HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2024 Vol.13, No.1 28–34

REM
Radiat Environ Med

Report

Changes in Particulate Matter (PM2.5 and PM10) Concentrations and Ambient Dose Equivalent Rates at Different Altitudes in Chiang Mai, Thailand

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Received 16 October, 2023; revised 24 November, 2023; accepted 5 December, 2023

Air pollution is one of the biggest problems in many cities worldwide. Chiang Mai is a city that also faces this problem, especially during the dry season. Due to its topography, Chiang Mai has various elevation areas, resulting in the dispersion of pollution at different altitude locations that should be measured in order to evaluate health hazards at different locations. In this study, the concentrations of PM2.5 and PM10 were measured at different altitudes in Chiang Mai, Thailand. At the same time, the ambient dose equivalent rate was monitored. The measurement results showed that the average concentration of PM2.5 and PM10 around urban areas was 23 ± 13 µg m^{-3} and 47 ± 18 µg m^{-3}, respectively, and was 14 ± 9 µg m^{-3} and 29 ± 14 µg m^{-3}, respectively, around outside urban areas. Moreover, a minor effect of altitude was observed from the measurement locations outside urban areas. The PM2.5 and PM10 concentrations tend to increase with increasing altitude. However, there was no significant difference in ambient dose equivalent rates at different altitudes. The average ambient dose equivalent rate in this study was observed at about 95 ± 12 nSv h^{-1}.

Key words: pollution, PM2.5, PM10, ambient dose equivalent rate, altitude

1. Introduction

With the continuous development of the city and rapid urbanization and industrialization, Chiang Mai province, Thailand, has become one of the few cities with the most severe air pollution in the world. Chiang Mai is the second-largest city in Thailand with a population of 1.7 million, and it has been a popular tourist destination for many decades due to its topography, climate, and cultural history. Since the last decade, Chiang Mai has been facing severe air pollution, especially during the dry season from February to May every year. Among air pollution, particulate matter (also called PM) is a major concern to public health. PM is the term for particles found in the air, including solid dust, smoke, and liquid droplets. The toxicity of PM is mainly due to particles with a diameter of less than 10 µm (PM10). Among these, PM2.5 particles

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https://doi.org/10.51083/radiatenvironmed.13.1_28

with a diameter of less than 2.5 μm have raised significant concerns about their impact on public health[1].

There were many days during the dry season in Chiang Mai when PM10 had reached 200 μg m^{-3} or over[2]. It should be noted that the Environmental Protection Agency (EPA) recommended the PM10 standard level should not exceed 150 μg m^{-3} over 24 hours[3]. Several researchers confirmed that the major source of ambient PM2.5 in Chiang Mai City during the dry season was mostly produced by the burning of biomass[4-6]. This issue has had a significant impact on Chiang Mai, not only on the economic and tourist industries, but as well as tremendously on public health, both short- and long-term.

Ambient air pollution is a major risk factor for the environmental threat to human health. Air pollution refers to the air that is contaminated with harmful pollutants or substances that are produced from natural sources such as radon gas and its progeny or from anthropogenic (man-made) sources such as the combustion of fuels in vehicles or industry production processes[7]. According to data from the World Health Organization (WHO), more than 90% of the world's population breathes air containing pollutants that adversely affect human health, and more than 6 million premature deaths annually are associated with air pollution[8]. This mortality is mostly due to exposure to PM, especially PM2.5 and PM10 which penetrate deep into lung passageways, and increase the risk of the burden of disease from stroke, cardiovascular disease, lung cancer, and both chronic and acute respiratory diseases[9-11].

Several research reported that the size and composition of PM vary widely in the atmosphere depending on the different meteorological conditions and could cause various health hazards in different locations[12, 13]. Furthermore, various meteorological and geographical parameters such as air temperature, altitude, and radiation are also involved in the dispersion and concentration of PM in the atmosphere[14]. There are several studies that have reported the altitude distribution that determines PM concentrations. Zona and team[15] reported that the highest average concentrations of PM2.5 were observed at the highest elevation areas, while the lowest averages were obtained at the low elevation areas near the seaside. On the contrary, Muhammad and his team[16] showed that the PM concentration decreased with increasing altitude.

