# DEM DATA ASSESSMENT FOR HYDROLOGIC APPLICATIONS: A CASE STUDY IN NAM KHEK WATERSHED, THAILAND

Wipop PAENGWANGTHONG[*a] and Sunya SARAPIROME[b]

[a] Graduate student, School of Remote Sensing, Suranaree University of Technology, Suranaree, Muang, Nakhon Ratchasima 30000, Thailand;
Tel: +66 44 22 4652, Email: wipop_p@hotmail.com

[b]Assistant Professor, School of Remote Sensing, Suranaree University of Technology, Suranaree, Muang, Nakhon Ratchasima 30000, Thailand;
Tel: +66 44 22 4652, Email: sunyas@sut.ac.th

**KEY WORDS:** Extracted stream position, Stream channel parameters, DEM generation and accuracy, Hydrologic application.

**ABSTRACT:** Hydrologic applications, e.g. locating potential sites for micro-hydropower generation, require parameters extracted from DEM data. These parameters include stream position and relative elevation in form of slope. They are parameters required for estimations, for example, area upstream and channel parameters for run-off and water-head estimation. More accurate DEM data can provide more accurate parameters. DEM data available in Thailand comes from several sources, i.e. SRTM-DEM, GDEM, RTSD-DTED2, and self-generated DEM (SG-DEM), which are different in acquiring methods, spatial resolution, spatial position and elevation accuracy. From different sources, DEM data can be normally generated from sets of remotely sensed data with different sets of control points and geometric correction methods. Therefore, their accuracy can affect the parameters which in turn will affect the applications. The purpose of the study is to assess the data quality and suitability of available DEM in Thailand for hydrologic applications in the scale of 30 m cell size fit to preliminary feasibility study in Nam Khek watershed. The Nam Khek watershed is characterized by mountainous area with main streams providing potential for micro-hydropower generation, tourist attraction and activities. Accuracy of the parameters in the area extracted from available DEM data is assessed based on reference data. Matching percentage for stream position and root mean square error for stream elevation are estimated and compared.

## INTRODUCTION

Due to having limited number of gauge stations in the study area, any hydrological applications, for example site suitability assessment of micro hydropower, deal specifically more with data from ungauged catchments. With reliable GIS techniques, it can definitely provide more trustable data of physical characteristics, particularly upstream drainage area, stream position, and elevation for run-off and water-head estimation. According to previous studies (IEE, 2010; Rojanamon, Chaisomphob, and Bureekul, 2009), such parameters at ungauged sites were estimated based on calculations starting from grid DEM data. For example, run-off estimation at ungauged point along the stream is more accurately estimated using its relationship to the catchment area upstream from that point (Sarapirome, Teaumroong, Kulworawanichpong, Ongsomwang, and Paengwangthong, 2010; Wirojanakud and Srivoramas, 2000). Identification of anomaly steepness stream segments can be carried out using relationship of slope of stream segment and catchment area upstream as well (Gonga-Saholiariliva, Gunnell, Harbor, and Metering, 2011; Wobus et al., 2006). To achieve the accurate catchment area upstream of any point along the stream, the accumulation of cells in raster-based sub-watershed is started from the most upstream cell down to the cell at that point. If the cell is shifted apart from the stream position only 1 or 2 cells, the accumulation of upstream cells or the catchment area upstream of the cell can be deviated more than several hundred to thousand times. This will greatly cause adverse effect to further analysis using this parameter. Therefore, apart from using effective and appropriate GIS techniques, parameters of any ungauged points can be more accurately estimated using trustable DEM data. The result will be more reliable than the conventional method.

DEM data available in Thailand come from several sources, i.e. SRTM, GDEM, RTSD-DTED2, and SG-DEM. They are different in acquiring methods, spatial resolution, and position and elevation accuracy. These DEM data are low cost or distribution for free. Therefore, before using DEM data for hydrological applications they should be selected, acquired, or generated, and assessed carefully to ensure that their accuracy fit for a certain level of applications.

