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Integration of Satellite Images and Echo-sounder Data for Mapping of Water Area: A Case Study of Huai Prue Reservoir in Thailand

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Abstract

In recent years, droughts, water shortages, and saltwater intrusion have caused bad effects on the socio-economic and livelihood. Weather and hydrological conditions dynamically change during the time that makes a single sensor data impossible for natural disasters such as flood and drought monitoring and management. Multi-sensor data can be applied for data integration and analysis for these applications. In this research, different remote sensing satellite platforms as microwave sensors as Shuttle Radar Topography Mission (SRTM) topographic data, Sentinel-1B Synthetic Aperture Radar (SAR), optical sensor as QuickBird data (GoogleEarth Pro) are integrated with ground survey echo-sounder and Global Navigation Satellite System (GNSS) data in real-time kinematic (RTK) mode. This research demonstrates the available data sources and free software functions for remote sensing and GIS analysis for a case study of Huai Prue Reservoir in Nakhon Nayok Province, Thailand. Water areas are temporal identified, analyzed, and compared based on SRTM data and Sentinel-1B SAR data with ground survey and echo-sounder, linking positioning using GNSS data. The topographic maps of these changes are presented for visual assessment.

Disciplinary: Civil Engineering (Hydrology), Geomatics and Spatial Technology (Navigation Application, Remote Sensing).

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1 Introduction

In the long term, the impact of climate change as sea-level rise, the increase in water exploitation in the countries upstream of the international river system, and the increase in water demand for internal development will make the situation worse. Droughts, water shortages, and saltwater intrusion are more frequent and severe. The year 2021 is forecasted to continue to be a year of little water, small flood flows to the Chao Phraya River delta, the risk of continued drought, water shortage, and saltwater intrusion in the dry season months of 2020-2021 affects agricultural production and people's livelihood at a high to a serious level (YongJin, 2020).

Remote sensing and GNSS technology can be applied for detecting drought areas. Different date of satellite images and field survey using echo-sounder with GNSS receiver is used for bathymetric mapping the water area of the reservoir in Nakhon Nayok province, central Thailand.

The multi-sensor approach in this study refers to different remote sensing satellite platforms as Microwave sensors as Sentinel-1B Synthetic Aperture Radar (SAR), Shuttle Radar Topography Mission (SRTM) data for the area's topographic information, Optical sensor as QuickBird data (GoogleEarth Pro.) for visual identifying the water area, Global Navigation Satellite System (GNSS) receiver measured in Real-time Kinematic (RTK) mode for collecting precise positioning data, and Echo-sounder sensor for bathymetric data processing and analysis. An in-situ data means ground survey data collection is at the same time as satellite data acquisition. This approach is applied in this research works as the ground survey was conducted on 25 June 2021 and Sentinel-1B SAR data was acquired on 28 June 2021.

Active remote sensing is used the microwave radiometers as their own energy (active sensors) to get the characteristics of the ground surface. Passive remote sensing is used the sun's energy (passive sensors) for measuring the ground features and the system cannot get the data without the sun energy at night or rainy and cloudy weather. The major advantages of active remote sensing (microwave data) over the passive one (optical data) are independent of all kinds of weather and can get usable data on rainy and cloudy days. Therefore, microwave spaceborne and airborne data can be applied for natural disaster applications such as flood and drought monitoring and management (Perrou et al., 2018). For intensive drought monitoring, ground survey and accuracy checking are conducted by using GNSS receiver for collecting the ground elevation, the unmanned boat with Echo-sounder also employed for measuring the water depth and reservoir floor elevation.

2 Literature Review

Drought is a major natural disaster that creates a negative impact on socio-economic development and the environment. Drought information is important and required for government and local management (Park et al., 2016). Drought is a serious natural disaster that has adverse effects on the environment and human activities. The hydrological drought takes place because of streamflow scarcity when water demand for socio-economic activities is more than the water supply as agricultural dams and reservoirs. Reservoir management is necessary for drought monitoring because the reservoirs and dams reserve water from upstream to downstream for water resources (Peter et al., 2015).

Satellite imagery is a single source of general information that can provide frequent, quick updates on reporting for natural disasters on a global scale, regional or national levels. Multi-sensor data can simplify implementation and monitoring that is consistent and comparable and can link hazards, risks, and climate (Petiteville, 2015).

2.1 Shuttle Radar Topography Mission (SRTM) Data

The SRTM data sets result from joint efforts of the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) to generate a near-global digital elevation model (DEM) of Earth using radar interferometry. SRTM was the primary (and virtually only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched in 2000 and flew for 11 days. NASA conducted an accuracy evaluation by collecting ground truth for the global validation and the results of this SRTM data as relative Height Root Mean Square (RMS) error as 8.7m for the Europe-Asia continent for testing accuracy of the data (Rodriguez et al., 2006). Since the continent-wide contains many countries that have not sufficient numbers of GPS benchmarks for different topographic conditions (Rodriguez et al., 2006), some similar studies have been conducted locally by using GPS with accuracy range from 0.5-10 m accuracy (Mukherjee et al., 2013).

SRTM elevation data on 22 February 2000 is available at a resolution of 30 x 30 m with map project as WGS84 and Earth Gravitational Model 1996 (EGM96) vertical (geoid) datum. The data was download at https://lpdaac.usgs.gov/products/srtmgl1v003 (Anantakarn et al., 2020). The SRTM Version 3.0 data have been improved over Version 2.0 of Global Digital Elevation Model (ASTER GDEM) Version 2.0 and the Global Multi-resolution Terrain Elevation Data 2010.

2.2 Optical Sensor as QuickBird Satellite Image (Google Earth Pro)

The Google Earth (GE) Pro software tool has developed quickly and has been widely used in many sectors. The high spatial resolution images released from GE Pro., as a free and open data source, have provided great supports for the traditional land use land cover mapping. They have been either treated as ancillary data to collect the visualization for water area detection and validation or used as a visualization tool for water detection. The satellite image with the highest spatial resolution is QuickBird (QB) data. The QB image has four multispectral bands (red, green, blue, and near-infrared) and one panchromatic band, with a resolution of 2.62 m and 0.65 m, respectively (SIC, 2020).

