



Seasonal Characteristic of Sky Conditions based on Clearness Index on Aceh Besar

Karakteristik Musiman pada Kondisi Langit berdasarkan Clearness Index di Aceh Besar

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Abstrak. Knowledge of the sky conditions in particular location is a fundamental to studies about climate and has applications for meteorology, industry, agriculture, architecture, engineering, studies of water resources development and solar energy conversion system. These conditions can be quantified by meteorological parameter such as the clearness index. Clearness index (K_T) is defined as the ratio of global solar irradiance measured at ground level and its counterpart the extra – terrestrial radiation at the top of the atmosphere. In this study, seasonal characteristic of sky condition in Aceh Besar (05.4°S and 95.46°W) has been carried out using K_T . One year (Jan 2020 – Dec 2020) measured data of daily average global radiation has been used to determines the daily and monthly variations of K_T . The result shows that for daily averages, K_T ranges from 0.19 to 0.70 with cloudy days are common days in Aceh Besar with hardly any very clear days. For monthly average, the month of January shows the highest K_T (0.55), while November shows the lowest K_T (0.41). Based on monthly averages of the daily K_T , monthly percentage cumulative frequency, and climatic conditions, the sky condition in Aceh Besar is classified into two seasonal periods. The dry season (January – March and June – September) has K_T values ranging between 0.44 and 0.55, while the wet season (April – May and October – December) has K_T ranging between 0.44 and 0.45.

Kata Kunci: Sky Conditions, Clearness Index, Dry Season, Wet Season, Aceh

Abstract. Pengetahuan tentang kondisi langit di suatu lokasi merupakan dasar untuk mempelajari tentang iklim dan memiliki aplikasi untuk meteorologi, industri, pertanian, arsitektur, teknik, studi pengembangan sumber daya air dan sistem konversi energi matahari. Kondisi langit dapat diukur dengan parameter meteorologi yakni clearness index (K_T). Indeks kejernihan didefinisikan sebagai rasio radiasi matahari global yang diukur di permukaan tanah dengan radiasi ekstra – terrestrial di bagian atas atmosfer. Pada penelitian ini telah dilakukan karakteristik musiman kondisi langit di Aceh Besar (05.4°LS dan 95.46°BT) dengan menggunakan K_T . Data satu tahun (Jan 2020 – Des 2020) pengukuran radiasi global rata – rata harian telah digunakan untuk menentukan variasi K_T harian dan bulanan. Hasil menunjukkan bahwa untuk rata – rata harian, K_T berkisar antara 0.19 hingga 0.70 dengan hari berawan merupakan kejadian yang paling umum di Aceh Besar dan hampir tidak ada hari yang sangat cerah. Untuk rata – rata bulanan, bulan Januari menunjukkan K_T tertinggi (0.55), sedangkan November menunjukkan K_T terendah (0.41). Berdasarkan rata – rata bulanan K_T harian, frekuensi kumulatif persentase bulanan, dan kondisi iklim, kondisi langit di Aceh Besar diklasifikasikan menjadi dua periode musim. Musim kemarau (Januari – Maret dan Juni

– September) memiliki nilai K_T berkisar antara 0.44 hingga 0.55, sedangkan musim hujan (April – Mei dan Oktober – Desember) memiliki nilai K_T berkisar antara 0.44 hingga 0.45.

Keywords: Kondisi Langit, Indeks Kebeningan, Musim Kemarau, Musim Hujan, Aceh

Introduction

The extra – terrestrial radiation emissions from the sun enters the atmosphere with a number of interactions. Some of the energy is absorbed and scattered by various atmospheric components in the atmosphere. These components include gases (water vapor, ozone, CO₂, N₂O, CO, O₂, CH₄ and N₂) [1 – 4], aerosols [5,6], and either of natural origin (marine, mineral, volcanic, biogenetic and cosmic) or from human activities. The fraction of the extra – terrestrial radiation that finally gets to the earth's surface is known as the global solar radiation. The global solar radiation is produced as incoming solar radiation emissions from the Sun which directly arriving on the ground is called direct radiation while another incoming radiation that are scattered and reflected in the atmosphere is known as the diffuse radiation [7,8].