The objective of the study is to compare the quality of DEM data available in Thailand for the hydrologic applications, particularly in terms of parameters related to locating potential sites for micro hydropower and to estimate their generation ability in the study area. Horizontal and vertical accuracy of all kinds of DEM data mentioned above were assessed with reference DEM data of the MOAC (Ministry of Agriculture and Cooperatives). These MOAC-DEM data have the highest spatial resolution and are distributed with very high cost. Due to very limited study budget, only several comparatively tiny areas of MOAC-DEM data supported by the Land Development Department (LDD) were employed as reference data. The matching percentage was used to assess agreement between the extracted and the reference stream position while the root mean square error is for assessing elevation accuracy along reference streams. The results of assessment can be used to compare which DEM data are more suitable for further applications.

**Study area**

The Nam Khek watershed in the northern part of Thailand was chosen for this comparative analysis. The area is located as a seam between Phitsanulok and Phetchabun Provinces (Figure 1), at north latitudes 16° 22" 32' to 17° 2" 46' and east longitudes 100° 28" 38' to 101° 5" 7'. The area extent is 1,861 square kilometers. It was chosen because its topography presents the good mixture of almost all kinds of terrain, namely mountainous, hilly, rolling to undulating, and valley flats. Also, the area is characterized by very long Nam Khek River, the flowing-through main stream which presents high potential on run-of-river type micro-hydropower. As confirmed in the study report of the National Energy Administration (NEA, 1988), there have been seven potential sites for run-of-river type of small hydropower plant.

The topography of the area is mainly characterized by high mountain ranges in the east. Elevation of the area is between 41 m to 1,805 m above MSL (mean sea level). The terrain altitude gradually decreases westward to the lower part which is characterized by undulating to rolling surface, alternated with valleys and narrow plains.

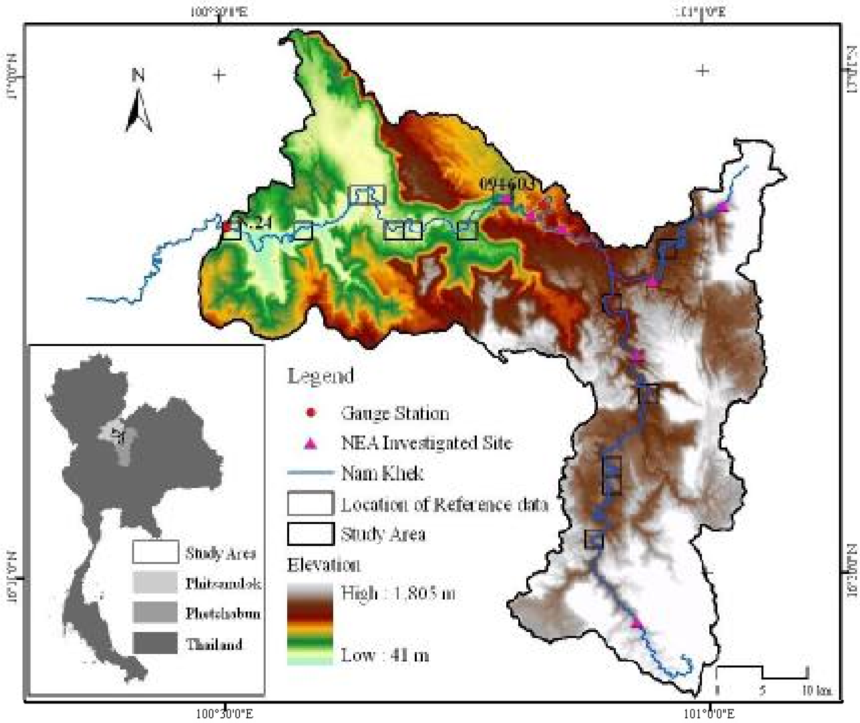


**Figure 1:** Topography of the study area, stream-gauge stations, and seven potential sites for run-of-river small hydropower plant investigated by NEA (1988).