2.3 Microwave Sensors as Sentinel 1 Synthetic Aperture Radar (SAR)

The Sentinel-1A satellite was developed by the European Space Agency (ESA) and launched on 03 April 2014. Then, the Sentinel-1B was launched on 25 April 2016 with the C-Band Synthetic Aperture Radar (SAR) that can acquire data in all kinds of weather conditions.

The availability of the new EO products, such as Sentinel-1A&B imagery, has the potential to facilitate flood and drought detection and monitoring of surface water changes because the data is dynamic in space and time (Bioresita et al., 2017). The Sentinel-1B Interferometric Wide swath mode is the wide operation mode for environmental monitoring and applications. This study uses Sentinel 1 data Interferometric Wide (IW) swath mode and level 1 with Ground Range Detected (GRD) products.

2.4 Global Navigation Satellite System (GNSS) receiver for Real-time Kinematic (RTK) Precise Positioning Data

The GNSS receiver is now becoming a low-cost device, with a smartphone size, GNSS receiver can be used for land and water mapping and civil engineering works (Anantakarn and Witchayangkoon, 2019). Applying an external GNSS antenna (Witchayangkoon, 2000), the available GPS App, and RTK software on Android OS, the GNSS receiver is a now more and more popular solution, including real-time RTK positioning and data collection for PPK (Anantakarn et al., 2019). Virtual Reference Station (VRS) is simply a method of Real-Time Kinematic (RTK) correction that requires the rover to send a position to the VRS network; the network then creates a virtual base near to the rover that is used for correction. All the communication is using a radio signal or internet connection, and a radio signal has distance limitation which is replaced by internet communication. Therefore, the Royal Thai Survey Department (RTSD) in Thailand has established the CORS networks that provide VRS/RTK networks via an internet connection to the land surveyor for cadastral mapping and civil engineering development.

2.5 Echo-sounder Sensor for Bathymetric Data Collection

In addition, unmanned surface vehicles (USV) are vehicles that operate on the surface of the water without a human operation for data acquisition. Because of the low-cost, easy, and capable features, so many unmanned surface vehicles have been developed and applied in many science and technology fields like geophysical exploration and environmental monitoring. A boat was developed as an unmanned operated boat that automatically navigated to selected destination points (Kaizu et al., 2011), the boat can measure the pollution of water such as dissolved oxygen and pH of the reservoir. The USV was designed as an automatic surface vehicle for coastal detection in taking photos (Subramanian et al., 2006). There was a GNSS system installing on the boat and a wireless internet connection for remotely controlling the system and navigating the vehicle. A single webcam camera is mounted in the front of the surface boat to assist in navigation. The images from the webcam camera provide a wide-angle view of the full image. An unmanned surface vehicle is called IRIS to survey pilot track lines for creating an environmental map of habitats in the bay of Florida, USA. The echo-sounder and topographic data were integrated for bathymetric mapping terrain analysis (Karim et al., 2017).

3 Methodology

Remote sensing method as satellite image collection and GNSS technology with echo-sounder data can be applied for mapping of water area as presented in Figure 1. Different date of satellite images and field survey using echo-sounder with GNSS receiver is used for bathymetric mapping the Water area of the reservoir in Nakhon Nayok province.

