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Classification of Sky Cover by the Clearness Index (Kt) in Maputo - Mozambique

Classificação da Cobertura do Céu pelo Índice de Tranmissividade Atmosférica (Kt) em Maputo - Moçambique

Clasificación de la Cobertura del Cielo por el Índice de Transmisividad Atmosférica (Kt) en Maputo - Mozambique

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Abstract
The present paper makes an analysis of the frequency of sky conditions in the city of Maputo/Mozambique based on the clearness index (Kt). From the determination of extraterrestrial solar radiation and measured data of four years of global daily radiation, Kt was calculated. Different sky conditions were classified according to the Escobedo criterion, which dispenses the data of direct and / or diffuse radiation in its classification. The city of Maputo, during the year, is observed more days with conditions of clear sky, in average of 120 days. And for cloudy sky conditions, the city of Maputo presents the least number of days, with an average of 48 days. The frequency of days for partially cloudy sky and partially clear sky conditions is 85 and 112 days respectively. The information generated in this paper can be used in future studies to project solar systems for thermal use or direct conversion of solar radiation into electricity.
Keywords: Cloudiness; City of Maputo; Clearness Index.

Resumo
O presente trabalho fez uma análise da frequência das diferentes condições do céu na cidade de Maputo/Moçambique com base no índice de transmissividade atmosférica (Kt). A partir da determinação da radiação solar extraterrestre e dos dados medidos de quatro anos de radiação global diária foi calculado o Kt. Diferentes condições do céu foram classificadas de acordo com o critério de Escobedo, que dispensa os dados de radiação direta e/ou difusa em sua classificação. Na cidade de Maputo, durante o ano, são observados mais dias com condições de céu limpo, em média de 120 dias. Para condições de céu nublado a cidade de Maputo apresenta o menor número de ocorrência, com uma média de 48 dias. A frequência de cobertura de céu para condições de céu parcialmente nublado e céu parcialmente claro é de 85 e 112 dias, respectivamente. As informações geradas neste trabalho podem ser utilizadas em futuros estudos para embasar projetos de sistemas solares de aproveitamento térmico ou conversão direta da radiação solar em eletricidade.
Palavras-chave: Nebulosidade; Cidade de Maputo; Índice de Transmissividade Atmosférica.

Resumen
El presente trabajo realizó un análisis de la frecuencia de diferentes condiciones del cielo en la ciudad de Maputo/Mozambique a partir del índice de transmisividad atmosférica (Kt). A partir de la determinación de la radiación solar extraterrestre y los datos medidos de cuatro años de radiación global diaria, se calculó el Kt. Las

diferentes condiciones del cielo se clasificaron según el criterio de Escobedo, que prescinde de datos de radiación directa y/o difusa en su clasificación. En la ciudad de Maputo, durante el año, se observan más días con condiciones de cielo despejado, en promedio 120 días. Para condiciones de cielo nublado, la ciudad de Maputo tiene el menor número de ocurrencias, con un promedio de 48 días. La frecuencia de cobertura del cielo para condiciones de cielo parcialmente nublado y parcialmente despejado es de 85 y 112 días, respectivamente. La información generada en este trabajo puede ser utilizada en futuros estudios para apoyar proyectos de sistemas solares para aprovechamiento térmico o conversión directa de la radiación solar en electricidad.
Palabras clave: Nubes; Ciudad de Maputo; Índice de Transmisividad Atmosférica.

1. Introduction

Solar radiation is the form of energy that most influences life on the earth's surface, for flora and fauna, through photosynthesis and adaptability to different biomes distributed on earth (De Souza et al. 2005; Li et al. 2015). Solar radiation can also be converted directly into electricity to provide energy for agricultural water pumping systems, precision irrigation, milling and threshing or have its thermal potential used for passive or active heating of environments, disinfection of wastewater and other products from rural activities (Calca, et al., 2021).

Of the total solar radiation incident at the top of the atmosphere, an average of 51% reaches the earth's surface influenced by the attenuation of atmospheric constituents, and this portion of the radiation receives the name of global solar surface irradiation (Ometto, 1981; Khorasanizadeh & Mohammadi, 2016; Liu & Jordan, 1960) This irradiation is the sum of the direct and diffuse components, being the most important parameters for photovoltaic and thermal solar energy simulation (Yao, et al., 2014; Dal Pai, et al., 2016). Global solar irradiation also implies the calculation of evapotranspiration, which influences irrigation and productivity systems (Almorox & Hontoria, 2004; Dumas, et al., 2015; Quej, et al., 2016).

