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

EnvironmentAsia 18(1) 2025 164-173
DOI 10.14456/ea.2025.13
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Association of Meteorology and Air Quality with Dengue Fever Incidence in Upper Northern Thailand

Pachara Sapbamrer[1], Preecha Chaichanan[2], Santipan Chiablam[3], Sittichai Pimonsree[4], and Sakesun Thongtip[3*]

[1]Montfort College, Muang District, Chiang Mai, Thailand
[2]Baan Piang Luang Health Promotion Hospital, Wiang Haeng District Public Health Office, Chiang Mai, Thailand.
[3]Department of Environmental Health, School of Public Health, University of Phayao, Phayao Province, Thailand
[4]Atmospheric Pollution and Climate Change Research Unit (APCC), School of Energy and Environment, University of Phayao, Phayao Province, Thailand

*Corresponding author: sakesun.th@up.ac.th
Received: March 19, 2024; Revised: August 7, 2024; Accepted: August 12, 2024

Abstract

Dengue fever is the most significant global health problem transmitted by *Aedes* mosquitoes. The present study aims to investigate the association of meteorology and air quality with dengue fever incidence in upper Northern Thailand within the period 2014 to 2022. Data was collected form a database of climate, air pollution, and dengue fever in upper Northern Thailand, namely from Chiang Mai, Lamphun, Lampang, Phrae, Nan, Phayao, Chiang Rai, and Mae Hong Son provinces. The highest morbidity rate of dengue fever was found during the rainy season. The rainy season had the highest relative humidity, total rainfall, rainfall days, visibility, cloud amount, and wind speed, while these were lowest during the summer season. All parameters of air pollutants, with the exception of 1-hr SO_2, were highest during the summer season and lowest during the rainy season. Importantly, multiple linear regression analysis was used to adjust covariates which found that cloud amount and rainfall days were positively associated with the morbidity rate of dengue fever ($\beta = 0.954 \pm 0.402$, p value = 0.018; and 0.659 ± 0.143, p value < 0.001, respectively). However, total rainfall had negative effects ($\beta = -0.029 \pm 0.008$, p value < 0.001). Regarding air pollution factor, only 1-hr O_3 was negatively associated with the morbidity rate of dengue fever ($\beta = 0.263 \pm 0.07$, p value < 0.001). Therefore, the optimal predictors for dengue cases in upper Northern Thailand were rainfall days, total rainfall, cloud amount, and ground ozone levels. The study's findings can enhance dengue surveillance by predicting morbidity, preparing for potential outbreaks, and implementing region-specific prevention measures.

Keywords: Air pollution; Climate; Mosquito; Dengue; Meteorology

1. Introduction

Dengue fever is the most significant vector-borne viral disease for global public health. This virus is transmitted to humans through the bite of an infected *Aedes* mosquitoes (*Ae. aegypti or Ae. albopictus*). The global incidence of dengue fever has dramatically increased over the past two decades, which is a public health challenge (CDC, 2023; WHO, 2023). In 2023, over 5 million cases and more than 5,000 dengue-related deaths were reported from 86 countries globally (WHO, 2023; ECDC, 2023). The Department of Disease Control in Thailand reported 156,097 cases and 167 deaths across all 77 provinces in 2023. Notably, the number of cases in 2023 increased approximately 3.5 times compared to 2022. The highest number of cases were reported in Thailand's Central region (46,989 cases) followed by the Northern region (35,511 cases), and the Northeastern region (33,539 cases) (Department of Disease Control, 2024).

Previous studies have investigated the association between meteorological factors and dengue transmission, with most of these studies finding an association between them. However, the results found in previous studies are inconsistent (Abdullah *et al.,* 2022). Studies conducted in Northwest Argentina and Singapore found that dengue cases were positively associated with temperature and rainfall, but negatively associated with wind speed (Gui *et al.,* 2021; Gutirrez *et al.,* 2022). In contrast, a study conducted in four Asian countries found a negative association with temperature and rainfall (Wang *et al.,* 2022). Sugeno *et al.* (2023) reports research conducted in the Lao People's Democratic Republic (LPDR) and indicated that the risk of dengue incidence deceased when heavy rain exceeds 200 mm. Additionally, a study conducted in Bangkok in Thailand's Central region, indicated that dengue cases were positively associated with relative humidity (RH) and suggested that, RH is the best predictor for dengue cases (Kumharn *et al.,* 2023. Another study conducted in 16 provinces in Thailand's Central region claimed that temperature, rainfall, RH, and wind speed are the best predictors for dengue cases (Langkulsen and na Sakolnakhon, 2022). It is therefore likely that variations across different areas or regions influence the predictors of dengue cases.