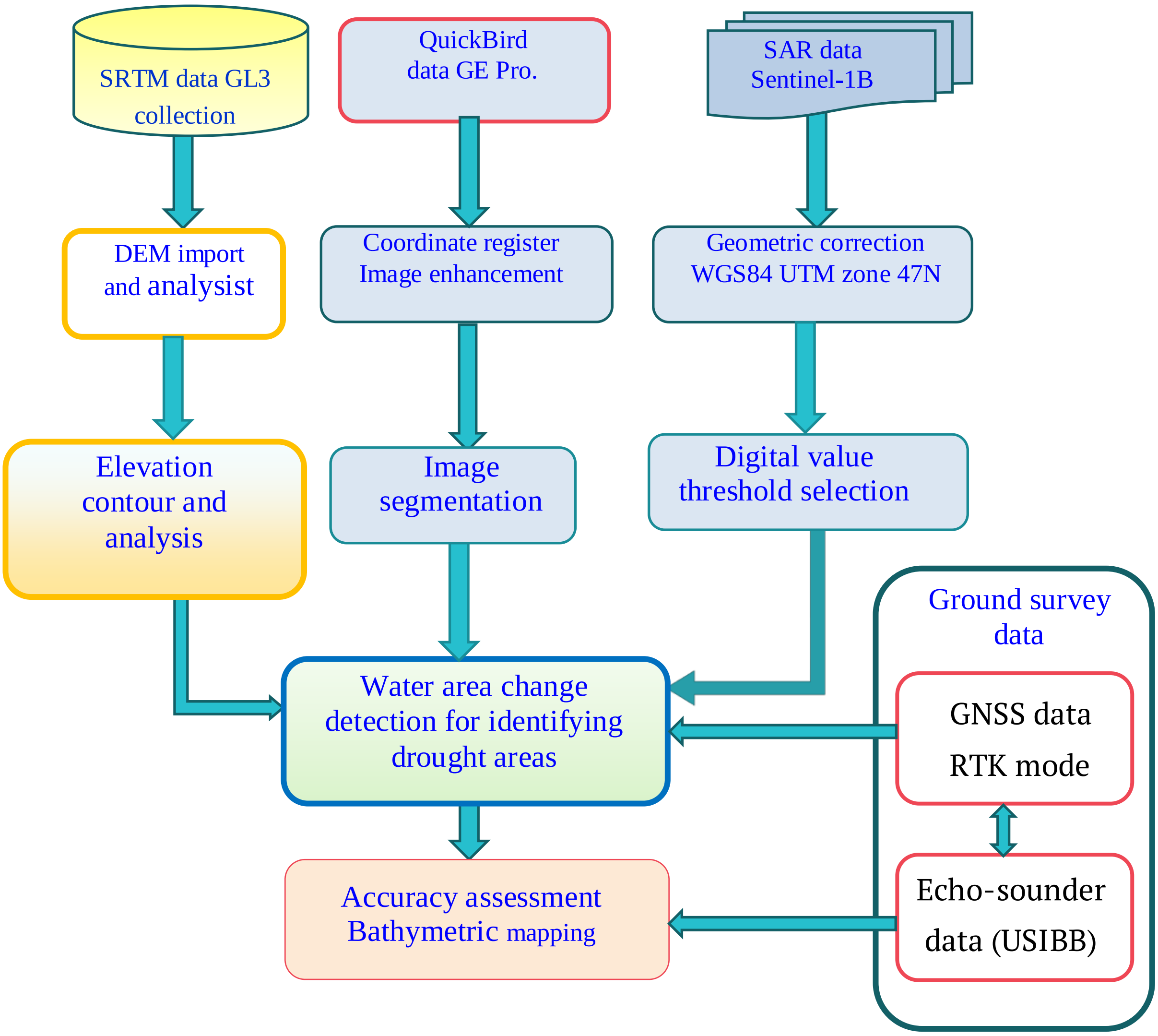


Figure 1: The main Methodology of the study (Source: the author)

In this study, we design and develop a floating boat Uthenthawai Smart IoT Bathymetry Boat (USIBB) is not required humans on the boat that has Echo-sounder and Global Navigation Satellite System (GNSS) system for bathymetric surveying.

Sentinel-1B SAR data were processed and analyzed by using free software ESA SeNtinel Applications Platform (SNAP) Version 8.0.5. Geographic Information System (GIS) data is analyzed and mapping by using Quantum GIS (QGIS) Version 3.14.

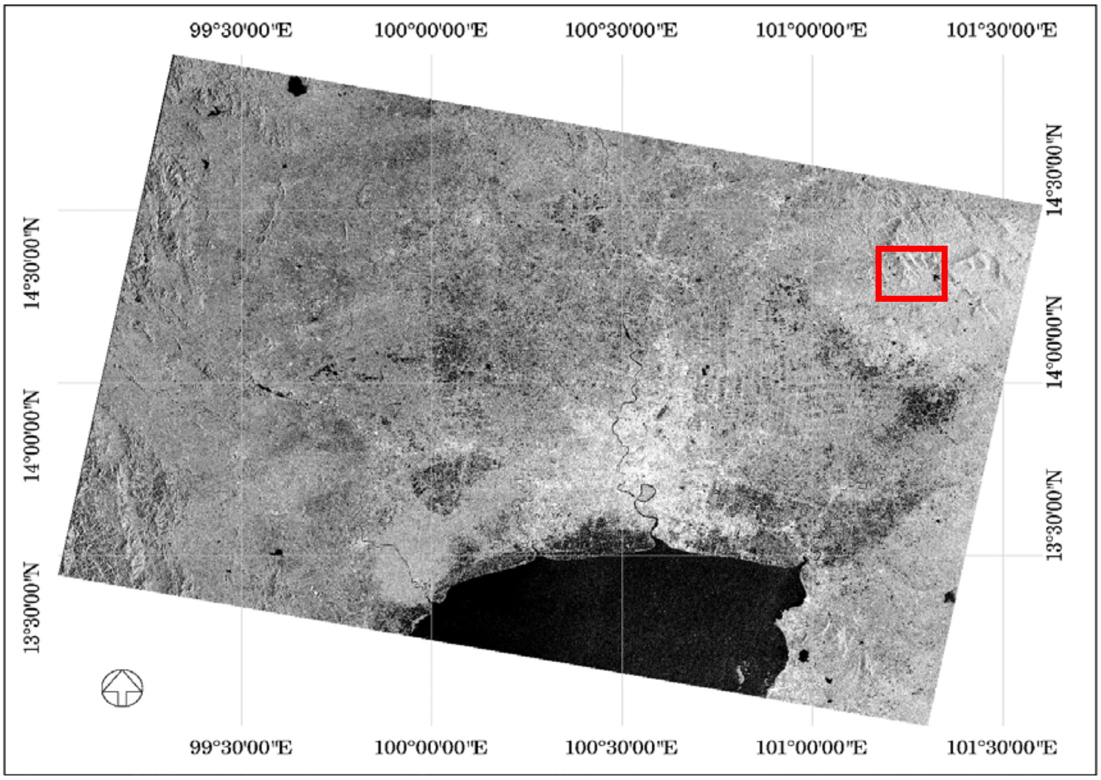
3.1 The Study Area

The study area is Huai Prue reservoir in Nakhon Nayok province, located in the central area of Thailand. The reservoir is for agricultural irrigation. The site is 120 kilometers Northeast of Bangkok and has geographic coordinates Latitude 14°18'47.50"N and Longitude 101°13'08.80"E.