**Available DEM data and their acquiring methods**

As mentioned above, DEM data recently available in Thailand are obtained from several sources. Their acquiring methods are different and result in the difference of their resolutions. Their sources, resolutions, and acquiring methods can be concluded and presented in Table 1.

**Table 1:** Characteristics of available DEM data in Thailand.

| Data | Source | Spatial resolution | Presented vertical resolution | Acquiring method |
|---|---|---|---|---|
| MOAC-DEM | LDD | 5 m | 1 mm | Digital photogrammetry of color air-photo stereo pairs. |
| SG-DEM | Researcher | 30 m | 1 cm | Interpolation of contour data from 1:50,000 topographic map of the RTSD using Topo to Raster function (ArcGIS™ 9.x). |
| RTSD-DTED2 | RTSD | 30 m | 1 m | SAR interferometry. |
| SRTM-DEM | CIAT-CSI | 90 m | 1 m | SAR interferometry with additional improvement techniques. |
| GDEM | ERSDAC | 30 m | 1 m | Digital photogrammetry of ASTER stereo pairs with additional improvement techniques. |

MOAC-DEM: According to LDD (2004), the detail sets of point data, the product of digital photogrammetry operated on color air-photos (with the claimed scale of 1:4,000), were converted to be grid DEM and contours of 2, 5 and 10 m interval for flat and mountainous areas, respectively. Their vertical accuracy was estimated to be at 2 m and 4 m (95% confidence interval) for flat (slope < 35%) and mountainous (slope > 35%) areas, respectively.

SG-DEM: The grid DEM data was generated using Topo to Raster interpolation function of ArcGIS™ version 9.x, with default parameters setting. The input vector data obtained from the RTSD which are spot heights, 20 m interval contour lines, and stream center lines of 1:50,000 topographic map.

RTSD-DTED2: According to Slater et al (2006) and Chaichana (2006), the SRTM project produced the grid DEM at one-arcsecond (approximately 30 m) intervals in latitude and longitude using SAR interferometry. The RTSD procured these data from the National Imagery and Mapping Agency (NIMA).

SRTM-DEM: Primarily, the SRTM-DEM data have been produced using radar images gathered from NASA's shuttle as same as the RTSD-DTED2. Before distributing them via internet, their spatial resolution was reduced to 90 m. Currently, the latest version has been improved using new interpolation algorithms and better auxiliary DEMs (Jarvis, Rubiano, Nelson, Farrow, and Mulligan, 2004).

GDEM: The GDEM data were generated using stereo pairs of ASTER images. Currently, it have been improved in processing i.e. water masking, smaller correlation kernel size, and bias removal (Tetsushi Tachikawal et al., 2011).

## METHODS

The conceptual framework of the study procedure is displayed in Figure 2. A number of 14 sheets of MOAC-DEM data were used as reference for accuracy assessment of stream position and elevation in other DEM data. The size of a sheet is 2 km x 2 km. Seven of them fall into mountainous terrain while 4 in hilly and undulating, and 3 in narrow valley flat (see Figure 1). All DEM data were prepared in common characteristics for fair assessment.

