EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/ea/index.html
EnvironmentAsia 10(2) (2017) 186-194
DOI

Health Risk Assessment of Nitrogen Dioxide and Sulfur Dioxide Exposure from a New Developing Coal Power Plant in Thailand

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Abstract

Krabi coal-fired power plant is the new power plant development project of the Electricity Generating Authority of Thailand (EGAT). This 800 megawatts power plant is in developing process. The pollutants from coal-fired burning emissions were estimated and included in an environmental impact assessment report. This study aims to apply air quality modeling to predict nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) concentration which could have health impact to local people. The health risk assessment was studied following U.S. EPA regulatory method. The hazard maps were created by ArcGIS program. The results indicated the influence of the northeast and southwest monsoons and season variation to the pollutants dispersion. The daily average and annual average concentrations of NO_2 and SO_2 were lower than the NAAQS standard. The hazard quotient (HQ) of SO_2 and NO_2 both short-term and long-term exposure were less than 1. However, there were some possibly potential risk areas indicating in GIS based map. The distribution of pollutions and high HI values were near this power plant site. Although the power plant does not construct yet but the environment health risk assessment was evaluated to compare with future fully developed coal fire plant.

Keywords: health risk assessment; AERMOD; hazard map; coal fired power plant; Thailand; GIS

1. Introduction

The environmental impact of coal-fired power plant has been known as a major source of gaseous pollutants such as sulfur dioxide (SO_2), oxide of nitrogen (NOx), carbon monoxide (CO) and carbon dioxide (CO_2). The emissions contributed global warming phenomenon and directly cause of human unhealthy. The proposed coal-fired power plant received strong antagonism from the locals and non-government organizations (NGO). They claim that exposure of coal pollutants would threaten marine life and human especially harm to human health such as birth defects and gene mutations; cancer. (Finkelman *et al*., 2002)

Therefore, the researcher needs to assessed health risk of population who living in the vicinity of a new Krabi coal-fired power plant project because the crucial increasing of coal-consumption for power generation. This study is going to used air dispersion modeling to predict ambient air concentration of pollutants at particular receptor. In Thailand, American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) has been accepted by department of pollution control as a tool to predict the pollution transportation in air for evaluated environmental impact. This method was similar practice to China (Zhao *et al*., 2010), Malaysia (Mokhtar *et al*., 2014) and India (Kesarkar *et al*., 2007). Thus, this study is used AERMOD for prediction the dispersion of selected pollutants as Sulfur dioxide (SO_2) and Nitrogen dioxide (NO_2). Secondly, Health risk assessment method of U.S. EPA is used to evaluate heath risk from a model prediction data following four steps as Hazard identification, Dose-response, Exposure assessment and Risk characterization. The Environmental Health Impact Assessment (EHIA) is an Environmental Impact Assessment (EIA) with a health component included in the appraisal process. Normally, health assessment in EHIA includes health issuesthat can be measured, such as chemical and pollution exposure concentrations while focusing less on qualitative information such as community perceptions of health issues (WHO, 2017).

2. Materials and Methods

2.1 Study site

A new coal-fired power plant is going to be developed near the present fuel power plant located at KlongKanan sub-district, NueaKhlong district, Krabi province, covering an area of 414.8 km^2, Fig. 1. From this power plant, there are two communities within 5 km distance; Khlongkanarn sub-district and

