A trend of surface solar radiation in Chiang Mai, Thailand

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Abstract. The solar radiation passing through the atmosphere to the earth surface has varied in both increasing and decreasing directions. The decreasing direction caused mainly by aerosols, which its properties can absorb and reflect solar radiation. The emission sources of aerosol are primarily from human activities. This study aims to delineate a trend of surface solar radiation in Chiang Mai by using data from 7 air quality monitoring stations, recording during 1995–2017 in urban and rural areas. According to the Mann Kendal Sen’s Slope analysis, the results show that surface solar radiation in Chiang Mai has presented the decreasing trends in 5 stations which located in urban areas while the other 2 stations located in rural areas have presented increasing trends. This could be basically explained that the difference and intensity of activities between urban and rural areas has affected the variation of surface solar radiation.

Keywords: Surface solar radiation, trend, Chiang Mai

1. Introduction
The decreasing trend of surface solar radiation reaching the Earth’s surface had been found in several regions. In Europe, Norris and Wild [1] found surface solar radiation had decreased with 2.7–3.5 Wm−2decade−1 during 1971–1986 and after that it has increased with 2.0–2.3 Wm−2decade−1. While in British Isles, it had been found that an average surface solar radiation has decreased with the value of 0.06 Wm−2 [2]. In terms of the global picture, Stanhill and Cohen [2] concluded that an average decreasing trend of global solar radiation were 0.46–0.56 Wm−2year−1 or 2.7 % per decade. If the population are taken into account, Alpert et al. [3] found that global solar radiation has decreased with the value of 0.41 Wm−2year−1 in the area with high density of population, and 0.16 Wm−2year−1 in the area of low density of population. In the Great Cairo, Robaa [4] also presented more abruptly decreasing trend in the urban area than the rural area with the value of 0.10 and 0.09 Wm−2year−1 respectively. Variation of solar radiation had presented in both a positive trend (Global Brightening) and a negative trend (Global Dimming) [2, 5]. Global Dimming is the phenomenon caused mainly by aerosols, then results in changing in clouds property including absorbing and reflecting solar radiation being through the earth’s atmosphere [2, 5]. The emergence of aerosols originates from both natural phenomena and human activities. The latter is the main source of aerosols releasing [6]. While aerosols are the intermediary particle in the formation of clouds causing to variation of solar radiation which has transmitted to the earth surface [2, 3, 6-8], it is apparent that reducing in surface solar radiation can affect the agricultural products and ecological system [2, 9-11]. However, there still be a lack of information on a trend situation of surface solar radiation in Thailand particularly, the regional centers as Chiang Mai city. Therefore, it is necessary to study the trend of surface solar radiation as it is
important information in the managing processes and preparing to cope with impacts from changing situation of surface solar radiation.

2. Study Area
Chiang Mai Province is located in the north of Thailand. The latitude is from 17 to 21 degrees north and the longitude is from 98 to 100 degrees east, with the sea level about 1,027 feet. Chiang Mai province covers an area of 20,107.057 square kilometers (figure 1). The topography of Chiang Mai is on the flood plain of the Ping river which is in between Thanon Thongchay range. Like its topography, it causes easy covering by air pollution over the Chiang Mai atmosphere.

3. Methodology
3.1. Data
The surface solar radiation (SSR) data used in this study is monthly data in unit of Watt per Square meters (Wm–2) from 7 air quality stations during 1995–2017, which have been recorded by the Meteorological Department (1 station), Pollution Control Department (2 stations), and Department of Alternative Energy Development and Energy Conservation (4 stations). In addition, the physical characteristics of each station were collected in order to analyze coupled with the SSR trends.

Figure 1. Location map of the study area.
3.2. Trend analysis
Mann-Kendall test and Sen’s slope estimates (MAKESENS 1.0) were applied for detecting and estimating trends in the time series of the annually atmospheric data. These methods are suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Sen’s method uses a linear model to estimate the slope of the trend and the variance of the residuals should be constant in time. In addition to the statistical calculations, MAKESENS also provides a simple graphical interface to assist the visual inspection of the time series and the statistical results [12].

4. Results and discussion

4.1. Results
The results of this study were presented in two parts consisting of the physical surroundings of the stations and the trends of SSR.