Regarding air pollution related to dengue cases, available previous studies have investigated the association between air pollution and dengue cases. A study in Taiwan showed that the levels of sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), and particulate matter-10 microns (PM_{10}) were positively association with dengue incidence, while particulate matter-2.5 microns ($PM_{2.5}$) showed an opposite effect (Lu *et al.,* 2023). Meanwhile, a Malaysian study found that air pollution index (API) levels do not have a significant effect on reported cases (Thiruchelvam *et al.,* 2018). Moreover, a study conducted in Thailand reported that extremely high temperatures in addition to SO_2 and $PM_{2.5}$ are negatively associated with dengue cases (Tewari *et al.,* 2023). Therefore, the available data is rather inconsistent due to geographical difference.

Upper Northern Thailand consists of eight provinces, including Chiang Mai, Lamphun, Lampang, Phrae, Nan, Phayao, Chiang Rai, and Mae Hong Son. This region in Thailand experiences three distinct seasonal periods, a rainy season, a winter season, and a summer season. During the winter season, the temperature in this region is cooler than other regions of Thailand (Amazing Thailand, 2024). The geographical conditions of this region are like a pan basin surrounded by mountains. This region is particularly affected by air pollution, especially particulate matter ($PM_{2.5}$), compared to other regions. Air pollutants in this area tend to accumulate and persist due to the geographical confinement of the pan basin (Chiang Mai University, 2024). Thus, upper Northern Thailand has a distinct geography, meteorological condition, and air pollution may have an impact on dengue epidemics in this region. This study therefore aims to visualize morbidity of dengue fever, meteorological parameters, and air pollutant levels classified by month, and to investigate the association of meteorology and air quality with dengue fever incidence in upper Northern Thailand within the period 2014 to 2022. The study's findings can enhance dengue surveillance by improving the prediction of dengue morbidity, aiding in outbreak preparedness, and contributing to disease prevention.

2. Methodology

2.1 Study design and research site

The study area is upper Northern Thailand, which includes eight provinces including Chiang Mai, Lumphun, Lampang, Phrae, Nan, Phayao, Chiang Rai, and Mae Hong Son. The geographical conditions of upper Northern Thailand are unique, consisting mostly of mountains with the highest peak at 2,565 metres (8,415 feet) (Amazing Thailand, 2024). The total forest area is 90,087.4 square kilometres (56,304,603.3 rai), accounting for 52.4% of forested areas in Thailand (Royal Forest Department, 2020). Thailand's climate is distinguished by three distinct seasons, rainy, winter, and summer (ARDA, 2024). During the winter season, this region experiences cooler temperatures than other areas in Thailand due to the inflow of cold air from the Chinese highlands (Academic Accelerator, 2024; Amazing Thailand, 2024). Annually, the maximum daytime temperature averages 33.2 °C, while the minimum nighttime temperature averages 22.5 °C. The region typically has an average of 91 rainy days, with total annual precipitation averaging 1,340 millimetres (WorldData, 2024). Upper Northern Thailand also faces significant air pollution issues during the winter season. Between 2016 and 2020, the daily average $PM_{2.5}$ concentrations frequently exceeded Thailand's National Ambient Air Quality Standards, ranging from 24% to 65% above the established limits (Sirithian and Thanatrakolsri, 2022).

In 2023, Northern Thailand recorded the highest morbidity rate for dengue fever among Thailand's regions. The provinces with the highest number of reported dengue cases were Mae Hong Son (2,748 cases), Chiang Mai (1,555 cases), and Chiang Rai (1,264 cases) (Department of Disease Control, 2024).

2.2 Data collection

Data for dengue fever in the eight provinces of upper Northern Thailand during the period 2014 to 2022 was obtained from the website of the Health Regional Medical Office 1, Ministry of Public Health (https://cmi.ciorh1.com/web/). The data on the website is presented as in-patient department (IPD) cases. The formula to calculate the morbidity rate of dengue fever is detailed below:

Morbidity rate of dengue fever
= (IPD cases / numbers of mid-year population) x 100,000

Data for mid-year population was obtained from the website of the Bureau of Epidemiology, Department of Disease Control, Ministry of Public Health (https://apps-doe.moph.go.th/boe/software/downloadpopulation.php).

