Accuracy of estimating a human-sighted visual range for short-term particulate matter concentration in Chiang Mai, Thailand

Theerawasttanasiri Nonthaphat [1*], Pattara-anantanop Nongnutch[1], Chamnankong Kingpikul [2], Samdangsuk Ithawara[1], and Winun Akkarin[1]

[1]Health Promotion Center Region 1 Chiang Mai, Department of Health, Thailand
[2] Office of the Expert Committee, Department of Health, Thailand

*Corresponding author: Theerawasttanasiri Nonthaphat, p.theerawattanasiri@gmail.com

ABSTRACT

Background: Haze crisis in the North Thailand has occurred more than decade. Although four air monitoring stations (Air4Thai) are installed in Chiang Mai, three stations are in the city. According to the California Department of Public Health, communities have used both measurement devices and visual estimates as the concentration of smog changes quickly. Therefore, particle levels are estimated from visual assessments or visual views as another measurement as well. This study aims to assess whether human-sighted visual range is reliable or not in Chiang Mai areas.

Objectives: To determine accuracy of human-sighted visual range to estimating short-term Particulate Matter (PM) concentration.

Methods: A retrospective study was conducted purposively among hospitals and Public Health Office at 25 districts in Chiang Mai province where DustBoy air measurement devices were installed and reported air quality including PM2.5, PM10, temperature and relative humidity. The human-sighted visual range (Hr) were reported by trained health staff following the manual applied from “Wildfire Smoke, A Guide for Public Health Officials”. The Hr were reported into six color levels: blue, green, yellow, light orange, dark orange, and red., three times per day in morning (9.00), afternoon (13.00) and evening (16.00). Data was collected between April and May 2018. Both data were matched according to the date and time, excepted data with relative humidity exceeded 65% were excluded. Descriptive statistics described general data and Cohen's kappa statistics analyzed the accuracy of Hr.

Results: Hr accuracy for PM10 was at a good level (79.21%) while Hr for PM2.5 was not useful (26.49%).

Conclusion: Human-sighted visual range could be applicable for PM10 assessments for community. However, it would not be effective in early-morning, twilight-hours, rainy day, cloudy or humidity >65%. Moreover, personal experience and judgment should be of concern.

Keywords: PM2.5, PM10, Human-sighted visual range, DustBoy, Low-cost sensor

1. Introduction

More than 80% of people and 97% of cities in Global are exposed to air pollutions that exceed the World Health Organization (WHO) air quality index (AQI) guidelines most are particulate matter (PM) [1]. Exposure to various air pollutants, including PM poses the greatest threat to human health because fine particles can travel deeper through the respiratory system than larger particles [2]. In Thailand, the Upper North including Chiang Mai province have faced to haze crisis during January to Early May more than decade. It is severe both in the concentration and the number of days exceeded the AQI of the PCD of Thailand [3]. Chiang Mai Province covers an area of approximately 22,436 square kilometers, the largest area in the country and divided into 25 districts. There are four standard air quality stations (Air4Thai) to monitor and report the air pollution situation. However, three are at central city in Mueang Chiang Mai district. Therefore, the report may not reflect and represent the pollution situation in rural districts.

In 2018, Climate Change Data Center (CCDC), Chiang Mai University has developed DustBoy; a low-cost air measuring device use light-scattering method [4]. Since, there has been a collaboration between Regional Health Portion Center 1 Chiang Mai and Chiang Mai University to provide DustBoy for 25 districts in Chiang Mai for report the air pollution situation in rural districts. However, due to the most characteristics of districts and sub-district areas are rural and valleys, the situation report from DustBoy devices at the district level may not be able to reflect the actual situation at the sub-district level. Moreover, there was limited budget to provide DustBoy cover 204 subdistricts.

A review of research, there were found that estimation Human-sighted Visual Range (Hr) [5, 6] was used in many states of the United States by observing how far it can be seen and then converting the value into the amount of short term PM2.5 or PM10 concentration (1 to 3 hr) for surveillance, risk communication and response to prevent and reduce health impacts from smog according to the actual conditions. This method that people can do by themselves. It can be basic information used to warn and help people in the rural area. According to the California Department of Public Health, some of communities do not have PM10 detectors devices. It is necessary to use observation or visual scenery as another device of measurement as well. This

ISSN: 2822-0587(Online)

is because the concentration of smog changes quickly. Therefore, particle levels are estimated from visual assessments or visual views by determination of the visibility distance and average PM2.5 or PM10 levels over a period of 1-3, 8, and 24 as shown in Figure 1.

