SO_2 DISPERSION MODELING EMITTED FROM HONGSA COAL-FIRED POWER PLANT TRANSBOUNDARY TO NAN PROVINCE, THAILAND

Supawan SRIRATTANA[1], Kitsanateen PIAOWAN[2,3]

DOI: 10.21163/GT_2020.151.09

ABSTRACT:
Coal-fired power plant in general is a major source of sulfur dioxide (SO_2) emission. SO_2 is a primary pollutant and known as a respiratory irritant. The aim of this paper is to present the methodologies and results of an application of the dispersion modelling AERMOD as a potential model to predict the air quality impacts of SO_2 released by the flue stack of Hongsa coal-fired power plant (HCPP) located in Lao People's Democratic Republic (Lao PDR) transboundary to five villages in Chaloem Phra Kiat district, Nan province, Thailand during dry season (October to February) between 2015 and 2017. The results show that the hourly and daily modeled maximum ground-level concentrations of SO_2 were lower than Thailand's air quality standard, at 780300 and µg/m^3, respectively. The highest hourly and daily SO_2 concentration were found at Ban Nam Ree village in January as high as 92.254 and 5.021 µg/m^3, respectively. In contrast, SO_2 deposition, Ban Huai khon village was modeled to suffer from the highest impact from SO_2 deposition as 0.003 g/m^2 via dry deposition.

Key-words: *Coal-Fired Power Plant, AERMOD, Transboundary, SO_2.*

1. INTRODUCTION

HCPP operated by Banpu Power Limited (BPP), RATCH Group (formerly named as Ratchaburi Electricity Generating Holding Public Company Limited (RATCH)), and Lao Holding State Enterprise (LHSE) in Sayabouri province, Lao PDR (Banpu Power Limited, 2007) **(Fig. 1)**. At this time, Lao PDR's highest-capacity power plant, providing a sustainable source of energy for both Laos and Thailand. It consists of three 626 MW-generating units with a total electric generating capacity of 1,878-MW. The lignite from the Hongsa mine is used as the primary fuel for this power plant, at approximately 14.3 million tons per year - of which its lignite reserves were initially estimated at 436.9 million tonnes (Banpu Power Limited, 2007). The power plant is 20 km from Thai-Loas border in Nan province of Thailand **(Fig. 2)**.

According to the HCPP's EIA, HCPP has the flue gas desulfurization (FDG) system, selective catalytic reduction (SCR) system, and electrostatic precipitator (ESP) system to control emission of air pollutant. The series of emission abatement can eliminate 97-99 %

[1]*Naresuan University, Department of Civil Engineering, 65000 Phitsanulok, Thailand, supawan.sritat@gmail.com;*

[2] *Naresuan University, Research Unit for Integrated Natural Resources Remediation and Reclamation (IN3R), Department of Civil Engineering, 65000 Phitsanulok, Thailand, Piaowan.k@hotmail.com;*

[3] *Naresuan University, Center of Excellence for Sustainability of Health, Environment and Industry (SHEI), 65000 Phitsanulok, Thailand, Piaowan.k@hotmail.com.*

of SO_2 (Breeze, 2019), lignite from the Hongsa Mine has contains substantial concentration of sulfur (S) 0.72% (Banpu Power Limited, 2007). Therefore, HCPP will release 2,110 tons of sulfur per year into the atmosphere. For this reason, fossil fuel combustion at power plants or even other industrial facilities are become largest sources of SO_2 emissions (Thepanondh et al., 2016).