Meteorological data for the eight provinces covering the research area and period was obtained from the website of the Northern Meteorological Center, Thai Meteorological Department, Ministry of Information and CommunicationTechnology (http://www.cmmet.tmd.go.th/forecast/pt/pt_map.php). The following meteorological conditions parameters were collected as follows;

- Pressure (hPa): mean, extreme maximum, extreme minimum
- Temperature (oC): mean, mean maximum, mean minimum
- % relative humidity: mean, mean maximum, mean minimum
- Total pan evaporation (mm): mean
- Total rainfall (mm): mean
- Rainfall days (days): mean
- Visibility (km): mean
- Cloud amount (scale 1-10): mean
- Wind speed (knots): mean

Air quality data in the eight provinces of upper Northern Thailand during the period 2014 to 2022 was collected from the website of the Air Quality Management Bureau, Pollution Control Department, Ministry of Natural Resources and Environment (http://air4thai.pcd.go.th/webV3/#/Download). The collected parameters included 24-hr $PM_{2.5}$, 24-hr PM_{10}, 1-hr O_3, 1-hr NO_2, 1-hr SO_2, and 1-hr CO.

2.3 Statistical analysis

A total of 864 datasets were classified by month, ranging from January to December. Regression model was used to impute the missing data by substituting missing data with a different value. The missing data was imputed using a regression model, which substituted a new value for the missing data. The morbidity rate of dengue fever, meteorological data, and air pollution levels classified by month were analyzed and shown using Microsoft Excel. Pearson correlation was used to investigate the association of meteorological and air pollution factors with the morbidity rate of dengue fever. The parameters that were significantly associated with the morbidity rate of dengue fever by Pearson correlation analysis (p value < 0.05) were included in the model of linear regression analysis.

2.4 Ethical Considerations

The study was approved by the Research Ethics Committee of the University of Phayao, Thailand (HREC-UP-HSST 1.1/019/67).

3. Results and discussion

3.1 Morbidity rate of dengue fever

The highest morbidity rate of dengue fever was found in July (22.78/100,000 population), followed by August (20.65/100,000 population) and September (14.86/100,000 population). These three months were classified as rainy season months. The lowest morbidity rate of dengue fever was found in February (1.09/100,000 population), followed by March (1.37/100,000 population) and January (1.87/100,000 population) (Figure 1). Dengue fever is a public health concern in tropical and sub-tropical regions and is transmitted by the *Aedes* mosquitoes (WHO, 2023; Kularatne and Dalugama, 2022). The results of the present study show that the highest dengue fever morbidity rate was in July, followed by August and September, which are all categorised as belonging to the rainy season. These results are consistent with a finding from a previous study in another region of Thailand. A study conducted in Nakhon Si Thammarat province, located in the southern region of Thailand, revealed that dengue cases increased from April, peaked in July, and declined by October (Abdulsalamet *et al.,* 2021). However, a study conducted in the central region of Thailand indicated that dengue cases during the winter season (from October to February) were higher than those during the rainy season (from June to September) (Langkulsen and na Sakolnakhon, 2022). A study conducted in Bangkok, in the central region of Thailand also stated that November had the highest dengue cases, followed by October and December, which are categorised within the winter season (Kumharn *et al.,* 2023). Given the significant variation in geographical and meteorological conditions across different regions of Thailand, these factors are likely to influence the predictors associated with dengue cases.