Cloudiness is a useful predictor of the solar resource because clouds are the major attenuating factors for solar irradiance (Smith, et al., 2017). The study of the sky cover is very important for the viable implantation of the photovoltaic energy in a certain place because the clouds are the main cause of the fluctuation of the photovoltaic energy in the grid (Bosch, et al., 2013). The clearness index (Kt) expresses the ratio between the global solar irradiation (H) and extraterrestrial solar irradiation (Ho) (Dal Pai, et al., 2016). This parameter not only quantifies the transparency of the atmosphere, but also explains the contamination of the atmosphere because of its direct relationship with the concentration of atmospheric components such as clouds. This work makes an analysis of the frequency of sky conditions in the city of Maputo/Mozambique based on (Kt).

2. Methodology

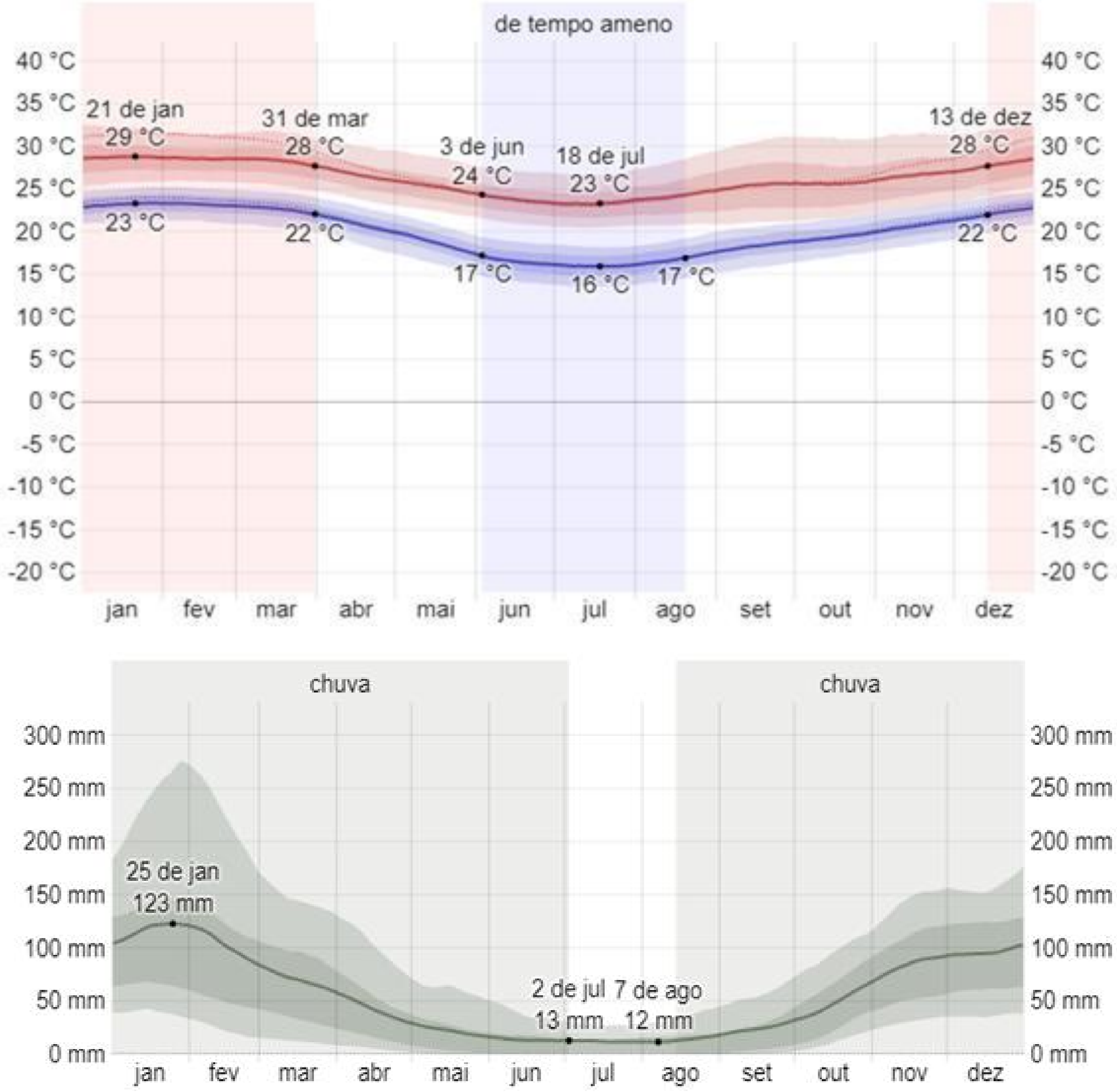
Mozambique is a country located on the southeastern coast of Africa between the parallels 10°27' and 26°56' of south latitude and the meridians 30°12' and 40°51' of east longitude. With an entire coastline of the Indian Ocean and a land area of 799,380 km2. Administratively, Mozambique is divided into 11 Provinces, as shown in the Figure 1.

