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Distribution of Insolation in the Hydrographic Area of Ipojuca River - Pe, Brazil

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ABSTRACT

Sunstroke is part of solar energy that spreads without the need for a material medium and is represented by the hours of the day that the solar disk remains visible on the earth's surface. The objective of this work is to characterize the climatic conditions of the sun using the interpolation method for the area of hydrographic area of the Ipojuca River and its surroundings, preparing a monthly and annually graphs for the period from 1962 to 2019. The average climatological data of the total monthly sunstroke and annually were generated by the simple interpolation method where the software was used in electronic spreadsheets, to extract the values of monthly, annual, median, standard deviation, coefficient of variance, maximum and minimum absolute values. Total sunstroke is greater than the cloud coverage in the period from August to March totaling 1861.8 hours and tenths, while in the same period the cloud coverage is 0.45 tenths. The incidences of insolation rates, above normality, are conditioned by low cloud cover, temperature fluctuations and low or no ground cover. The sunlight is important for agricultural purposes, generations of energy for industrial parks, energy distributors, and climatic studies that are scarce or widespread. It is observed that the deviations are positive, showing increases in the monthly and annual values; even though the straight line trends show insignificant reductions for the period studied. The trend lines of the respective 12 months are negative and without insignificance, which agrees with the calculations of the moving averages, stating that there has been a reduction in insolation in the next 9 year and after 10 years the insolation rates return to the average level historical.

INTRODUCTION:

Souza *et al*. (2008) stated that solar energy is an equally important element in influencing the atmospheric processes and climatic variability of the planet Earth, which contributes to the heating of the air and soil, photosynthesis and evaporation. Differences in the radiation balance are of fundamental importance for atmospheric and terrestrial processes, changing the ambient temperature, the vertical profile and the local or regional atmospheric circulation.

Sansigolo *et al*. (2013) stated that studies involving the time series of climatic elements should be superimposed and analyzed statistically nonparametric, having a more rigid mathematical basis for the theoretical models of climatic description.

Santos (2014) explains that solar radiation is the main modulator of atmospheric dynamics, and provides energy that stimulates oscillations in the general circulation of the atmosphere, supplying energy to living beings on the planet.

Holanda *et al*. (2016) carried out the monitoring of insolation as being a relevant activity for the agricultural sector, power generation and heat source, and analyzed the average insolation buoyancy in the municipal area of Caruaru. They showed that more in-depth and specific studies for the Brazilian semiarid region, including methodological ones, have to carry out the energy balance, with approaches to the influence on biomes.

Medeiros *et al.* (2018) showed that in the State of Piauí, because it is located close to the Equator line, occurs a higher incidence of sunstroke directly on the surface. According to the authors, the absence of clouds, the thermal fluctuation, the records of fires and fires can change the radiation or insolation rates, in the regions studied, between the months of July to October, favoring an increase in the radioactive absorption of short waves and increase in radiation.

Kozmhinsky *et al.* (2018) distinguished the insolation climatic in the State of Pernambuco by the kriging interpolation method and produced representative maps of monthly and annual variations, accounting for the low and high variability of the insolation. The records showed insolative oscillations higher than the normal patterns in the regions of the hinterland and high hinterland dependent on low cloud cover, and thermal fluctuations higher than normal patterns.

Medeiros (2018) compared the insolative indices in the Brazilian capitals and detected low insolative indices in the capital Rio Branco. The capitals with the highest insolation rates are: Fortaleza, Teresina, Goiana, João Pessoa and Natal, Aracaju and Recife In the other capitals, insolative rates were lower than the records of the capital of Pernambuco.

The objective of this work is to study the climatic conditions of the sunstroke using the interpolation method for the Ipojuca River Basin (IRB) and its surroundings, creating graphs representative of the monthly and annual variations and the accounting for low and high variabilities of the heat stroke from 1962 to 2020.

MATERIAL AND METHODS:

The IRB, is entirety in the State of Pernambuco, and is located between 08º 09' 50” and 08º 40' 20” south latitude, and 34º 57’ 52” and 37º 02’ 48” west longitude. Due to its elongated molding in the west-east direction, this area has a strategic position in the state space, serving as an extensive water link between the Metropolitan Region of Recife and the Sertão Region of Pernambuco. The upper, middle and middle sections of the area are located in the regions of the Sertão and Agreste, while the lower section is located in the Mata Zone, as well as the coastal strip of the State. (Figure 1).

Figure No. 1: Partial view of the Ipojuca River and its surroundings in the hydrographic area. Source: Medeiros (2021).

According to the Köppen, in the IRB the climate classification (1928) is characterized by three climatic types: Bsh (semi-arid hot climate with summer rains and dry winter), “Am” (Monsoon climate) and “AS” (Tropical climate with season summer drought). These classifications are in accordance with studies by Alvares *et al*. (2014) and Medeiros *et al*. (2018).