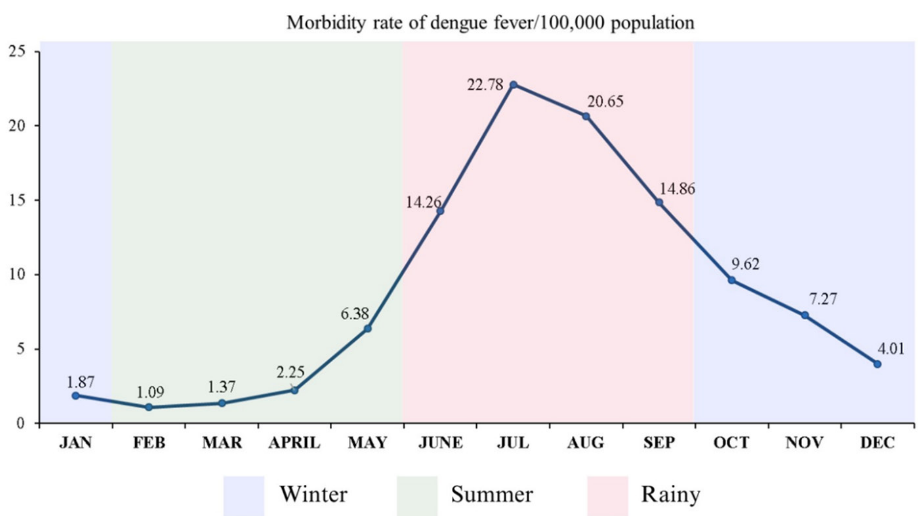


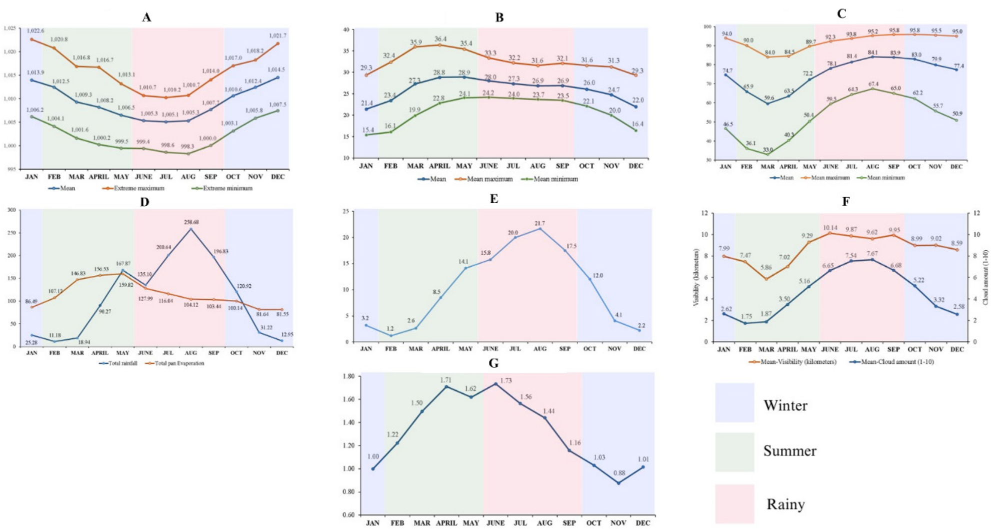
Figure 1. Morbidity rate of dengue fever in upper Northern Thailand, classified by month during the period 2014 to 2022

3.2 Meteorological conditions

The rainy season had the highest relative humidity, total rainfall, rainfall days, visibility, cloud amount, and wind speed, while these were lowest during the summer season. The lowest pressure was found during the rainy season and the highest was in the winter season. In contrast, the highest temperature was found in summer season and the lowest in the winter season (Figure 2). It is possible that there are two periods of peak total rainfall in upper Northern Thailand, as depicted in Figure 3. The first period exhibits the highest total rainfall in May, followed by a decrease in June, and the second period shows a peak for total rainfall in August. Consequently, the results of the two analyses did not display a consistent pattern of association. Additionally, it is possible that heavy rainfall may lead to the removal of mosquito eggs and larvae, thereby reducing the overall mosquito population (Benedum *et al.,* 2018; Hossain *et al.,* 2023). A moderate amount of rainfall is sufficient to create additional breeding sites and promote the growth of the mosquito population (Abdulsalam *et al.,* 2022; Seidahmed and Eltahir, 2016; Wang *et al.,* 2022). Wongkoon *et al.,* (2013) suggested that increased rainfall days may trigger a higher number of *Aedes* larvae and incidence of dengue fever. Therefore, rainfall days could be a significant factor to create additional breeding sites for mosquito populations.

3.3 Air pollutant levels

All parameters of air pollutants, except 1-hr SO_2, had the highest levels in the summer season (during February and March), while the lowest levels were found in the rainy season (during June and September) (Figure 3). The spread of dengue disease may be attributed to air pollution. The results indicate that all parameters of air pollutants (PM_{10}, $PM_{2.5}$, O_3, NO_2, and CO), except SO_2, were highest during the summer season, while the lowest levels were found in the rainy season. Previous studies also stated that the highest levels of these air pollutants were found in the summer season, yet the highest numbers of dengue cases were reported during the rainy season (Kliengchuay *et al.,* 2021; Thongtip *et al.,* 2022; Wongkoon *et al.,* 2013). Specifically, haze pollution concentrations are higher during the dry or summer season in



A) Pressure (hPa), B) Temperature (ºC), C) % Relative humidity,
D) Total rainfall and total pan evaporation (mm), E) Rainfall days (days),
F) Visibility (km) and cloud amount (1-10), G) Wind speed (knots)

Figure 2. Meteorological conditions in upper Northern Thailand, classified by month during the period 2014 to 2022

Thailand. This increase is attributed to several factors, including seasonal haze, the burning of agricultural biomass, forest fires, and open field burning (Kliengchuay *et al.,* 2021; Nangola *et al.,* 2023; Thongtip *et al.,* 2022).