	Smoke guide (2008)		Montana (2013)		Colorado (2013)		Alaska (2013)	
Air Quality Index Category	V_r (km)	Mass (μg/m^3)	V_r (km)	Mass (μg/m^3)	V_r (km)	Mass (μg/m^3)	V_r (km)	Mass (μg/m^3)
Good	17.71	38	21.41	33.6	16.1	40	16.1	40
Moderate	9.66	88	14.01	51.1	8.05	80	9.66	80
Sensitive Groups	4.83	138	8.05	88.6	4.83	175	4.83	175
Unhealthy	2.42	351	3.38	201	2.42	300	2.42	300
Very Unhealthy	1.61	526	2.09	338.5	1.61	500	1.21	500
Hazardous	<1.61	>526	<2.09	>338.5	<1.61	>500	<1.21	>500

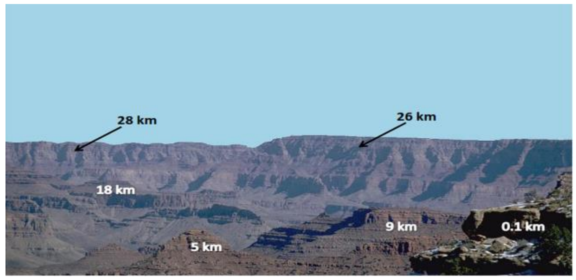


Figure 1: Example of determining PM concentration and Human visibility distance (Hr) in the United States.

2. Methods

2.1 Study Area

The study areas were purposive among hospitals and public health offices at 25 districts in Chiang Mai province where DustBoy air measurement devices were installed and had good signal internet to report data.

2.2 Study Design

This was a retrospective study conducted among 25 district hospitals and health offices in Chiang Mai province. Data was collected between April and May 2018. Air quality Data was automatic reports from DustBoy including concentration of PM2.5, PM10, temperature and relative humidity. Data of human-sighted visual range (Hr) were reported by trained public health offices following the manual of "Wildfire Smoke, A Guide for Public Health Officials" [5, 6].

2.3 Sample size and sampling

The samples were 25 districts of hospitals and public health offices, purposively selected in Chiang Mai province where DustBoy devices were installed, had good signal internet to report data, and 2 -3 health officer staff per office who were trained in monitoring and reporting about human-sighted visual range (Hr).

2.4 Research Instruments

1) Air quality measurement : DustBoy device is an outdoor air quality sensor which was researched and developed by the Climate Change Data Centre (CCDC), Chiang Mai University [4]. It can measure PM10, PM2.5, temperature and relative humidity with

displayed in real time. It's acceptable level of confidence by comparing the measurement results with the standard Beta Ray measuring device of the Pollution Control Department Thailand both at the beginning and after one year of using, the end of use, the correlation value (Correlation Coefficient R2) equal to 0.80. Data from DustBoy was automatic report via internet to in CCDC sever, Chiang Mai University.

2) Human-sighted visual range guideline : this study applied "Wildfire Smoke, A Guide for Public Health Officials 2018" [5, 6] to be a guideline and for visibility distance, visual assessments in Chiang Mai, Thailand as shown in Figure 2.

US EPA (2008)			Hr For PM2.5 or PM10 (TH)	
Air Quality	**PM2.5 or PM10 Avg 1-3 hrs. (μg /m^{-3})**	**Visual distance (Km.)**	**Color report**	**Air Quality**
Good	0 – 38	> 17.0	Blue	Good
Moderate	39 – 88	9.0 – 16.9	Green	Moderate
Sensitive Groups	89 – 138	5.0 – 8.9	Yellow	Sensitive Groups
Unhealthy	139 – 351	3.1 – 4.9	Light Orange	Unhealthy
Very Unhealthy	352 – 526	1.5 – 3.0	Dark Orange	Very Unhealthy
Hazardous	> 526	< 1.5	Red	Hazardous

Figure 2: Applying "Wildfire Smoke2018" to human-sighted visual range in Chiang Mai, Thailand

Visual distances: the distance of observation points and targets landmark were calculated and set up via Google Map and practice to 2-3 health officer staff of each district.

Assess visible range: to estimate visibility in kilometers, face away from the sun and determine the limit of the visibility range by looking for targets at known distances (Kilometer). The visible range is the point at which even high-contrast objects (e.g., a dark building or mountain viewed against the sky at noon) totally disappear shown in Figure 3.