Figure 1 - Map of Mozambique.

Source: Aler (2017).

To carry out the work, data were used of global solar irradiation of the National Institute of Meteorology of Maputo (INAM) (latitude 25.58 ° S, longitude 32.36 ° E, altitude 70 m). The climate of the city is tropical and conceptualized as Aw according to the Köppen climate classification. The city contains two main seasons, hot and rainy (October to March), and cold and dry (April to September). Maputo City has an average maximum temperature of 29 °C that occurs in the month of January, and an average minimum temperature of 16 °C that occurs in the month of July. The highest rainfall is in the summer, which reaches up to 123 mm in the month of January, and the lowest rainfall is in the winter, which reaches up to 12 mm in the month of August (Figure 2). The average annual rainfall in Maputo city is 814 mm.

Figure 2 - Average maximum and minimum temperatures, and average monthly rainfall in Maputo.



Source: WeatherSpark.com.

The H data were recorded on the four-year 2004, 2005, 2008 and 2009 and measured by a CM 6B pyranometer - Kipp & Zonen and the data were recorded by a Kipp & Zonen datalogger. The date was made available in the daily partition in cal/cm² later converted for the unit of MJ/m². The Equation 1 was used to calculate the daily extraterrestrial radiation on a horizontal surface (Ho) according to Iqbal (1983), as a function of the solar constant (Isc).

$$H_0 = \frac{24}{\pi} I_{SC} E_0 \left[\left(\frac{\pi}{180} \right) \omega_S (\sin\delta \sin\emptyset) + (\cos\delta \cos\emptyset \sin\omega_S \right] \quad MJm^{-2}day^{-1} \quad \text{(Eq. 1)}$$

Where Isc is the solar constant which is usually accepted with value of 1367 W.m-2 which for daily value equivalent 118.108 MJ m^{-2} day^{-1}. The orbital eccentricity correction factor (Eo), which is a dimensionless quantity, can be calculated by the Equation 2.

$$E_0 = 1{,}00011 + 0{,}034221.\, cos\Gamma + 0{,}00128.\, sen\Gamma + 0{,}000719.\, cos2\Gamma + 0{,}000077.\, \mathrm{sen}2\Gamma \qquad \text{(Eq. 2)}$$

Where Γ is the day angle (radians) which can be calculated by the Equation 3, where n is the number of the day of the year, starting from first January. The solar declination (δ) can be calculated in degrees by the Equation 4. The hour angle ωS (degrees) on a horizontal surface can be calculated by the Equation 5 and the maximum possible number of daylight hours (photoperiod) is given by the Equation 6.

$$\Gamma = (2\pi(n-1))/365 \quad \text{(Eq. 3)}$$

$$\delta = \left(\frac{180}{\pi}\right)(0{,}006918 - 0{,}399912.\,cos\Gamma + 0{,}070257.\,sen\Gamma - 0{,}006758.\,cos2\Gamma + 0{,}000907.\,sen2\Gamma - 0{,}002697.\,\cos3\Gamma + 0{,}00148.\,\mathrm{sen}3\Gamma) \quad \text{(Eq. 4)}$$

$$w_s = \arccos(-tg\phi.tg\delta) \quad \text{(Eq. 5)}$$

$$N = \frac{2w_s}{15} \quad \text{(Eq. 6)}$$

The classification of the conditions of sky cover was carried out according to the criterion proposed by Escobedo et al. (2009) which according to KT classifies the sky conditions into 4 types of sky cover (Table 1). The same criterion for classification of the conditions of sky cover based on Kt was also used by Dal Pai (2021) in his work about Effect of sky cover on CO2 assimilation.