The geographical features of Chiang Mai province have various elevation areas due to its location in a natural basin surrounded by high mountain ranges, therefore, the dispersion of PM concentrations at different altitudes should be measured in order to evaluate health hazards at different locations. In this study, the concentrations of PM2.5 and PM10 were measured at different altitudinal levels in Chiang Mai, Thailand to investigate the correlations between the altitude levels and the concentrations of PM2.5 and PM10. Furthermore, the measurement of the ambient dose equivalent rate at different altitudes was performed together with the measurement of PM in order to study the relationship between the ambient dose equivalent rate and PM concentration at different altitudes. The ambient dose equivalent rate is related to natural background radiation such as radon, cosmic rays, and terrestrial gamma rays, and exposure to natural background radiation is considered as a factor in increasing the risk hazard to public health[17].

2. Materials and methods

2.1. Study areas

The measurements of PM concentration and ambient dose equivalent rate were performed in typical public outdoor areas of Chaing Mai province, Thailand. The measurement locations can be categorized into two groups: the urban areas group and the outside urban areas group. The measurement locations in the urban areas group are located in the urban areas of Chiang Mai City, which covers around 40 km^2 of the Mueang Chiang Mai district in the city center. Figure 1 shows the measurement locations, which were recorded as coordinates using the Google Maps application on a smartphone during the measurements at 10 measurement points around Chaing Mai province. The map was plotted using free software, the Google Earth Pro software (version 7.1). The coordinates and altitudes of the measurement locations are shown in Table 1. The measurements were conducted on February 2–8, 2023. The weather was cool in the morning but hot during the day, with clear skies throughout the entire measurement period. The temperature, humidity, and pressure during the measurements were monitored on the website of Weather Underground (available access from https://www.wunderground.com/history/weekly/th/mueang-chiang-mai). The average temperature, humidity, and sea level pressure were reported at around 25.6 ± 8.4 ℃, 57.8 ± 32.3 %, and 975.1 ± 2.9 hPa, respectively.

2.2. Measurement method

The PM2.5 and PM10 concentrations were measured using a portable air quality monitor (Aeroqual Series 500; Aeroqual Inc., New Zealand). Aeroqual Series 500 is designed for portable, accurate, and real-time surveying of common outdoor pollutants such as PM2.5, PM10, and CO_2. During the measurement, the Aeroqual monitor was handheld approximately 1 m above the ground. The Aeroqual monitor was programmed to continuously measure 5-minute average concentrations of PM2.5 and PM10, and the measurement was performed for 5 measurement cycles at a measurement location. Data

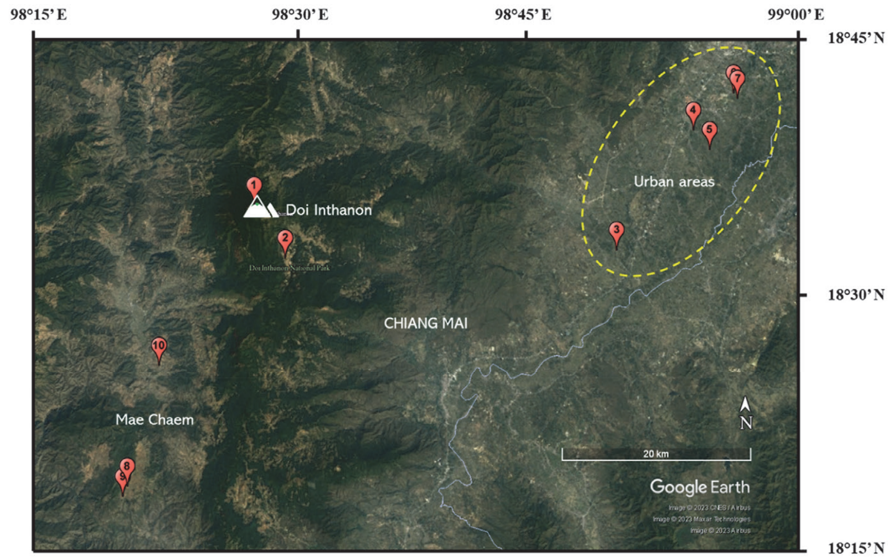

Fig. 1. Map of measurement locations in Chiang Mai province, Thailand.

Table 1. Location and description of the study areas

No.	Name	Latitude (°N)	Longitude (°E)	Altitude (m.a.s.l)*	Description
1	Location No.1	18.3523	98.2914	2560	The top of Inthanon Mountain was surrounded by forest.
2	Location No.2	18.3239	98.3104	1290	A small village in the Doi Inthanon National Park.
3	Location No.3	18.3315	98.5055	300	Urban area
4	Location No.4	18.4007	98.5533	310	Urban area
5	Location No.5	18.3860	98.5632	300	Urban area
6	Location No.6	18.4216	98.5759	320	Urban area near the airport
7	Location No.7	18.4157	98.5813	310	Urban area near the airport
8	Location No.8	18.1942	98.2143	850	A small village in the Mae Chaem district, near the Doi Inthanon National Park.
9	Location No.9	18.1907	98.2127	820	A small village in the Mae Chaem district, near the Doi Inthanon National Park.
10	Location No.10	18.2633	98.2338	560	A small village near the Doi Inthanon National Park.