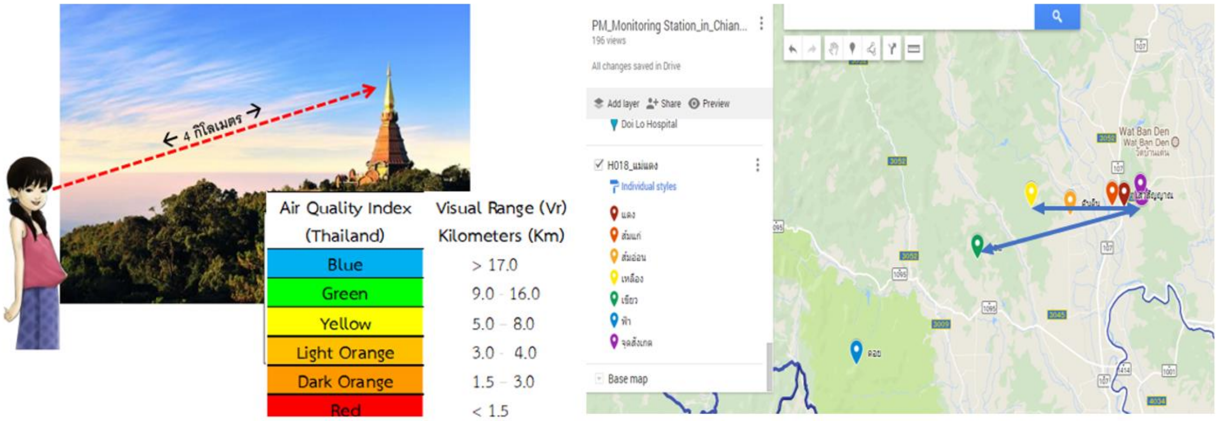
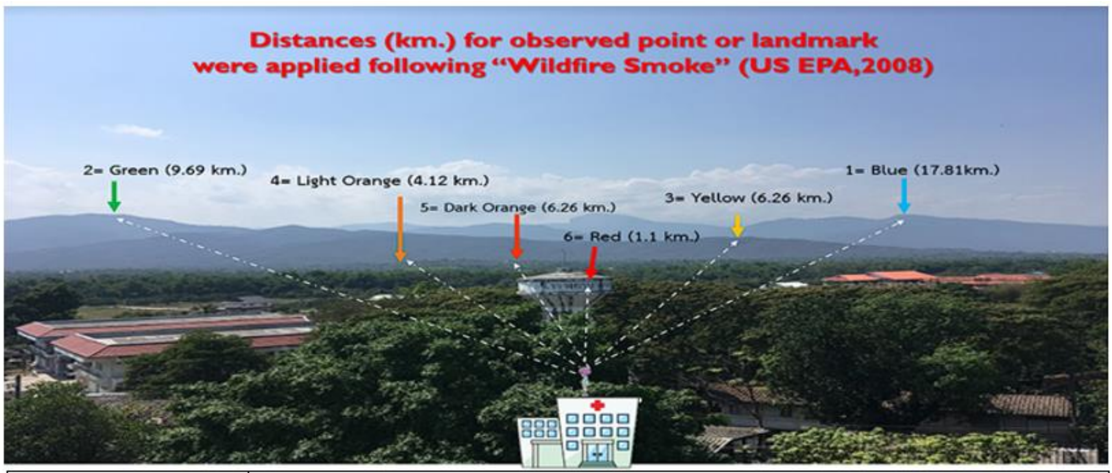


Figure 3: The visual distances for target landmark setting via Google Map.

3) Report form: the report form was developed by the research team according to the guidelines. The data was divided into six colors; blue, green, yellow, light orange, dark orange, and red, following below and show in Figure 4.



Item/ District	Color to report 2/ Visual distance (Km.)					
Color to report	Blue	Green	Yellow	Light Orange	Dark Orange	Red
Air Quality	Very Good	Good	Moderate	Unhealthy	Very Unhealthy	Hazardous
PM2.5 (µg/m³)	0 - 25	26 - 37	38 - 50	51 - 75	76 - 90	91 +
PM10 (µg /m³)	0-38	39-88	89-138	139-351	352 - 526	527 +
Visual distance(Km.)	> 17	9.0 – 16.9	5.1 – 8.9	3.1 – 5.0	1.5 – 3.0	< 1.5

Figure 4: Applying visual distance to report PM2.5 and PM10 situation in Chiang Mai, Thailand.

