



## Determination of linke turbidity factor from the precipitable water vapor and visibility data

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### Abstract

The Linke turbidity factor ( $T_L$ ) is calculated from of direct solar radiation in a clear day. The data between years 2011-2013 from three measurement stations including Chiang Mai, Ubon Ratchathani and Songkhla were used in the calculation. The relationship between  $T_L$  with the precipitable water vapor and visibility in a mathematical model was investigated. The results showed that the relationship has a relatively high of reliability. The model was validated using independent data do not take modeling, found that predominantly high correlations and relatively high coefficients of variation were obtained for the linear relationships at whole dataset.  $T_L$  models were used to calculate nationwide, found that the Linke turbidity factor is high in the dry season (November-April), and decrease in the rainy season (May-October).

**Keywords:** Linke turbidity factor, Precipitable water vapor, Visibility, Direct solar radiation

### 1. Introduction

In many solar applications, an accurate data of solar irradiance components under cloudless conditions is very important. Usually, the first step for estimating the solar irradiance for all sky condition is clear sky irradiance [1]. The attenuation of solar radiation through a clean dry atmosphere versus a real atmosphere is an indication of the atmospheric turbidity. Study of atmospheric turbidity is essential in climatology, meteorology and for monitoring of atmospheric pollution [2]. In a dry and clean atmospheric condition, solar irradiance is attenuated by permanent atmospheric of which containing gases, air molecules and ozone. These contents are nearly invariable. Two additional attenuation processes, namely scattering by aerosol particles and the absorption by water vapor, take place in a real atmosphere. It is useful to state here that the presence of aerosols in the atmosphere can be quantified by visibility [3].

One of the most important factors for assessing the air pollution in local areas is atmospheric turbidity. It is also the main parameter for maneuvering the solar radiation's attenuation reaching the Earth's surface under cloudless sky conditions [4]. The attenuation caused by the two processes, scattering by aerosols and absorbing by water vapor, is known as the atmospheric turbidity which is commonly represented by Linke turbidity factor [5-9].

In this paper, we study the calculation method in order to determine the Linke turbidity factor, of which has the physical numerical significance in a clean and dry atmospheres equivalent to the real humid and turbid atmosphere. For Thailand, there are studied very little about

atmospheric turbidity. This lack of data has to be applied in the field of solar energy at different positions. In this research, the objective is to find a mathematical model in order to calculate. The Linke turbidity factor, which are related with precipitable water vapor and visibility data. The result could reduce the cost in measure the direct solar radiation for no measuring stations.

### 2. Materials and methods

In this research, there are three measurement stations are Chiang Mai (18.78 °N, 98.98 °E) in the North, Ubon Ratchathani (15.25 °N, 104.87 °E) in the North-east, and Songkhla (7.20 °N, 100.60 °E) in the South. The data includes temperature, relative humidity, cloud, visibility and direct solar radiation. The precipitable water vapor ( $w$ ) is calculated by the relation between the temperature of the weather and the relative humidity from data of an upper air at the three meteorological stations at Chiang Mai, Ubon Ratchathani and Songkhla [10-12]. The water vapor from upper air data was analyzed in order to find the relation between the temperature and the relative humidity of which is a surface data at the same stations [12-14]. Three years (2011-2013) of the above data is used in order to estimate the Linke turbidity factor. A selection of the data that corresponds to clear sky conditions is applied for that reason. This criterion consists to choose data where the direct normal solar irradiance is greater than 200 W/m<sup>2</sup> and the cloud data on the same day were used which must contain at less than 1 part of the sky 10 parts [2, 5].