The rainy season begins in February and ends in August. The rainy quarter occurs between the months of May and July and the dry months occur between October and December. The elements that cause rain in the IRB are the Intertropical Convergence Zone, high level cyclonic vortices, northeast trade winds, steam and humidity forming clouds and causing moderate to strong precipitations, activation of instability lines and convective clusters, orography and heat exchange (Medeiros, 2016).

The average climatological data of the monthly and annual sunshine were determined by the simple interpolation method, where the software was used in electronic spreadsheets, to extract the monthly and annually values of the median, standard deviation, coefficient of variance, maximum and minimum absolute values, of the period from 1962 to 2020, formulating their graphs and trends, to the municipalities near to the IRB. The interpolated values were compared with the data from National Institute of Meteorology (INMET, 2021), represented in the Atlas of Solar Irradiation in Brazil, whose values are consistent with their climatic normals from the period 1962-2020.

Table 1 shows the names of the municipalities and their respective geographical coordinates, followed by the period of study of their series.

Table No. 1: Location of municipalities, geographic coordinates, period of observation of insolation data for the area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Parameters/municipality	Longitude	Latitude	Altitude	Observed period
Arcoverde	-37,0556	-8,4336	794	1962-2020
Agrestina	-35,9536	-8,4578	458	1962-2020
Alagoinha	-36,7739	-8,4661	717	1962-2020
Altinho	-36,0597	-8,4906	530	1962-2020
Amaraji	-35,4472	-8,3778	386	1962-2020
Belo Jardim	-36,4208	-8,3333	727	1962-2020
Bezerros	-35,7528	-8,2433	553	1962-2020
Cachoeirinha	-36,2375	-8,4839	572	1962-2020
Caruaru	-35,9158	-8,2383	539	1962-2020
Chã Grande	-39,2361	-7,7211	466	1962-2020
Escada	-35,2333	-8,3667	145	1962-2020
Gravatá	-35,5431	-8,2006	460	1962-2020
Ipojuca	-35,0058	-8,5144	62	1962-2020
Pesqueira	-36,6972	-8,3531	791	1962-2020
Poção	-36,7053	-8,1836	904	1962-2020
Pombos	-35,3961	-8,1386	341	1962-2020
Primavera	-35,3475	-8,3483	367	1962-2020
Riacho das Almas	-35,8592	-8,1381	443	1962-2020
Sairé	-35,7089	-8,3267	628	1962-2020
Sanharó	-36,5664	-8,3639	726	1962-2020
São Caitano	-36,1375	-8,3283	639	1962-2020
Tacaimbó	-38,1533	-9,1089	621	1962-2020
Venturosa	-38,9694	-7,9286	638	1962-2020
Vitória de S. Antão	-35,6347	-8,8383	253	1962-2020

RESULTS AND DISCUSSION:

Figures 2 to 13 show the monthly fluctuations of heatstroke and its trend line for the IRB. In Figure 14 the annual heatstroke, Figure 15 the distribution of the heatstroke anomaly, Figure 16 the maximum and minimum absolute heatstroke and its respective historical average, Figure 17 the histogram of the average heatstroke and the polynomial trend.

The months of January (Figure 2) have a negative trend line and a low level of significance. The oscillations of the sunstroke flow between 215 hours and tenths in the Tacaimbó municipality for 250 hours and tenths in Poção. The Arcoverde, Alagoinha, Escada, Pesqueira, Porção and Pombos municipalities, with high insolation values, stand out. The Cachoeira, Caruaru, Gravatá and Tacaimbó municipalities have low levels of insolation.

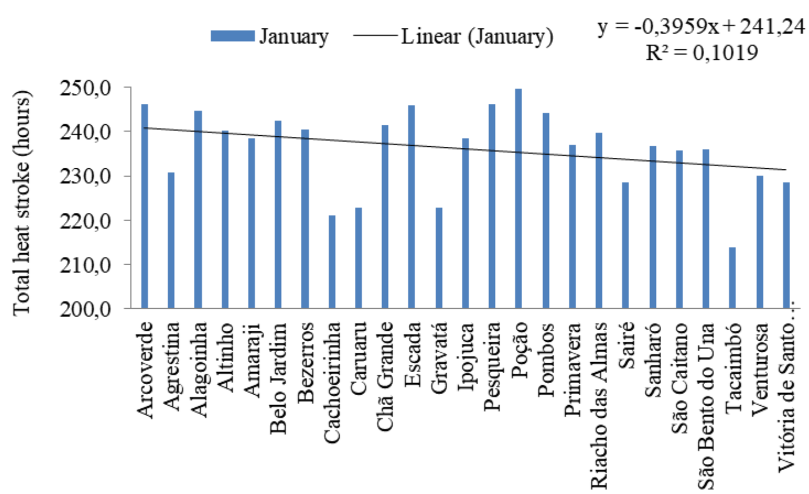

Figure No. 2 - Total sunshine for the month of January and its trend line in the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The variability of the heatstroke in February is shown in Figure 3. The insolation rates range from 192.3 hours and tenths in the Tacaimbó municipality, for 220 hours and tenths in Escada. The Cachoerinha, Caruaru and Tacaimbó municipalities had the lowest insolation rates. In the Escada, Ipojuca and Pombos municipalities there are high insolations.