* Meter above the sea level (m.a.s.l)

were stored on board the monitor and downloaded after completed measurements via the Aeroqual software to a laptop.

The ambient dose equivalent rates were measured using a survey meter (1 in×1 in cylindrical NaI(Tl) scintillation, TCS-171; Hitachi, Ltd.; Tokyo, Japan). Notably, this portable NaI(Tl) scintillation survey meter has been generally used in survey projects of the ambient dose equivalent rate distribution[17, 18]. This survey meter was calibrated using a ^{137}Cs source. The calibration factor was 0.98 for a dose rate range below 1 μSv h^{-1}. The ambient dose equivalent rate measurements were conducted 1 m above the ground for five measurements in five different directions at each measurement location, with the time constant of a measurement being 30 s.

3. Results and discussions

3.1. Altitudinal variation of PM2.5 and PM10

The average concentrations of PM2.5 and PM10 at different altitudes ranging from 300 to 2560 m.a.s.l. were measured to investigate the relationship between the PM concentration and altitude. The altitude of the measurement locations in the urban areas is about 300 m.a.s.l., and at these locations were observed the concentrations of PM2.5 and PM10 in the range 10–44 μg m^{-3} with an average of 23±13 μg m^{-3} and 30–75 μg m^{-3} with an average of 47±18 μg m^{-3}, respectively. For the measurement locations in the outside urban areas group, the altitudes range from 560 to 2560 m.a.s.l. The concentrations of PM2.5 and PM10 observed in this group

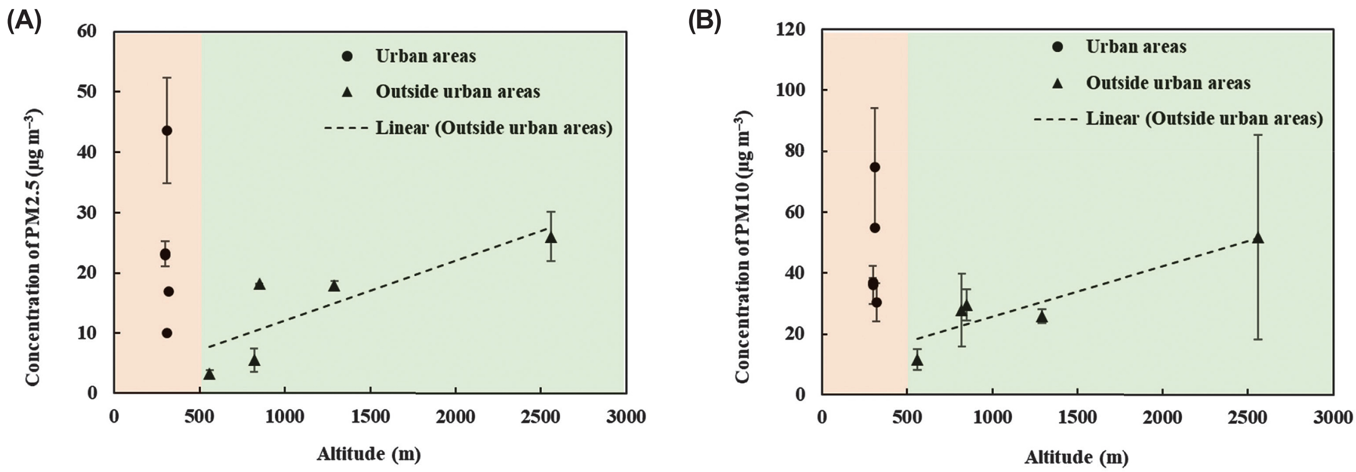

Fig. 2. Variations of (A) PM2.5 and (B) PM10 concentrations at different altitudes.