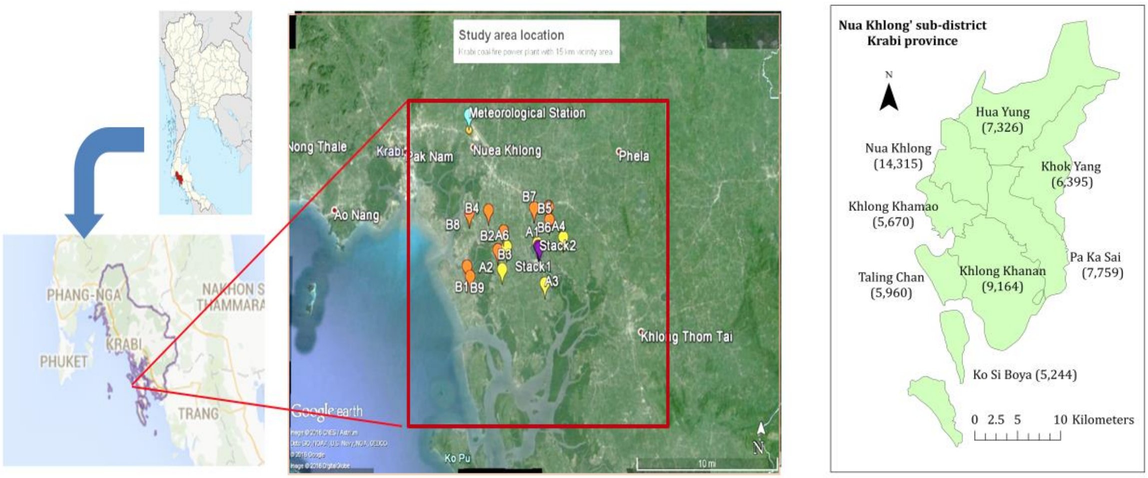


Figure 1. Study area location in Krabi province, covered 15 km radius from the power plant (left) and Nuaklong's administrative sub-district location with the number of population in each sub-district (right)

Pakasai sub-district and two sub-districts located within 20 km; Talingchan sub-district and Klongkhemao sub-district. There are approximately 14,000 people living in this area . The data were from Royal Gazette (in Thai). 109 (53 ง special): 1. April 22, 1992 and Royal Gazette (in Thai). 113 (62 ก): 5-8. November 20, 1996.

2.2 Descriptive of power plant

The new coal-fired power plant is planned to produce power 700 MW in addition to the old natural fuel oil 340 MW power plant. This new plant will use pulverized coal technology and high grade sub-bituminous with low sulfur content (EGAT, 2014). This coal will be imported from Indonesia, Australian and South Africa by shipping through Andaman Sea. This new power plant unit could burn 7260 tons coal per day or 2.3 million tons per year. Various air pollution control systems such as Electrostatic Precipitator, Flue Gas Desulphurization and Selective Catalytic Reduction were proposed to be installed to control particulate, acid gases and nitrogen oxide, respectively. Plant's specification was summarized in Table 1.

2.3 Air dispersion modeling

The American Meteorological Society Environmental Protection Agency Regulatory Model (AERMOD) modeling system used in this study was run with a commercial interface, AERMOD View (Version 8.8.9) (Lakes Environmental Software). The steps involved in AERMOD modeling are shown in Fig. 2. The required meteorological data for AERMOD including wind direction, wind speed, ceiling height, total cloud cover, direct normal radiation and relative humidity were also obtained from measurement data of Thailand Meteorological Department. The input data of new power plant emissions were from EHIA report which were provided by Electricity Generating Authority of Thailand (EGAT, 2016).

AERMOD is based on the steady state Gaussian dispersion equation. If the ground is taken to be the reference height ($z=0$), with the x axis of the co-ordinate system aligned along the wind direction at the source, the one-hour average concentration (C(x,y,z)) can be described in terms of the Gaussian distribution, equation 1.

Table 1. Comparison of current power plant and new coal-fired power plant specification

Parameter	Specification	
	The current fuel power plant	The new coal-fired power plant
Capacity (MW)	340	700
Number of stack	1	1
Stack height (m)	155	200
Stack diameter (m)	4.4	7.5
Stack velocity (m/s)	15.85	20.46
Exit gas temperature (K)	370	368
Flow rate gas (m^3/s)	241	733.34
Exit SO_2 rate (g/s)	145	53
Exit NO_x rate (g/s)	98	99

$$C(x,y,z) = \frac{Q}{u} P_y\{y_x x\} P_z\{z_x x\} \quad (1)$$

Where: Q is the source emission rate, u is the effective wind speed, P_y and P_z are the probability density function (pdf) for the lateral and vertical concentration distributions, respectively.

2.4 Model validation

The root-mean-square error is used to validate the predicting results. It measures of the differences between values predicted by a model and the values actually observed in equation 2. The RMSE shows the sample standard deviation of the differences between predicted and observed values. These individual differences are called *residuals* when the calculations are presented over the data sample that was used for estimation, and are called *prediction errors* when computed out-of-sample.

