論 文 内 容 の 要 旨

Abstract

Floods are one of all the major natural disasters, affecting to human lives and economic loss. Understanding floods behavior using simulation modelling, of magnitude and flow direction, is the challenges of hydrological community faces. Most of the floods behaviors are depended on mechanism of rainfall and surface data sets (topography and land cover) that is specific for some area on ground truth observation data. Remote sensing datasets possess the potential for flood prediction systems on a spatially on datasets. However, the datasets are confined to the limitation of space-time resolution and accuracy, and the best apply of these data over hydrological model can be revealed on the uncertainties for the best flood modelling. Furthermore, it is important to recommend effective of data collecting to simulate flood phenomena. For modelling nearby the real situation of the floods mechanism with different data sources, the difficult task can be solved by using distributed hydrological models to simulate spatial flow based on grid systems. Therefore, the objective of this dissertation is to contribute the correction and evaluation of remote sensing sources for flood prediction through basin scales, and application of the model to demonstrate the approach of flood risk estimation method on small area. It also aims to present and create general methodology for runoff analysis using the remote sensing data sources to model the flood simulation.

Table content

1. Introduction

Floods are one kinds of disaster around the world, affecting to human lives and make economic losses. Flood mitigations have two guidelines, structural and nonstructural, are selected by social and also investment. To minimize resistance from stakeholder of flood mitigation project, the nonstructural is the essential for decreasing flood damage using flood forecasting which use flood simulation for decision and design. Understanding floods behavior using simulation modelling, of magnitude and flow direction, is the challenges of hydrological community. For actual of flood behavior in magnitude, the best input dataset are ground truth observation data, rain gauge, topographical and land cover data. The flow direction of the actual flood mechanism is spatial heterogeneity to represent on quadrate grid system. The flood modeling to conform to real situation has two components, input dataset and flow distribution algorithm. This mechanism of flow distribution can be modeled by using distributed hydrological modelling, to require the spatial input data. The ground truth dataset, rainfall, elevation and land use, is normally observed based on point data, are specific in some convenient area.

Floods modeling have been gotten on the barriers because of non-spatially datasets, rainfall and ground surface, all of which are usually observed by remote sensing. Remote sensing datasets possess the potential for flood prediction systems on a spatially on datasets. However, the datasets, satellite base rainfall, digital elevation model and global land cover, are confined to the limitation of space-time resolution and accuracy. The best application of these data over hydrological model for the flood prediction can be revealed on the uncertainties for the best flood modeling. Furthermore, it is important to recommend effective of data collecting to simulate flood phenomena. For modeling nearby the real situation of the floods mechanism with different data sources, the difficult task can be solved by using distributed hydrological models to simulate spatial flow based on grid systems.

Remote sensing technology provides key information for evaluating the local, regional, and global water balance. These datasets can potentially be used to predict floods, but some limitations are imposed by the coarse resolution of the information in space and time, the sampling interval, and retrieval uncertainties. To optimally apply these data, it needs to understand the information content of each dataset and determine the best way to apply them specifically to flood prediction. In some cases, the monitored information (e.g digital elevation model and precipitation) is directly used in the flood prediction model. In other cases, the remote sensing information is used as forcing for continental scale land surface models that perform water and energy flux analysis. The outputs of these models are potentially useful for flood prediction (e.g. soil and surface moisture states, vegetation interception, actual evaporation). Even when uncertainties are involved, these models are able to capture anomalies in terms of runoff conditions.

2. Research objective

The objective of this research is to contribute the correction and evaluation of remote sensing sources for flood prediction through basin scales, and application of the model to demonstrate the approach of flood loss estimation method on small area. This research mainly motives to explore uncertainties in flood simulation caused by limitations of data, accuracy or resolution of source. It will similarly to present and create general methodology for runoff analysis using the remote sensing data sources to model the flood simulation. Therefore, the remote sensing datasets can be used to predict floods with an acceptable level of accuracy, and the specific goal of this work is to reveal the remote sensing data for basin area of flood simulation as closely as possible. In order to achieve the goal, this study is to follow research question:

1. How do flood simulation based on hydrological modeling, using satellite remote sensing datasets?
2. What are the effects of DEM sources on flood estimation?
3. What are the impacts of surface roughness based on different land cover sources on flood simulation results?
4. What are the results from different rainfall sources driven by the Distributed Hydrological modeling?
5. What are the applications of flood modeling approaches for estimating floods to map flood hazard to analyze flood damage?