The reporter can choose the method to report; online report: three times daily reports through the internet to the CCDC server, in the morning (9:00), afternoon (13.00) and evening (16.00); manual report(paper): in case of internet failure, data were report by manual after completed report three times daily, collected and sent to researcher weekly.

2.5 Data Collection

Data were collected from DustBoy device and human-sighted visual range (Hr) from 1st April to 15 May 2018 as follow.

1) Data from DustBoy device included concentration of PM2.5, PM10, temperature and relative humidity which were automatic recorded and collected to CCDC sever. Data of relative humidity that higher than 65% was excluded.

2) Data from Human-sighted visual range (Hr) were reported by 2-3 trained staff of district hospital or public health office.

3) Both data were matched according to the corresponding date and time, others were excluded. Completed matching data were equal to 782 records.

2.6 Data Analysis

Descriptive statistics including number and percentage were described in general data. This study used Cohen's Kappa statistics to analyze the accuracy of human-sighted visual rage of PM2.5 and PM10. The Kappa statistic (K) [7] is frequently used to test interrater reliability. The importance of rater reliability lies in the fact that it represents the extent to which the data collected in the study are correct representations of the variables measured. Measurement of the extent to which data collectors (raters) assign the same score to the same variable is called interrater reliability. While there have been a variety of methods to measure interrater reliability, traditionally it was measured as a percentage agreement, calculated as the number of agreement scores divided by the total number of scores.

The Kappa statistic [8] was diagnostic accuracy or percentage agreement which was classified into six levels as no agreement (<0), slight agreement (0.0–0.20), fair agreement (0.21–0.40), moderate agreement (0.41–0.60), substantial agreement (0.61–0.80) and almost perfect agreement (0.81–1.00) In this study, the multi-contingency table (6X6) to analyze Cohen's Kappa statistics is based on the study of Marco Vanetti [9]. The accuracy of human-sighted visual rage of PM2.5 and PM10 for three accuracy following:

1) User's accuracy: it was calculated by percentage of dividing the numbers of correctly classified in each color category by

the numbers of total completed data (column total).

2) Producer's accuracy: it was calculated by percentage of dividing the numbers of correctly classified in each color category by the numbers of total completed data (row total).

3) Overall accuracy: represents total classification accuracy. It is obtained by dividing the total numbers of correctly both classified by the total numbers of matching data. The drawback of this measure is that it does not tell us about how well individual classes are classified.

The diagnostic accuracy or percentage was classified into six levels as excellent (90–100 %), very good (80-90%), good (70–80%), sufficient (0.6 - 0.7), bad (0.5 - 0.6), and test not useful (< 50%).

2.7 Ethical Clearance

This research was approved by the Human Research Ethics Committee, Department of Health, No. 404/2020, sub-project 1.4 Development of surveillance and risk communication system to increase health literacy: a case study of haze and PM2.5 crisis in the North Thailand.

3. Results

3.1 Completed matching data

Figure 5 shows the amount of human-sighted visual range reports were 2,971 records and DustBoy device reports were 2045 records. Then matching data according to the corresponding date and time data were 1,598 records, then excluded data with relative humidity exceeded 65%. Finaly the completed data were 782 records (54.57%).

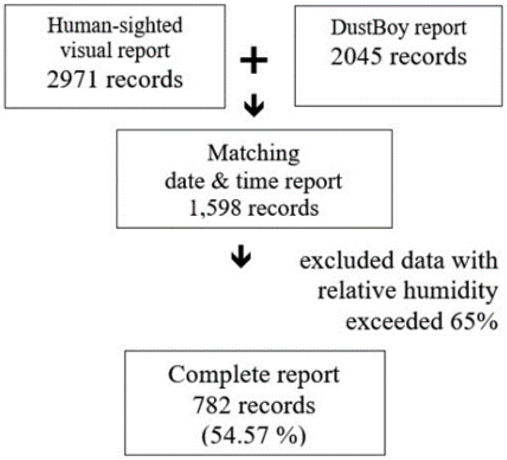


Figure 5: Matching data for date & time and excluded data with relative humidity exceeded 65%.