Fig 1. Hongsa coal-fired power plant in Sayabouri province, Lao People's Democratic Republic *(Source of data: http://www.hongsapower.com/index.php?model=cms&view=item&layout=page&id=1).*

Importantly, SO_2 not only affects the atmosphere, but it also causes irritation to the human respiratory system (Charlene Marie Becka, 2014). Thus, monitoring of transboundary SO_2 from Lao PDR to Thailand is essential for risk management of the two countries. However, Thailand's air quality monitoring station is unable to service to all areas in Chalerm Phrakiat District. Therefore, the dispersion modeling is the best alternative method for checking and predicting the concentration of SO_2 emitted from HCCP's stack which may effected to air quality of Chalerm Phrakiat District (Cimorelli et al., 2005)) and the American Meteorological Society-Environmental Protection Agency Regulatory Model (AERMOD) is the standard model used by the EPA when evaluating pollutant dispersion from an industrial source (Charlene Marie Becka, 2014). Moreover, the dispersion modeling is a potential method of solution for many types of air pollutant such as PM_{10}, $PM_{2.5}$, Mercury, Arsenic, NO_X and NO_2 (Hysenaj, 2019).

The AERMOD model has been used in many research to predict or evaluate the air pollutant dispersion such as Mr. Khanh T. Tran (2011) was used AERMOD to predict the air quality impacts of SO_2 emitted by Luminant Martin Lake Coal Plant in Texas (Mr. Khanh T. Tran, 2011) ; Mark D.Gibson et al. (2013) was used AERMOD to evaluate concentration of $PM_{2.5}$, NO_X and SO_2 from traffic in Nova Scotia, Canada (Gibson et al., 2013); Nattawut Jittra et al. (2015) was used AERMOD to evaluate of NO_x and SO_2 dispersion in Maptaphut Industrial Complex Area, Thailand (Jittra Nattawut et al., 2015) ; Thepanondh et al. (2016) was used AERMOD to forecast SO_2 concentrations from petroleum refinery complex in Thailand (Thepanondh et al., 2016).

Consequently, in this paper describes the methods and results of air dispersion modeling that predict the ground-level concentrations of hourly and daily of SO_2 from continued operation of flue stack of the HCCP couple with the study monthly deposition of SO_2 into the area of Chaloem Phra Kiat district. Finally, SO_2 impacts predicted by the AERMOD model will be compared against the hourly and daily of Thailand's air quality standard (PCD, 2001).

2. STUDY AREA AND DATA

Fig 2(A) was represented the location of HCPP. As can be seen in **Fig. 2(B)**, the modeling domain was 50 km x 50 km, centered at the HCPP's stack, it was covered five villages in Thailand as followed; Ban Huai Khon village (23 km from the power plant), Ban Kiew Chan village (22 km from the power plant), Ban Nam Chang village (18 km from the power plant), Ban Nam Ree village (20 km from the HCPP), and Ban Mom Chao Charoen village (26 km from the HCPP), respectively **(Fig. 2(C))**. The description of study area was shown in **Table 1**.

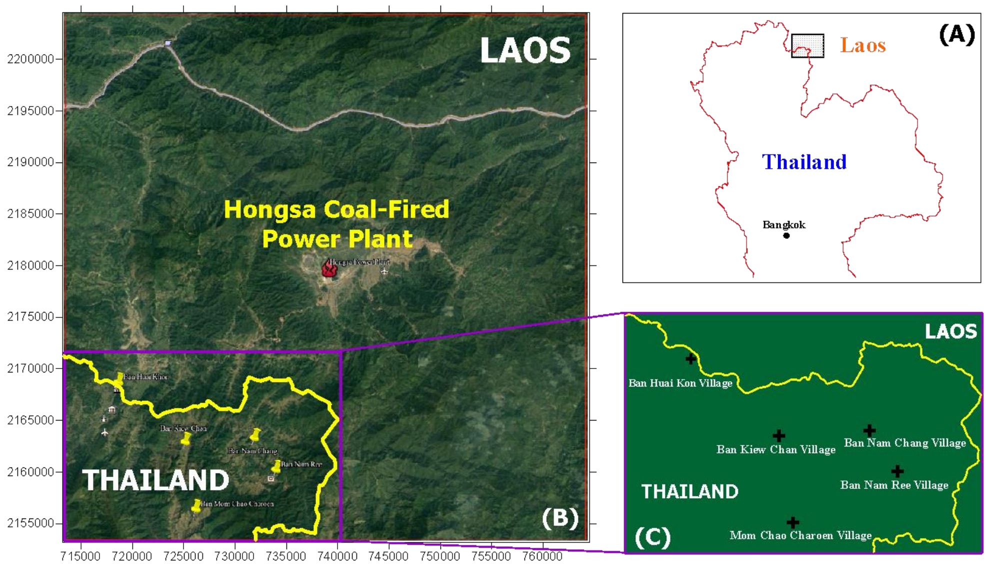

Fig. 2. Location of HCPP and five receptor areas in Chaloem Phra Kiat district, Nan Province, Thailand (Ban Huai Khon village, Ban Kiew Chan village, Ban Nam Chang village, Ban Nam Ree village, and Ban Mom Chao Charoen village).

