site now provide calibration to discharge of this same discharge estimator. The software has generated the water depth of 1 meter at least automatically for clear explained of the flood drain direction. The illustrated display shows the strong response of the discharge estimator to inundation, and the capability to predict ongoing flooding if its present value is known (Figure 9).

Figure 9 Sample profile site display for the study area. Flows above the dot line, at this location, are identified as floods, and map displays can show, each distance, which sites have exceeded this threshold

The Nong Khot, Bueng Kaen Nakhon, and Bueng Thung Sang lakes were selected as an example to illustrate the process in detail. Figure 10 presents the flood drain direction from Nong Khot lake and flow to Bueng Kaen Nakhon lake and the last flow to Bueng Thung Sang lake, respectively. In the north, water flow direction was the normal water level of 180 m and it flows to Bueng Kaen Nakhon lake and Bueng Thung Sang lake, western part of the municipality of Khon Kaen.

The advancement in the mobile GIS field survey technology has led to the availability of realtime data sets. These vital information about the surface terrain, DEM, for flood using which the disaster management authorities can take necessary steps for helping the victims. This section analyses the prodigious flood situation that occurred in the municipality in Khon Kaen, in September 2020 by using DEM based along with the meteorological observations.

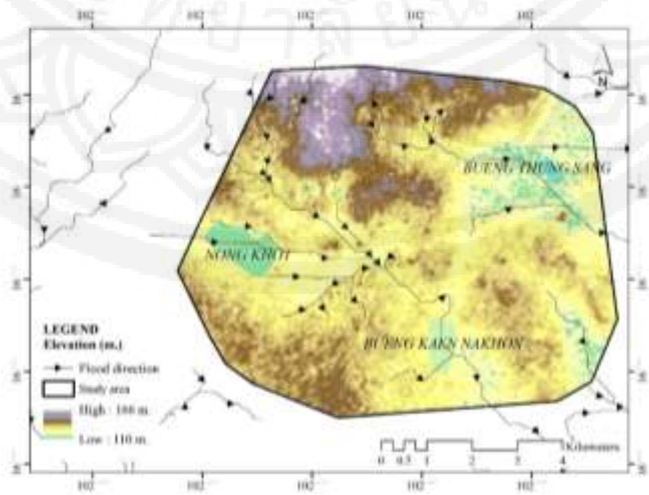


Figure 10 Flood drain direction

Field verification

The flood drain direction was verified using observed data of the water level at hydrological stations and field flood height measurements. Referring interviewing the villager as reveals in Figure 11, flood from the northwest and west flow into Bueng Kaen Nakhon lake and flow to the southeast direction. For flood of the northeast direction flow into Bueng Thung Sang and finally drain into Pra Kue River. Additionally, the flood drain direction agreed the result of Figure 10.

Figure 11 Field verification

Conclusion

This study used an elevation measurements survey conducted by mobile field survey application from November to December 2019, it was collected with 156 points of coordinate locations over the area. The data was generated by using ArcGIS software in spatial analysis function, the DEM was created for thematic map. From DEM data, the flood drain direction simulation was generated using ArcGIS software. The highest value was 166 m in the north of the area and the lowest value was 110 m in the south of the area, respectively. All point depth soundings were processed and vertical referenced to WGS 1984 (World Geodetic System of 1984). The three main water resources consist of Nong Khot, Bueng Kaen Nakhon and Bueng Thung Sang lakes in which is the lowest terrains.

In the present investigation, an attempt was made to evaluate and map the water resources surface terrain of Nong Khot, Bueng Kaen Nakhon and Bueng Thung Sang lakes in the municipality of Khon Kaen. Spatial interpolation of water resources terrain surface parameter was carried out through GIS. DEM data was useful generated the flood drain direction simulation over the study area. The research is presented the flood drain direction simulation from Nong Khot lake and drain to Bueng Kaen Nakhon lake and the last drained to Bueng Thung Sang lake, respectively. The analysis of the results drawn the work revealed that GIS is an effective tool for the preparation of various digital thematic layers and maps showing the spatial distribution of various water resource surface terrain parameters. Furthermore, GIS makes the water resource surface terrain maps in an easily understood format. The interpreted accuracy assessment with respect to Ordinary Kriging indicated that less value of RMSE than inverse distance weight interpolation technique. The implemented mobile GIS platform provides the basic GIS functionalities and location. The client/server GIS framework that was developed is an independent application, which can be run in every modern mobile smartphone without requiring to any other additional software. This application helps the field parties to gather data from water resources field survey and provide inputs for monitoring and protection.