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2} \quad (2)$$

Where; N is the number of data, O_i is the observed data and P_i is the predicted data. In this study, the observed data was obtained from EGAT in with 4 stations (A1-A4). The information will compare with observed data in 1-hour average concentration of each months in 2015 from EGAT. However, only simulation from the old stack is input as an emission source to validate performance of modeling.

2.5 Geographic information system (GIS)

The Geographic Information System (GIS) has been used as a tool for hazard area identification (Teerapattarada *et al*., 2015), (Mitmark and Jinsart, 2016). In this study, air pollution distribution and risk areas were mapping to compare short-term and long-term exposure risk areas. To measure distances, a geodesic calculator was used to convert Bath-Geo WGS84 projection coordinates (longitude/latitude) into the Universal Transverse Mercator (UTM) Zone 47(47N). Spatial data of stack's co-ordinates, predicted air pollution values from AERMOD, Exposure concentration and HI were prepared in spread sheet before upload in the GIS map using ARCGIS 10.2. The ordinary kriging running mode was selected for self-maps illustration (Childs, 2004).

2.6 Health risk assessment (HRA)

Inhalation Exposure concentration (EC_{inh}) is quantified as described in equation 3.

$$EC_{inh} = \frac{\mathrm{C \times ET \times EF \times ED}}{AT} \quad (3)$$

Where: C: concentration of each pollutants, NO_2 and SO_2 (µg/m^3), were predicted from AERMOD; ET: exposure time (24 hours/day); EF: exposure frequency (350 day/year); ED: exposure duration (30 years); AT: average time (for non-carcinogens, AT = ED in years × 365 days × 24 hours/day; for carcinogens, AT = 70

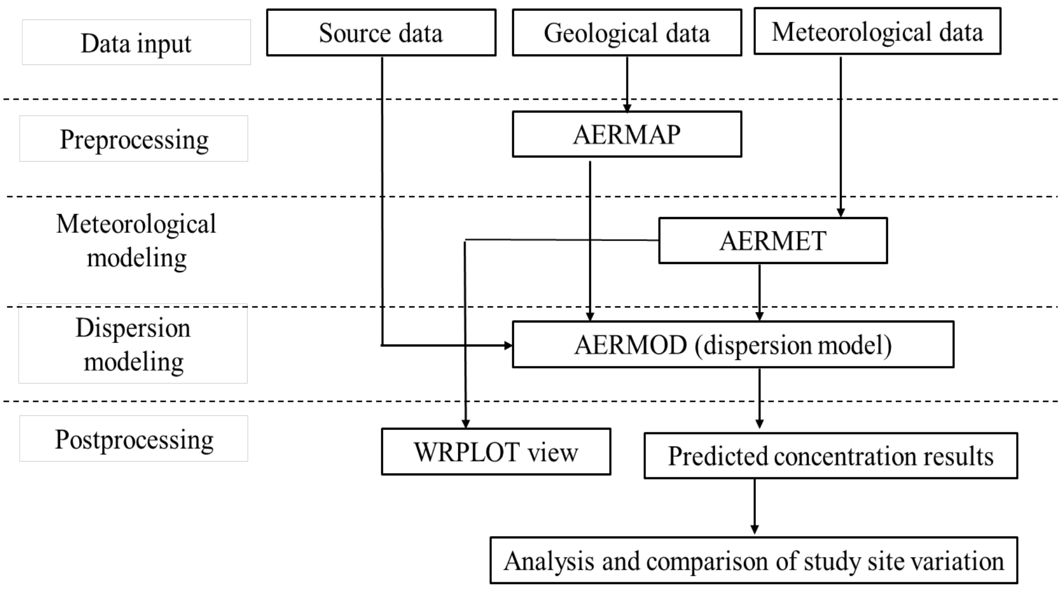


Figure 2. Flow in AERMOD modeling system

years × 365 days × 24 hours/day). For non-carcinogenic health risk due to inhalation, risk characterization is performed by quantifying the hazard using the Hazard Quotient (HQ) equation (4) which is defined following the U.S. EPA method (U.S. EPA, 2009);