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The direct solar radiation over all of solar spectrum at the earth's surface is described in terms of Linke turbidity factor [6]. For the Linke turbidity factor ( $T_L$ ), the following equation is used for its calculation [2, 7-8].

$$T_L = \frac{1}{\delta_R m_a} \ln\left(\frac{I_{sc} E_0}{I_n}\right) \quad (1)$$

where  $T_L$  is the Linke turbidity factor (dimensionless),  $I_n$  is the direct solar radiation impinging on the earth's surface ( $W/m^2$ ) for clear sky conditions,  $I_{sc}$  is the solar constant ( $1,367 W/m^2$ ),  $E_0$  is the earth's eccentricity correction factor and  $m_a$  is the relative optical air mass for local condition,  $\delta_R$  is the integral optical thickness of a cloudless atmosphere. For the calculation of  $\delta_R$ , given by Louche et al. [6] and adjusted by Kasten [7] is used in this analysis.

$$\delta_R = (6.6296 + 1.7513m_a - 0.102m_a^2 + 0.0065m_a^3 - 0.00013m_a^4)^{-1} \quad (2)$$

The relative optical air mass ( $m_a$ ) can also be approximated by the following function of solar elevation, where  $\alpha$  is the solar elevation in degrees [2, 7],  $z$  is the altitude in meter of the measurement location [3, 8]. Relative optical air mass has shown the following.

$$m_a = \left(\frac{1}{\sin \alpha + 0.15(\alpha + 3.885)^{-1.253}}\right) \exp(0.0001184z) \quad (3)$$

The Linke turbidity factor from direct solar radiation was analyzed to find the relation between the precipitable water vapor and the visibility which is surface data from the same stations. Base on the results of the regression analysis, a multilinear predictive model to predict  $T_L$  as a function of the two parameter is proposed. Then, result is used to formulate the Linke turbidity factor model which can be used for calculating  $T_L$  in other meteorological stations of which does not have the measuring direct solar radiation. The performance of model was assessed based on some commonly used statistical indicators. Two statistical estimators of mean bias error (MBE) and root mean square error (RMSE) are used to evaluate the accuracy of the model.

### 3. Results and discussion

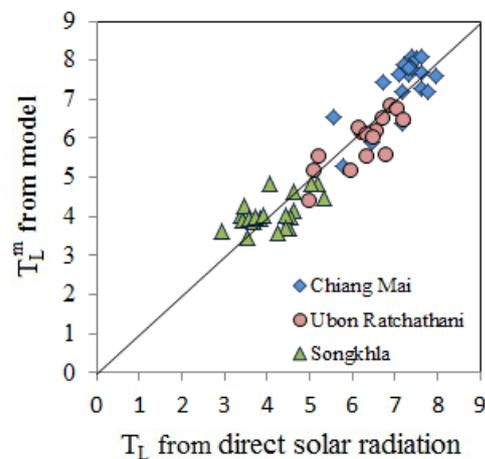
The clear sky is selected from three years (2011-2013) at three stations. The different numbers of clear sky days are 57, 64 and 55 clear sky days for Chiang Mai, Ubon Ratchathani and Songkhla, respectively. The values of  $T_L$  will be calculated from direct solar radiation measurements in the clear day using the Eq. (1). The relation between  $T_L$  from direct solar radiation, precipitable water vapor, and visibility from the same station were calculated using the average daily during the years 2011-2013 under clear sky condition. They are clearly correlated in a linear equation. The empirical model under investigation is as follows.

$$T_L^m = 10.75896 - 0.74781w - 0.28336V_{vis} \quad (4)$$

where  $T_L^m$  is the Linke turbidity factor which is model for calculation (dimensionless),  $w$  is precipitable water vapor in centimeters,  $V_{vis}$  is the visibility data in kilometers.