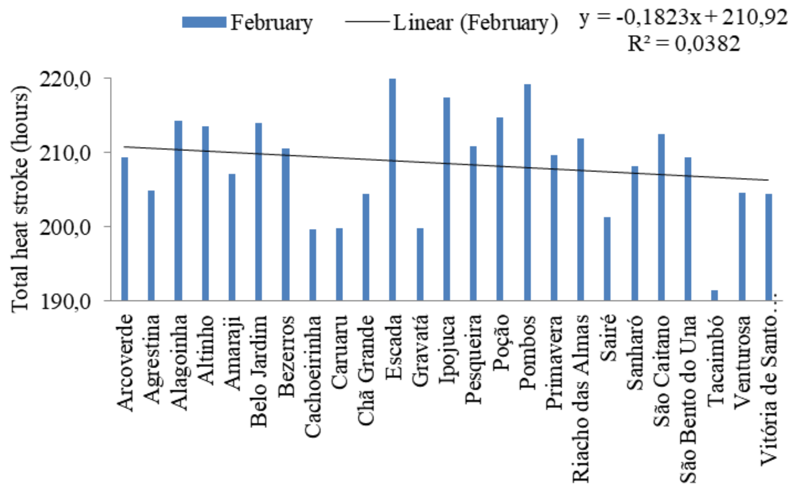

Figure No. 3: Total sunshine in February and its trend line in the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The month of March (Figure 4) has a straight line with negative slope and an insignificant R^2, ranging from 195.5 hours and tenths in Tacaimbó municipality to 229.2 hours and tenths in Arcoverde. In the Cachoeirinha, Caruaru, Gravatá and Tacaimbó municipalities were registered low insolations and high insolations in the Arcoverde, Escada and Ipojuca municipalities.

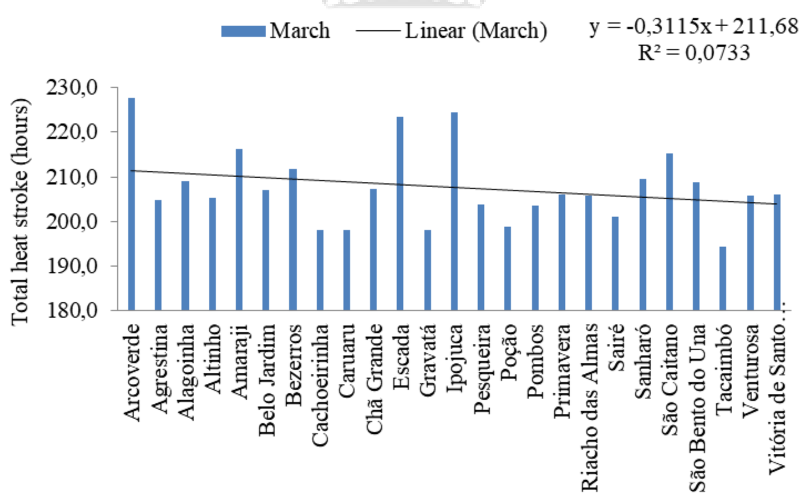

Figure No. 4: Total sunshine for the month of March and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The month of April recorded heatstroke swings between 173.2 in the Cachoeirinha, Caruaru and Gravatá municipalities with 219.8 hours and tenths. In the Arcoverde and Ipojuca municipalities the total insolation is 219.2 hours and tenths. Figure 5 shows a line with a negative slope and a low level of significance. These fluctuations are due to local effects such as high cloud cover, aid from the transient factors of meso and micro scale (Figure 5).

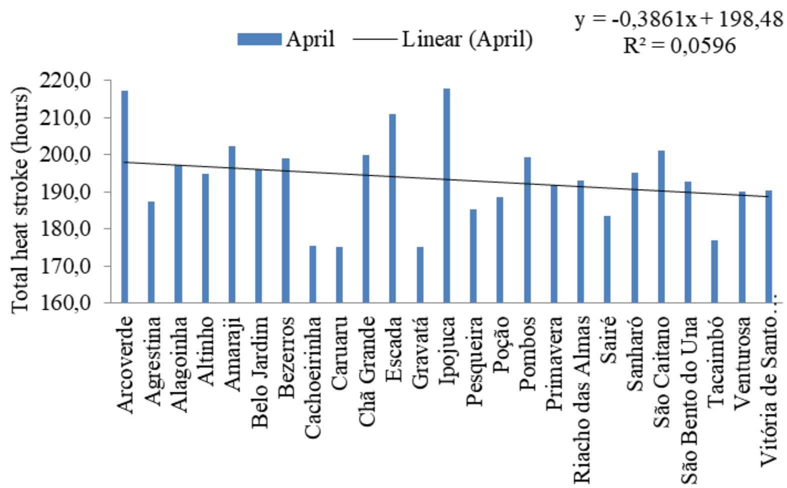

Figure No. 5: Total sunshine in the month of April and its trend line in the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Figure 6 shows the insolative fluctuations in May and its trend line for the hydrographic area of the Ipojuca River. The trend line has a negative slope and a low level of significance R^2. In the Cachoeirinha, Caruaru, Gravatá and Tacaimbó municipalities there are low levels of insolation. The Arcoverde, Agrestina, Escada, Ipojuca and São Caitano municipalities register the high incidences of insolation. The fluctuations in total sunshine in the month of May flow from 169.8 hours and tenths to 230 hours and tenths.