3.2 Accuracy Hr for short-term PM2.5 concentration

Table 1: Multi-contingency table (6x6) for Classification the matching colours of PM2.5. The total matched data was 782 records. The correctly classified colours were Blue (95), Green (102), Yellow (28), and Light Orange (6) respectively. However, Dark Orange (0), and Red (0) were incorrectly.

Table 1: Multi-contingency table (6x6) for Classification accuracy of Human-sighted visual range for PM2.5

Human-Sighted Visual Range	DustBoy device						Total
	Blue	Green	Yellow	Light Orange	Dark Orange	Red	
Blue	95	4	0	0	0	0	99
Green	152	102	18	6	0	0	278
Yellow	126	155	28	21	2	0	332
Light Orange	18	62	18	6	2	0	106
Dark Orange	0	22	10	11	0	0	43
Red	0	0	3	7	4	0	14
Total	391	345	77	51	8	0	872

It was found that user's accuracy for PM2.5 of Blue was 95.96% which defined to excellent levels. However, Green (36.69%), Yellow (29.57%), Light Orange (5.66%), Dark Orange (0%), and Red (0%) were lower than 50% and these define as test not useful. Producer's accuracy for PM2.5 of all colours were lower than 50% including Blue (24.30%), Green (29.57%), Yellow (36.36%), Light Orange (11.77%), Dark Orange (0%), and Red (0%). These define as test not useful. Overall accuracy was 26.49% and lower than 50% which defined as and the Kappa statistic (κ) was equal to 0.06 which defined as no agreement (Table 2).

Table 2: Multi-contingency table (6x6) to analyses User's Accuracy, Producer's Accuracy and Overall accuracy for Human-sighted visual range for PM2.5

Draw confusion matrix for 6 classes.

Truth data

Classifier results	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Classification overall	User's accuracy (Precision)
Class 1	95	4	0	0	0	0	99	95.96%
Class 2	152	102	18	6	0	0	278	36.691%
Class 3	126	155	28	21	2	0	332	8.434%
Class 4	18	62	18	6	2	0	106	5.66%
Class 5	0	22	10	11	0	0	43	0%
Class 6	0	0	3	7	4	0	14	0%
Truth overall	391	345	77	51	8	0	872	
Producer's accuracy (Recall)	24.297%	29.565%	36.364%	11.765%	0%	No data		

Overall accuracy (OA): 26.491%

Kappa[1]: 0.06

Table 3 interprets that the results of estimating the human-sighted visual range for PM2.5 has an accuracy lower than 50 percent (26.49%) or the test is not useful and the Kappa statistic was at no agreement level (κ =0.06).

Table 3: Different measurement of User's Accuracy, Producer's Accuracy and Overall accuracy for Human-sighted visual range for PM2.5

Overall Hr accuracy of PM2.5 = (95+102+28+6) / 872 X 100 = 26.49 % (<50%)		
Range Colour	**Producer's Accuracy**	**User's Accuracy**
Blue	= 95 / 391 x 100 = 24.30 % (<50%)	= 95 / 99 x 100 = 95.96 % (<50%)
Green	= 102 /345 x 100 = 29.57 % (<50%)	= 102/278 x 100 =36.69% (<50%)
Yellow	= 28 /77 x 100 = 36.36 % (<50%)	= 28 /332 x 100 = 8.43 % (<50%)
Light Orange	= 6 / 51 x 100 = 11.77 % (<50%)	= 6 / 106 x 100 = 5.66 % (<50%)
Dark Orange	= 0 / 8 x 100 = 0 %	= 0 / 43 x 100 = 0 %
Red	= 0 / 0 x 100 = 0 %	= 0 / 14 x 100 = 0 %

Tables 4 presents multi-contingency table (6x6) for classification the matching colours of PM10. The total matched data was 782 records. The correctly classified colours were Yellow (287), Green (229), Light Orange (91), Blue (80), and Dark Orange (27), and Red (10) respectively.