Determining the solar radiation and the shadows effect more accurately is possible by using and processing the satellite images. However, its use is limited because of its high cost [9]. Moreover, accurately quantifying the global solar radiation on a surface is a complex task that requires analyzing geometric, geographical, astronomical, physical and meteorological characteristics of the site of study [1]. Its difficult to determine the phenomena in the Earth's atmosphere because of particles and molecules present in it are highly variable. One of the ways of easily estimating surface, which is a requirement for design purposes, is by establishing the sky conditions at the locality. These conditions can be quantified by meteorological parameter such as the clearness index [10,11,12].

Clearness index is defined as the ratio of global solar irradiance measured at ground level and its counterpart the extra – terrestrial radiation at the top of the atmosphere. The clearness index describes the solar radiation extinction in the atmosphere, which includes effects due to clouds but also effects due to radiation interactions with other atmospheric parameters and thereby measures how transparent the Earth's atmosphere is to solar radiation [13 – 17]. It furthermore determines variations in atmospheric conditions and the availability of solar radiation at any location. Clearness index values taking an interval of 0 to 1, however, it usually varies from about 0.8 in clear sky conditions to near 0 in cloudy conditions [18]. In terms of the classification of sky conditions, clearness index is widely used due to their dependency on global solar radiation [15]. Although sky conditions are difficult to predict, it can be categorized in terms of the weather parameters prevailing under clear sky, partially cloudy and overcast conditions [19].

Furthermore, knowledge of the sky conditions in particular location is a fundamental to studies about climate and has applications for meteorology, industry, agriculture, architecture, engineering, studies of water resources development and solar energy conversion system. This is important to estimate the output values of flate plate collectors, photovoltaic system, and also for the design and construction [8,20]. Some of researchers have used the clearness index to study the sky conditions of their locality among which Hawas and Choudhury [15,21] worked on data for Indian location. A study Barbaro [22] studied for locations in Italy, Saunier [23] examined locality of Bangkok, and Al – Riahi [24] worked on data for Baghdad. The locality of Kumasi, Ghana was carried out [25]. In Nigeria, similar studies have also been carried out where a study Ideriah and Suleman [10] investigate Ibadan, a study Kuye and Jagtap [14] studied Port – Harcourt, Udo [12] examined Ilorin, a study Okogbue and Adedokun [26] carried out for Ie – Ife, and one study Egeonu [27] worked on Nsukka location. However, the studies about sky condition in Indonesia is limited, particularly on local area.



In this study, one year (Jan 2020 – Dec 2020) measured data of daily average global radiation in Aceh Besar Regency has been used to determine the daily and monthly variations of the clearness index. Moreover, the monthly clearness index is used to identified seasonal characteristic of sky condition in Aceh Besar. This studies can be applied to each area of Aceh Province, in order to quantify and characterize the sky condition in the whole country and it allows to identify the regions with the greatest potential for harnessing solar energy. Furthermore, characterization of the sky conditions in Aceh Besar, Indonesia is undertaken.

Methodology

Location and Description of the Studied Area

As shown in Figure 1, the study area is located in Aceh Besar Regency, Aceh Province, Indonesia, at 05.37°N and 95.53°E in far northwest of Sumatera Island. In the west and east, Aceh Besar border the Indian Ocean and Malacca Strait, respectively. These region has an unique topographic condition because surrounded by three highlands which are hilly areas in the east, Mount Seulawah in the southeast, and Bukit Barisan Mountain while the west region with lowland stretched in the center in the valley of these three highlands. Therefore, it contribute to the local climate characteristic in Aceh Besar, especially on rainfall variability. According to Köppen climate classification, Aceh Besar similar to many regions in Indonesia is categorized into wet tropical climate (Am) where rainfall variability is the greatest. The climatological station were installed in this area is under Indonesian Agency for Meteorology, Climatology, and Geophysics known as Aceh Climatological station.