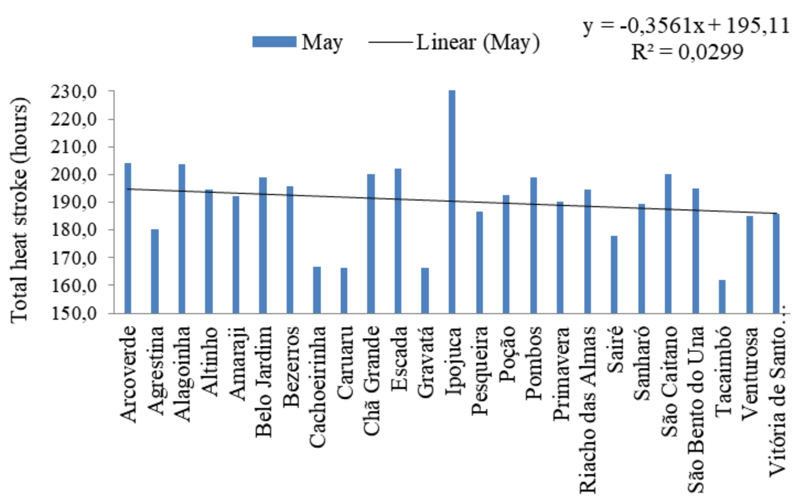

Figure No. 6: Total sunshine for the month of May and its trend line for the area of the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The fluctuations in the total sunstroke indices (Figure 7) occur between 140 hours and tenths in the Cachoeirinha, Caruaru, Gravatá and Tacaimbó municipalities, and 220 hours and tenths in the Ipojuca municipality, according to the monthly distribution shown in Figure 7. The month of June has a negative slope and low significance R^2. The fluctuations in disordered heat stroke are caused by the transient factors of the atmospheric systems of meso and micro scale and the local and regional contributions in accordance with the results obtained by Medeiros *et al.* (2018).

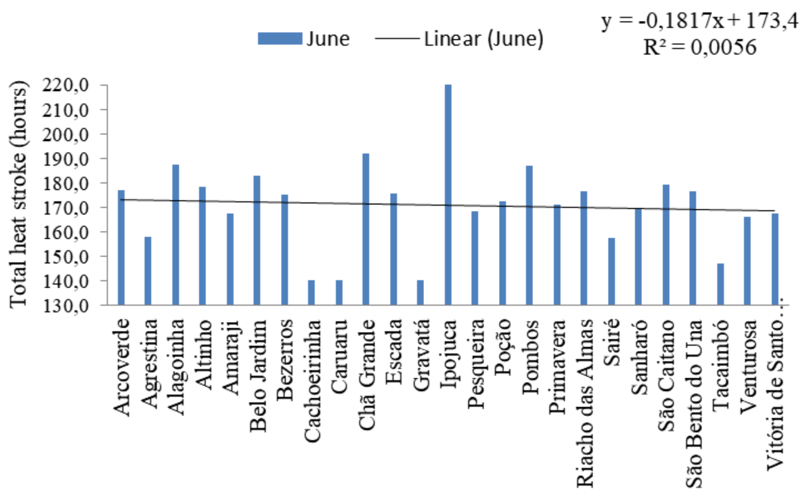

Figure No. 7: Total sunshine for the month of June and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The month of July (Figure 8) is characterized by a negative trend and an insignificant R^2. Total sunshine fluctuates between 140 hours and tenths in the Cachoeirinha, Caruaru, Gravatá, Poção and Tacaimbó municipalities, for 230 hours and tenths in Ipojuca. With insolations ranging from 191.1 to 198.3 there are the Arcoverde, Chã Grande, Escada and Pombos municipalities.