Table 1 - The Kt intervals for sky cover classification.

Kt Intervals	Sky Cover
$0 \leq K_t < 0{,}35$	Cloudy sky
$0{,}35 \leq K_t < 0{,}55$	Partially cloudy sky
$0{,}55 \leq K_t < 0{,}65$	Partially clear sky
$0{,}65 \leq K_t < 1$	Clear sky

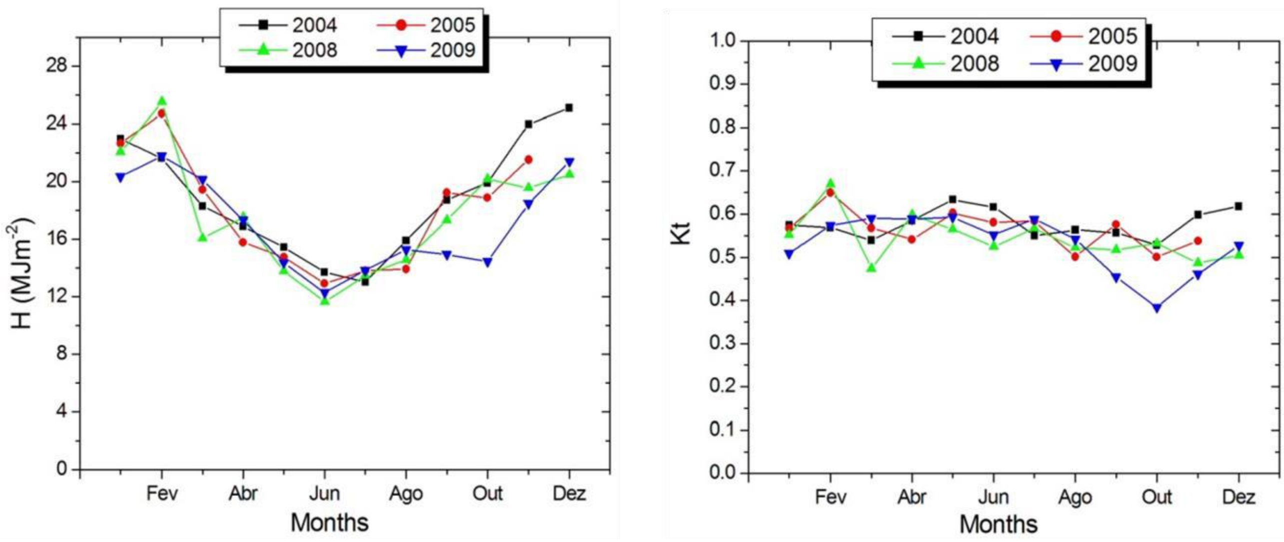
Source: Escobedo, et al., (2009).

3. Results and Discussion

The mean monthly values of global solar irradiation (Figure 3a) due to the influence of solar declination accompany the seasonality, where the lowest values are observed in the winter months and the highest values in the summer months. These values vary between 11.6 MJ/m2 in the month of June and 25.5 MJ/m2 in the month of February, and an average of 17.96 MJ/m2.

For Kt (Figure 3b), the effect of solar declination is reduced and there is a greater dependence on atmospheric transparency. Where the months of the summer period have lower values and the winter months, due to the low cloudiness they present higher values.

Figure 3 - Annual evolution of monthly averages of daily global solar irradiation and Kt.