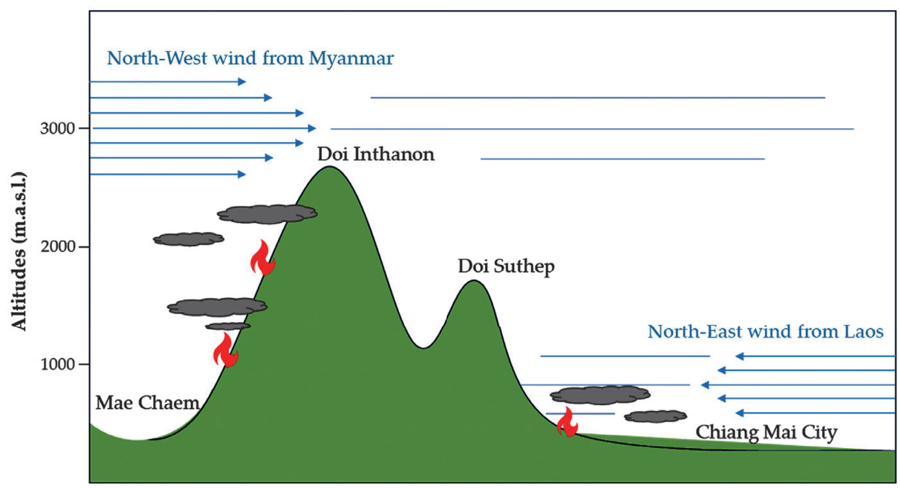

Fig. 3. Atmospheric profile across Chiang Mai province in the dry season.

ranged from 3–26 μg m^{-3} with an average of 14 ± 9 μg m^{-3} and 12–52 μg m^{-3} with an average of 29 ± 14 μg m^{-3}, respectively, as shown in Figure 2.

The observed PM concentrations showed that the average PM concentrations in urban areas are higher than those observed outside urban areas for both PM2.5 and PM10. A similar result was found by Khamkaew *et al.*[6)], in which they found that the average PM2.5 concentration at Chiang Mai University (an urban area) was higher than that at Doi Ang Khang (an outside urban area). They also revealed that biomass burning was a major source of PM2.5 in Chiang Mai City during the dry season, which is probably caused by large areas of open burning in the upper part of Northern Thailand and neighboring countries. This is probably because Chiang Mai City (the urban area) is situated in a natural basin area at a low altitude (<500 m.a.s.l.) surrounded by high mountains. During the dry season, the Asian Winter Monsoon circulates two main airflow channels, as shown in Figure 3, one at about 500 m.a.s.l., originating from the North-East and passing through from Laos, and another one at 3000 m.a.s.l., originating from the North-West and passing through from Myanmar[19)]. These seasonal winds are responsible for bringing pollution from Laos into the eastern part of Chaing Mai (urban areas group) and from Myanmar into the western part of Chiang Mai (outside urban areas group)[19)]. Due to the topography of Chiang Mai City with its valleys and basins, the winds are limited, and PM cannot be dispersed and keeps accumulating[20)]. This atmospheric dynamic explains why PM accumulates

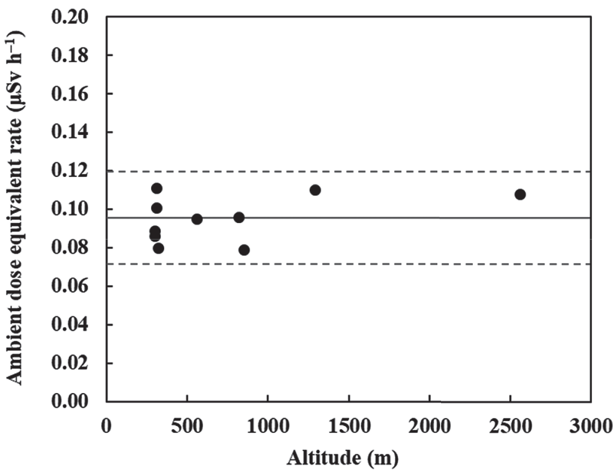

Fig. 4. The plot of ambient dose equivalent rates at different altitudes. The solid line denotes an average value of the ambient dose equivalent rate. The dashed lines denote the expanded uncertainty of the mean value (k = 2).

in basins in Chiang Mai urban areas, and it also explains variations in some spatial heterogeneities of PM concentrations.