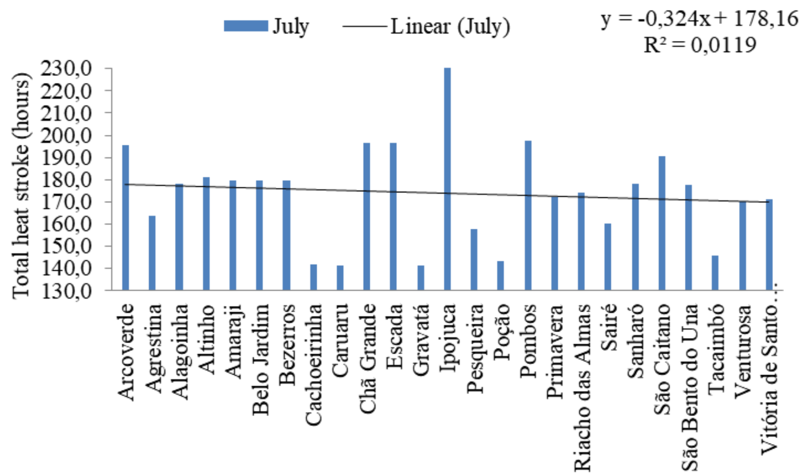

Figure No. 8: Total sunshine for the month of July and its trend line for the area of the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

In Figure 9 there is the variability of the total insolation of the month of August and its oscillations flow between 161.3 hours and tenths in the Tacaimbó municipality, to 260 hours and tenths in the Arcoverde, Ipojuca and Pombos municipalities. The month of August is marked with a negative trend line and an insignificant R^2.

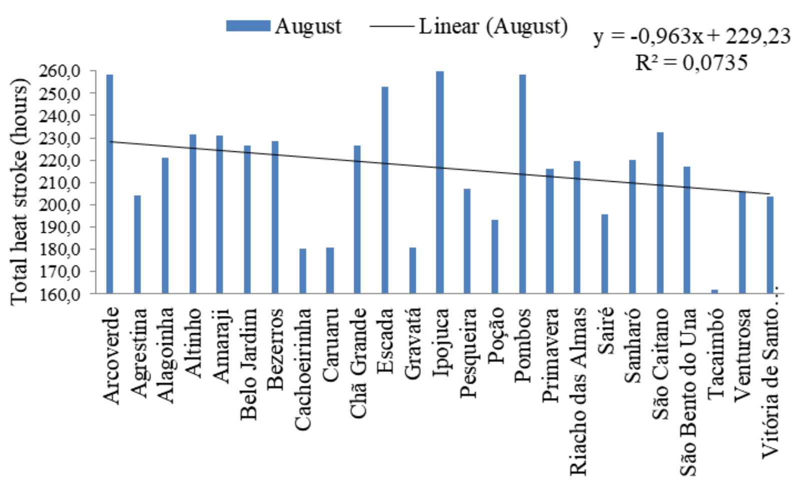

Figure No. 9: Total sunshine for the month of August and its trend line for the area of the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The Cachoeirinha, Caruaru, Gravatá and Tacaimbó municipalities had the lowest insolation rate, and in the Arcoverde, Ipojuca and Pombos municipalities, the highest insolations are registered. The month of September (Figure 10) has an insignificant R^2 and the trend line is negative.

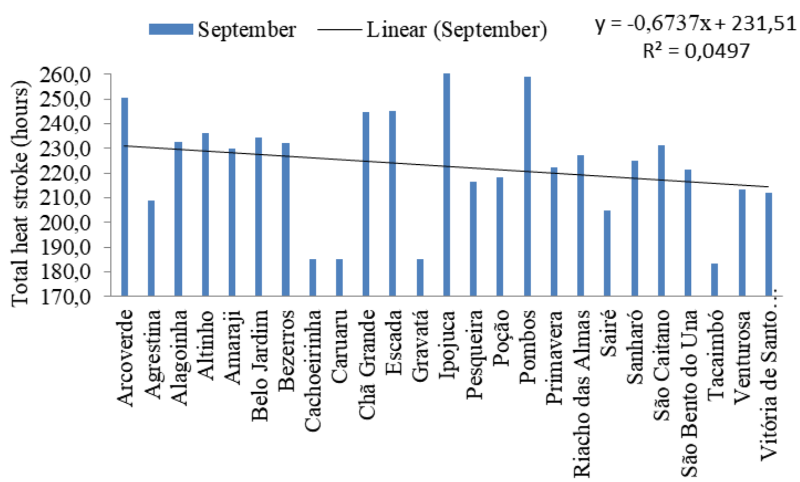

Figure No. 10: Total sunshine for the month of September and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The month of October (Figure 11) has insolation fluctuations that flow from 230 hours and tenths in Tacaimbó to 294.6 hours and tenths in the Arcoverde municipality. The municipalities with high insolation are Arcoverde, Escada, Pombos and the ones with low insolation stand out Tacaimbó. The month of September is characterized by a negative trend line and a low R^2. Between October, November and December there is a period distinguished by low cloud cover, allowing high rates of direct sunlight to pass through the soil surface.