4.1.1 The physical characteristics of the stations. Starting from the Doi Inthanon (Mae Klang) air quality monitoring station, it is located on the road heading to Doi Inthanon—the highest mountain in Thailand. The station is located at the office of the Waste Management Center next to the waterfall and surrounded by forest areas. Doi Inthanon (Radar) air quality monitoring station is the second station and is located at Sirindhorn Neutron Measurement Station, which is the highest area of Doi Inthanon and mostly covering the forest area. Doi Inthanon (Tourist Center) air quality monitoring station is the third station located at the office of Doi Inthanon National Park. The area is surrounded by mountains and located nearby the Doi Inthanon Royal Agricultural Station which has prevailing agricultural activities. The fourth station is Chiang Mai (San Sai) air quality monitoring station which is the location of the Academic Service Center 7, Ministry of Energy and surrounded by community and agricultural areas. (35t) Chiang Mai Government Center Air quality station is the fifth station located in the government center Chiang Mai. Its surroundings mostly covered by government offices and commercial stores with crowded traffic during the workdays. (36t) Yupparaj Wittayalai School Air quality station located in the downtown has heavy traffic during drop-off and picking-up times. In addition, this station is closed to the road and near the intersection in the city. Lastly, Chiang Mai (48327) Air quality station is a station on the road and near the Chiang Mai International Airport.

4.1.2 The trend of solar radiation in Chiang Mai during 1995-2017. The result shows that SSR from five stations have decreasing trend including Doi Inthanon (Tourist center) Air quality station, Chiang Mai (Sansai) Air quality station, (35t) Chiang Mai Government Center Air quality station, (36t) Yupparaj Wittayalai School Air quality station, and Chiang Mai (48327) Air quality station. The other two stations tend to increase comprising Doi Inthanon (Mae Klang) Air quality station and Doi Inthanon (Radar) Air quality station. Recently, there are no reference values of SSR generally standard. However, there are some SSR studies in the specific issue, for example, the Department of Alternative Energy Development and Energy Conservation studies SSR in content of the potential of solar energy [13] in Thailand, and found that the national SSR values are between 220 and 232 Wm⁻²year⁻¹, which is considered to be a suitable value using for alternative energy production. The other specific study of SSR is the efficiency of photosynthesis of rice. The most efficient photosynthesis can be achieved when the solar radiation intensity is about 434.78 Wm⁻² [14]. If the solar radiation intensity is low during the grain fill stage, it will make yields reduction and poor-quality grains [10, 15]. Therefore, in this study, apply the values of the average SSR of Thailand and the SSR of rice’s efficiency of photosynthesis as reference criteria in describing the differences in surface solar radiation range in each station. The SSR of two stations, Doi Inthanon (Mae Klang) Air quality station and Doi Inthanon (Radar) Air quality station, settled up in the remote areas on the top of the mountain show the variation during the year 2005-2014. The slope are positive and their SSR values in the range 123.43–240.74 Wm⁻² and
91.40–302.97 Wm\(^{-2}\), respectively. The average annual values of the two stations are approximately 192.84 Wm\(^{-2}\) and 189.15 Wm\(^{-2}\). When compared to the SSR average of Thailand, the calculated SSR values of Doi Inthanon (Mae Klang) Air quality station (figure 2) and Doi Inthanon (Radar) Air quality station (figure 3) are lower than the reference value of the national SSR.

For the other five air quality stations including Doi Inthanon (Tourist center), Chiang Mai (Sansai), (35t) Chiang Mai Government Air Quality Station, (36t) Yupparaj Wittayalai School Air quality station, and Chiang Mai (48327), their variations of SSR during 2005–2017 presented in the negative slope, which means the downward trend shown in figure 4 to figure 8. Their values in the range 106.49–251.15 Wm\(^{-2}\), 129.84–261.83 Wm\(^{-2}\), 35.28–252.87 Wm\(^{-2}\), 62.48–284.23 Wm\(^{-2}\) and 225.90–356.10 Wm\(^{-2}\), respectively. The average annual values of the five stations are approximately 172.74 Wm\(^{-2}\), 201.12 Wm\(^{-2}\), 152.81 Wm\(^{-2}\), 160.12 Wm\(^{-2}\) and 284.50 Wm\(^{-2}\).