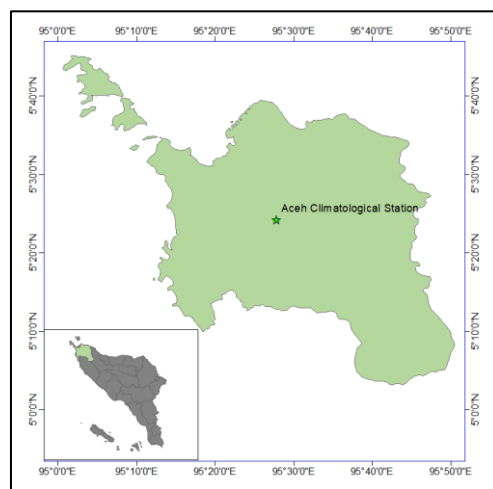


Figure 1. Study Area

Solar radiation data

The data for this study was obtain from Aceh Climatological Station which is located in the north of Aceh Besar regency, (05.4°N, 95.46°W, and 64 meters). The two – year solar irradiance dataset (January 2020 – December 2021) was measured by a set of instruments called the Automatic Solar Radiation Station (ASRS). ASRS were installed over 15 locations in Indonesia records 10 minutes – averaged values of solar irradiance with three pyranometers and one pyrhelimeter. The pyranometers measure the global horizontal irradiance or GHI (the total amount of shortwave radiation received from above by a surface horizontal to the surface), diffuse horizontal irradiance or DHI (the amount of radiation that has been scattered by molecules and particles in the atmosphere and comes equally from all directions) and reflected irradiance (the radiation that has been reflected by the earth's surface). The pyrhelimeter measure the direct normal irradiance (DNI) or the amount of solar radiation received by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the



direction of the sun at its current position in the sky. Detailed description of the instrumentation and measurement site where the dataset used in this study were acquired can be found in Sianturi [28]. The recorded data are an instantaneous value, referred to as solar irradiance, and have units of W/m². The parameter used in this research was global horizontal irradiance (GHI).

GHI is used to find daily average clearness index for the corresponding location. The daily values of the clearness index (K_T) for the study can be computed by [20,30]:

$$K_T = H/H_0 \tag{1}$$

Where H is the measured global solar radiation and H_0 is the daily extra – terrestrial solar radiation at the top of the atmosphere. The daily amount of extra – terrestrial radiation H_0 for the locations have been found by using the equation 2 [20,30]:

$$H_0 = \frac{24 \times 3.6 \times 10^{-3} \times I_{sc}}{\pi} \left(1 + 0.033x \cos \frac{360D}{365} \right) \left(\cos \phi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180} \sin \phi \sin \delta \right) \tag{2}$$

Where I_{sc} is the solar constant = 1367 Wm², D is day of the year [20], ϕ is station’s latitude (- 5.4°), δ is solar declination (degrees), ω_s is the sunrise hour angle and $\pi = 3.142$.

The solar declination angle was calculated using [20,30]:

$$\delta = \phi_L \sin \left[\frac{2\pi(d_n - d_r)}{d_y} \right] \tag{3}$$

Where ϕ_L is the latitude of the Tropic of Cancer (23.45° N), d_n is the Julian day number of the year, which ranges from 1 on 1 January to 365 on 31 December, $d_r = 284$, and d_y is the average number of days per year with a value of 365.