In order to receive the answers of research question based on the main objective. Specific objective as following:

1. To apply the distributed hydrological model as the Rainfall-Runoff-Inundation model that is a combination of rainfall-runoff processes and flood modeling.
2. To explore the accuracy, bias correction of DEM data set and to evaluate flood simulation results from different topography sources.

3. To explore the accuracy of both approaches, satellite land cover data sources and surface roughness coefficient, and to evaluate flood modeling results from different surface roughness data sets.
4. To explore the accuracy of rainfall sources, rain gauge spatial, satellite, and simulated products, investigate bias correction of the satellite rainfall product as a demonstration, and evaluate runoff simulation results from different rainfall sources.
5. To apply of flood simulation model for water resource management in flood hazard mapping for flood damage cost estimation.

3. Methodology (Scope of the dissertation)

The geographical point of this study is the Yoshino river basin in Japan and the Upper part of Nan river basin in Thailand which are representative of flood disaster area. First, Yoshino river basin is rich in high resolution of temporal and spatial data in hydrologic information. Second, Nan river basin has low resolution datasets. This datasets all of both areas will be used to evaluate accuracy of remote sensing data and to verify flood simulation. In this study, it proposes an implementation of the remote sensing datasets to input to distributed hydrological model including inundation processes, Rainfall-Runoff-Inundation (RRI) Model, to obtain analytical result of flood characteristic in the river basin and local area. The satellite base rainfall is the spatial and up-to-date data, have explored more ten years ago.

The six rainfall products were used in this study, of which two are high resolution dataset and three are low resolution dataset. The accuracy of each product was assessed at time scale by comparing with the rain gauges. Using the six products as input to the RRI model, their outputs have performed an accuracy assessment with observation discharge at runoff station on the five performance statistical coefficients.

Global Precipitation Measurement (GPM) is a high resolution on temporal scale, which is moderately significant for effective uses such as flash flood warning systems. Tropical Rainfall Measuring Mission (TRMM), which is one type of the satellite base rainfall, has been observed since 1998. CPC Morphing Technique (CMORPH) is a global precipitation analyses for real-time monitoring of global scale developed by NOAA's Climate Prediction Center [CPC]. The CMORPH resolution of 0.25 degree spatial and 3-h temporal product is implemented. Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) is a satellite-based precipitation product that are implemented by using the artificial neural networks (ANN) to estimate rainfall intensity based on merged infrared product of brightness temperature from geostationary satellite. Grid Point Value (GPV) data provided from Japan Meteorological Agency (JMA) calculated with Global Spectral Model (GSM) and MesoScale Model (MSM).

Six open source DEMs are represented by the different contained accuracy and coverage were invested for this study. The 10m-mesh DEM have been provided from GSI the Geographical Survey Institute (GSI) of Japan (GSI-DEM), with scales between 1:5,000 and 1:25,000. The Advanced Space Borne Thermal Emission and Reflection Radiometer-Global Digital Elevation Model (ASTER GDEM) was established from two international agencies, the METI (Ministry of Economy, Trade, and Industry) of Japan and the NASA (National Aeronautics and Space Administration). The topography represented by digital elevation model (DEM) is Shuttle Radar Topography Mission (SRTM) in the year 2000, which is a useful produce for application fields. The SRTM DEM has the resolution about 90 meters, is a source of surface data for flood modelling. The Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) has been published by the U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA). GMTED2010 was firstly provided on 2010 that GTOPO30 at 30 arc-seconds data (GTOPO30) was reconstructed for a new digital global elevation model. Hydrological data and maps based on Shuttle Elevation Derivatives at multiple Scales (HydroSHEDS) is provided as reconstructed from elevation data of the Shuttle Radar Topography Mission (SRTM) based on the 3 arc-second resolution that hydrologically conditioned is a main procedure to apply void-filling, filtering, stream burning, and upscaling techniques. Global 30Arc-Second Elevation (GTOPO30) is published from U.S. Geological Survey for free available on 1993 to represent a global digital elevation model (DEM).