3.4 Association of meteorological and air pollution factors with the morbidity rate of dengue fever

The Pearson correlation coefficient investigating the association of meteorological and air pollution factors with the morbidity rate of dengue fever in upper Northern Thailand is presented in Table 1. Meteorological factors associated with the morbidity rate of dengue fever included pressure, temperature, relative humidity, visibility, cloud amount, total rainfall, and rainfall days. The associated air pollution factors were 24-hr $PM_{2.5}$, 24-hr PM_{10}, 1-hr O_3, 1-hr NO_2, and 1-hr CO. Importantly, the present study finds that the morbidity rate of dengue fever is positively associated with total rainfall when analyzed using Pearson correlation, but negative association when analyzed using multiple linear regression, as reported in Table 2.

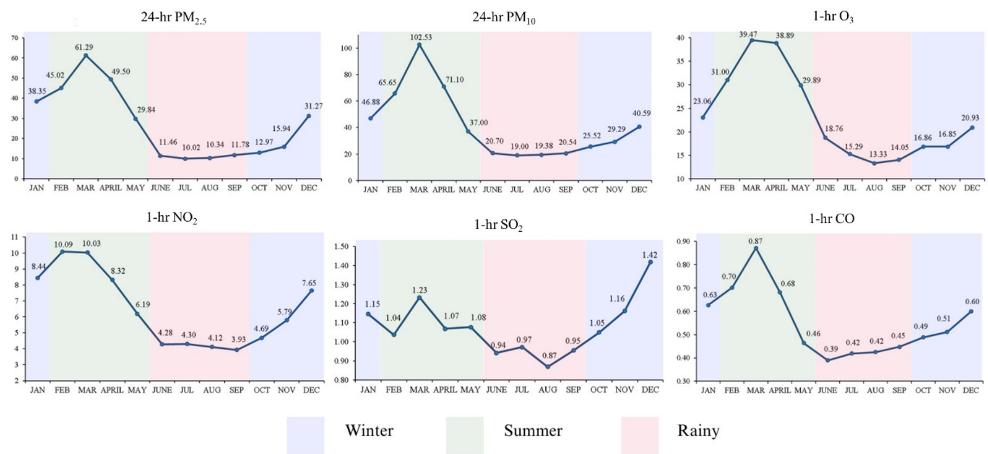


Figure 3. Air pollutant levels in upper Northern Thailand, classified by month during the period 2014 to 2022

Table 1. Pearson correlation coefficient (r) for investigating the association of meteorological and air pollution factors with the morbidity rate of dengue fever in upper Northern Thailand

Parameters		*r*	*p*-value
Climate	Pressure (hPa)	- 0.332	< 0.001**
	Temperature (°C)	0.177	< 0.001**
	Relative humidity (%)	0.306	< 0.001**
	Visibility (km)	0.184	< 0.001**
	Cloud amount (1-10)	0.433	< 0.001**
	Wind speed (knots)	0.001	0.972
	Total pan evaporation (mm)	- 0.042	0.218
	Total rainfall (mm)	0.306	< 0.001**
	Rainfall days (days)	0.439	< 0.001**
Air pollution	24-hr $PM_{2.5}$ (ug/m^3)	- 0.289	< 0.001**
	24-hr PM_{10} (ug/m^3)	- 0.333	< 0.001**
	1-hr O_3 (ppb)	- 0.323	< 0.001**
	1-hr NO (ppb)	- 0.168	< 0.001**
	1-hr CO (ppm)	- 0.157	< 0.001**
	1-hr SO_2 (ppb)	- 0.077	0.024

r = Pearson correlation coefficients, ***p* value < 0.01

3.5 Multiple linear regression analysis of the association between meteorological and air pollution factors and the morbidity rate of dengue fever