![Figure 2. Trend of surface solar radiation at Doi Inthanon (Mae Klang) Air quality station.](image1)

![Figure 3. Trend of surface solar radiation at Doi Inthanon (Radar) Air quality station.](image2)
When compared to the average SSR of Thailand, the solar radiation of Doi Inthanon (Tourist center), Chiang Mai (Sansai), (35t) Chiang Mai Government Air Quality Station, and (36t) Yupparaj Wittayalai School Air quality station are lower whereas the SSR of Chiang Mai (48327) air quality monitoring station is quite higher than the reference values of Thailand. In addition, when compare SSR from each station to the SSR of rice’s efficiency of photosynthesis, the values of all stations are lower than the SSR of rice’s efficiency of photosynthesis (434.78 Wm⁻²). This situation makes a concern the impact of SSR decreasing on the rice yield, being the major crop of Chiang Mai. However, considering the change in the solar radiation intensity at Doi Inthanon (Mae Klang) Air quality station (figure 2), Doi Inthanon (Radar) Air quality station (figure 3), Doi Inthanon (Tourist center) Air quality station (figure 4), Chiang Mai (Sansai) Air quality station (figure 5), (35t) Chiang Mai Government Center Air quality station (figure 6), (36t) Yupparaj Wittayalai School Air quality station (figure 7) and

**Figure 4.** Trend of surface solar radiation at Doi Inthanon (Tourist center) Air quality station.

**Figure 5.** Trend of surface solar radiation at Chiang Mai (Sansai) Air quality station.
Figure 6. Trend of surface solar radiation at (35t) Chiang Mai Government Center Air quality station.

Figure 7. Trend of surface solar radiation at (36t) Yupparaj Wittayalai School Air quality station.

Chiang Mai (48327) Air quality station (figure 8), it can be concluded that the change in the surface solar radiation of all stations can be considered as the highest value during April. From then on, the solar radiation turns to decrease during the rainy season and then increases again in the winter.

4.2. Discussion
The results of the seven monitoring stations in Chiang Mai have been shown the variation of surface solar radiation trend. There are two stations settled on the mountain and their surroundings mostly natural environment; whereas, the other five stations located in city with the built environment, high automobile dependency and intensive activities. The SSR trends of the former are increasing, while those of the latter are decreasing. The land use activities are the main factor to emit aerosol
to the atmosphere, in which clouds property has high capacity to absorb and reflect solar radiation being through the earth’s atmosphere. [5] As Alpert et al. [3] and Robaa [4] report their findings that urban areas tend to have a decreasing trend of solar radiation more than the rural areas.

Therefore, we can explain the physical characteristics of the area around air quality monitoring stations. Firstly, Doi Inthanon (Tourist center) air quality monitoring station is surrounded by the community and agriculture area. Secondly, Chiang Mai (Sansai) air quality monitoring station is located in an urban area and highly dense housing. Thirdly, (35t) Chiang Mai Government Center air quality monitoring station located in the center of Muang Chiang Mai district has a various activities including commercial and residential uses with congested traffic. Fourthly, (36t) Yupparaj Wittayalai school air quality monitoring station located on the roadside in the downtown is high commuting of school trips. Fifthly, Chiang Mai (48327) air quality monitoring station located in a dense community. Sixthly, Doi Inthanon (Mae Klang) air quality monitoring station is located near the Mae Klang waterfall and surrounded by the forest and sparsely populated community. Lastly, Doi Inthanon (Radar) air quality monitoring station is encircled by the forest.

Regarding the physical characteristics and the SSR trends of all the air quality monitoring stations, we can summarize the output into two categories. The first is the air quality monitoring station in the urban area, including Doi Inthanon (Tourist center) Air quality station, Chiang Mai (Sansai) Air quality station, (35t) Chiang Mai Government Center Air quality station, (36t) Yupparaj Wittayalai School Air quality station, and Chiang Mai (48327) Air quality station, where the station has a SSR decreasing tendency because their surrounding areas have intense activities such as traffic, residential, commercial and agricultural functions. These activities release air pollutant, which will affect the solar radiation to reach the earth’s surface.

Secondly, the SSR of the air quality monitoring stations in the rural area, including Doi Inthanon (Mae Klang) air quality monitoring station and Doi Inthanon (Radar) air quality monitoring station tend to slightly increase because they encompass with rare human activities and low air pollution emission. These results of the study are consistent with other recent studies [1-8, 16].

5. Conclusion
According to Mann–Kendall Test and Sen’s Slope estimates, the trend of annual data on surface solar radiation acquired from 7 stations in Chiang Mai showed that the surface solar radiation trends in urban
stations had been decreased during 1995–2017 while inverse trends had been found in the rural stations. These could be explained by the different activities between urban and rural areas, which result in releasing air pollution to the surrounding atmosphere and then affecting to surface solar radiation passing through the atmosphere to the earth’s surface both direct and indirect effects.

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