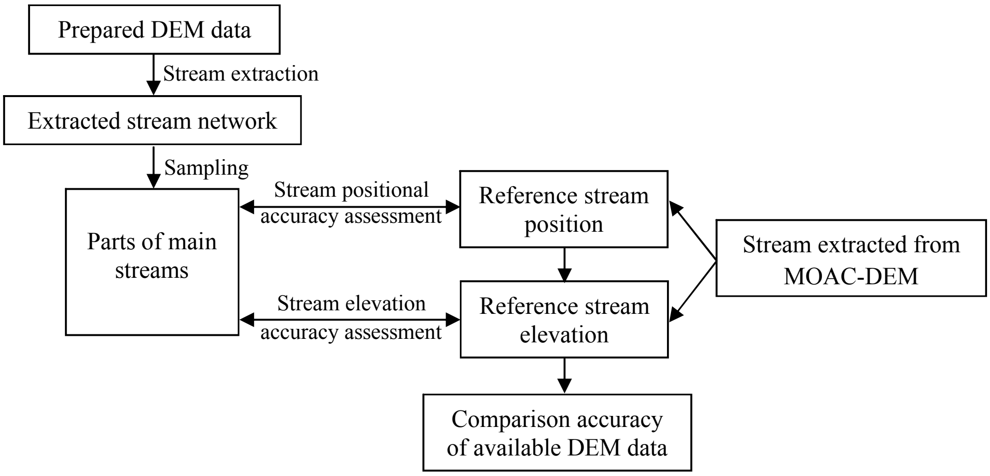


**Figure 2:** Conceptual framework of the study.

Steps of the procedure are as follows:

1) Resampling cell size of all DEM data to be 30 m x 30 m, which approximately matches the actual channel width of the Nam Khek River.

2) Extracting stream networks from all DEM data using flow accumulation process of Hydrology function in Spatial Analyst Tools of ArcMAP™.

3) Reclassifying grid cells corresponding to stream network with 2 for MOAC-DEM, with 1 for other DEMs, and with 0 for all non-stream cells.

4) Overlaying stream layers extracted from other DEMs, one at a time, with stream data sheets extracted from MOAC-DEM.

5) Assessing accuracy of stream position and elevation based on reference streams extracted from 14 sheets of MOAC-DEM. Two groups of sampling sheets of reference data (MOAC-DEM) were used for different purposes. All sheets were for assessment in all kinds of terrain. Seven sheets of them were for mountainous terrain. A group was emphasized in mountainous terrain because the site suitability for micro-hydropower was concentrated more in this type of terrain. Matching percentage was used for assessing stream position accuracy whereas Root Mean Square Error (RMSE) was for stream elevation. To estimate matching percentage, overlay analysis by means of summation was operated. Resulting cells of 3 and 2 represented matching and non-matching cells of reference stream respectively. The matching percentage can be expressed as 100 x ((matching cells)/(matching cells + non-matching cells)). Any DEM data providing the higher matching percentage have the more accurate stream position. Comparing elevation with cells along reference streams, RMSE of each DEM was calculated by use of equation (1) (ASPRS, 1990). Any DEM data providing the higher RMSE have the less elevation accuracy or depicts the higher difference in elevation when compared to reference data.

$$RMSE = \sqrt{\left[\frac{1}{n}\sum_{i=1}^{n}\left(Z_i - \acute{Z}_i\right)^2\right]} \qquad (1)$$

where $n$ is a number of cells of reference streams, $Z_i$ is cell elevation of reference data, $Z_i$ is cell elevation of other DEM.

## RESULTS OF DEM DATA ASSESSMENT

### Stream position accuracy

Examples of extracted streams of all DEM data in 3 sheets of MOAC-DEM are displayed in Figure 3. From visual observation, the stream extracted from GDEM shifts away from the reference stream more than ones from others, followed by the one from SRTM-DEM. The rests agree more with the reference. Matching percentages in mountainous and all kinds of terrains are shown in Tables 2.