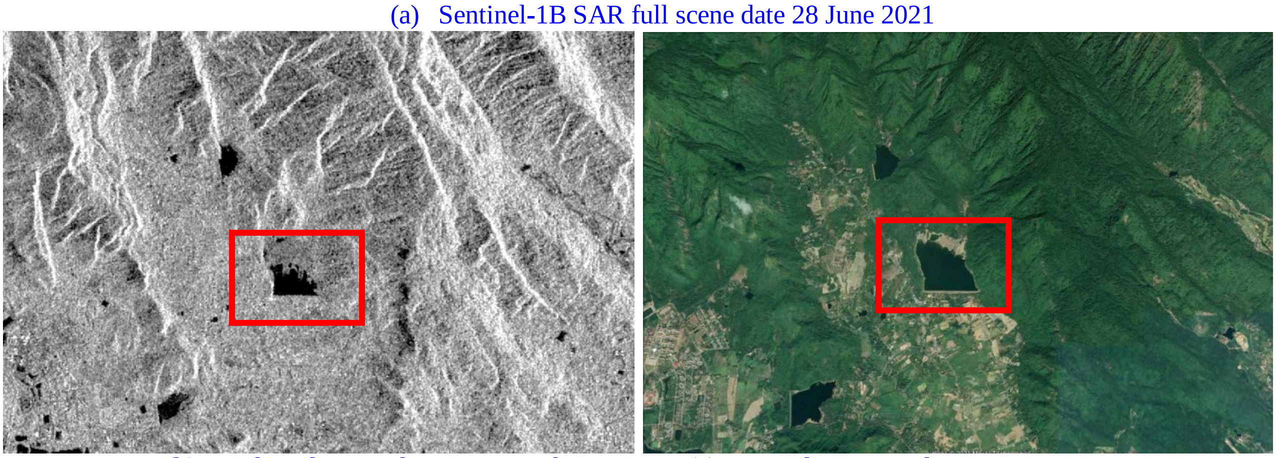
3.2 SRTM Topographic Data

SRTM Version 3 elevation data dated 22 February 2000 is the free-of-charge data provided at https://e4ftl01.cr.usgs.gov/MEASURES/SRTMGL1.003/2000.02.11/SRTMGL1_page_1.html. The data has a resolution of 30m x 30m with the WGS84 map project and Earth Gravitational Model 1996

(EGM96) vertical (geoid) datum. The data covers one degree of Latitude and Longitude, as a subset of the study area at Huai Prue agricultural reservoir.



(a) Sentinel-1B SAR full scene date 28 June 2021



(b) QuickBird image date 02 December 2019 (c) Sentinel-1B SAR date 28 June 2021

(d) GNSS data RTK mode water area check (e) Echo-sounder data (USIBB)

Figure 2: Multi-sensor data analysis for identifying the drought area.

3.3 Satellite image QuickBird Data

The QuickBird (QB) data is a high spatial resolution image, released from GE Pro. The QB satellite image with the highest spatial resolution is a free and open data source, which has provided great supports for the traditional land use/cover mapping. The data is used for visualizing water area detection and validation or used as a visualization tool for land use/cover maps. This QB data of the Huai Prue reservoir is acquired on 02 December 2019 as shown in Figure 2(c).

3.4 Sentinel-1B Synthetic Aperture Radar (SAR)

Sentinel-1B Level-1 Ground Range Detected (GRD) products consist of focused SAR data that has been detected, multi-looked, and projected to ground range using an Earth ellipsoid model. The resulting product has approximately square spatial resolution pixels and square pixel spacing 10m by 10m with reduced speckle. The data is High Resolution for Interferometric Wide (IW) swath mode with vertical-transmit and vertical-receive (VV) polarization. The data acquisition is updated on 28 June 2021 and with the ground survey data collection on 25 June 2021 as displayed in Figure 2(a). The Sentinel-1B of Huai Prue reservoir Figure 2(b) can be downloaded at ESA Copernicus Open Access Hub at https://scihub.copernicus.eu/dhus/#/home.

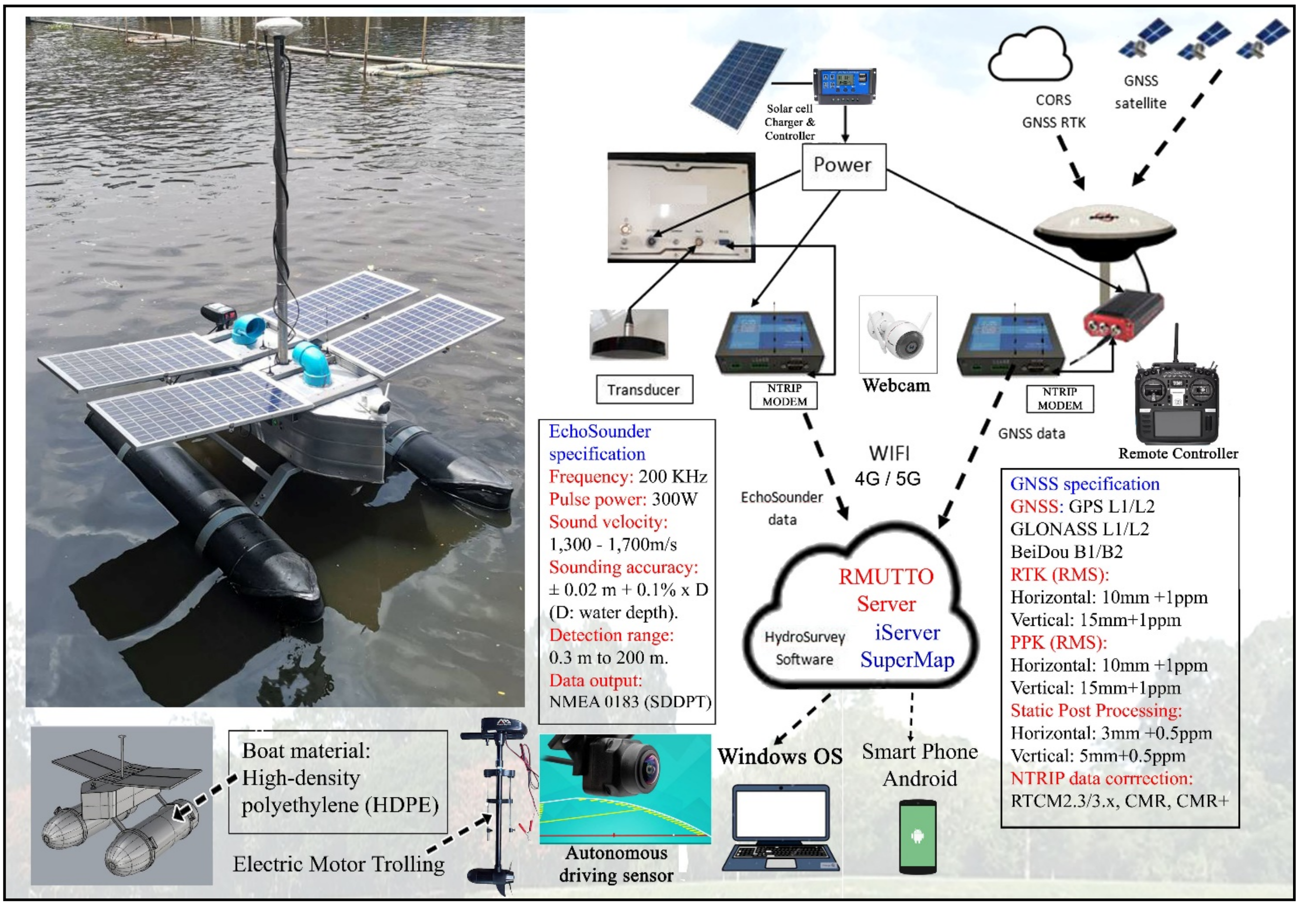


Figure 3: Design and development of USIBB for Echo-sounder and GNSS data collection