The sunrise hour angle was evaluated using [20,30]:

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta) \tag{4}$$

Thus, by monitoring the cumulative frequency for a given month of the year, the statistical distribution of clearness index for a given location is known defined the cumulative frequency (f) in terms of percentage as [31],

$$\frac{\text{number of days with } K_T \leq K_T \text{ (fixed value)}}{\text{number of days in the month}} \times 100 \tag{5}$$

Results and Discussion

Global Solar Radiations

The average monthly global solar radiation on horizontal surface in Aceh Besar for one year is given in Table 1. It can be seen that in an average year the total global solar radiation received on a horizontal surface at Aceh Besar is 4722.1 W/m². The average daily global solar radiation received on a horizontal surface at Aceh Besar ranges 5379.5 W/m² in February to 3938.3 W/m² in December. The values are similar to the average daily radiation on most of Indonesia areas which approximately around 4 kWh/m² or 4000 W/m² [32]. The intensity of solar radiation increases in March – April and August – September as the sun approaches the equator, on the contrary in June – July and December – January the intensity of solar radiation decreases as the sun moves away from the equator.



Table 1. Average monthly solar radiation for Aceh Besar

Months	GHI (W/m ²)
Jan	5160.1
Feb	5379.5
Mar	5274.0
Apr	4703.4
May	4290.4
Jun	5175.0
Jul	4535.5
Aug	5302.6
Sep	4565.9
Oct	4387.1
Nov	3953.4
Dec	3938.3
Average	4722.1

Daily Variation of The Clearness Index

Aceh Besar has two of seasonal pattern, there are dry months and wet months. As shown in monthly rainfall variability in Aceh Besar on Figure 2, dry months occur on January – March and June – September, while the wet months occur on April – May and October – December. The peaks of monthly rainfall variability are similar to the pattern of variation of daily clearness index (Kt).

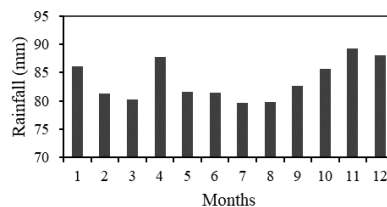


Figure 2. Monthly Rainfall Variability of Aceh Besar (Aceh Climatological Station)

The daily variations of the clearness index for one – year period (2020) is presented in Figure 3. Dry months has Relative clear days mainly exist in the dry months. However, during the wet months, the days could have Kt values higher comparable to Kt values for the clear days in dry months. As shown in the Figure 3, the values of daily clearness index in 2020 ranged between 0.19 and 0.70 in the dry months while the values in the wet months vary between 0.16 – 0.62. The highest value (0.70) was recorded on August, 16th. Also, typical clear days during the wet and cloudy periods could have the higher values for the clearness index, corresponding to values recorded in the dry months. This can be attributable to the rainfall’s removal and washout of dust aerosol particles suspended in previous days or days, which consequently led to the very clear sky in the subsequent days or days.

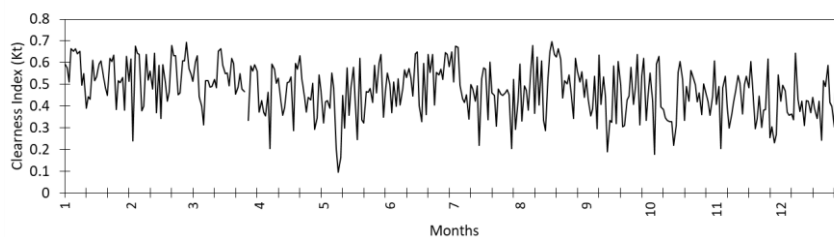


Figure 3. Daily variations of monthly mean daily clearness index in Aceh Besar



The days with very clear skies ($K_T \geq 0.65$) is rare in Aceh Besar, throughout one – year study, 15 days was recorded as very clear skies and commonly occurred in the dry months. On the other hand, the clear skies with $K_T \geq 0.60$ is very common especially in the dry months. As shown in Table 2, total days with clear skies ($K_T \geq 0.60$) or 66 days were found in the observation period. Of these, 55 days occurred in the dry months while 11 days were observed in the wet months. The cloudy skies ($0.12 \leq K_T \leq 0.34$) particularly occurred in the wet months (with total number of 24 days in the dry months and 32 days in the wet months). The high occurrence of days with ($K_T \geq 0.60$) was found in January, February and August. Its implies that the global solar radiation received at the Earths surface consists mainly of the beam (direct) radiation component However, the high occurrence of days with ($0.12 \leq K_T \leq 0.34$) was found during wet months (May, September, October and November). During the wet months, the global solar radiation received on surface consist mainly of diffuse radiation which arises majorly from the intense forward scattering of global solar radiation mainly by altostratus, thin cirrus and alto – cumulus clouds ^[16]. Furthermore, the majority of the days are cloudy days with hardly any very clear days.