$$HQ = \frac{EC}{RfC} \tag{4}$$

$$HI = \sum HQ \tag{5}$$

Where: EC = exposure air concentration (µg/m^3); RfC = reference concentration (µg/m^3). HQ of less than one (HQ <1) indicates that pollutant concentration is below the reference concentration (RfC) value whereby the potential risk is within acceptable levels. In this case, no action required to reduce the pollutant's level. Therefore, HQ < 1 is considered the area is not at risk. Nevertheless, it should be noted that HQ > 1 does not necessarily suggest a likelihood of adverse effects (U.S. EPA, 2009). According to EPA's Integrated Risk Information System, IRIS report, RfC of NO_2 and SO_2 are not available in the integrated risk information system (IRIS, U.S. EPA) so we used WHO guideline values (WHO, 2017) to calculate HQ by equation (4). To define the risk areas of NO_2 and SO_2, the hazard index (HI) is calculated from the sum of HQ as in equation (5). It is used to assess the overall potential for non-carcinogenic defects posed by more than one chemical. HI <1 indicates that there is no significant risk of non-carcinogenic effects. Conversely, HI >1 indicates the chance of non-carcinogenic effects occurring, with a probability of increasing health risk (U.S. EPA, 2009a).

3. Results and Discussion

3.1 The modeling validation

The Root Mean Square Error (RMSE) values have been used to measure the differences between observed and simulated concentration. From the annual data, RMSE, NO_2 and SO_2 concentrations at ground level at station A1-A4 were ranged between 3.89 - 5.91 and 12.89 - 25.16 respectively (Table 2). In case of SO_2 concentrations, the RMSE values at station A3 were not considered due to lacking in the number of observed data < 70 %. For the seasonal variation analysis, wet season and dry season, the RMSE results of some stations decreased due to the simulating results in dry season were better than in wet season. The best results in validation of NO_2 concentration occurred at station A4 that RMSE was 1.93. Likewise, in SO_2 concentration, the best validation occurred at station A4 in dry season with RMSE 7.47.

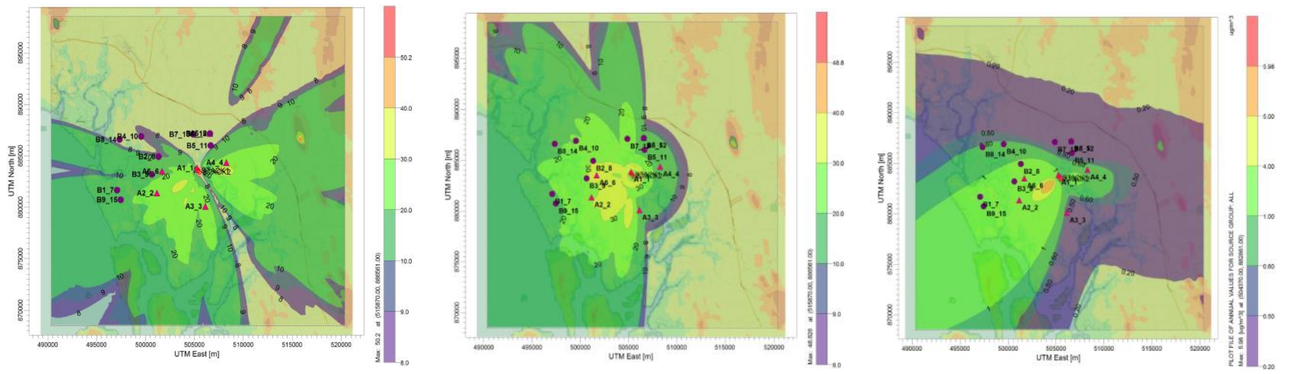
3.2 The modeling simulations

The prediction results from AERMOD cover 15 km of radius a new developed coal-fired power plant including 2 stacks. One-hour average NO_2 and SO_2 concentration dispersion diagrams were represented in Figs. 3 and 4. Those diagrams are variated in wet season (May-October) and dry season (November-April), influencing by seasonal monsoon. In the wet season, pollutants are generally dispersed to the south of sources whereas the pollutants are obviously dispersed to the west of sources in dry season. Meanwhile, the diagrams illustrate dispersion of NO_2 and SO_2 in annual averaging time scale. However, the annual dispersion diagrams of both pollutants are likely dispersed in the same direction which are from the sources to the southwest.