Table 1.

Description of study area.

Location Name	**°N (latitude)**	**°E (longitude)**	**Elevation (above sea level)**
Hongsa Power Plant's stack	19.689909	101.282035	569.51 m
Ban Huai Khon village	19.596120	101.085101	561.04 m
Ban Mom Chao Charoen village	19.486062	101.154309	884.41 m
Ban Nam Chang village	19.546757	101.208972	919.17 m
Ban Nam Ree village	19.519160	101.228409	923.33 m
Ban Kiew Chan village	19.543990	101.145521	974.50 m

3. METHODOLOGY

3.1. AERMOD Dispersion Modeling

AERMOD is relatively a recent model developed by the American Meteorology Society (AMS) and United States Environmental Protection Agency (US EPA). The steady-state plume model of AERMOD assumes that a plume spreads both vertically and horizontally, leading to Gaussian concentration distributions (U.S. EPA, 2004). The concentration algorithm of AERMOD considers the effects of vertical variation of wind, temperature, and turbulence profiles. It is recommended by the US EPA for examining the effects of sources on receptor that are generally within 50 km of the source. For distances up to 50 km from the source of emission, AERMOD results are considered accurate because AERMOD is the models for demonstrating regulatory compliance in the near field (less than 50 km) (Rood, 2014). This study employed the AERMOD dispersion model (version 9.6.5) to predict and compare ambient air concentrations and deposition of SO_2. This version is currently the latest version of the model that has been approved by the US Environmental Protection Agency.

AERMOD required two preprocessors, AERMAP View and AERMET View, in order to run data. The preprocessor AERMAP View (Version 9.6.5) has been employed to obtain terrain elevations at these receptors using the GTOPO30/SRTM30 data with a resolution of 1,000 meters (U.S. EPA, 2018). The meteorological data preprocessor AERMET View (version 9.6.5) has been employed to prepare the meteorological data. The meteorological data in this study ordered from webpage of Lakes Environmental Software (https://www.weblakes.com /services/met_order.html). Meteorological data formats has been processed by Weather Research and Forecasting (WRF) model, Grid Resolution 4 km. WRF model can compute accurate windfields anywhere in the world. It is comprised of surface met data file, upper air met data file and AERMET input files for 3 years, 2015 to 2017.

3.2 Receptors

The multi-tier grid receptors and discrete cartesian receptors with a total discrete cartesian receptors of 65 places were used as a tool for SO_2 concentration monitoring in modeling domain **(Fig. 4)**. Note that in AERMOD, when specifying discrete cartesian receptors, it is necessary to specify the position of a source relative to the receptor is assigned (Jittra Nattawut et al., 2015). The multi-tier grid receptors have varying resolutions from the center by a total of 5,081 receptors: 250 m within the first 5 km, 500 m between 5 km and 10 km, and 1,000 m between 10 km and 25 km.

3.3 Input parameters

The input data were obtained from the information provided in the HCPP's EIA (Banpu Power Limited, 2007). The modeling domain was 50 km x 50 km centered at the HCPP (19.69068 °N (latitude), 101.2782°E (longitude)). The emission rate has been converted to grams per second (g/s) in as required by the AERMOD model by assuming that the boilers operate continuously, i.e. 8,760 hours per year. Furthermore, stack heights and exit velocities were identified as important factors that may affect pollutant dispersion and atmospheric concentrations in the region (Lee et al., 2014). The input parameters for the AERMOD model are summarized in **Table 2**.