In this study, two land cover data sources (MODIS and AVHRR) are selected to evaluate the flood modeling. Moderate Resolution Imaging Spectroradiometer (MODIS) data have spatial resolution from 250 m to 1 km and offer the possibility for time series coverage at moderate resolution. MCD12Q1 is one of global MODIS land cover product, which data product is generated at annually over ten years using a supervised classification. The global land cover classification (GLCC) is presented for land cover data, provided in 2008. The GLCC based on 1 kilometer of resolution is Advanced Very High Resolution Radiometer (AVHRR) NDVI composites, this data set is used in the land cover characterization.

The dissertation comprises of 7 chapters are outline in **Figure 1** that in **Chapter 1**, the motivation and research problem is presented, the research objectives are also started in this chapter. **Chapter 2** is the modification and implementation of distributed hydrological modeling (RRI model) that are included by the GPU coding for speedup and VOXEL model for convenient on input and output. **Chapter 3** presents the accuracy of the six DEM sources evaluated by the referent elevation points that are used to estimate bias correct coefficient based on the linear transformation, and then the data are driven by the distributed hydrologic model (RRI) to reveal the impact of the topography sources. **Chapter 4** shows the performance of land cover data sets to estimate the surface roughness on the Manning's coefficient that area used to drive in the RRI model for presenting an uncertainty. **Chapter 5** has three topics as evaluation of rain gauges spatial distribution algorithms, remote sensing data sets, and bias correction methods, based on the RRI model results (runoff data). **Chapter 6** is the application of the remote sensing data sets on flood forecasting and flood risk assessment. **Chapter 7**, the main contribution are summarized. In the chapter, the conclusions and recommendations are explained. The details of the each chapter are descripted in below.