Table 2. Comparison of Root Mean Square Error (RMSE) value from observed and simulated concentrations and Standard Deviation (SD)

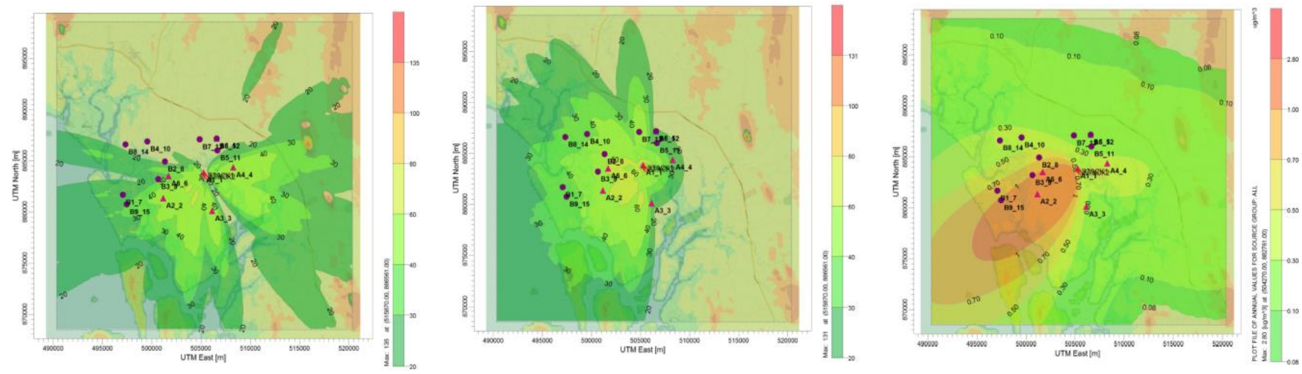
Pollutant	Station	Annual		Wet Season		Dry Season		Percentage of observed data
		RMSE	SD	RMSE	SD	RMSE	SD	
NO_2	A1	4.24	4.97	3.11	0.24	5.19	5.88	91.18
	A2	5.91	5.76	3.89	5.28	7.52	3.44	88.42
	A3	3.89	4.57	5.52	6.31	2.19	2.48	82.2
	A4	5.82	6.32	8.51	7.62	**1.93**	2.38	90.26
SO_2	A1	12.89	13.59	3.62	0.64	18.46	16.09	71.37
	A2	25.16	15.76	16.48	14.44	31.55	9.41	77.63
	A3	14.08	12.51	15.38	17.27	9.75	6.77	25.87*
	A4	21.43	17.28	29.81	20.85	**7.47**	6.52	87.83

* observed data < 70%



a. One-hour average wet season b. One-hour average dry season c. Annual average

Figure 3. Dispersion of NO_2concentration over Nua-khlong district, Krabi and vicinity



a. One-hour average wet season b. One-hour average dry season c. Annual average

Figure 4. Dispersion of SO_2 concentration over Nua-khlong district, Krabi and vicinity

In comparison of the maximum one-hour ground level concentration (GLC) of NO_2 and SO_2 in 15 km vicinity area, it was found that one-hour NO_2 concentration in wet season is 50 μg/m^3 and dry season is 49 μg/m^3, and one-hour SO_2 concentration in wet season is 135 μg/m^3 and dry season is 131 μg/m^3. For the annual average concentration, the maximum NO_2 and SO_2 GLC are 2.8 and 6.0 μg/m^3. The location of maximum concentration was found in the east of sources at 515870 N, 886561E (UTM system), which place out of selected sensitive area.

3.3 *Health risk assessment*

3.3.1 Hazard quotients

The HQs of NO_2 and SO_2 are calculated from equation 3. HQs of short-term (1-hour, daily) and long-term (annual) non-carcinogenic health risks were shown in Tables 3 and 4. All sites have HQ < 1 which could mean no potential adverse health effects exist during short term average concentration. The HQs of long term annual concentrations also less than one meaning no adverse health effect. However, the worse-case scenario health risk assessment was used 1-hour short-term exposure to describe. It is divided into two type following local seasonal climate. The results show that some receptors present the HQs value of SO_2 exceed than 1 in 1-hour short-term both wet season and dry season whereas NO_2 in every location is lower than 1. This can be described that these areas are able to possibly occur health impact from SO_2 more than the others areas in worse-case scenario when the power plant operating. This HRA should be evaluated again when the new developing is operation in order to compare the emitted pollutants which are simulation and real observation.