3.5 GNSS Data RTK Mode for Water Area Measurement

GNSS data RTK mode was recorded continuously for every 2 meters by walking on the bank of Huai Prue reservoir as presented in Figure 2(d). The GNSS data was at a precise level at Horizontal RMS less than 4cm by applying VRS/RTK networks provided by Royal Thai Survey Department (RTSD) facility CORS networks. The ground survey for GNSS data collection was on 25 June 2021, it can be the in-situ data as the ground survey was conducted on 25 June 2021 and Sentinel-1B SAR data was acquired on 28 June 2021.

3.6 Echo-sounder Data for Bathymetric Mapping

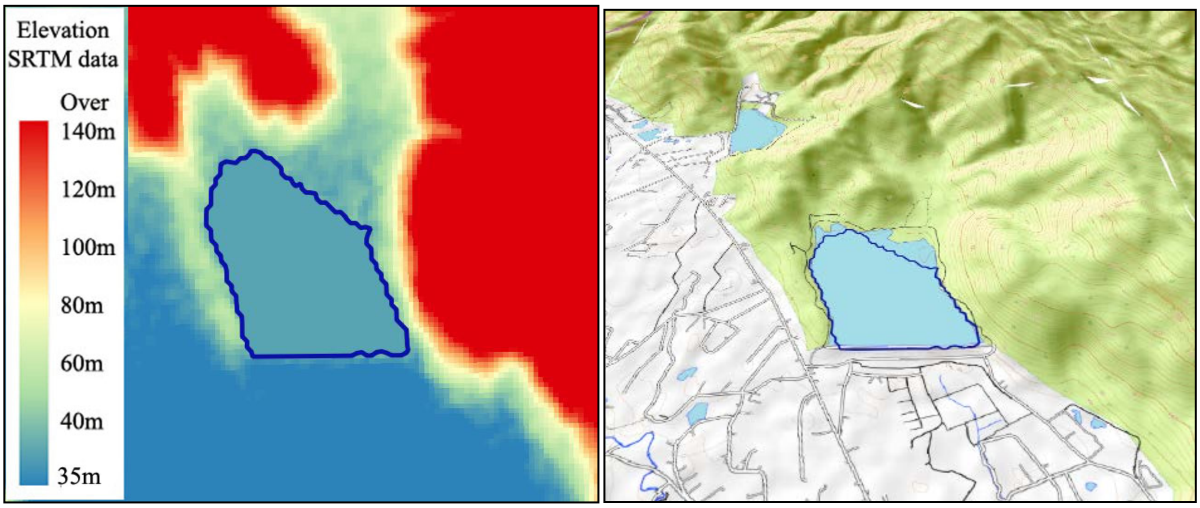
Uthenthawai Smart IoT Bathymetry Boat (USIBB) does not require humans on the boat that has Echo-sounder and Global Navigation Satellite System (GNSS) system for bathymetric surveying (Jawak et al., 2015). The Smart IoT Boat consists of Sounder Equipment and GNSS receiver is integrated and installed as illustrated in Figure 3. The data were recorded at 5 seconds intervals while the boat run crossing the path on Huai Prue reservoir as shown in Figure 2(e). The ground survey for echo-sounder data collection was on 25 June 2021.

4 Result and Discussion

Sentinel-1B SAR data were processed and analyzed by using free software ESA Sentinel Applications Platform (SNAP) Version 8.0.5. Geographic Information System (GIS) data is analyzed and mapping by using Quantum GIS (QGIS) Version 3.14.

4.1 Water area Detection from SRTM Topographic Data

The STRM data is at a resolution of 30m x 30m with map project as WGS84 and Earth Gravitational Model 1996 (EGM96) vertical (geoid) datum. The data dated 22 February 2000 covers one degree of Latitude and Longitude. It was a subset of the study area at Huai Prue agricultural reservoir. The elevation contour lines were generated from the DEM (SRTM data) raster extraction with the interval of one-meter height value. And the water area as an area with s slope equal to zero was detected at the elevation level 44m as illustrated in Figure 4(a) and the 3D perspective view of the reservoir as shown in Figure 4(b). The result shows that the water surface area of Huai Prue reservoir is (980,230.980 m^2) on 22 February 2000.

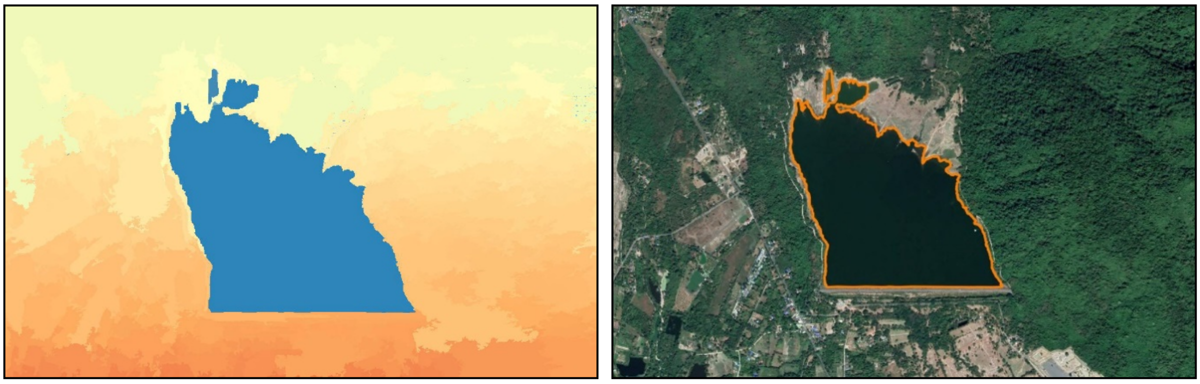


(a) Contour elevation at 44m SRTM data (b) Water area viewed in 3D perspective view