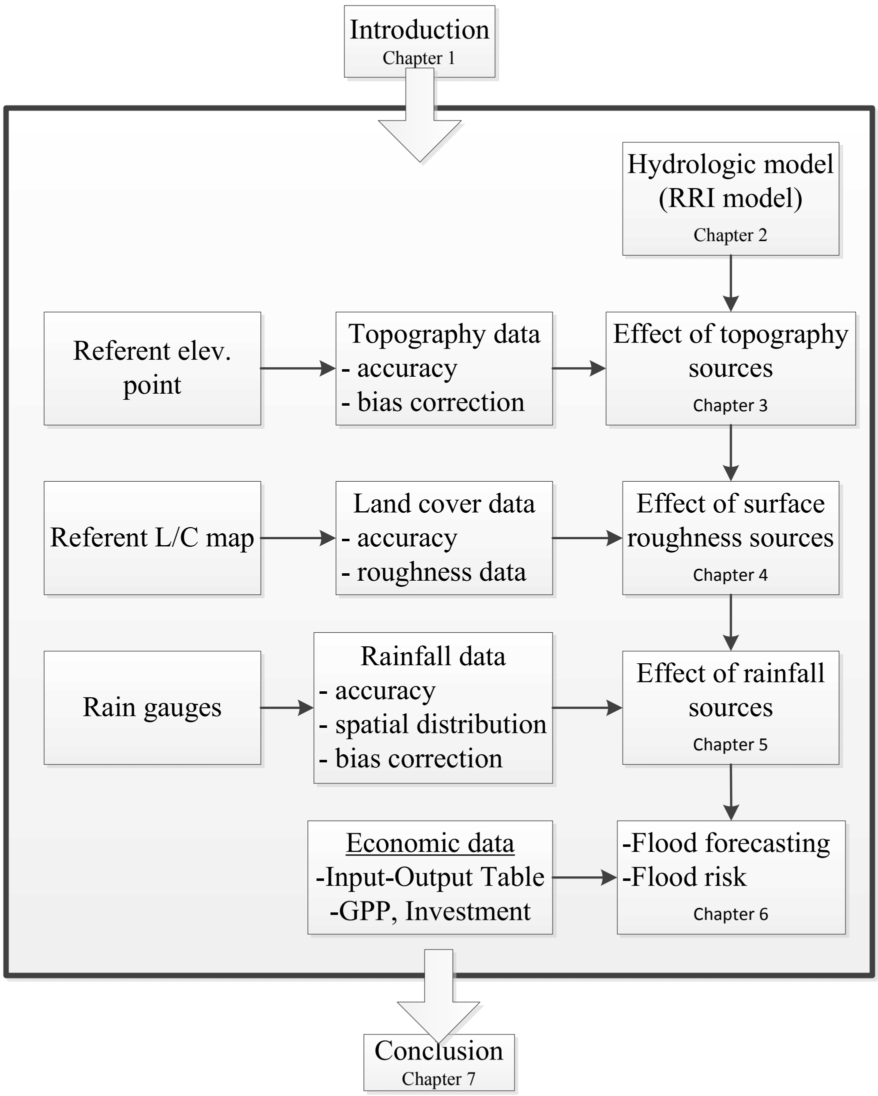

Figure 1 Outline of the dissertation

4. Hydrological modeling (Chapter 2)

Developing a distributed hydrologic model (RRI model) in modification and implementation formwork was presented. The framework consisted with three modules: (i) VOXEL model assisted the RRI model such as input and output data sets; (ii) GPU coding based on the NVIDIA CUDA was applied into the RRI model to accelerate the computed time, and (iii) the satellite data sets were implemented in flood simulation by using the RRI model. The VOXEL model as a 3D array was used to integrate the data sets in two groups, watershed data (DEM and Land cover) and rainfall data (spatial and temporal), for the input data, and the output data were runoff and inundation depth in spatial and temporal scale. Second, the GPU on NVIDIA CUDA coding could made a speedup is about 2.6x on the complex terrain represented by the Nan river basin area, with two resolution size (500 m and 1,000 m). Finally, the RRI model was demonstrated by using the satellite data sets such as SRTM DEM (topography), GLCC (land cover), and TRMM (rainfall). This module presented the method for setup model parameter as Manning's coefficient of land cover surface, Green-Amp parameter of soil type, and dimension of river.

5. Bias correction of DEM sources and their effect on runoff estimation and inundation area (Chapter 3)

The investigation of DEM affect to accuracy, bias correction, and flood estimation, was assessed. The accuracy assessment was done by using the field observation data sets, referent elevation points, referent land cover map, and rain gauges. The accuracy of three variables evaluated a performance with statistical approach. The DEM data validated the accuracy only the Shikoku area where the GCPs points have been surveyed by the GPS. From six candidate DEMs were GSI-DEM, ASTER GDEM, SRTM, GMTED2010, HydroSHEDS, and GTOPO30, that the GSI-DEM was a high accuracy among the five DEMs. However, the high accuracy DEM was only provided in Japan, for the international open sources, the ASTER GDEM was the high accuracy. For DEM data sources, a spatial linear transformation was implemented to correct the elevation of the DEMs. The correction algorithm could improve the accuracy responding with the coarse resolution DEMs (HydroSHEDS and GTOPO30), while the high resolution (GSI-DEM, ASTER GDEM, SRTM, and GMTED2010) had a small sensitivity. The bias correction DEMs was investigated on the effect to estimate runoff and inundation area. Based on the DEM data and simulation results, Shikoku is the mountain complex terrain to contain with a steep slope, while Nan river basin is the mountain area where represent with the mild slope. In the Shikoku Island, ASTER DEM is suitable to apply for runoff simulation using distributed hydrologic modeling, have estimated from stereo matching. SRTM presented a performance for runoff and inundation simulation in the Nan river basin, have explored from LiDAR laser scan with Shuttle.

6. Estimation of surface roughness based on land cover data sets and their effect on the distributed hydrologic model simulation (Chapter 4)

The second variable as the land cover data, MODIS and AVHRR land cover products were collected and evaluated for the both study areas. MODIS with MCD12Q1 outperformed the AVHRR products on the both sites. The satellite based land cover data sets were used to represent a surface roughness based on the Manning's coefficient that is the important parameter for runoff estimation. The Manning's coefficient produced from the MODIS data also showed higher performance than the AVHRR roughness products. The significant performance of satellite remote sensing data run by the GPU-RRI model is implemented in investigating the impact of corrected and estimated on satellite products sources. The evaluation of the different in runoff results when using the three Manning's coefficient map from satellite and aerial observation in distributed hydrologic model as RRI model is involved. This investigation recommends the use of MODIS, AVHRR or other Manning's coefficient estimation approaches for large watersheds provide a reasonable estimate of Manning's coefficient for simulating runoff hydrographs. Manning's n coefficient based on the MODIS presented higher performance than the AVHRR that was evaluated by using runoff data estimated from the hydrological modeling.