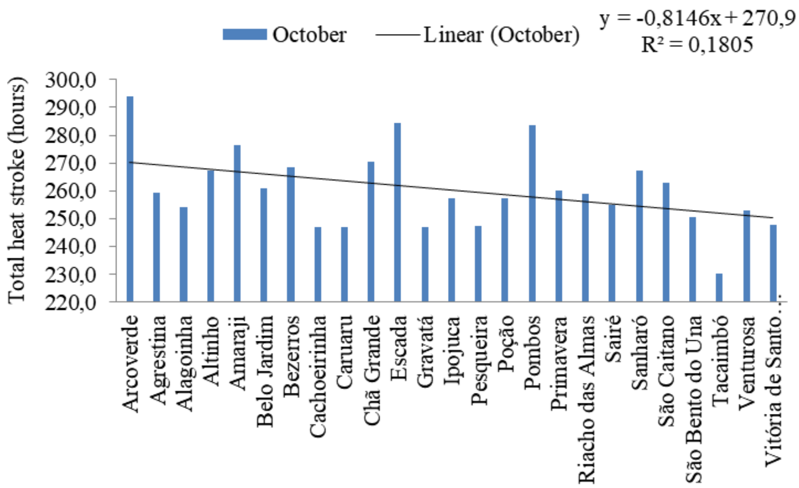

Figure No. 11: Total sunshine for the month of October and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Figure 12 shows the oscillations of total sunshine in the month of November and its line of negative and insignificant trend (R^2). Insolation fluctuations flow between 243.2 hours and tenths in the Tacaimbó municipality, for 280 hours and tenths in the Escada municipality. These fluctuations are caused by the transient atmospheric systems of meso and micro scale in the studied area.

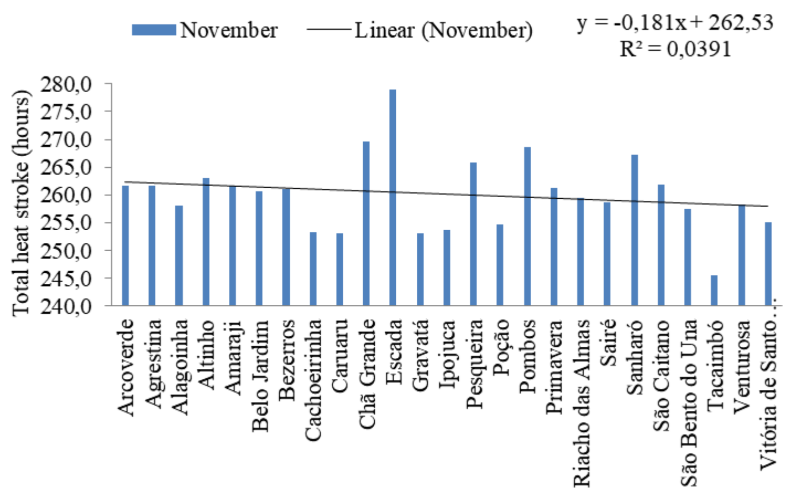

Figure No. 12: Total sunshine for the month of November and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The month of December (Figure 13) presents a straight negative trend and R^2 of moderate significance. Insolation fluctuations fluctuate between 236.1 hours and tenths in the Tacaimbó municipality, for 259.4 hours and tenths in the Escada and Pombos municipalities.

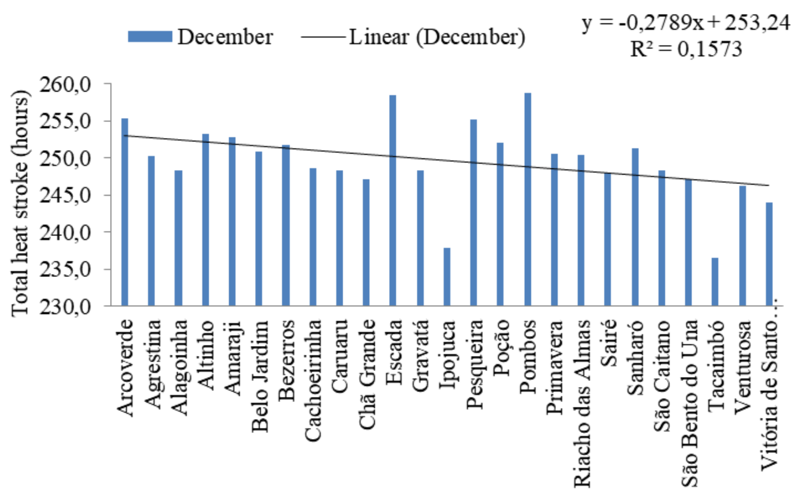

Figure No. 13: Total sunshine for the month of December and its straight line to the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

According to Silva *et al.* (2012) these oscillations between the abundance of monthly insolative rates are conditioned by the prevailing meteorological fluctuations of each period of the year or months, for example, low cloud cover, and not by the photoperiodic classes, where coupled the thermodynamic variability of the South Atlantic Anticyclone, from the South Atlantic Convergence Zones in the NEB region.

The total annual heatstroke and its trend line for the Ipojuca River Basin are shown in Figure 14, with a negative trend line and an R^2 of 6.4 of significance showing reductions in the studied variable. The municipalities of Arcoverde, Alagoinha, Altinho, Amaraji, Belo Jardim, Chã Grande, Escada, Ipojuca, Pombos and São Caitano have annual insolation rates greater than 2693 hours and tenths. The municipalities of Agrestina, Cachoeira, Caruaru, Gravata and Tacaimbó have heat stroke ranging from 2395 to 2398.8 hours and tenths.