3.3.2 Hazard Index

The hazard index (HI) summarized pollutants hazard quotient (HQs) of nitrogen dioxide and sulfur dioxide are computed to determine short-term (daily) and long-term (annual) non-carcinogenic health risks and showed in Table 5. Based on the hazard index (HI) obtained a potential for adverse health impact occurred during 1-hour short-term dispersion of coal power plant pollutants described for the worse-case scenario, the HI in some sensitive receptors are more than one because of the effect from SO_2 concentration. However, the

Table 3. ECs and HQs value of NO_2 in short-term and long-term exposure at Nua-khlong district, Krabi

Area	Name	Nitrogen dioxide (NO_2)							
		1-hour Wet Season		1-hour dry Season		Daily		Annual	
		EC (μg/m3)	HQ	EC (μg/m^3)	HQ	EC (μg/m3)	HQ	EC (μg/m^3)	HQ
A1	Krabi power plant	1.91	0.02	22.34	0.22	6.79	0.07	0.21	0
A2	Kohpod village	25.38	0.25	25.58	0.26	5.91	0.06	1.67	0.02
A3	Ban khongwailek school	25.74	0.26	13.41	0.13	3.94	0.04	0.28	0
A4	Tungsakhon School	27.93	0.28	14.73	0.15	6.3	0.06	0.39	0
A5	Tungprasan village	1.51	0.02	11.45	0.11	2.75	0.03	0.19	0
A6	Huasok village	16.11	0.16	32.08	0.32	5.06	0.05	1.03	0.01
B1	Bankhlongrua school	13.35	0.13	18.00	0.18	3.48	0.03	0.81	0.01
B2	Klongkanarn temple	9.00	0.09	26.55	0.27	4.35	0.04	0.61	0.01
B3	Klongmark school	13.81	0.14	29.89	0.30	4.67	0.05	0.95	0.01
B4	Klongkanarn admin organization	7.79	0.08	20.43	0.20	3.19	0.03	0.35	0
B5	Pakasai village	5.63	0.06	15.54	0.16	3.54	0.04	0.25	0
B6	Tungprasarn hospital	1.52	0.02	11.50	0.11	2.76	0.03	0.19	0
B7	Nongpakcheak village	1.61	0.02	27.75	0.28	3.83	0.04	0.23	0
B8	Talingchan village	5.33	0.05	18.12	0.18	2.73	0.03	0.35	0
B9	Banklhongyuan school	15.90	0.16	18.42	0.18	3.68	0.04	1.02	0.01

health risk assessment focuses on short-term daily and long-term annual exposure from pollutants. The results of both short-term (daily) and long-term dispersion shows acceptable level of these pollutants by presenting in hazard index (HI) less than one in all sensitive areas.

On the other hand, among 15 sites valuation A5 and B6 were performed less impact to health due to located upwind position as shown on annual wind rose. Similarly, health risk estimation was obtained from a study conducted by (Mokhtar *et al*., 2014). They assessed health risk from exposure pollutants of coal-fired power plant in Malaysia. Their HQs results described that the study of pollutants dispersion in their site study have possibly a potential adverse health effects presenting in short-term exposure of sulfur dioxide. The comparison of risk assessment in worse-case scenario (1-hour average HQs) between the new Thailand power plant and Malaysia power plant found that the Thailand's power plant presents lower the tendency of risk than Malaysia's power plant due to the lower of HQs. This can be claimed that the new developing power plant is safe for human health.

Table 4. ECs and HQs value of SO_2 in short-term and long-term exposure at Nua-khlong district, Krabi