Multiple linear regression analysis for adjusting covariates found that cloud amount and rainfall days were positively associated with the morbidity rate of dengue fever (β = 0.954 ± 0.402, *p* value = 0.018; and 0.659 ± 0.143, *p* value < 0.001, respectively). However, total rainfall had a negative effect (β = -0.029 ± 0.008, *p* value < 0.001). Among the air pollution factors, only 1-hr O_3 was found to be negatively associated with the morbidity rate of dengue fever (β = 0.263 ± 0.07, *p* value < 0.001) (Table 2). The transmission of dengue could be notably affected by the optimal climatic conditions for mosquito species serving as vectors. Interestingly, after adjusting the co-variates using multiple linear regression analysis, the results indicate that the morbidity rate of dengue fever was positively associated with cloud amount and rainfall days, but negatively associated with total rainfall. This is in contrast to most previous studies which claim that dengue cases are positive associated with rainfall (Gutirrez *et al.,* 2022; Gui *et al.,* 2023; Kumharn *et al.,* 2023; Langkulsen and na Sakolnakhon, 2022). Nonetheless, some previous studies found a negative association between total rainfall and dengue cases (Abdulsalam *et al.,* 2022; Faruk *et al.,* 2022; Wang *et al.,* 2022). Cloud amount is a measure of the extent of cloud cover in the sky, with the scale ranging from 1 (minimal cloud cover) to 10 (complete sky obscured). This parameter is part of the comprehensive set of parameters collected by the Meteorological Center in Northern Thailand (Northern Meteorological Center, 2023). Periods with minimal cloud cover tend to be the sunniest, significantly affecting temperature variations. When clouds are present, they trap and re-emit heat radiated from the Earth's surface, resulting in a slower decrease in temperatures. This has a notable impact on the dengue virus and directly affects the reproduction and survival of the *Aedes* mosquito vector in the environment (Abdulsalam *et al.,* 2022). The optimal temperature for transmission of *Aedes* mosquito vectors varied in the range between 21.3 °C and 34 °C (Hossain *et al.,* 2023). Therefore, this study suggests that rainfall days and cloud amount are the optimal predictors for dengue cases in upper Northern Thailand. Interestingly, our results showed that only 1-hr O_3 was negatively associated with the morbidity rate of dengue fever when analysed using multiple linear regression. Our results are consistent with Yip *et al.* (2022), which suggested that ground levels of ozone have a strong immediate effect on dengue cases. Scientific evidence demonstrates that ozone has a deterrent impact on both *Aedes aegypti* and *Aedes albopictus* (Wan-Norafikah *et al.,* 2016). Our results therefore suggest that ground ozone levels are a predictor for dengue cases in upper Northern Thailand.

Table 2. Multiple linear regression for investigating the association of meteorological and air pollution factors with the morbidity rate of dengue fever in upper Northern Thailand

Parameters		β	SE	*p*-value
Climate condition	Pressure (hPa)	- 0.310	0.295	0.294
	Temperature (°C)	0.11	0.285	0.701
	Relative humidity (%)	- 0.049	0.118	0.678
	Visibility(km)	- 0.453	0.287	0.116
	Cloud amount (1-10)	0.954	0.402	0.019*
	Total Rainfall (mm)	- 0.029	0.008	< 0.001**
	Rainfall days (days)	0.659	0.143	< 0.001**
Air pollutants	24-hr $PM_{2.5}$ (ug/m^3)	- 0.019	0.028	0.497
	24-hr PM_{10}(ug/m^3)	- 0.029	0.034	0.393
	1-hr O_3 (ppb)	- 0.263	0.07	< 0.001**
	1-hr NO (ppb)	0.194	0.131	0.139
	1-hr CO (ppm)	3.43	2.039	0.093
	1-hr SO_2 (ppb)	- 0.071	0.488	0.884
	Constant	323.12	300.66	0.283

*p value < 0.05, **p value < 0.01

4. Conclusion

This investigation revealed that the highest morbidity rate for dengue fever in upper Northern Thailand coincided with the rainy season, whereas the peak levels of air pollution were observed in the summer season. The morbidity rate for dengue fever was positively associated with rainfall days and cloud amount, but negatively associated with total rainfall and ground ozone levels. Therefore, rainfall days, total rainfall, cloud amount, and ground ozone levels are the optimal predictors for dengue cases in upper Northern Thailand. This study's findings can be used to improve dengue surveillance to predict dengue morbidity, prepare for outbreaks, and prevent diseases. Government authorities and relevant agencies can utilize these parameters to forecast dengue morbidity and implement strategies to control the spread of *Aedes* mosquitoes, particularly during the rainy season. This study focused exclusively on upper Northern Thailand, therefore further research is recommended in other regions of Thailand to determine the specific predictors relevant for those areas.

Acknowledgement

This work was supported by the University of Phayao, Thailand, under grant number 221/2567.