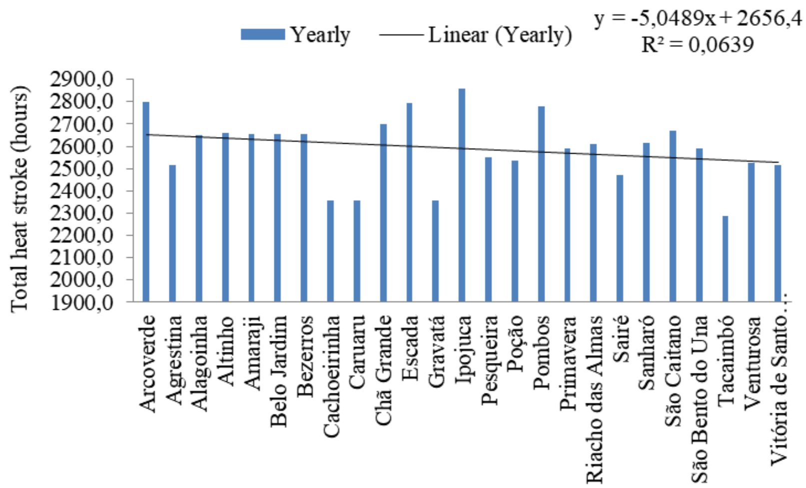

Figure No. 14: Total annual sunshine and its trend line for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Silva *et al.* (2013) and Medeiros (2016) stated that the variability of cloud cover in the state of Piauí - PI is conditioned by the elements that provoke rain in the different areas of their rainfall regimes. Between April and September, cloud cover in the southern region of the state of PI varies from 26% to 45%, in the central and northern regions of the study area, sunlight flows from June to December, cloud coverage flows from 25 to 45%, and 50% being consistent with the results obtained by Tubelis *et al.* (1988). These results corroborate with those from the present study.

The anomalies of total annual sunshine for the IRB area are shown in Figure 15. The municipalities with positive anomalies oscillating between 48.2 hours and tenths (Riachão das Almas) at 2937 hours and tenth in the Ipojuca municipality stand out. The Alagoinha, Altinho, Amaraji, Belo Jardim and Bezerros municipalities have heat stroke anomaly of 62 hours and tenths. The indices of negative anomalies of heatstroke range from 50.9 to 299.7 hours and tenths; the municipalities of Cachoeirinha, Gravatá and Tacaimbó stand out with the lowest negative indices and Pesqueira, Porção and Agrestina with high negative values.

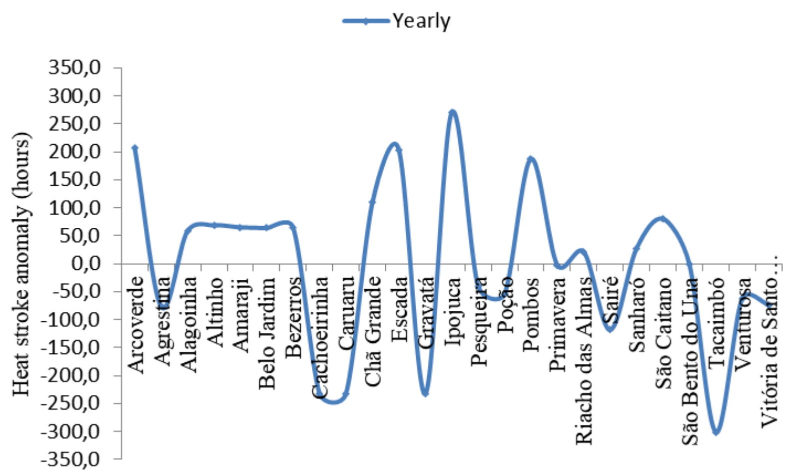

Figure No. 15: Anomaly of total annual sunshine for the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Figure 16 represents the observed heatstroke and the estimate of the moving averages for 5 and 10 years in the studied area. The observed insolative procedure follows the insolation estimates for the average moving oscillations of the 5 and 10 years, the fluctuations of the insolations registered with a decrease in its amplitude and with flatness between years. Assessments of 10-year moving averages are more representative than for five years. In the next 10 years, the insolation values will be equal to the annual average for the period 1962-2020.