Area	Name	Sulfur dioxide (SO_2)							
		1-hour wet Season		1-hour dry Season		Daily		Annual	
		EC (μg/m3)	HQ	EC (μg/m^3)	HQ	EC (μg/m3)	HQ	EC (μg/m^3)	HQ
A1	Krabi power plant	2.92	0.10	48.97	1.74	14.33	0.51	0.43	0.02
A2	Kohpod village	46.46	1.65	48.49	1.72	10.9	0.39	2.99	0.11
A3	Ban khongwailek school	52.57	1.86	23.29	0.83	7.31	0.26	0.5	0.02
A4	Tungsakhon School	50.75	1.80	25.94	0.92	12.02	0.43	0.74	0.03
A5	Tungprasan village	2.71	0.10	20.22	0.72	4.64	0.16	0.35	0.01
A6	Huasok village	27.84	0.99	58.37	2.07	9.13	0.32	1.86	0.07
B1	Bankhlongrua school	26.10	0.93	32.73	1.16	6.07	0.22	1.43	0.05
B2	Klongkanarn temple	15.71	0.56	51.11	1.81	7.98	0.28	1.09	0.04
B3	Klongmark school	24.46	0.87	53.27	1.89	8.25	0.29	1.69	0.06
B4	Klongkanarn admin organization	13.59	0.48	36.44	1.29	5.54	0.2	0.61	0.02
B5	Pakasai village	10.94	0.39	27.83	0.99	6.02	0.21	0.45	0.02
B6	Tungprasarn hospital	2.77	0.10	20.30	0.72	4.66	0.17	0.35	0.01
B7	Nongpakcheak village	2.78	0.10	53.05	1.88	6.93	0.25	0.4	0.01
B8	Talingchan village	11.92	0.42	33.07	1.17	4.73	0.17	0.6	0.02
B9	Banklhongyuan school	28.99	1.03	32.42	1.15	6.49	0.23	1.81	0.06

3.4 Hazard map analysis

Evaluation of the interpolation method was used ordinary kriging method because of the best performance (Thepanondh and Toruksa, 2011). Mapping the hazard index of coal-fired pollutants from AERMOD modeling prediction was performed by ArcGIS. The results, the hazard map from ArcMAP ordinary kriging can describe the difference of hazard zone of pollutants exposure. The site distribution of annual average hazard index (HI) wind rose is shown in Fig. 5. HI of A2, A6 and B3 where located within 5 kilometers' radius around emission sources may evaluate as higher risk than the others locations because these areas located near emission source and average wind direction mostly blows from north-eastern and occasionally blows from south-western. This climate factors will induce pollutants from the sources to the area south-west direction of the power plant. Therefore, these receptors may expose the pollutants more than others areas due to locate near source. In addition, the HIs distribution over Nuakhlong district is acceptable risk because of the values less than 1 but the probably highest risk area which is A2 Khlongkanan sub-district should be mark as pollutant alert area for worse-case scenario.

4. Conclusions

The overall results and findings from this study were aimed to apply in health risk assessment. This study presents the evaluation approach for estimating the ambient air pollution concentration in Krabi province while the power plant is not actually operated yet. The dispersion of emitted pollutants from a new development planned coal-fired power plant, including two stacks were simulated by the American Meteorology Society Environmental Protection Agency Regulatory Model (AERMOD) version 8.9.0. Air pollutants determined in this study were SO_2 and NO_2. The forecasting results presented that the impact area from those pollutants were considered in 15 km of radius vicinity area. The results of analysis indicated that the influence of the northeast and southwest monsoons result in pollutants dispersion in different seasons. The health risk evaluation in this study was conducted on the ambient air concentration predicted from AERMOD modelling. The model was designed the predicted distance within 15 kilometers from emission sources. Further areas were interpolating values. Therefore, the HI values are calculated from its assumption. However, the assessment should be tested after the new power plant has been operated. Based on health risk assessment (HRA), the hazard quotient (HQ) was conducted to determine health assessment of nitrogen dioxide and sulfur dioxide exposure. As the non-carcinogenic health risk, a potential for adverse health risk was obtained by the HQs value >1 at any receptors. For the HQs of NO_2, and SO_2, these can be acceptable health risk at all receptors both short-term (daily exposure) and long-term (annual exposure) health effects. Additionally, HQs (1-hour exposure) are used to describe worse-case

Table 5. Hazard index of the pollutants in short-term (1-hour, daily) and long-term (annual) exposure