7. Evaluation of different bias correction methods of satellite rainfall sources and their impact on the distributed hydrologic model (RRI model) results (Chapter 5)

The significant performances done by accuracy assessment of rainfall sources were assessed by three modules: (i) evaluating the best spatial interpolation algorithm for rain gauges, (ii) investigation the high performance of satellite rainfall products and (iii) correcting methodology of satellite rainfall. The rain gauge data sets as a point data were interpolated into grid data sets with five algorithms, Inverse Distance Weight (IDW), Thiessen Polygon (TSP), Simple Kriging (SKG), Ordinary Kriging (OKG), and Surface Polynomial (SPL).

The IDW outperformed as high performance algorithm in the Shikoku area that represented with the dense rain gauge network area, while the sparse rain gauge network area was the Nan river basin that the SKG was suitable algorithm. According to considering in the situation of rain gauge network, the Shikoku Island is dense area of rain gauge data, while

Nan river basin is a sparse rain gauge data. The IDW was also suitable method for interpolating from point to grid and simulating runoff on flood event, for the Shikoku area. In the Nan river basin, The SKG interpolated with semi-variogram model had performance to establish a rain gauge spatial distribution and estimate runoff with the GPU-RRI model.

Satellite and simulation based rainfall data sets as GPV, GPM, GSMaP, TRMM, CMORPH and PERSIANN, evaluated the accuracy using the rain gauges data sets as point data. For the high resolution data, GSMaP showed the high accuracy for the Shikoku in Japan, while CMORPH outperformed among other sources in the Nan area in Thailand, on the international sources. According to specify in the Shikoku area, the GPV outperformed among the five remote sensing data, but it has been only provided in Japan. The hydrological model (RRI model) was driven for flood events that the different five rainfall spatial interpolation products were simulated on a temporal scale to match the observed streamflow data. For satellite based rainfall products, GPV and GSMaP in Japan and GPM in Thailand as the high resolution data showed a performance to simulate runoff on the hydrological modeling. For low resolution of satellite rainfall, TRMM presented high performance.

Developing a bias correction method of satellite data sets to make more their accuracy was investigated. The bias correction method evaluated with five algorithms (Mean ratio, Geometrics transformation, Linear transformation, Data assimilation, and Quantile mapping) and two schemes (Temporal and Spatial), only GPM and TRMM in the Nan river basin, Thailand as the demonstration. The temporal scheme had better suitable method than the spatial scheme in small different to compare with rain gauge data. The three algorithms (Linear, Geometrics, Data assimilation) showed the high performance among ten candidate algorithms, resulting in runoff products. The bias correction module has only demonstrated in the Nan river basin, spatial bias correction scheme is higher performance than Time series scheme. Bias correction with Data assimilation algorithm is suitable for supervised method, while an unsupervised method is Linear and Geometrics transformation algorithm.

8. Application of satellite data sets for flood simulation (Chapter 6)

The application of flood simulation has two main approaches: flood forecasting and flood risk assessment. The first approach, the river basin scale simulation is run as firstly that is uses to identify as the boundary condition of small area to reveal a high resolution results. The methodology of simulation in specific area to make more resolution of the results was the point for this approach to present a flood hazard map. The second approach based on small area results, the flood risk assessment consist hazard and vulnerability data. The high risk is identified as maximum hazard and vulnerability, but minimum on both data is low risk. The classification of risk level is modeled by the decision tree model to create the flood risk map. The streamflow for estimating the flood risk map was the main point of this approach.

9. Conclusion and recommendation for further studies (Chapter 7)

Outcomes of this research are improved satellite remote sensing data sets by providing increased accuracy performance on flood simulation, improved quantification of flood uncertainty, and a understanding of flood forecasting and risk assessment. Significant contribution proposed in this dissertation should contain:

- VOXEL model and GPUs have potential to assist the hydrological modeling for input and output data
- Accuracy of satellite data sets were revealed by using the field observation data based on statistical approach.
- Bias corrections with transformation methods have efficiency to make more accurate precision values.
- Satellite data sets were applied to simulate and evaluated for flood estimation by using hydrologic model.
- Hydrologic flood model with satellite data sets were implemented for flood forecasting and risk assessment as demonstration.

Future work covering this study should contain:

- The next generation of GPU implementation in hydrological modeling has more potential development in high level computer language and new hardware technology.
- The land cover evaluation is needed to confirm this observation for different watersheds and different method for estimating Manning's coefficient.
- The bias correction studies should assess comparative advantage of complex algorithm in mathematics of bias correction techniques, and application in a radar rainfall study.
- The risk assessment used two dimensions for validation, is needed to include the frequency and temporal magnitude for assessing the flood risk map to make more accuracy of flood management.