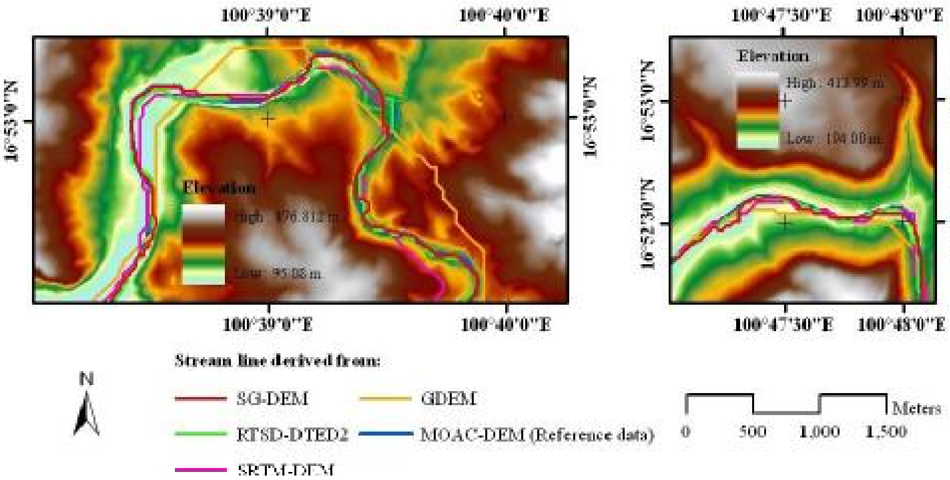


**Figure 3:** Examples of extracted streams of all DEM data in 3 sheets of the reference data (MOAC-DEM).

**Table 2:** Stream position accuracy of all DEM data in mountainous and all kind of terrains.

| | All terrains | | Mountainous terrain | |
|---|---|---|---|---|
| | n | Matching ratio | n | Matching ratio |
| MOAC-DEM | 1,340 | 1.00 | 776 | 1.00 |
| SG-DEM | 757 | 0.56 | 427 | 0.55 |
| RTSD-DTED2 | 815 | 0.61 | 451 | 0.58 |
| SRTM-DEM | 237 | 0.18 | 120 | 0.15 |
| GDEM | 77 | 0.06 | 55 | 0.07 |

Among available DEM data, it is obvious that DEM data of RTSD-DTED2 provide the best stream position accuracy. Their matching ratios with reference data are 0.58 and 0.61 in mountainous and all kinds of terrains, respectively. The accuracies of SG-DEM are lower (0.55 and 0.56) but not much different from the RTSD-DTED2's. GDEM data provide the least stream accuracy. Accuracy of the SRTM is poor compared to ones of the RTSD-DTED2 and SG-DEM.

**Stream elevation accuracy**

The stream elevation accuracy in mountainous and all kinds of terrains of each available DEM, in term of RMSE, is reported in Table 3. Again, the DEM data of RTSD-DTED2 provide the best stream elevation accuracy. Their RMSEs are 6.41 m and 5.41 m in mountainous and all kinds of terrains. For this assessment, SRTM-DEM data carry the highest RMSEs which are as high as 22.25 m and 18.77 m. These RMSE are not much different from the ones of GDEM (17.18 m and 18.55 m.). The elevation accuracies of SG-DEM (16.79 m and 14.52 m) are not much better than of GDEM and SRTM-DEM.

**Table 3:** RMSE of elevation of each DEM in mountainous and all kinds of terrains when compared to elevation of reference streams.

| | All terrains | | | | | Mountainous terrain | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | n | Min | Max | Ave | RMSE | n | Min | Max | Ave | RMSE |
| MOAC-DEM | 1340 | 40.84 | 698.21 | 390.18 | 0.00 | 776 | 193.00 | 698.22 | 590.60 | 0.00 |
| SG-DEM | 1340 | 40.44 | 695.92 | 379.79 | 14.52 | 776 | 189.78 | 695.93 | 578.59 | 16.79 |
| RTSD-DTED2 | 1340 | 39.00 | 716.00 | 393.20 | 5.14 | 776 | 194.00 | 716.00 | 595.41 | 6.41 |
| SRTM-DEM | 1340 | 54.00 | 728.00 | 407.68 | 18.77 | 776 | 206.00 | 728.00 | 611.92 | 22.25 |
| GDEM | 1340 | 35.00 | 784.00 | 390.95 | 18.55 | 776 | 205.00 | 784.00 | 595.50 | 17.18 |

## CONCLUSION AND RECOMMENDATION

Related to hydrological applications, the accuracies in terms of stream position and elevation of recently available DEM data in Thailand were assessed by comparing to the MOAC-DEM data which are claimed to be the best reference. The results can be concluded that DEM data of RTSD-DTED2 provide the best accuracies. Of SG-DEM data are about moderate. SRTM-DEM and GDEM data express the lowest accuracies in both terms. No significant difference in accuracies according to kinds of terrains is observable.