Table 2. Number of day occurrence of clear skies ($K_T \geq 0.6$) and cloudy skies ($0.12 \leq K_T \leq 0.34$) for 2020 at Aceh Besar

Months	No. of days	
	$K_T \geq 0.6$	$0.12 \leq K_T \leq 0.34$
January	12	2
February	12	0
March	6	2
April	2	3
May	3	7
June	8	1
July	3	6
August	10	4
September	4	9
October	3	8
November	2	9
December	1	5

Seasonal Variation of The Clearness Index

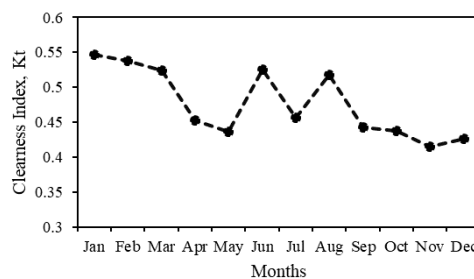


Figure 4. Seasonal variations of monthly mean daily clearness index in Aceh Besar

The monthly variations of the clearness index is presented in Figure 4. The values of the clearness index show strong seasonal variations with a peak value of 0.55 in January and the lowest value recorded in November. Monthly average values range from 0.41 – 0.55 and an average value of about 0.48 was recorded for one – year (2020). The seasonal pattern of monthly average value related with



equinox. An equinox is an event in which a planet’s subsolar point passes through its equator and occur two times every year, one around March 21 and another around September 22. Aceh Besar as the part of Indonesia and located in equator, is affected by these equinox. At equinox events occur, the sun is directly overhead at noon and the equator area has an abundant solar beam especially on March and September.

The monthly percentage cumulative frequency distribution of daily clearness index are presented in Table 3. The range in value of monthly average clearness index in Aceh Besar is 0.35 – 0.64. Referencing the works of [33,34] that reported use of K_t values of 0 – 0.15, >0.15 – 0.7, and >0.7 for overcast, cloudy and clear sky conditions, respectively. This reveals that sky condition for Aceh Besar is predictably to be mostly cloudy annually. As such, diffuse solar radiation is expected in enormous quantity within the study area. Very clear days is very rare in Aceh Besar, it shown on Table 3, that For $K_t > 0.65$ ranging from 27.10 – 93.33 in January – march (dry months) and 87.10 – 93.55 in July – August. This implies that the frequent days with very clear days ranging from 6.1 % to 12.9% and 6.45% to 12.9% for Jan – Mar and Jul – Aug, respectively. Moreover, its can be defined that on January and July, the atmosphere having just been cleansed by the rains on wet months before so the sky condition is clear.

Table 3. Monthly percentage cumulative frequency distribution of daily clearness index for Aceh Besar