Table 2.
The input parameters for the AERMOD model (Banpu Power Limited, 2007).

Parameter	Value
Stack elevation	569.51 m (above sea level)
Stack inside diameter	7.5 m
Physical stack height (meter above ground)	250 m
Stack exit temperature	75 ^{0}C
Stack exit velocity	26 m/s
Stack SO_2 emission	263.56 g/s

4. RESULTS AND DISCUSSIONS

4.1 Main wind from Laos to Thai

The wind field distribution plays an important role in the study of air distribution model (Boulghobra et al., 2016).

The wind field distribution plays an important role in the study of air distribution model. Therefore, the wind field distribution were evaluated for 12 months between 2015 and 2017. The average wind field distribution at the HCPP station was dominated by northeast and southwest winds. From October to February, wind obtained from measured data were blown from northeast to southwest while from March to September were blown from southwest to northeast (**Fig. 3**).

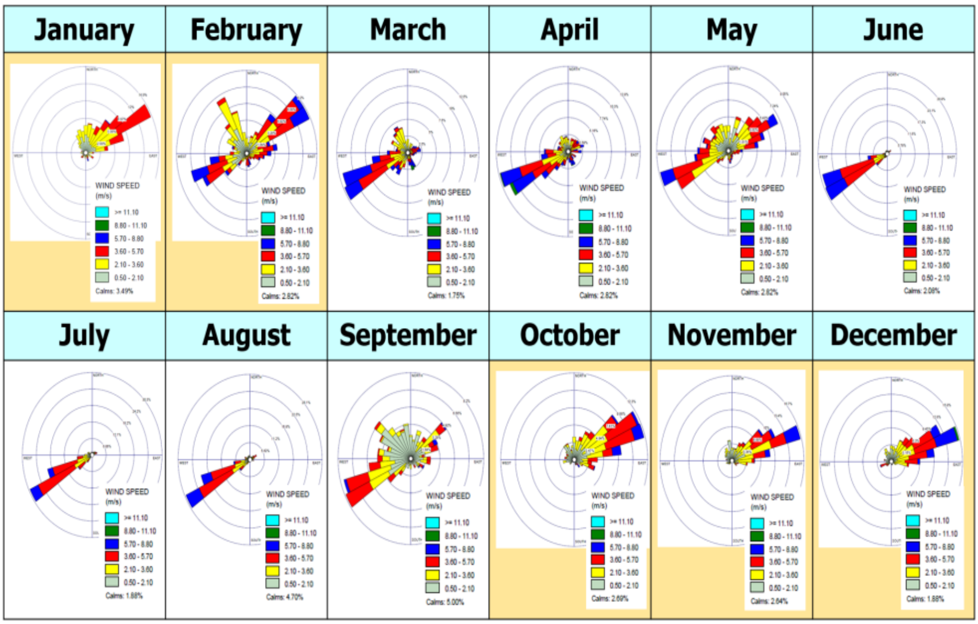

Fig. 3. Main wind from Lao PDR to Thai for 12 months between 2015 and 2017.

4.2 Modeled concentrations of SO_2

Hourly and daily maximum ground-level concentrations of SO_2 at each of the villages were computed. **Fig. 4** presented the hourly and daily concentrations contour map of SO_2 over a period of 3 years, the modeled concentration was calculated as 99th percentile. The both concentration of SO_2 per hourly and daily were lower than Thailand's air quality standard, at 780 and 300 μg/m^3, respectively (PCD, 2001). The modeled results were focused on the day season (October to February) of each year because the wind is blow from Lao PDR to Thailand, Chaloem Phra Kiat district will suffered from HCPP's air pollution (**Fig. 3**).