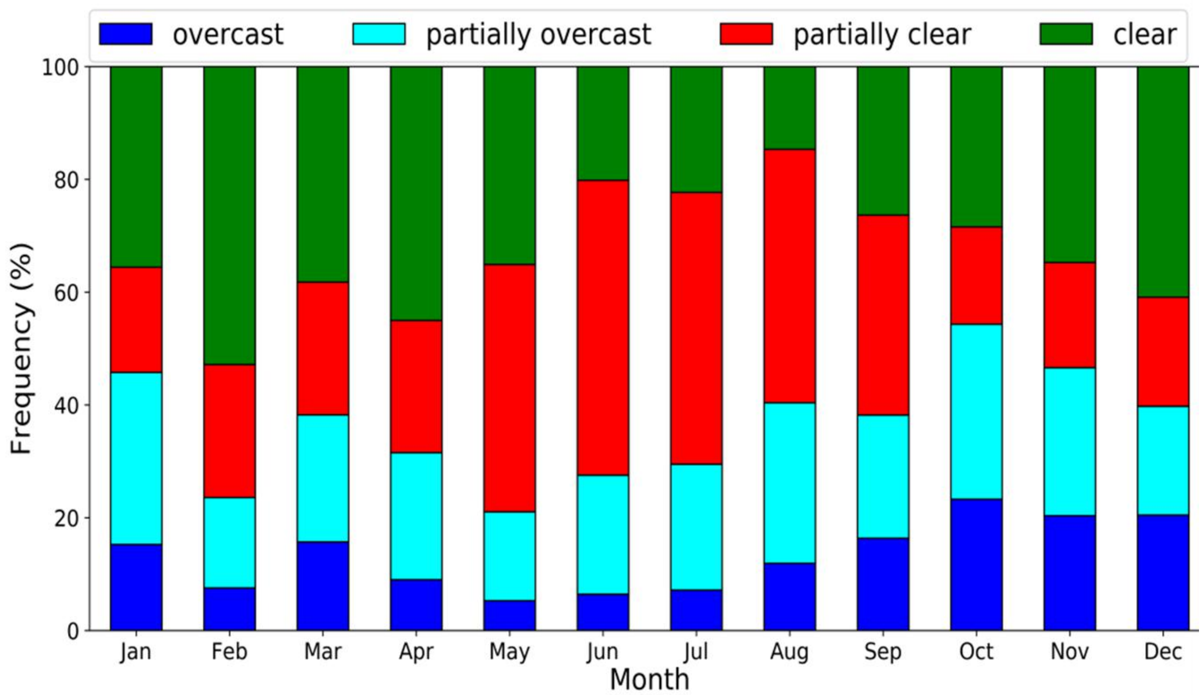


Source: Authors.

In October 2009, the Kt reached the lowest transmissivity of all year's 0.38 and the month of February 2008 had the highest transmissivity 0.67. The annual average incidence of global solar irradiation on the surface of the earth in Maputo city is 0.55. The average value of the clearness index was like the values founded in urban region of Cuiaba city, Mato Grosso state, Brazil (Alves, et al., 2007)

In Figure 4 the hot and rainy season tends to present a higher frequency (average) of days with cloudy sky. In this season observe greater concentration of clouds during the year. The month of October presents 0.23 of cloudy sky days and the month of May presents 0.05 of cloudy sky day.

Figure 4 - Annual evolution of the monthly average daily frequency of sky conditions in the city of Maputo.



Source: Authors.

For the partially cleared sky condition the month of June had a mean frequency of days 0.52 and the month of October had the lowest average frequency of days 0.17. This is due to the low concentration of cloudiness that is associated with low precipitation in the cold and dry season. And for the condition of clear sky, it is observed that the city of Maputo presents a hot and rainy season that is not accompanied with a greater concentration of clouds, what causes that the months of that time show average frequencies majors for conditions of sky clean. The month of February presented 0.53 of clean days and the month of September presented a value of 0.15. And the similar value was founded in Trans-Himalayan Region in Nepal (Poudyal, et al., 2012).

4. Conclusion

From this study, we obtained the following conclusions:

- ✓ The city of Maputo presents a maximum global solar irradiation in the month of February 32.23 MJ/m^2 and minimum in the month of June in the value of 1.84 MJ/m^2. The annual average of global solar irradiation in the city of Maputo is 17.96 MJ/m^2.
- ✓ The city of Maputo presents days with greater concentration of cloudiness in the hot and rainy season while days of clear sky in the cold and dry season. Throughout the year, it observes in average 120 days of clear sky conditions and 48 days of cloudy sky conditions.
- ✓ The frequencies for days of partially cloudy and partially clear sky conditions are 85 and 112 days respectively.

Based on the information presented, it is suggested for future studies to use the classification of the sky cover (clearness index) in the development of statistical models that can estimate the incidence of other components of solar radiation for Maputo/Mozambique, such as sky-diffuse and the direct-beam. This information can also be used in future studies to support the development of solar systems for thermal use (passive or active environments heating) or direct conversion of solar energy into electricity.

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