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Research Article

CHARACTERIZING AND MONITORING $PM_{2.5}$ CHANGESIN MAP TA PHUT INDUSTRIAL ESTATE

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ABSTRACT

The changes of daily fine particular matter ($PM_{2.5}$) maximums are characterized and monitored in Map Ta Phut Industrial Estate situated in Rayong, the eastern province of Thailand. To achieve the goal, descriptive statistics and cluster analysis are utilized for identifying the essential patterns or characteristics of $PM_{2.5}$ changes. The exponentially weighted moving average (EWMA) control chart then is applied in detecting to see whether the process shift is meeting set the daily Thailand's national air quality standard. The results of work are taken by the only one monitoring station; the Health Promotion Hospital Map TaPhut (29T). It indicates that a seasonal and period of time during a day are impact on $PM_{2.5}$ changes. The $PM_{2.5}$ maximum are high in Winter while medium and low values are in Summer and Rainy season. In addition, the $PM_{2.5}$ maximums are high from morning to early afternoon, slightly high from midnight to early morning, medium from afternoon to early evening and low from evening to midnight, respectively. Finally, the EWMA control chart potentially exhibits a critical signal as pointing out the eight days (December 8 to December 15 of 2021) not in-control state. The obtained findings are advantageous as a guideline to manage and control the number of days not exceeding the Thai limit or even though decrease the number of days exceeding the Thai limit.

Keywords: $PM_{2.5}$, Map Ta Phut Industrial Estate, Cluster Analysis, EWMA Chart.

INTRODUCTION

Map Ta Phut Industrial Estate is the largest industrial park of Thailand sited in Map Ta Phut sub-district, Mueang Rayong District, Rayong Province. It is founded on March 28, 1989 by the state enterprise under Industrial Estate Authority of Thailand, Ministry of Industry which is responsible for the development and establishment of industrial estate where factories for various industries are orderly and systematically clustered together [1, 2]. Map Ta Phut Industrial Estate is not only being a part of Thailand's eastern seaboard economic region but also consisting of diverse plants such as petrochemicals, oil refinery, power, steel, chemical and fertilizer plants, etc. That is why leads to a pile of significant pollution problems; according to the World Resources Institute, Map Ta Phut is "...one of Thailand's most toxic hot spots with a history of air and water pollution, industrial accidents, illegal hazardous waste dumping, and pollution-related health impacts including cancer and birth deformities." [3, 4]. $PM_{2.5}$ referred to a class of particulate pollutant with diameters measured generally 2.5 microns or smaller is one of the seriously major air pollutants which Map Ta Phut Industrial Estate stands up to nowadays. $PM_{2.5}$ can infiltrate the blood stream through the respiratory system and move throughout the body therefore it cause extensive health effects including asthma, lung cancer and health disease also may connect to low birth weight and increase severe respiratory infections and stroke [5].The air quality standard of $PM_{2.5}$for 24-hour mean is equal 25 $\mu g / m^3$ proclaimed by the World Health Organization (WHO) while Thailand's standard is set twice of WHO's, 50 $\mu g / m^3$ .The Air Quality and Noise Management Bureau reported the daily $PM_{2.5}$ maximums at the Health Promotion Hospital Map Ta Phut (29T) were frequently over the standard level [6] then it is necessary to notify and warn residents that it may harm their health. Some researchers versatility conducted statistical tools for working on analysis of particulate pollutants; $PM_{2.5}$ and PM_{10}; for example, comparing compositions and sources of $PM_{2.5}$and $PM_{10}$with descriptive statistics particularly box plot [7], building a model on regression analysis [8], detecting for airborne particulate matter by Bayesian approach [9], classifying five main pollutants included PM_{10} by cluster analysis and predicting AQI with neural networks[10], characterizing and monitoring of fine particular matters with control charts [11, 12], etc. This work then initially uses descriptive statistics and cluster analysis in a referenced period (Phase I) to identify the basic patterns and characteristics of $PM_{2.5}$ changes. The Exponentially Weighted Moving Average control chart or EWMA control chart is finally practiced in Phase II to validate if $PM_{2.5}$ changes are in-control process.