References

Abdulsalam FI, Yimthiang S, La-Up, A, Ditthakit P, Cheewinsiriwat P, Jawjit W. Association between climate variables and dengue incidence in Nakhon Si Thammarat Province, Thailand. Geospatial Health 2021; 16(2). https://doi.org/10.4081/gh.2021.1012.

Abdullah NAMH, Dom NC, Salleh SA, Salim H, Precha N. The association between dengue case and climate: A systematic review and meta-analysis. One Health 2022; 15: 100452. https://doi.org/10.1016/j.onehlt.2022.100452.

Academic Accelerator. Northern Thailand: Encyclopedia, science news & research reviews. [Internet]. [cited March 1, 2024] available from: https://academic-accelerator.com/encyclopedia/northern-thailand.

Agricultural Research Development Agency (Public Organization) (ARDA). Season in Thailand. [Internet]. [cited March 1, 2024] available from: https://www.arda.or.th/detail/6130.

Amazing Thailand, Tourism Authority of Thailand. History & geography & geology: Northern Thailand. [Internet]. [cited March 1, 2024] available from: https://www.tourismthailand.org/Articles/plan-your-trip-history-and-geography-geology.

Benedum CM, Seidahmed OME, Eltahir EAB, Markuzon N. Statistical modeling of the effect of rainfall flushing on dengue transmission in Singapore. PLoS neglected tropical diseases 2018; 12(12): e0006935. https://doi.org/10.1371/journal.pntd.0006935.

Center of Disease Control and Prevention (CDC). Data and map: Dengue. [Internet]. [cited March 1, 2024] available from: https://www.cdc.gov/dengue/statistics-maps/data-and-maps.html.

Chiang Mai University. Solving air pollution with sustainable innovations. [Internet]. [cited March 1, 2024] available from: https://sdgs.cmu.ac.th/en/ArticleDetail/fb233801-27c4-4170-85fe-f0684f11ff4b/f1d05c91-44b0-4c64-a5d9-2f87f300088b.

Department of Disease Control, Ministry of Public Health. Vector-borne diseases dashboard. [Internet]. [cited March 1, 2024] available from: https://ddc.moph.go.th/dvb/pagecontent.php?page=1269&dept=dvb.

European Centre for Disease Prevention and Control (ECDC). Dengue worldwide overview. [Internet]. [cited March 1, 2024] available from: https://www.ecdc.europa.eu/en/dengue-monthly.

Faruk MO, Jannat SN, Rahman MS. Impact of environmental factors on the spread of dengue fever in Sri Lanka. International journal of environmental science and technology 2022; 19(11): 10637-10648. https://doi.org/10.1007/s13762-021-03905-y.

Gui H, Gwee S, Koh J, Pang J. Weather factors associated with reduced risk of dengue transmission in an urbanized tropical city. International journal of environmental research and public health 2021; 19(1): 339. https://doi.org/10.3390/ijerph19010339.

Gutierrez JA, Laneri K, Aparicio JP, Sibona GJ. Meteorological indicators of dengue epidemics in non-endemic Northwest Argentina. Infectious Disease Modelling 2022; 7(4): 823-834. https://doi.org/10.1016/j.idm.2022.10.004.

Hossain S, Islam MM, Hasan MA, Chowdhury PB, Easty IA, Tusar MK, Rashid MB, Bashar K. Association of climate factors with dengue incidence in Bangladesh, Dhaka City: A count regression approach Heliyon. 2023; 9(5): e16053. https://doi.org/10.1016/j.heliyon.2023.e16053.

Information Technology and Communication Center. Royal Forest Department. Table 2 forest area separate province year 2020. [Internet]. [cited March 1, 2024] available from: https://forestinfo.forest.go.th/Content.aspx?id=10400.

Kliengchuay W, Worakhunpiset S, Limpanont Y, Meeyai AC, Tantrakarnapa K. Influence of the meteorological conditions and some pollutants on PM_{10} concentrations in Lamphun, Thailand. Journal of environmental health science & engineering 2021; 19(1): 237-249. https://doi.org/10.1007/s40201-020-00598-2.

Kularatne SA, Dalugama C. Dengue infection: Global importance, immunopathology and management. Clinical medicine 2022; 22(1): 9-13. https://doi.org/10.7861/clinmed.2021-0791.

Kumharn W, Piwngam W, Pilahome O, Ninssawan W, Jankondee Y, Chaochaikong S. Effects of meteorological factors on dengue incidence in Bangkok city: a model for dengue prediction. Modeling Earth Systems and Environment 2023; 9(1): 1215-1222. https://doi.org/10.1007/s40808-022-01557-6.