Months	Values of f for $K_T \leq K_T$ (fixed value)											
	0.00 – 0.19	0.20 – 0.29	0.30 – 0.34	0.35 – 0.39	0.40 – 0.44	0.45 – 0.49	0.50 – 0.54	0.55 – 0.59	0.60 – 0.64	0.65 – 0.69	0.70 – 0.74	0.75 – 0.79
January (31)	0.00	0.00	0.00	0.00	9.68	19.35	25.81	54.84	64.52	87.10	100	100
February (29)	0.00	0.00	3.45	6.90	17.24	20.69	34.48	44.83	58.62	89.66	100	100
March (30)	0.00	0.00	0.00	6.67	10.00	13.33	40.00	56.67	83.33	93.33	100	100
April (30)	0.00	0.00	10.00	13.33	33.33	50.00	56.67	83.33	96.67	100	100	100
May (30)	0.00	3.33	13.33	26.67	33.33	50.00	73.33	73.33	93.33	100	100	100
June (30)	0.00	0.00	0.00	3.33	13.33	26.67	33.33	53.33	76.67	100	100	100
July (31)	0.00	0.00	9.68	19.35	19.35	38.71	70.97	83.87	90.32	93.55	100	100
August (31)	0.00	0.00	3.23	12.90	19.35	29.03	38.71	54.84	67.74	87.10	100	100
September (30)	0.00	3.33	6.67	30.00	36.67	56.67	66.67	80.00	86.67	100	100	100
October (31)	0.00	3.23	6.45	25.81	38.71	54.84	64.52	77.42	90.32	100	100	100
November (30)	0.00	0.00	20.00	30.00	46.67	56.67	73.33	93.33	93.33	100	100	100
December (31)	0.00	0.00	3.23	16.13	41.94	70.97	80.65	87.10	96.77	100	100	100

Table 4. Seasonal classification of average clearness index values.

Period	K_T Values
Dry Seasons	
a. January, February, March	0.55, 0.54, 0.52
b. June, July, August, September	0.53, 0.46, 0.52, 0.44
Rainy Season	
a. April, May	0.45, 0.44
b. October, November, December	0.44, 0.41, 0.43

Several authors have used similar pattern of seasonal classification without a distinctive method on how to group average monthly clearness index values into a particular class interval that is free from ambiguity. Considering the number of data used in this study, in choosing class intervals, it is observed that most of the estimated daily clearness index values fall within the range of 0.3 – 0.64. For class intervals of 0 – 0.19 and 0.2 – 0.29 a range of unity is used to group the daily clearness index.



This is informed by the fact that few daily clearness index falls within these class intervals. For the other class intervals i.e. 0.3 – 0.34 to 0.65 – 0.69 a range of 0.04 is used. The essence is to avoid over population of each class interval and observe the spread of data. Based on monthly average clearness index, monthly percentage cumulative frequency, and the prevalent climatic conditions, the following season period can be classified in Table 4 and subsequently in the organization of average monthly clearness index periods into seasonal classification patterns.

The two season period is classified as shown in Table 3, the first dry season begin in January and the second dry season begin in June. During the rainy season, May and November stand out clearly as months of least average monthly clearness index. On the first rainy season (April – May), the three months immediately before (i.e January – March), increases as the months progress into the peak of rainy season ($0.55 > 0.54 > 0.52$). For the second rainy season, the month before (i.e September) has similar monthly clearness index with October. It should be noted that the month of September is classified under dry season months and October is in the rainy season months. This implies that in Aceh Besar, September could at times be regarded as dry season months and at times as rainy season months. The variation of clearness values on the beginning of the second rainy season (October – December) shows that the seasonal atmospheric attenuation is not too significant during the onset of the rainy season.

Conclusion

The analysis of global solar radiation on horizontal surface Aceh Besar is presented in this study using measured solar radiation intensity from Automatic Solar Radiation System in Aceh Climatological Station. Global solar radiation data is used to estimate clearness index. The daily clearness index in Aceh Besar ranges 0.19 – 0.70 and 0.16 – 0.62 in the dry months and wet months respectively. Monthly average values range from 0.41 – 0.55 and an average value of about 0.48. Clearness index is affected by climatic conditions and movement of the sun. Climatic condition are related to the content of water vapor in the atmosphere, the scattering by air molecules and miscible gases, the presence of aerosols and the effect of ozone, and meteorological factors (temperature, precipitation, humidity). The sky conditions at Aceh Besar have been classified in two seasonal period. The two season period is classified into four as defined by the monthly averages of daily clearness index, monthly percentage cumulative frequency, and climatic conditions. Most of the days in Aceh Besar are mainly cloudy and there are hardly days with very clear skies. It should be noted that clear day can occur at any time of the year although the chances are higher.

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