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MATERIALS AND METHODS

The Health Promotion Hospital Map TaPhut (29T) is the delegate of monitoring stations to characterize and monitor $PM_{2.5}$ changes in Map Ta Phut Industrial Estate. The observational data was measured an average 24-hour value of $PM_{2.5}$ maximums($\mu g/m^3$) from November 1, 2020 to December 15, 2021 as recorded by the Air Quality and Noise Management Bureau, Pollution Control Department [6].Data then was divided into 2 sets. The first set was utilized for Phase I (from November 1, 2020 to October 31, 2021) to identify patterns and characteristics of $PM_{2.5}$ changes. The other one was considered for Phase II (from November 1 to December15, 2021)to test if the changes of $PM_{2.5}$ maximums are in-control status or not. Given x_i be a series of daily $PM_{2.5}$ maximums recorded at time i ; i set from November, 1, 2020 to December, 15, 2021. The procedure of work was following these two steps.

1. To characterize the basic patterns and characteristics of $PM_{2.5}$ changes basing on Phase I, descriptive statistics like mean, standard deviation including box plot and cluster analysis were employed. Cluster of variables in cluster analysis was also applied in classifying both 12 months and 24 time periods during a day with similar characteristics into respective groups in a way that the degree of relationship between two variables is maximal if they belong to the

same group and minimal otherwise. The agglomerative hierarchical method was applicable because no prior knowledge on the number of the particular patterns. Groups of variables are drawn from the individual entities by combining the smallest distance ($D=\{d_{ik}\}$) and connecting the corresponding variables, say, U and V, to get cluster (UV). Then, cluster U and V are joined. The distance between (UV) and any other cluster W are computed as Equation 1 [13].

$$d_{(UV)W}=\min\{d_{UW},d_{VW}\} \quad (1)$$

where d_{UW} and d_{VW} are severally the distances between the smallest distance of clusters U and W, and clusters V and W.

2. To monitor the changes of $PM_{2.5}$, The EWMA control chart was practicably exercised. At each time i,the EWMA statistic or z_i is calculated as Equation 2.

$$z_i=\lambda x_i+(1-\lambda)z_{i-1} \quad (2)$$

where λ be smoothing parameter valued $0<\lambda\le 1$, x_i be daily $PM_{2.5}$maximumat time i followed normal distribution and the starting value z_0 usually set to the in-control process mean. The control limits in any time of EWMA control chart, upper/lower control limits, are also computed as Equation 3.

$$UCL_i/LCL_i=\mu_0\pm L\sigma\sqrt{\left(\frac{\lambda}{2-\lambda}\right)\left[1-(1-\lambda)^{2i}\right]} \quad (3)$$

where μ_0 and σ be respectively the mean and standard deviation of in-control process and L be the width parameter of control limits. The z_i statistic versus time i is then pictured into the EWMA control chart composing the previously stated control limits. Ifany z_i statistic is far out the upper control limit (UCL_i) or plotted under the lower control limit (LCL_i), then the process mean is judged as the out-of-control status. The only positive deviations which go beyond the UCL_i are investigated because the daily $PM_{2.5}$ maximums are merely required not to surpass the Thailand's national air quality standard.

RESULTS

The results of work are as follows.

1. The line graph of daily $PM_{2.5}$ maximums in a recently passing year (November 1, 2020 to October 31, 2021) in Map Ta Phut Industrial Estateis drawn in Figure 1.