Acknowledgments

This research was supported by Sustainable Infrastructure Research and Development Center, Khon Kaen University (KKU). Spatial thank would like to deliver to the municipality of Khon Kaen for supporting essential data and information.

References

Ableson, F. (2013). *jQuery Mobile and JSON, Learn how to Create Mobile Web Applications Powered by jQuery Mobile.* Retrieved from https://www.ibm.com/developerworks/xml/tutorials/x-jquerymobile jsontut/index.html

Achilleos, G. A. (2011). The Inverse Distance Weighted interpolation method and error propagation mechanism - creating DEM from an analogue topographical map. *Journal of Spatial Science*, *56(2)*, 283-304.

Choosumrong, S., Raghavan, V., Jeefoo, P., & Vaddadi, N. (2016). Development of Service Orinted Web-GIS Platform for Monitoring and Evaluation using FOSS4G. *International Journal of Geoinformatics*, *12(3)*, 67-77.

DMSG, (2001). *The Use of Earth Observing Satellites for Hazard Support: Assessments & Scenarios.* USA: Final Report, Department of Commerce.

Goovaerts, P. (1997). *Geostatistics for Natural Resources Evaluation.* Oxford: Oxford University Press.

Haq, M., Akhtar, M., Muhammad, S., Paras, S., & Rahmatullah, J. (2012). Techniques of Remote Sensing and GIS for flood monitoring and damage assessment: A case study of Sindh province, Pakistan. *The Egyptian Journal of Remote Sensing and Space Sciences*, *15*, 135-141.

Hilldale, R. C., & Raff, D. (2008). Assessing the Ability of Airborne LiDAR to Map River Bathymetry. *Earth Surface Process and Landforms*, *33(5)*, 773-783.

Kinzel, P. J., Wright, C. W., Nelson, J. M., & Burman, A. R. (2007). Evaluation of an Experimental LiDAR for Surveying a Shallow, Braided, Sand-Bedded River. *Journal of Hydraulic Engineering*, *133(7)*, 838-842.

Kourgiala, N., & Karatzas, G. (2011). Flood management and a GIS modelling method to assess flood-hazard areas - a case study. *Hydrological Sciences Journal*, *56(2)*, 212-224.

Ly, S., Charles, C., & Degre, A. (2013). Different methods for spatial interpolation of rainfall data for operational hydrology and hydrological modeling at watershed scale. *Biotechnology, Agronomy and Society and Environment, 17(2),* 392-406.

Merwade, V. M., Maidment, D. R., & Goff, J. A. (2006). Anisotropic Considerations while Interpolating River Channel Bathymetry. *Journal of Hydrology*, *331(3)*, 731-741.

Ozkan, S. P., & Tarhan, C. (2015). Detection of Flood Hazard in Urban Areas Using GIS: Izmir Case. *Procedia Technology*, *22*, 373-381.

Pavlova, A. I. (2017). Analysis of Elevation Interpolation Methods for Creating Digital Elevation Models. *Optoelectronics, Instrumentation and Data Processing*, *53(2)*, 86-94.

Phillip, G. M., & Watson, D. F. (1982). A precise Method for Determining Contoured Surfaces. *The APPEA Journal*, *22(1)*, 205-212.

Wu, C. Y., Mossa, J., Mao, L., & Almulla, M. (2019). Comparison of different spatial interpolation methods for historical hydrographic data of the lowermost Mississippi River. *Annals of GIS*, *25(2)*, 133-151.