Table 4: Multi-contingency table (6x6) for Classification the matching colours of PM10

Human-Sighted Visual Range	Dust Boy Device (PM10)						Total
	Blue	Green	Yellow	Light Orange	Dark Orange	Red	
Blue	80	17	2	0	0	0	99
Green	16	229	29	3	1	0	278
Yellow	0	29	287	6	5	0	332
Light Orange	0	2	6	91	6	1	106
Dark Orange	0	1	6	6	27	3	43
Red	0	0	0	1	3	10	14
Total	101	278	330	107	42	14	872

Table 5 describes multi contingency table (6x6) to analyse User's Accuracy, Producer's Accuracy and Overall accuracy for Human-sighted visual range for PM10. User's accuracy for PM10 of Blue (80.81%), Green (82.37%), Yellow (86.45%) and Light Orange (85.85%) were defined to very good level, Red (71.43%) was at good level and Dark Orange (62.79%) was at sufficient level. Producer's accuracy of all colours was at mor than 50% including, Green (82.37%), Yellow (86.97%), Light Orange (85.05%) were in very good level, Blue (79.21%) and Red (71.43%) were at good level, and Dark

Orange (64.29%) was at sufficient level. Overall accuracy was 83.03% and which defined as very good level and the Kappa statistic (κ) was equal to 0.77 which defined as substantial agreement level (Table 5).

Table 5: Multi-contingency table (6x6) to analyses User's Accuracy, Producer's Accuracy and Overall accuracy for Human-sighted visual range for PM10

Draw confusion matrix for 6 classes.

Truth data

Classifier results	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Classification overall	User's accuracy (Precision)
Class 1	80	17	2	0	0	0	99	80.808%
Class 2	16	229	29	3	1	0	278	82.374%
Class 3	5	29	287	6	5	0	332	86.446%
Class 4	0	2	6	91	6	1	106	85.849%
Class 5	0	1	6	6	27	3	43	62.791%
Class 6	0	0	0	1	3	10	14	71.429%
Truth overall	101	278	330	107	42	14	872	
Producer's accuracy (Recall)	79.208%	82.374%	86.97%	85.047%	64.286%	71.429%		

Overall accuracy (OA): 83.028%

Kappa[1]: 0.765

Table 6 interprets that the accuracy of estimating the human-sighted visual range for PM10 was at very good level and the Kappa statistic was at substantial agreement level (κ =0.77).

Table 6: Different measurement of User's Accuracy, Producer's Accuracy and Overall accuracy for Human-sighted visual range for PM10

	Overall Hr accuracy of PM10 = (80+229+287+91+27+10) / 872 X 100 = 79.21 %	
Range Colour	**Producer's Accuracy**	**User's Accuracy**
Blue	= 80 / 101 x 100 = 79.21 % (good)	= 80 / 99 x 100 = 80.81 % (very good)
Green	= 229 /278 x 100 = 82.37 % (very good)	= 229 /278 x 100 = 82.37 % (very good)
Yellow	= 287 /330 x100 = 86.97 % (very good	= 287 /330 x100 = 86.45 % (very good)
Light Orange	= 91 / 107 x100 = 85.01 % (very good)	= 91 / 107 x 100 = 85.85 % (very good)
Dark Orange	= 27 / 42 x 100 = 64.29 % (sufficient)	= 27 / 42 x 100 = 62.79 % (sufficient)
Red	= 10 / 14 x 100 = 71.43 % (good)	= 10 / 14 x 100 = 71.43 % (good)

4. Discussion

Analysis of accuracy estimating human-sighted visual range (Hr**)** for PM2.5. The result found that only User's accuracy of Blue (95.96%) was at very good level. However, User's accuracy (0-36.69), Producer's accuracy (0-36.36%) and Overall accuracy (26.49%) were lower than 50% which defined as the test was not useful and the

Kappa statistic was at no agreement level (κ =0.06). The result of Hr for PM10 found that User's accuracy (62.79 % - 86.45%) and Producer's accuracy (64.29% - 86.97%%) were at sufficient level to very good level. was at sufficient level accuracy Overall accuracy was very good level (were 83.03%) and the Kappa statistic defined as substantial agreement level (κ=0.77). The results of this study are consistent with studies by William C. Malm, Bret Schichtel, and Jenny Hand and colleagues [10].

The result could imply that estimation human-sighted visual range (Hr) for PM10 was applicable for district and subdistrict community in Chiang Mai province or the district in the North Thailand. However, although the results of estimating PM10 are at the good to very good level, the estimating of this method is not effective during the early morning, dusk, or during rain, very cloudy or relative humidity higher than 65%. Moreover, experience, expertise and judgment of the reporter should be concern. Therefore, this method must always be used in conjunction with measuring with an air measurement device to ensure accuracy and increase the observation skills of the reporter. The results of this study are consistent with studies by William C. Malm, Bret Schichtel, and Jenny Hand and colleagues [10].

1) Limitations of the topography of the study area

Because many hospitals have topographical conditions that are not conducive to setting observation points (landmarks), such as being in an area obscured by tall buildings, being located on a flat area, etc., it is not possible to determine the visibility distance according to the standard surveillance set.