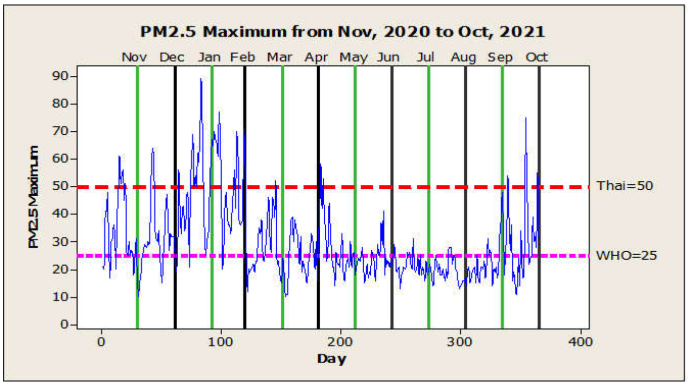

Figure 1: Line graph of daily $PM_{2.5}$ maximums in Map Ta Phut Industrial Estate

For Figure 1, most of days in November to December, 2020 and January to February and October of 2021 are high values which they also lie between the WHO and Thai limits. In addition, medium values are mostly in March to June and then they gradually decrease to low values in July to September. Furthermore, the daily $PM_{2.5}$ maximums in Map Ta Phut Industrial Estate last year were vary from 10 to 89 $\mu g/m^3$ with successively their mean and standard deviation 30.02 and 14.29 $\mu g/m^3$.

The box plot of monthly $PM_{2.5}$ maximums was accordingly in Figure 2.

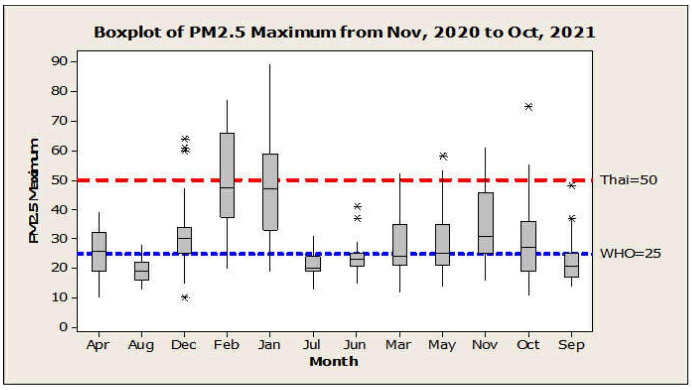

Figure 2: Box plot of monthly $PM_{2.5}$ maximums in Map Ta Phut Industrial Estate

For Figure 2, the dispersions of $PM_{2.5}$ maximums in January and February of 2021 are higher than other months. There are 5 points known as outliers exceeding the Thai limit in December 2020 (3 points), May (1 point) and October (1 point) of 2021. Each of 2 outliers is in June and September of 2021 also above the WHO limit but not over the Thai limit. Based on the agglomerative hierarchical method of cluster analysis, two dendograms are succeeding demonstrated for classifying 12 months and 24 time periods in Figure 3 and Figure 4. For combining months relied on $PM_{2.5}$ maximums, it reveals there are three separated clusters. Cluster 1 contains 6 months; November, January, March, June, July and August ,denoted the low values of $PM_{2.5}$ maximums. Cluster 2 holds 3 months; December, April and September, presented the medium values while the three remaining months; February, May and October, are in Cluster 3 stand for the high values of $PM_{2.5}$ maximums.