Receptor	Name	Hazard Index (HI)			
		1-hour wet Season	1-hour dry Season	Daily	Annual
A1	Krabi power plant	0.12	1.96	0.58	0.02
A2	Kohpod village	1.90	1.98	0.45	0.12
A3	Ban khongwailek school	2.12	0.96	0.30	0.02
A4	Tungsakhon School	2.08	1.07	0.49	0.03
A5	Tungprasan village	0.11	0.83	0.19	0.01
A6	Huasok village	1.15	2.39	0.37	0.08
B1	Bankhlongrua school	1.06	1.34	0.25	0.06
B2	Klongkanarn temple	0.65	2.08	0.33	0.04
B3	Klongmark school	1.01	2.19	0.34	0.07
B4	Klongkanarn sub-district administration organization	0.56	1.50	0.23	0.03
B5	Pakasai village	0.44	1.14	0.25	0.02
B6	Tungprasarn hospital	0.11	0.83	0.19	0.01
B7	Nongpakcheak village	0.11	2.16	0.28	0.02
B8	Talingchan village	0.48	1.35	0.20	0.02
B9	Banklhongyuan school	1.19	1.33	0.27	0.07

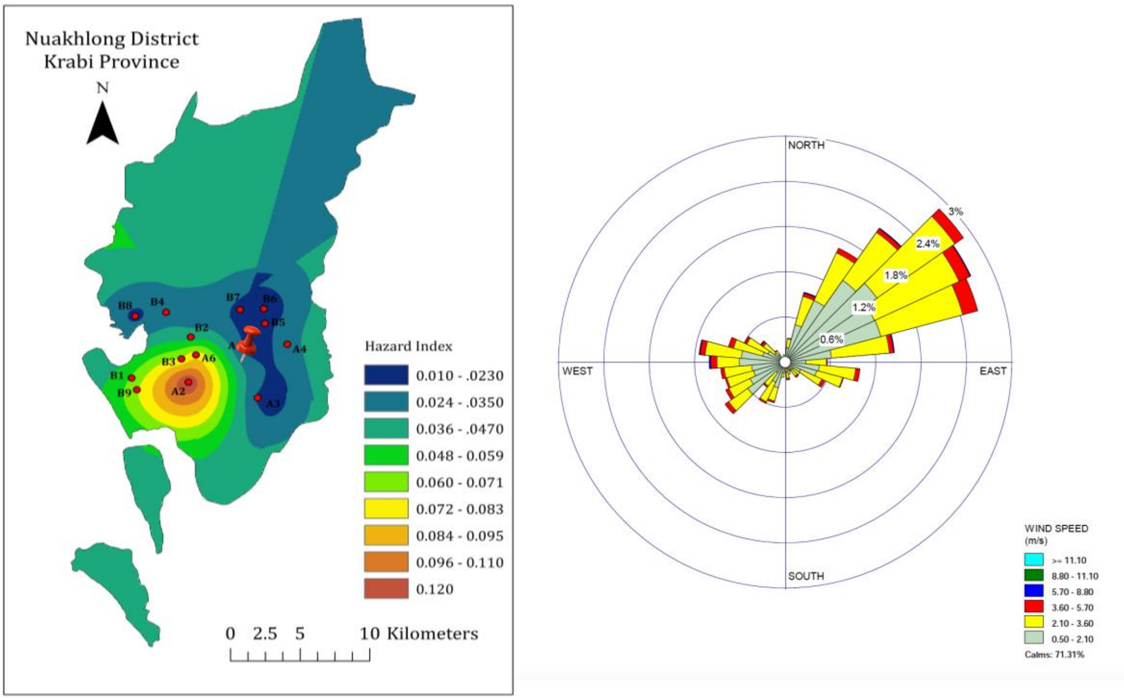


Figure 5. Site distribution of hazard index (HI) in annual average and annually wind rose,
A1 represented power plant location

scenario of pollutants exposure if they occur and how seasonal monsoons and climate affect pollutant exposure areas. The risk areas were identified by hazard index (HI) and the impact sites were illustrated by Geographic Information System. These types of approaches and further study for health impact mapping area may offer a comprehensive strategy to the decision-making processes of the further coal-fired power plant development sites and the environmental management policy.

Acknowledgements

This study was supported by the Sci Super III Fund (Ratchadaphiseksomphot Endowment Fund), Chulalongkorn University. The authors are deeply appreciated all data information from Thailand Meteorological Department, and Electricity Generating Authority of Thailand.

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Received 20 April 2017
Accepted 22 June 2017

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