Langkulsen U, na Sakolnakhon KP. Identifying high-risk areas of dengue by meteorological factors in Thailand. IOP Conference Series: Earth and Environmental Science 2022; 987(1): 012001. https://doi.org/10.1088/1755-1315/987/1/012001.

Lu HC, Lin FY, Huang YH, Kao YT, Loh EW. Role of air pollutants in dengue fever incidence: evidence from two southern cities in Taiwan. Pathogens and global health 2023; 117(6): 596-604. https://doi.org/10.1080/20477724.2022.2135711.

Nangola S, Thongtip S, Saoin S, Kloypan C, Pimonsree S, Tantrakarnapa K. Factors related to club cell protein 16 (CC16) and quality of life in Northern Thailand. EnvironmentAsia 2023; 16(1): 169-183. https://doi.org/10.14456/ea.2023.15.

Northern Meteorological Center, Thai Meteorological Department. Meteorological data in Northern Thailand. [Internet]. [cited March 5, 2024] available from: http://www.cmmet.tmd.go.th/forecast/pt/pt_map.php.

Seidahmed OM, Eltahir EA. A sequence of flushing and drying of breeding habitats of *Aedes* aegypti (L.) prior to the low dengue season in Singapore. PLoS neglected tropical diseases 2016; 10(7): e0004842. https://doi.org/10.1371/journal.pntd.0004842.

Sirithian D, Thanatrakolsri P. Relationships between meteorological and particulate matter concentrations ($PM_{2.5}$ and PM_{10}) during the haze period in urban and rural areas, northern Thailand. Air, Soil and Water Research 2022; 15. https://doi.org/10.1177/11786221221117264.

Sugeno M, Kawazu EC, Kim H, Banouvong V, Pehlivan N, Gilfillan D, Kim H, Kim Y. Association between environmental factors and dengue incidence in Lao People's Democratic Republic: a nationwide time-series study. BMC Public Health 2023; 23(1): 2348. https://doi.org/10.1186/s12889-023-17277-0.

Tewari P, Ma P, Gan G, Janhavi A, Choo ELW, Koo JR, Dickens BL, Lim JT. Non-linear associations between meteorological factors, ambient air pollutants and major mosquito-borne diseases in Thailand. PLoS neglected tropical diseases 2023; 17(12): e0011763. https://doi.org/10.1371/journal.pntd.0011763.

Thiruchelvam L, Dass SC, Zaki R, Yahya A, Asirvadam VS. Correlation analysis of air pollutant index levels and dengue cases across five different zones in Selangor, Malaysia. Geospatial health 2018; 13(1): 613. https://doi.org/10.4081/gh.2018.613.

Thongtip S, Srivichai P, Chaitiang N, Tantrakarnapa K. The influence of air pollution on disease and related health problems in northern Thailand. Sains Malaysiana 2022; 51(7): 1993-2002. http://doi.org/10.17576/jsm-2022-5107-04.

Wang Y, Wei Y, Li K, Jiang X, Li C, Yue Q, Zee BC, Chong KC. Impact of extreme weather on dengue fever infection in four Asian countries: A modelling analysis. Environment international 2022; 169: 107518. doi: 10.1016/j.envint.2022.107518.

Wan-Norafikah O, Lee HL, Norazizah A, Mohamad-Hafiz A. Repellency effects of an ozone-producing air purifier against medically important insect vectors. Tropical biomedicine 2016; 33(2): 396-402. PMID: 33579110.

Wongkoon S, Jaroensutasinee M, Jaroensutasinee K. Distribution, seasonal variation & dengue transmission prediction in Sisaket, Thailand. Indian journal of medical research 2013; 138(3): 347-53. PMID: 24135179.

WorldData. The climate in Thailand. [Internet]. [cited March 5, 2024] available from: https://www.worlddata.info/asia/thailand/climate.php.

World Health Organization (WHO). Dengue and severe dengue. [Internet]. [cited March 5, 2024] available from: https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue.

World Health Organization (WHO). Dengue - Global situation. [Internet]. [cited March 5, 2024] available from: https://www.who.int/emergencies/disease-outbreak-news/item/2023-DON498.

Yip S, Him NC, Jamil NI, He D, Sahu SK. Spatio-temporal detection for dengue outbreaks in the Central Region of Malaysia using climatic drivers at mesoscale and synoptic scale. Climate Risk Management 2022; 36: 100429. https://doi.org/10.1016/j.crm.2022.100429.