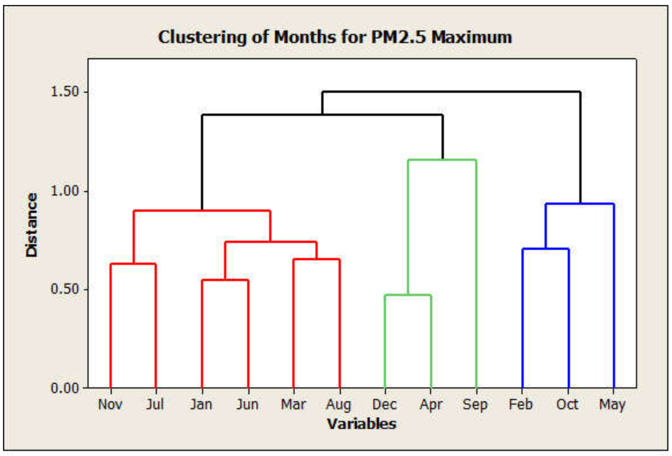

Figure 3: Dendogram of clustering the twelve months for $PM_{2.5}$ maximums

For grouping time periods during a day relied on $PM_{2.5}$ maximums, it shows there are four distinct clusters. Cluster 1 contains 7 hours (T1-T7: 0:00 am. to 7:00 am.) denoted the slightly high values of $PM_{2.5}$ maximums. Cluster 2 holds 6 hours (T8-T13: 7:00 am. to 1:00 pm.)

presented the high values of $PM_{2.5}$ maximums. Cluster 3 covers 5 hours (T20-T24: 7:00 pm. to 0:00 am.) stated the medium values while the 6 remaining hours (T14-T19: 1:00 pm. to 7:00 pm.) are in Cluster 4 stand for the low values of $PM_{2.5}$ maximums.

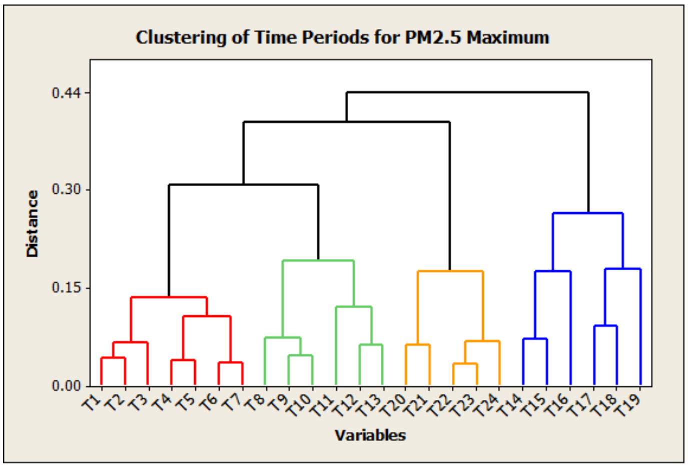

Figure 4: Dendogram of clustering the twenty-four time periods for $PM_{2.5}$ maximums

2. Map Ta Phut Industrial Estate was just supplied $PM_{2.5}$data in the past few years thus the in-control mean and standard deviation of daily $PM_{2.5}$ maximums were not known from a reference period. The in-control mean (μ_0) and standard deviation (σ) of daily $PM_{2.5}$ maximums are then realized from Phase I. Moreover, the significant 2 parameters, λ and L , of EWMA control chart are estimated from simulation study corresponding to the in-control average run length (ARL_0). Owing to the change of $PM_{2.5}$ maximums are appraised as small process shift, λ and L , are then respectively chosen as 0.05 and 2.492 corresponding to suggestion of Borror *et al.,* [14]. The upper and lower control limits vary and up to the value of i as computing in Equation 3. Once the z_i statistics were plotted, the EWMA control chart of daily $PM_{2.5}$ maximums depicted in Figure 5.

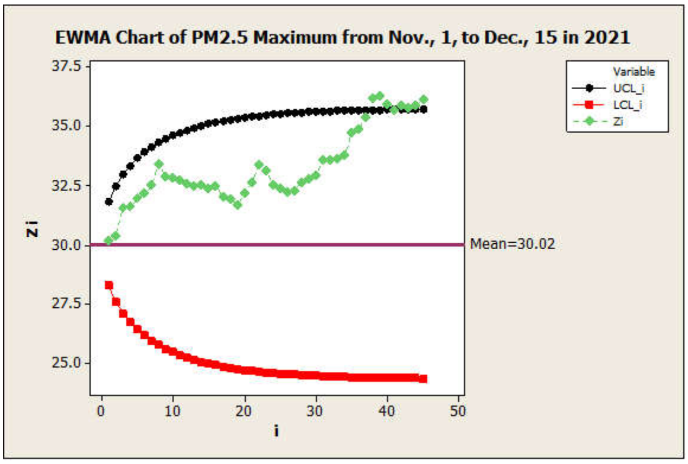

Figure 5: EWMA control chart of daily $PM_{2.5}$ maximums in Map Ta Phut Industrial Estate