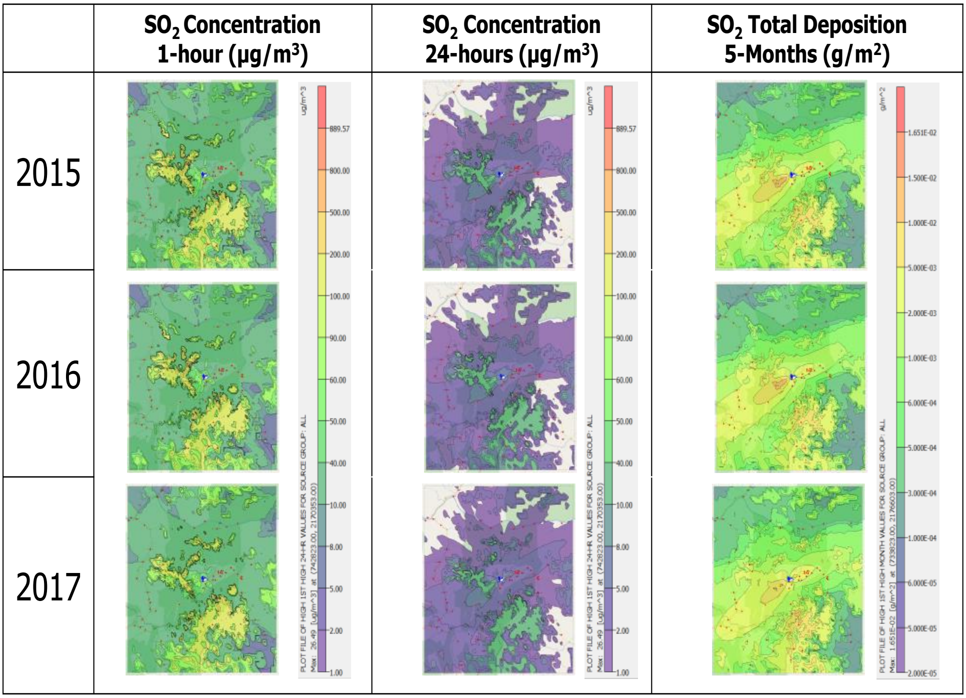

Fig. 4. The hourly and daily concentrations contour map, and monthly deposition of SO_2 based on emissions from the HCCP's stack during the dry season (October to February) between 2015 and 2017.

The highest hourly SO_2 concentration were found at Ban Nam Ree village in January as high as 92.254 μg/m^3. The data of hourly concentration of each month can be explained as follows: 92.254 to 8.796 μg/m^3 in January, 32.830 to 9.246 μg/m^3 in February, 51.041 to 12.352 μg/m^3 in October, 68.001 to 14.955 μg/m^3 in November, and 54.703 to 15.698 μg/m^3 in December, respectively (**Fig. 5(A)**). For daily concentration, the data trends were similar to hourly concentration, the highest concentration was 5.201 μg/m^3 displayed at Ban Nam Ree village in January as well (**Fig. 5(B)**).

Although, the amount of SO_2 in air is at acceptable low levels in this area. However, SO_2 causes irritation to the human respiratory system when it is breathed in. It irritates the nose, throat, and airways to cause coughing, wheezing, shortness of breath, or a tight feeling around the chest. The effects of sulfur dioxide are felt very quickly and most people would feel the worst symptoms in 10 or 15 minutes after breathing it in (Brian Chi-ang Lin and Zheng, 2017). Therefore, every dry season (October to February) people living in Chaloem Phra Kiat district should prepare for facing with SO_2. Interestingly, the concentration of SO_2 can change significantly with season, location, and geography. Ban Kiew Chan Village, Ban Nam Ree village and Ban Nam Chang village are located in higher geography than Ban Huai Khon village and Ban Mom Chao Charoen village (**Table 1** and **Fig. 6**).