Figure 4: Water surface area identification (980,230.980 m^2) SRTM on 22 February 2000

4.2 Water Area Detection from QuickBird Data (GE Pro)

QuickBird data is a high spatial resolution image which GoogleEarth Pro acquires from an optical satellite sensor on 02 December 2019. The data is exported from GoogleEarth Pro software and natural color composite as three colors as red, green, and blue bands. This image was georeferenced in WGS84 UTM zone 47N and processed by using QGIS Version 3.1 Software. To extract the water area, the function image segmentation is the plugin of Orfeo ToolBox. This function allows performing various segmentation algorithms on a simple and common image. Available segmentation algorithms of the Mean-Shift segmentation algorithm produce the water area as the classified image of unique labels that can be identified the segmented regions as shown in Figure 5(a). The raster image of segmentation was vectorized into polygon vector format for overlay with the original image. This process is applied for accuracy assessment by visualization of the vector polygon overlaying on the background image. In Figure 5(b), the reservoir was full water as we can see the water area result got its maximum area on 02 December 2019 as on the QuickBird image. The result of this process produces that polygon vector of the water surface of Huai Prue reservoir with the water area as 890,404.541 m^2 on 02 December 2019.



(a) Raster image segmentation (b) Vectorized segmentation into polygon

Figure 5: Water surface area identification (890,404.541 m^2) from QuickBird image dated 02 December 2019.

4.3 Water Area Detection from Sentinel-1B SAR Data

Sentinel-1B SAR, acquired on 28 June 2021, is in GRD product and swath mode IW that covers approximately 250km x 200km with vertical-transmit and vertical-receive (VV). The Sentinel-1B was a subset in the Huai Prue reservoir area and performed geometric correction with terrain data supported algorithm to the map project WGS 84 UTM zone 47N for further GIS analysis. SAR data were processed by using SNAP Ver 8.0.5 for geometry and radar backscatter analysis. The radiometric correct was analyzed for selection threshold from digital value. The water body is visually identified in the range 30-100 value as displayed in Figure 6. The threshold function is clustering all the pixels with digital value (DN) from 30 to 100 into one group as water area, and the pixel with DN value is out of this range as less than 30 or more than 100 DN value as non-water area. Then water area as resulted in the yellow polygons as showed in Figure 6. These polygons attracted from Sentinel-1B SAR data are then compared with the ground survey as GNSS data RTK measurement mode. In comparison with QuickBird image date 02 December 2019, this finding shows that the water availability was significantly reduced as it was detected on 28 June 2021. The analysis found that polygon vector of the water surface of Huai Prue reservoir with the water area as 480,274.065 m^2 on 28 June 2021

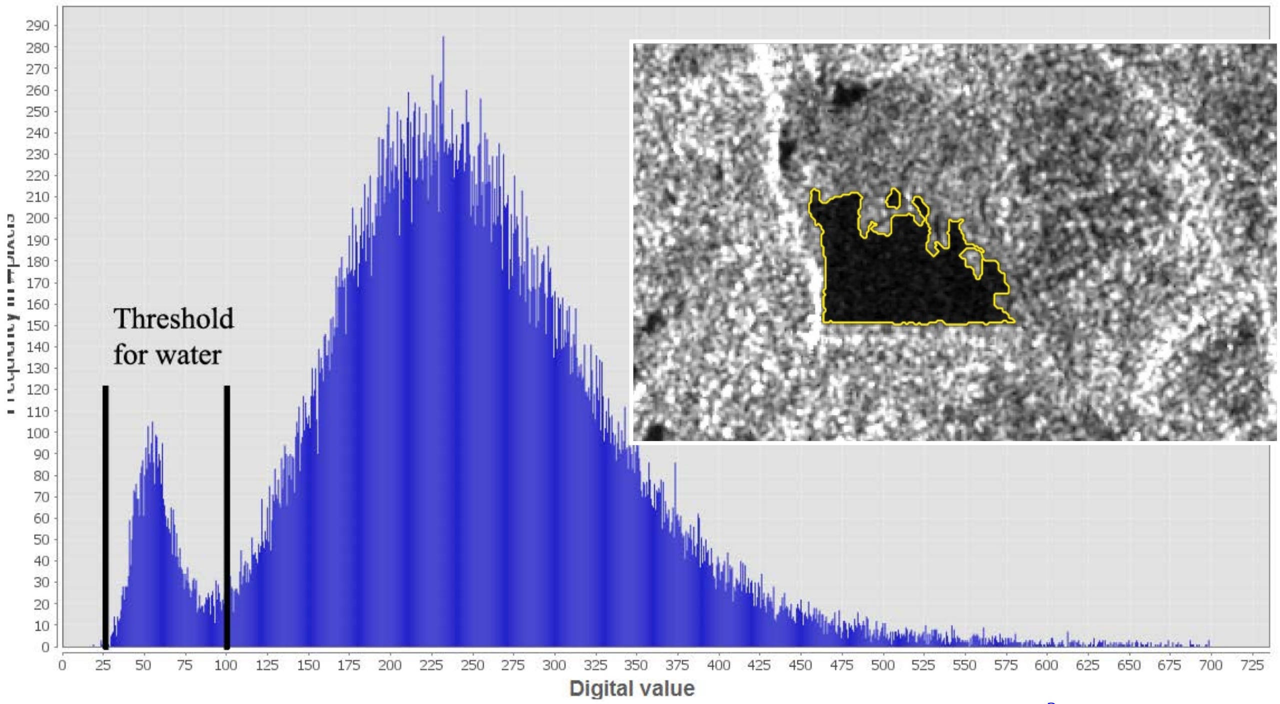
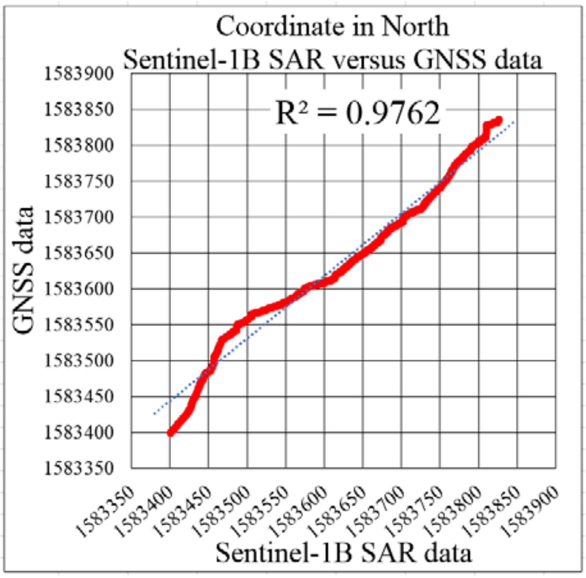