There are 8 points of z_i statistics (December 8 to December 15 of 2021) displayed in Figure 5 fall outside the UCL_i , therefore the process mean of $PM_{2.5}$ changes can be notified as out-of-control state.

CONCLUSION AND DISCUSSION

Characterizing and Monitoring $PM_{2.5}$ changes in Map Ta Phut Industrial Estate is simultaneously concluded and discussed as follows.

1. The $PM_{2.5}$ changes are medium values in September (continuation between Rainy season and Winter), December (middle of Winter) and April (middle Summer). Then, they move to slightly high and high values in October (ending of Rainy season) February (Winter) and May (ending of Summer).Finally, they drift to low values in March (beginning of Summer), June, July and August (Rainy season), November and January (beginning of Winter).It may imply that $PM_{2.5}$ changes are influenced by a seasonal effect corresponding to a result of clustering of 12 months.
2. The $PM_{2.5}$ changes are also relating to time periods during a day. Regarding to clustering of 24 time periods, The $PM_{2.5}$ changes are highest values from morning to early afternoon (7:00 am. to 1:00 pm.), slightly high values from midnight to early morning (0:00 am. to 7:00 am.), medium values from evening to midnight (7:00 pm. to 0:00 am.) and low values from afternoon to early evening (1:00 pm. to 7:00 pm.), respectively.
3. The daily $PM_{2.5}$ maximums of Phase II (from November 1 to December 15, 2021) are sketched as Figure 6. It displays there are only 4 days exceeding the Thai limit; November 3, November 8, December 5 and December 8.

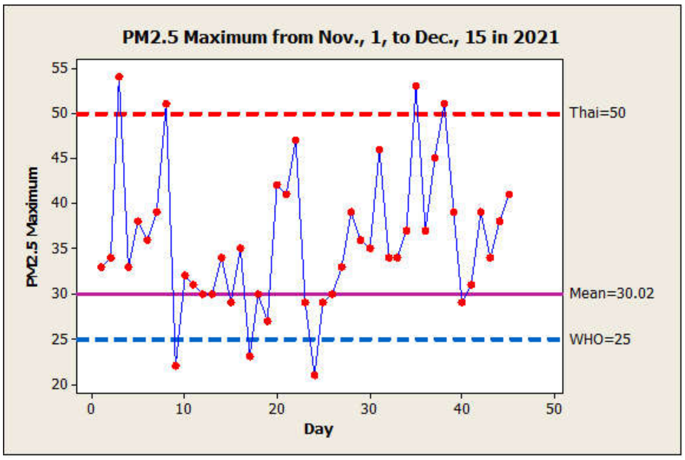

Figure 6: Line graph of daily $PM_{2.5}$ maximums in Map Ta Phut Industrial Estate for Phase II

The EWMA control chart clearly performs as a practicable device for investigating small persistent changes of $PM_{2.5}$ maximums. Therefore, the EWMA control chart is simultaneously not only indicating but also warning the 8 days (since December 8 to December 15 of 2021) to precaution. Contrarily, Figure 5 fails to notify 7 out of 8 days (since December 9 to December 15 of 2021) are out-of-control states.

4. As of the obtained findings, the authorizer may compatibly administer, direct and preserve a level of $PM_{2.5}$ maximums in accordance with WHO and Thai limits. Moreover, the one who authorize should control the number of days exceeding the Thai limit not higher or reduce the number of days exceeding the Thai limit in following next years to less than 2020 and 2021.

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