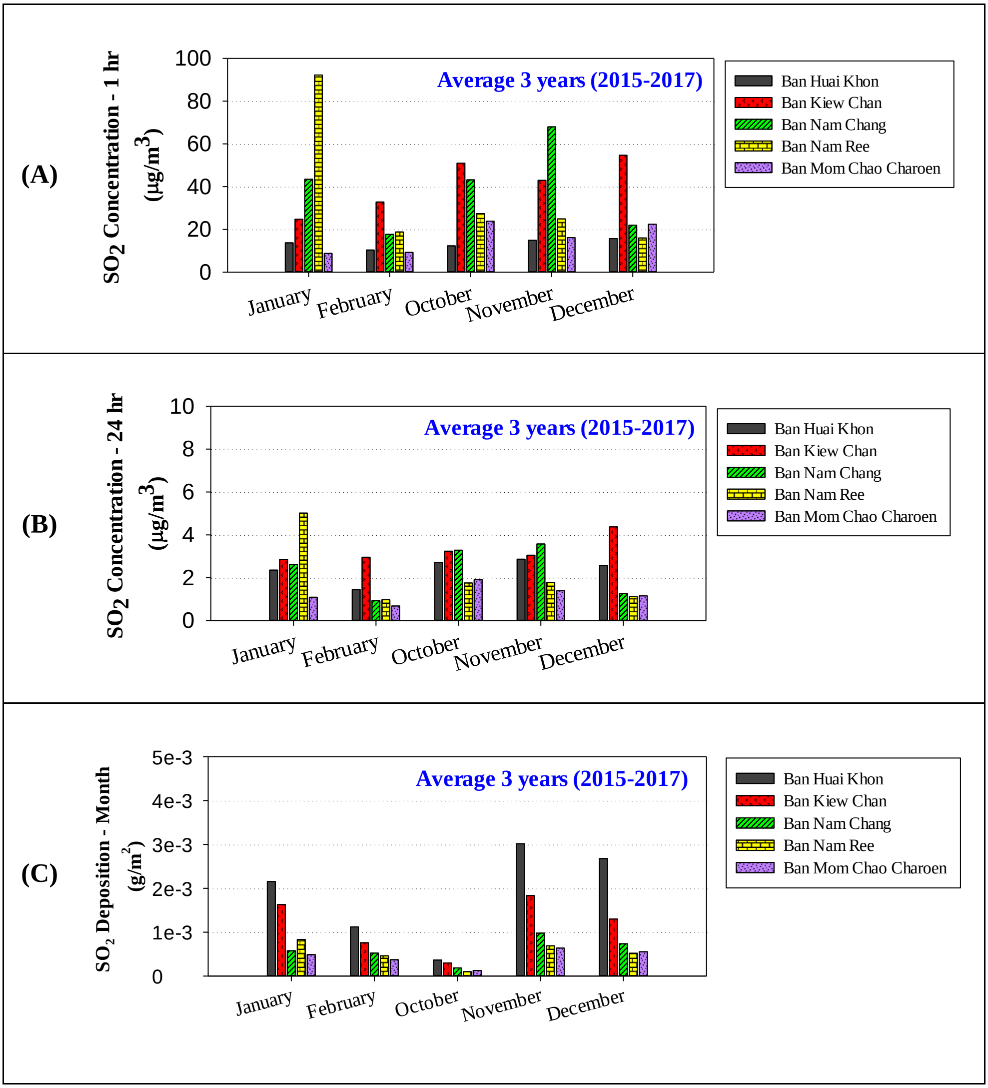

Fig.5. Modeled results of hourly concentrations, daily concentrations and SO_2 deposition at five villages in 5 months based on emissions from the HCCP's stack during the dry season (October to February) between 2015 and 2017.

Therefore, if considering the topography height of the HCPP' stack combined with stack height (569.51m + 250m = 820 m) and turbulent in air. the plume can be risen up to same altitude of the three which high SO_2 concentration. This hypothesis can support why the three villages have high modeled concentrations of SO_2.

4.3 SO_2 Deposition

The behavior of SO_2 after releasing into the air, it can be transform into acid rain by mix and react with water, oxygen, and other chemicals. Acid was eliminated from atmosphere by wet deposition (snow, rain, fog, mist, sleet, hail, dew, and etc.) and dry deposition (gas, dry particles, vapor, and aerosols) (Baedecker et al., 1992; U.S. EPA, 2008). The harmful effect of acid rain is considered as one of the most serious environmental problems and it becomes a major local ecological problem in most of the countries of the world (Haradhan Kumar Mohajan, 2018).