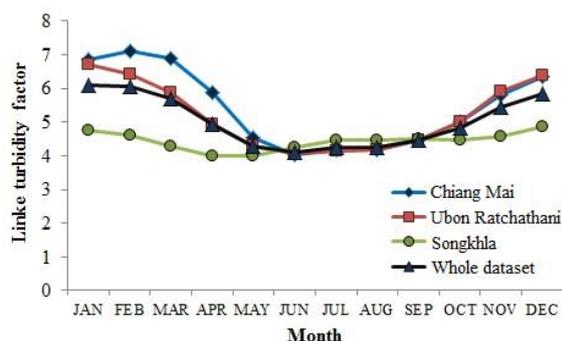
This relation was obtained by last squares fitting to 176 data points from three stations (2011-2013) only clear sky condition. This result was compared  $T_L$  to that reported by this research, Chaâbane et al. [2] and Cucumo et al. [8] based on the relationship of direct solar radiation, which is the same data at the same time. The actual values (Eq.1) of the  $T_L$  were compared. Model in this research showed the best performances according to its MBE and RMSE. The MBE was 0.029 and Shows the RMSE was 0.481, which are in good agreement than other methods.

The model is retested with independent data under clear sky conditions, which has never been used in the modeling by using the data of year 2014 at the same stations to verify the accuracy of the model. It is observed that the value of  $T_L$  from the model and the direct solar radiation are in good agreement (shown in Figure 1), which the MBE was 0.061, the RMSE was 0.543, and the correlation coefficient ( $R^2$ ) was 0.87.



**Figure 1** Comparison between the Linke turbidity factor calculated from the model and the direct solar radiation by using the clear day data of year 2014

We use the model to calculate the Linke turbidity factor from monthly average of the precipitable water vapor and visibility during the years 2011-2013 of 85 stations nationwide. It was found that, the Linke turbidity factor is associated systematically with the precipitable water vapor and visibility. The monthly Linke turbidity factor for three stations is showed in Figure 2. Moreover, there are seasonal variations consistent with Esposito et al. [15] and Utrillas et al. [16] found that the atmospheric turbidity is less in the rainy season and high value in the dry season, which is constantly changing according to season and geography. Consider the whole dataset,  $T_L$  has changed by the time of year during January to March. It were higher and then gradually reduced to a minimum in June. After that, there is an increasing trend. That is, the Linke turbidity factor is high in the dry season (November-April), and decrease in the rainy season (May-October), as well as the stations in Chiang Mai and Ubon Ratchathani. Meteorological stations in Songkhla which is in the south, Linke turbidity factor is relatively constant, it has changed slightly throughout the year, this is due to the seasons are different from other stations and aerosols mainly originate from the sea. Consistent with Chaâbane et al. [2] found that the correlation between atmospheric turbidity is essentially due to dust particles maritime type, which comes from the sea. Chiang Mai in the North region is higher than all stations during the



**Figure 2** Monthly variation of the Linke turbidity factor using the average monthly data during the years 2011-2013 of eighty-five nationwide stations.

months of December to March. The greatest value in February consistent with Chantaket et al. [17]. That is, during the month of February-March with the burning of agricultural waste materials to provide farmland including fog and forest fires which are a major source of aerosols.

#### 4. Conclusions

The estimating method for Linke turbidity factor has been evaluated by recomputed the direct solar radiation for clear sky conditions, for three meteorological stations. Data between years 2011-2013 were used. The method has shown to decrease the uncertainty of the response of the model in terms of MBE and RMSE. Moreover, the Linke turbidity values obtained by the proposed method have been retested with independent data under clear sky conditions, which has never been used in the modeling by using the data of year 2014 of the same stations to verify the accuracy of the model. From the study, the predominantly high correlations and relatively high coefficients of variation were obtained for the linear relationships at the Chiang Mai, Ubon Ratchathani and Songkhla stations. The Linke turbidity factor associated systematic with precipitable water vapor and visibility data. Model showed the best performances according to its MBE and RMSE was 0.029 and 0.481 respectively, which are in good agreement than other methods. The model is used to calculate the  $T_L$  from monthly average of the precipitable water vapor and visibility during the years 2011-2013 of 85 stations across the country. Found that, the Linke turbidity factor is high in the dry season (November-April), and decrease in the rainy season (May-October), which there are seasonal variations.

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