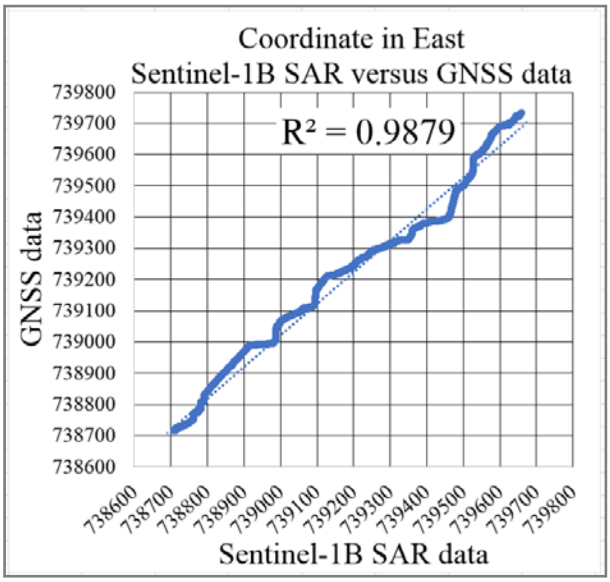
Figure 6: Histogram and threshold for identifying water surface area (480,274.065 m^2) dated 28 June 2021 as in yellow polygons

4.4 Accuracy Assessment by Using Ground Survey Data

The results of SRTM elevation, QuickBird image, and Sentinel-1B SAR data were compared to ground survey data with GNSS data RTK measurement mode and Echo-sounder of precise positioning and water depth data. As we apply the in-situ data as the ground survey was conducted on 25 June 2021 and Sentinel-1B SAR data acquired on 28 June 2021.



(a) Comparison of coordinate in North



(b) Comparison of coordinate in East

Figure 7: The correlation of positioning of Sentinel-1B SAR data and GNSS data RTK mode

The accuracy of water area detection from Sentinel-1B SAR data can be assessed by overlaid its boundary and GNSS data as presented in Figure 8. The GNSS data is graphed in a red color line and the water area detected from Sentinel-1B SAR is plotted in a yellow color line.

4.5 Bathymetric Map and Water Level Measurement by Using the Echo-sounder System

Uthenthawai Smart IoT Bathymetry Boat (USIBB) is the system with integration of GNSS data RTK mode (RTSD reference network) and Echo-sounder to measure the water depth and the position height values to calculate the reservoir floor elevation. These data were recorded in the 5-second intervals and the boat has traveled at the average speed of 0.7m/s with many crosses paths of Huai Prue reservoir. The reservoir floor values were recorded in elevation points (.csv format) and generated the bathymetric map by applying terrain analysis (GIS software). As triangulated irregular network (TIN) surface was generated for elevation map then elevation contour lines of the reservoir were generated as in Figure 8.