10. LIST OF PUBLICCATION

<u>Dissertation submitted for the degree</u>

1. Title: Spatial Bias Correction of Satellite Data Sets for Reginal Flood Assessment: The data sets evaluated on accuracy assessment with field observation data and on flood estimation using hydrological modeling.

<u>Peer reviewed papers:</u>

1. K. Pakoksung, M. Takagi, 2015, Remote Sensing Data Application for Flood Modeling: JAST, 26, 115-122.
2. K. Pakoksung, M. Takagi, 2015, DIGITAL ELEVATION MODELS ON ACCURACY VALIDATION AND BIAS CORRECTION IN VERTICAL: Modeling Earth Systems and Environment, 2(1), 1-13. DOI :10.1007/s40808-015-0069-3
3. K. Pakoksung, M. Takagi, 2016, Assessing Flood Losses in Thailand, using Remote Sensing Data and Input-Output Table: Journal of Society for Social Management Systems. 2015 (**accepted**).
4. K. Pakoksung, M. Takagi, 2016, Efficient River Basin Scale Runoff Simulation using GPUs-accelerated Rainfall-Runoff-Inundation Model: *Environmental Earth Sciences journal* (**submitted**).
5. K. Pakoksung, M. Takagi, 2016, Assessment and Comparison of Digital Elevation Model (DEM) Products in Varying Topographic, Land Cover Region and Its Attribute: *Journal of the Indian Society of Remote Sensing* (**submitted**).
6. K. Pakoksung, M. Takagi, 2016, Effect of Spatial Distribution of Ground Rainfall Products on River Basin Responses of a Distributed Hydrological Model: *Journal of Spatial Hydrology* (**submitted**).
7. K. Pakoksung, M. Takagi, 2016, Effect of Satellite Based Rainfall Products on River Basin Responses of Runoff Simulation on Flood Event: *Hydrological Sciences Journal* (**submitted**).
8. K. Pakoksung, M. Takagi, 2016, Modeling the Distribution of Rainfall Intensity using Daily Data: *Engineering Journal* (**submitted**).
9. K. Pakoksung, M. Takagi, 2016, Effect of Land Cover based Surface Roughness on Runoff estimation : (in **preparing**)
10. K. Pakoksung, M. Takagi, 2016, Effect of Bias Correction Methodologies on Runoff estimation : (in **preparing**)
11. K. Pakoksung, M. Takagi, 2016, Flood simulation in small area based on the condition data from river basin area : (in **preparing**)
12. K. Pakoksung, M. Takagi, 2016, Flood hazard and risk assessment in small area based on the macro economic data : (in **preparing**)

<u>Oral presentation on conference:</u>

1. K. Pakoksung, M. Takagi, 2014, Satellite Based Application for Flood Simulation, Asian Association on Remote Sensing 2014, Oct 2014, Nay Pyi Taw, Myanmar.
2. K. Pakoksung, M. Takagi, 2015, Vertical Accuracy Validation of Digital Elevation Models (DEMs) in Shikoku Island, Japan, Asian Association on Remote Sensing 2015, Oct 2015, Manila, Philippines.

<u>Poster presentation:</u>

1. K. Pakoksung, M. Takagi, 2015, Remote Sensing Data Application for Flood Modeling, 23-IIS-forum, Tokyo, Japan.
2. K. Pakoksung, M. Takagi, 2016, VOXEL Model Assisted Distributed hydrological Modeling, 24-IIS-forum, Tokyo, Japan.

11. CURRICULUM VITAE

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Feb, 2001	-same as above- (graduated).
Jun, 2001	Master's degree, Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Thailand (enrolled).
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Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Thailand, "HYDRAULICS BEHAVIOR OF FLOW THROUGH AN OUTLET WORK : CASE STUDY OF NONG KHO RESERVOIR" involved in during Master's program.

Oct, 2013 – present

Special Scholarship Program (SSP), Infrastructure Systems Engineering, School of Engineering, Kochi University of Technology, "Spatial Bias Correction of Satellite Data Sets for Reginal Flood Assessment: The data sets evaluated on accuracy assessment with field observation data and on flood estimation using hydrological modeling" involved in during Doctoral program.