2) Limitations in efficiency of estimation This is because the method for estimating fine dust particles from the field of view is ineffective during early morning, dusk, rainy, cloudy, or relative humidity above 65%, and the accuracy Estimates are based on experience. Individual expertise and consideration Should be used in conjunction with measurement with the DustBoy dust meter to ensure accuracy and develop the expertise of the estimator.

3) Remote area limitations

Because the DustBoy device works using electrical energy, and must use internet signals to send and receive data from the device to the server. Therefore, in areas that use solar cells or have frequent power outages, unclear and unstable internet signal which may affect the connection and transmission of information, causing the information to be incomplete and cause data analysis to be inaccurate.

4) Estimating human-sight visual range contains much uncertainty

This uncertainty stems from sighting on nonblack bodies (e.g., green forested landmarks, snow-covered peaks), difficulty judging when an object is just barely visible, variations in the atmosphere and thickness of the smoke across the line of sight, and assuming the atmosphere remains constant after using an instantaneous.

5. Conclusion

This study assessed the accuracy of human-sighted visual range (Hr) estimation for PM2.5 and PM10. For PM2.5, accuracy was limited, with user accuracy for the blue category at 95.96%, but overall accuracy and Kappa statistic were below acceptable levels (κ = 0.06). In contrast, PM10 estimation achieved good to very good accuracy, with user and producer accuracies ranging from 62.79% to 86.97%, an overall accuracy of 83.03%, and substantial agreement (κ= 0.77). To enhance accuracy, the method should be used alongside air measurement devices.

Acknowledgement

This research was under the research program of “Development of Mechanism and Monitoring System for Surveillance and Emergency Risk Response to Promote Health Literacy on COVID-19 Pandemic” which support by Health Systems Research Institute (HSRI). The authors would like to thank Chiang Mai Provincial Public Health Office, District Hospitals and District Public Health Offices, Climate in Chiang Mai and Change Data Center, Chiang Mai University (CCDC, CMU).

References

[1] World Health Organization. WHO Global Ambient Air Quality Database (2019) 2019 [cited 2024 Agust 20]. Available from: http://www.who.int/airpollution/data/cities/en/.

[2] Schlesinger WH, Reckhow KH, Bernhardt ES. Global change: The nitrogen cycle and rivers. Water Resources Research. 2006;42(3).

[3] Pollution Control Department (PCD) Thailand. Thailand State of Pollution 2020 2020 [cited 2024 July 20]. Available from: https://www.pcd.go.th/pcd_news/12628/.

[4] Climate Change Data Center (CCDC). Chiang Mai University. The calibration of DustBoy Model : Low Cost Sensor for PM2.5 measurement device 2023 [cited 2023 August 20]. Available from: https://www.cmuccdc.org/uploads/reports/evaluation_report.pdf.

[5] U.S. Environmental Protecon Agency (EPA). Wildfire Smoke: A Guide for Public Health Officials: California: Environmental Protection Agency; 2018.

[6] U.S. Environmental Protecon Agency (EPA). Wildfire Smoke State Policies for Reducing Indoor Exposure: Environmental Law Instute, Washington, D.C; 2024.

[7] Mary L. McHugh. Interrater Reliability: The Kappa Statistic2012 [cited 2024 July 20]:[22(3):276-82. PMID: 23092060; PMCID: PMC3900052. pp.]. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3900052/.

[8] Onuwa Okwuashi MI, Etim Eyo, Aniekan Eyoh, Okey Nwanekezie, Dupe Nihinlola Olayinka, Daniel Okon Udoudo & Beulah Ofem,. GIS Cellular Automata Using Artificial Neural Network for Land Use Change Simulation of Lagos, Nigeria 2021 [cited 2024 July 20]; Vol. 4, No. 2; 2012. Available from: file:///D:/Publication/@%20IJPHAP/Reference/GIS_Cellular_Automata_Using_Artificial_Neural_Netw.pdf.

[9] Marco Vanetti IG, Angelo Nodari,. Confusion matrix online calculator 2012 [cited 2024 May 20]. Available from: https://www.marcovanetti.com/pages/cfmatrix/?noc=6.

[10] William C. Malm BS, & Jenny Hand,. Wildfire Smoke, A Guide for Public Health Officials, US EPA, 2016: U.S. Environmental Protection Agency; 2016.