Acid Rain is a local environment pollution but global concern (Haradhan Kumar Mohajan, 2018) because it can damage plants, animals, soil, water, and building materials (U.S. EPA, 2008). Moreover, acid rain causes trees in forests to grow more slowly, and in some sensitive species it can even make the leaves or needles turn brown and fall off (U.S. EPA, 2008). At the same time, acid rain causes the release of substances such as aluminum from the soil. Aluminum can be very harmful to trees and plants. Once released into soil, aluminum can end up in streams, rivers, and lakes, where it can harm or even kill fish (U.S. EPA, 2008). Acid rain possesses higher levels of hydrogen ions (H^+) that can effected decreases the pH (potential hydrogen) scale of ecosystems (Katar Singh, 2007). Typical pH values of acid rain for anthropogenic emissions may be in the range of 3.5–5. The pH value between 5 and 8 is the ideal pH range for the plants' growth, and out of these ranges in soils, plants face difficulties to germinate or grow (Lazarus et al., 2006).

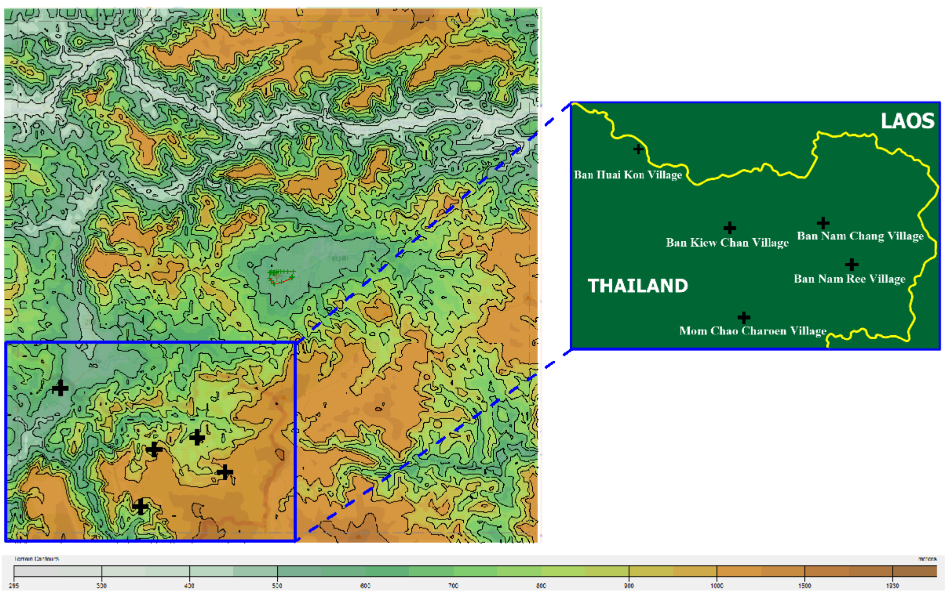

Fig. 6. Terrain characteristic of the study domain.

As can be seen in **Fig. 5(C)**, it is clear that Ban Huai khon village was predicted to suffer from the highest impact from SO_2 deposition emitted from the HCCP's stacks. The highest monthly SO_2 deposition during a period of 5 months was predicted as high as 0.003 g/m^2 in November via dry deposition. Unfortunately, Ban Huai khon village has many important sensitive areas such as Thai-Laos immigration border, school, hospital and agricultural area which is the main occupation of the people who live in this area.

5. CONCLUSIONS

AERMOD air dispersion model was evaluated for its performance to predict ground level SO_2 concentrations as emitted from the HCPP's stack. This model processed information about the emission rates of SO_2, local meteorological conditions, and other local information, such as terrain data, land use, and the location of receptors to predict maximum hourly, daily, period average concentrations, and deposition. Wind rose diagrams analysis showed that the wind directions is blow from HCCP through study area from October to February every year. Location and topography are plays important role on the SO_2 concentration. The highest predicted SO_2 concentrations was projected at Ban Nam Ree village in January while highest SO_2 deposition was found at Ban Huai khon village. The results from this study were more useful for understanding the SO_2 concentration distributions in this study case.