However, to achieve the conclusive results, more sampling areas and other regions including kinds of terrain are suggested to try. With different purpose of applications, assessment methods and results can be varied as well.

## ACKNOWLEDGEMENT

The authors gratefully acknowledge the following agencies in contributing different kinds of DEM data for assessment in this study: the Land Development Department (LDD), Royal Thai Survey Department (RTSD), the Consortium for Spatial Information of the Consultative Group on International Agricultural Research (CGIAR-CSI) and Earth Remote Sensing Data Analysis Center (ERSDAC).

## REFERENCES:

ASPRS., 1990. American society for photogrammetry and remote sensing: accuracy standards for large-scale maps. Photogrammetric Engineering and Remote Sensing, 56(7), pp. 1068-1070.

Gonga-Saholiariliva, N., Gunnell, Y., Harbor, D., and Metering, C., 2011. An automated method for producing synoptic regional maps of river gradient variation: Procedure, accuracy tests, and comparison with other knickpoint mapping methods. Geomorphology, 134(2011), pp. 394-407.

IEE., 2010. Numerical tools, GIS database and Public Cadastre to support SHP implementation. SMART - Strategies to Promote Small Scale Hydro Electricity Production in Europe. Intelligent Energy Europe, Belgium.

Jarvis, A., Rubiano, J., Nelson, A., Farrow, A., and Mulligan, M., 2004. Practical use of SRTM data in the tropics - Comparisons with digital elevation models generated from cartographic data. CIAT (International Center for Tropical Agriculture).

LDD., 2004. Mapping Project on Natural Resources and Property Management of the Ministry Agriculture and Cooperatives. Land Development Department, [Online]. Available: http://www.ldd.go.th/gisweb/pdf/ortho.pdf. (in Thai)

NEA., 1988. Master Plan of Mini Hydropower Development (Final Report). Ministry of Science Technology and Energy.

Rojanamon, P., Chaisomphob, T., and Bureekul, T., 2009. Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. Renewable and Sustainable Energy Reviews, 13(9), pp. 2336-2348.

Sarapirome, S., Teaumroong, N., Kulworawanichpong, T., Ongsomwang, S., and Paengwangthong, W., 2010. Locating Potential Alternatives for Micro-Hydropower Plants along Streams within Low-Relief River Basin using GIS. In: The 31st Asian Conference on Remote Sensing.

Slater, J. A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J., 2006. The SRTM data "Finishing" process and products. Photogrammetric Engineering and Remote Sensing, 72(3), 237-247.

Chaichana, S., 2006. Background of L7018 map series. [Online] Available: http://eco-town.dpim.go.th/article/detail.php?id=826. (in Thai)

Tetsushi Tachikawal, Manabu Kaku, Akira Iwasaki, Dean Gesch, Michael Oimoen, Zheng Zhang, . . . Claudia Carabajal., 2011. ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results. Jet Propulsion Laboratory, USA.

Wirojanakud, P., and Srivoramas, R., 2000. Flow properties of the runoff from basins in the northeast region. Research Center of Water Resource, Ubonratchathani University. (in Thai)

Wobus, C., Whipple, K. X., Kirby, E., Snyder, N., Johnson, J., Spyropolou, K., . . . Sheehan, D., 2006. Tectonics from topography: Procedures, promise, and pitfalls. Geological Siciety of Anerica, Special Paper 398.