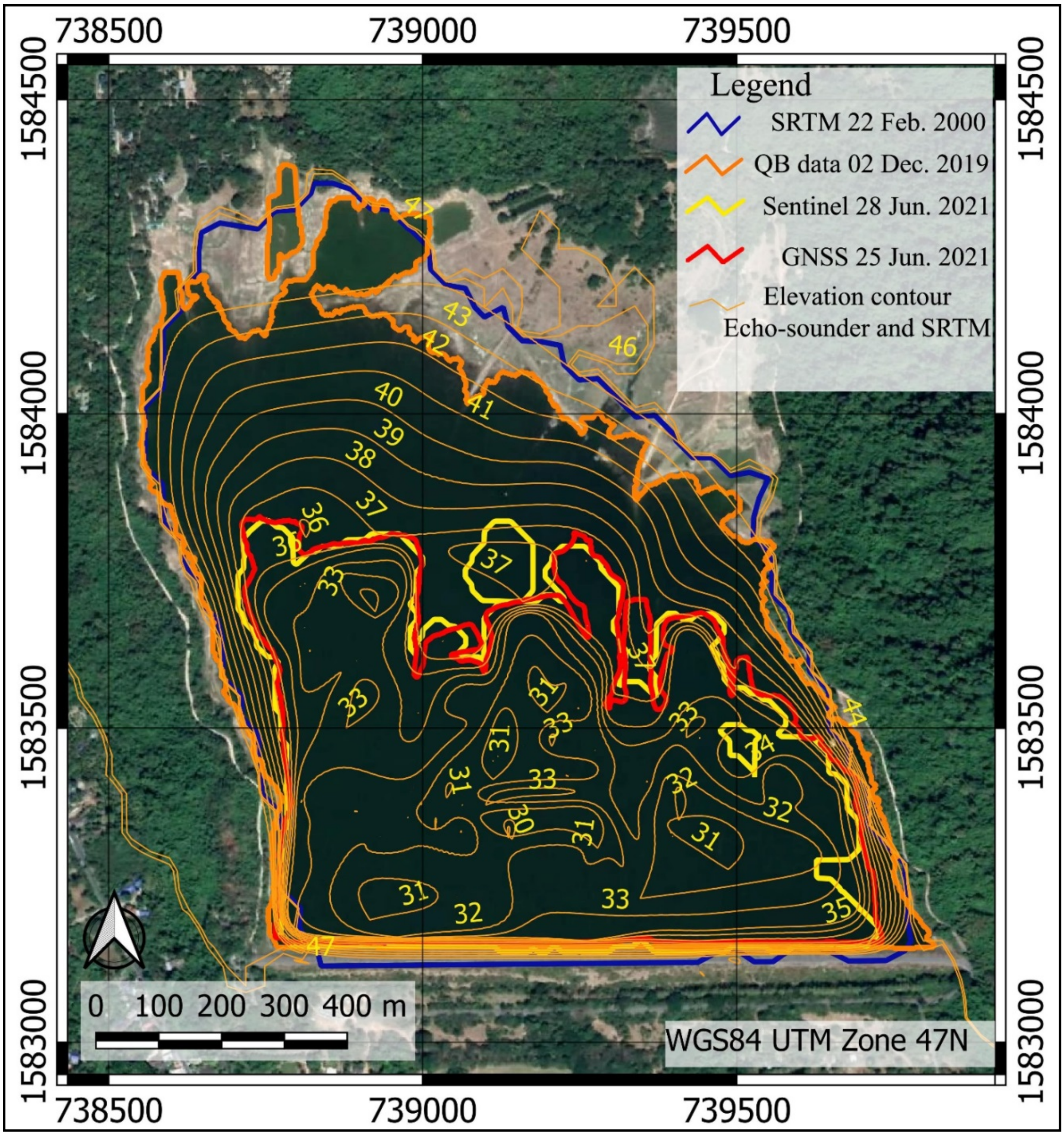


Figure 8: Bathymetric map with GNSS data RTK mode and Echo-sounder data.

5 Conclusion

During recent years, droughts, water shortages, and saltwater intrusion are more frequent and severe that has adverse impacts on the economy. As the weather and hydrological conditions changes all the time, a single sensor cannot meet the requirement of disaster monitoring. Droughts can be monitored as the reservoir water levels can be detected by multi-sensor data. These data have come from satellite microwave sensors as SRTM and Sentinel-1B SAR data, an optical sensor is QuickBird image, ground survey data with Echo-sounder and GNSS data. The research provides a processing method for multi-sensor data integration for water area detection.

The Sentinel-1B SAR data shows high accuracy and high correlations to coordinate positioning of GNSS data RTK mode and the correlation coefficients (R square) in linear regression is 0.9762 in North and 0.9879 in East. Water area identification on 22 February 2000 (SRTM data) as 980,230.980 m^2 that can be detected as 890,404.541 m^2 on 02 December 2019. This area is reduced to 480,274.065 m^2 on 28 June 2012 as analyzed on Sentinel-1B SAR data with a ground survey with Echo-sounder and GNSS data. The topographic map of these changes is plotted for accuracy and visualization assessment. The research also demonstrates the free data sources and free software function for remote sensing and GIS analysis.

6 Availability of Data and Material

Raw data and analysis data can be provided upon contacting the corresponding authors

7 Acknowledgment

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8 References

Anantakarn, K., & Witchayangkoon, B. (2018). Accuracy assessment of L-band Atlas GNSS system in Thailand. *International Transaction Journal of Engineering Management & Applied Sciences & Technologies, 10*(1), 91-98.

Anantakarn, K., Sornchomkaew, P., Phothong, T. (2019). Improve Quality of Global DEM for Topographic Mapping: Case Study of Petchaburi Province, Thailand. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 10*(9), 10A09H, 1-9.

Bioresita, F., Puissant, A., Stumpf , A., Male, J. P. (2017). Active and passive remote sensing data time series for flood detection and surface water mapping. *Geophys Res Abstr, 19,* EGU2017-10082

Jawak, S.D., Vadlamani, S.S., Luis, A.J. (2015): A Synoptic Review on Deriving Bathymetry Information using Remote Sensing Technologies. Models, Methods and Comparisons. Adv. Remote Sens. 2015, 4, 147–162.

Kaizu, Y., Iio, M., Yamada, H., Noguchi, N. (2011). Development of unmanned airboat for water-quality mapping. Biosystems Engineering, 109(4), 338-347.

Karim, H., Hashim, M.G., and Salleh, M.R. (2017). A Blending Technique for Topographic and Hydrographic DEMs for River Alignment Modelling. *Geomatics and Geospatial Technology (GGT) 2017*, Kuala Lumpur. ISPRS Archived.

Mukherjee, S., Joshi, P.K., Ghosh, A., Garg, R.D., Mukhopadhyay, A. (2013). Evaluation of vertical accuracy of open source Digital Elevation Model (DEM). *Int J Appl Earth Obs Geoinf*, *21*, 205–217.

Park, S., Im, J., Jang, E., & Rhee, J. (2016). Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. *Agricultural and forest meteorology*, *216*, 157-169.

Peter, S. J., De Araújo, J. C., Herrmann, H. J. (2014). Flood avalanches in a semiarid basin with a dense reservoir network. *J Hydrol (Amst)*, *512*, 408–420

Petiteville, I., Ward, S., Dyke, G., Steventon, M., Harry, J. (2015). *Satellite Earth Observation in Support of Disaster Risk Reduction*. Special 2015 WCDRR Edition, European Space Agency (ESA), 84p.

Rodriguez, E., Morris, C., and Eric Belz, J. (2006). A Global Assessment of the SRTM Performance. *Photogrammetric Engineering & Remote Sensing*, *72*(3), 249–260.

SIC (2020). *Satellite Imaging Corporation*. https://www.satimagingcorp.com/satellite-sensors/quickbird/

Subramanian, A., Xiaojin, G., Wyatt, C.L., Stilwell, D. (2006). Shoreline Detection in Images for Autonomous Boat Navigation. *Signals, Systems and Computers, 2006. ACSSC'06. Fortieth Asilomar Conference, Pacific Grove*, CA, USA., 1, 999-1003.

Witchayangkoon, B. (2000). *Elements of GPS Precise Point Positioning*. Ph.D. Thesis, University of Maine, USA. DOI: 10.13140/RG.2.1.3282.6402

YongJin, Y. (2020). *History of Drought in Thailand*. https://borgenproject.org/ drought-in-thailand/

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