REFERENCES

Baedecker PA, Reddy MM, Reimann KJ, et al. (1992) Effects of acidic deposition on the erosion of carbonate stone — experimental results from the U.S. National Acid Precipitation Assessment Program (NAPAP). *Atmospheric Environment. Part B. Urban Atmosphere* 26: 147-158.

Banpu Power Limited. (2007) Environmental Impact Assessment of Hongsa Power Plant, Mining Development and Transmission Line Priject (Final report).

Boulghobra N, Koull N and Benzaoui T. (2016) Four decades period of climatic data for assessing the aeolian hazard in the region of Touggourt (Low Algerian Sahara). *Geographia Technica*,, **11**(1),13-22.

Breeze P. (2019) Chapter 3 - Coal-Fired Power Plants. In: Breeze P (ed) *Power Generation Technologies (Third Edition).* Newnes, 33-70.

Brian Chi-ang Lin and Zheng S. (2017) *Environmental Economics and Sustainability,* New York City, United States: John Wiley & Sons

Charlene Marie Becka. (2014) A case study of sulfur dioxide concentrations in Muscatine, Iowa and the ability for AERMOD to predict NAAQS violations. *Civil and Environmental Engineering.* MS (Master of Science): University of Iowa.

Cimorelli AJ, Perry SG, Venkatram A, et al. (2005) AERMOD: A dispersion model for industrial source applications. Part I: General model formulation and boundary layer characterization. *Journal of applied meteorology* 44: 682-693.

Gibson MD, Kundu S and Satish M. (2013) Dispersion model evaluation of PM2.5, NOx and SO2 from point and major line sources in Nova Scotia, Canada using AERMOD Gaussian plume air dispersion model. *Atmospheric Pollution Research* 4: 157-167.

Haradhan Kumar Mohajan. (2018) Acid Rain is a Local Environment Pollution but Global Concern. *Open Science Journal of Analytical Chemistry* 3: 47-55.

Hysenaj M. (2019) Dispersion Model Prospective of Air Pollution in Tirana. *Geographia Technica*, **14** (2), 10-19.

Jittra Nattawut, Pinthong Nattaporn and Thepanondh Sarawut. (2015) Performance Evaluation of AERMOD and CALPUFF Air Dispersion Models in Industrial Complex Area. *Air, Soil and Water Research* 8: 87-95.

Katar Singh. (2007) *Environmental Economics: Theory and Applications* New Delhi: SAGE Publications Pvt. Ltd.

Lazarus BE, Schaberg PG, Hawley GJ, et al. (2006) Landscape-scale spatial patterns of winter injury to red spruce foliage in a year of heavy region-wide injury. *Canadian Journal of Forest Research* 36: 142-152.

Lee HD, Yoo JW, Kang MK, et al. (2014) Evaluation of concentrations and source contribution of PM10 and SO2 emitted from industrial complexes in Ulsan, Korea: Interfacing of the WRF–CALPUFF modeling tools. *Atmospheric Pollution Research* 5: 664-676.

Mr. Khanh T. Tran. (2011) AERMOD Modeling of SO2 Impacts of the Luminant Martin Lake Coal Plant.

PCD. (2001) Ambient air quality standard of Thailand. Pollution Control Department (PCD).

Rood AS. (2014) Performance evaluation of AERMOD, CALPUFF, and legacy air dispersion models using the Winter Validation Tracer Study dataset. *Atmospheric Environment* 89: 707-720.

Thepanondh S, Outapa P and Saikomol S. (2016) Evaluation of dispersion model performance in predicting SO2 concentrations from petroleum refinery complex. 11: 2129-2135.

U.S. EPA. (2004) AERMOD: DESCRIPTION OF MODEL FORMULATION. September 2004 ed.

U.S. EPA. (2008) Learning About Acid Rain: A Teacher's Guide for Grades 6 through 8. April 2008 ed.: U.S. EPA,.

U.S. EPA. (2018) User's Guide for the AERMOD Terrain Preprocessor (AERMAP). April, 2018 ed.: U.S. EPA,.