Furthermore, the observed results showed that altitude has a minor effect on the distribution of PM concentrations in the measurement locations outside urban areas with altitudes of 560 – 2560 m.a.s.l. As can be seen in Figure 2, the concentration of PM2.5 and PM10 tends to increase with increasing altitude. As mentioned above, the wind at an altitude of 3000 m.a.s.l. has become a significant carrier of pollution from Myanmar into the western part of Chiang Mai, which is the measurement location of the outside urban areas group. Moreover, pollution from forest fires and burning of agricultural residues tends to travel to high altitudes due to the expansion of industrial crops such as soybean and maize monoculture, which has increased dramatically in the highlands of this area. Choommanivong *et al.* [21] proposed an atmospheric model that shows biomass burning in Southeast Asia travels to an altitude of up to 3000 m. Therefore, the PM concentration at higher altitudes tends to be greater than at lower altitudes in this area. A similar result was found by Zona *et al.*[15], they observed the highest average PM2.5 concentrations at the highest elevation areas, while the lowest averages were observed at the low elevation areas near the seaside. Although they mentioned that their research still does not provide sufficient data on the behavior of PM at different elevations, but they pointed out that this behavior might be related to turbulence caused by the thermal-dynamic properties of the air, which affect the transport of aerosols.

3.2. Ambient dose equivalent rate

The ambient dose equivalent rate at different altitudes in Chiang Mai City is shown in Figure 4. The ambient dose equivalent rates in this study area were observed in the range of 80–110 nSv h^{-1} with an average value of 95 ± 12 nSv h^{-1}. The absorbed dose rates in air were estimated in the range 64–90 nGy h^{-1}, with an average of 77 ± 10 nGy h^{-1} using a dose conversion factor of about 1.23 Sv Gy^{-1} from the ICRP Publication 116[22]. According to the report data from UNSCEAR (2000)[23], the world's absorbed dose rates in the air are in the range of 24 to 160 nGy h^{-1}, with an average of 57 nGy h^{-1}, which is a little lower than the average value obtained in this study. The average absorbed dose rate obtained in this study was also slightly higher than the average value observed in the eastern, western, and southern parts of Thailand, which was reported by Kranrod *et al.*[24] with an average value of 41 ± 4 nGy h^{-1}. This is because Chiang Mai is located in a high-radon potential area[25] and situated in a basin of granite rock associated with active faults[26, 27]. Therefore, the natural background radiation from radon and its progeny, and particularly terrestrial radiation from granite rocks, may contribute to the radiation doses in the Chaing Mai area more than in other parts of Thailand.

Figure 4 shows the plot of ambient dose equivalent rates at different altitudes. The measurement results were statistically compared using t-tests. A difference of $p < 0.05$ was considered statistically significant. The results showed that no significant difference was found in ambient dose equivalent rates at different altitudes; therefore, no correlation between ambient dose equivalent rate and altitude was observed in this study.

4. Conclusions

In this study, the concentrations of PM2.5 and PM10 were measured together with the ambient dose equivalent rate at different altitudes (ranging from 300 to 2560 m.a.s.l.) in Chiang Mai, Thailand. The measurement locations were divided into two groups: the urban areas group and the outside urban areas group. The average concentration of PM2.5 and PM10 in the urban areas group was (23 ± 13) μg m^{-3} and (47 ± 18) μg m^{-3}, respectively, which is higher than the average value of the outside urban areas group. The average concentration of PM2.5 and PM10 in the outside urban areas group was (14 ± 9) μg m^{-3} and (29 ± 14) μg m^{-3}, respectively. Moreover, the observed results showed that altitude has a minor effect on the distribution of PM concentrations in the measurement locations outside urban areas with altitudes 560 – 2560 m.a.s.l., the concentrations of PM2.5 and PM10 tend to increase with increasing altitude. However, there was no significant difference in ambient dose equivalent rates at different altitudes. The ambient dose equivalent rates in this study area were observed in the range of 0.080 – 0.110 μSv h^{-1} with an average value of 0.095 ± 0.012 μSv h^{-1}. The variation of PM2.5 and PM10 concentrations and ambient dose equivalent rates at different altitudes obtained in this study provided useful information to Chaing Mai residents and tourists. The information on PM2.5, PM10, and radiation exposure levels is essential and interesting for developing a pollution prevention and radiological protection culture among citizens and engaging in a dialogue on the policy to control pollution.

Acknowledgements

This research was made possible with support from the Faculty of Associated Medical Sciences, Chiang Mai University, Thailand, for the visiting professor program (Prof. Dr. Shinji Tokonami). In addition, this work was partially supported by JSPS KAKENHI Grant Numbers JP16K15368 and JP20H00556.

Author Contributions

Conceptualization, S.T. and C.K.; Methodology, R.Y.; Formal analysis, M.K., and W.P.; Investigation, R.Y., C.K., T.T., S.S., S.S., K.R., P.B. and S.T.; Data acquisition and interpretation, C.K. and W.P.; Supervision, C.K. and S.T.; Validation, W.P., C.K. and S.T.; Writing-original draft, C.K., and W.P.; Writing-review and editing, C.K., W.P., and S.T. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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