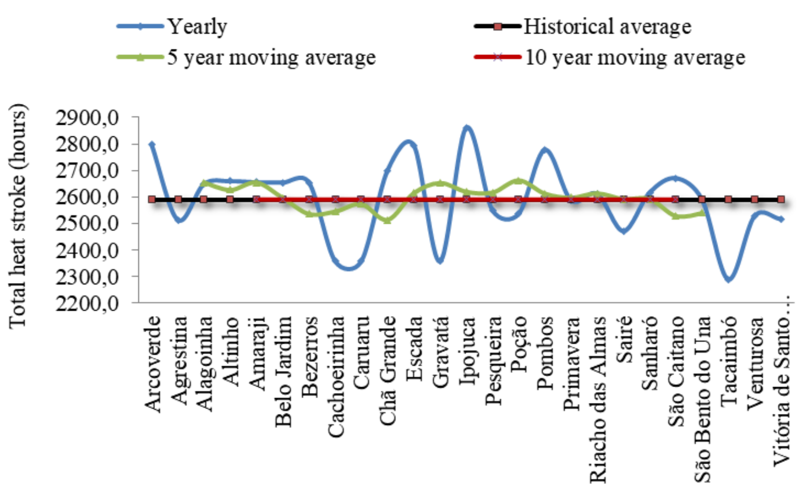

Figure No. 16: Total annual sunshine, historical average and its 5 and 10-year moving averages in the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

Figure 17 covers the variations of maximum total, average and absolute minimum insolations in the IRB area. The maximum insolation flows between 217.7 hours and tenths in the month of April to 294 hours and tenths in the month of October. The maximum annual insolation registered was 2860.6 hours and tenths. With a record of minimum annual heatstroke of 2289.7 hours and tenths and with monthly heatstroke between 140.3 hours and tenths in the month of June to 245.6 with monthly heatstroke between 140.3 hours and tenths. The average annual heat stroke is 2590.8 hours and its monthly fluctuations fluctuate between 171 hours and tenths in the month of June to 260.3 hours and tenths in the month of October. The oscillations of the sunstroke follow the behavior of the cloud cover, the variability of the rainy season and its aid of the transient factors of meso and micro scale.

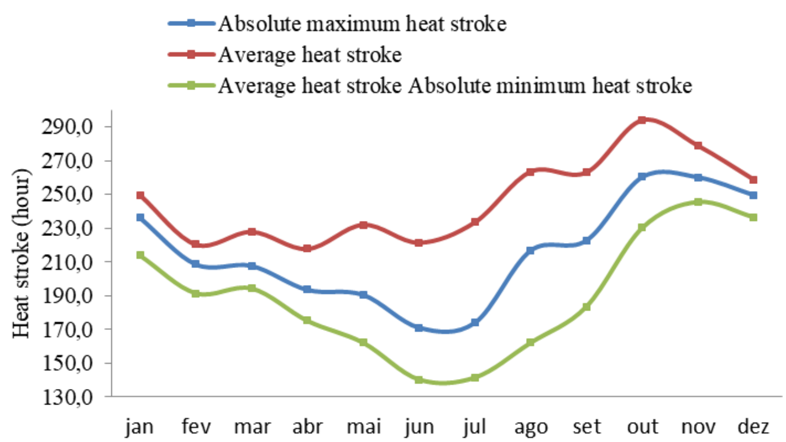

Figure No. 17: Total absolute maximum, average and absolute minimum insolation in the hydrographic area of the Ipojuca River in the period 1962-2020. Source: Medeiros (2021).

The Table 2 shows the best regression coefficients $R^2 = 0.1019$ (January) $R^2 = 0.1805$ (October) and $R^2 = 0.1573$ (December). The worst regression coefficients are registered in June ($R^2 = 0.0056$) and July ($R^2 = 0.0119$), respectively. This means that the higher this value, the better the model will approach the averages. When smaller values are registered, they indicate the degree of distance between the model and its averages. It is concluded that in the other months the model distances from the averages.

Table No. 2: Linear equation, regression coefficient (R^2), historical monthly and annual average of heatstroke from 1962 to 2020. Source: Medeiros (2021).

Months	Linear equation	R^2	Average
January	y= -0,3959x+241,24	0,1019	236,1
February	y= -0,1823x+210,92	0,0382	208,5
March	y= -0,3115x+211,68	0,0733	207,6
April	y= -0,3861x+198,48	0,0596	193,4
May	y= -0,3561x+195,11	0,0299	190,4
June	y= -0,1817x+173,40	0,0056	171,0
July	y= -0,3240x+178,16	0,0119	173,9
August	y= -0,9630x+229,23	0,0735	216,7
September	y= -0,6737x+231,51	0,0497	222,7
October	y= -0,8146x+270,90	0,1805	260,3
November	y= -0,1810x+262,53	0,0391	260,1
December	y= -0,2789x+235,24	0,1573	249,6
Yearly	y= -5,0489x+2656,4	0,0639	2590,7

With a positive line and R^2 of high significance, the polynomial curve is increasing between August and January and shows decreases from February to July. It can be seen in Figure 18 that the months of October to December concentrated the highest monthly averages of insolation, flowing from 770.1 hours and tenths corresponding to 30% of the annual insolation. In the months from February to August there is 52% of the value of annual sunshine. The lowest rates of insolatives are registered between September and January, which is a characteristic of the northeastern region of Brazil.

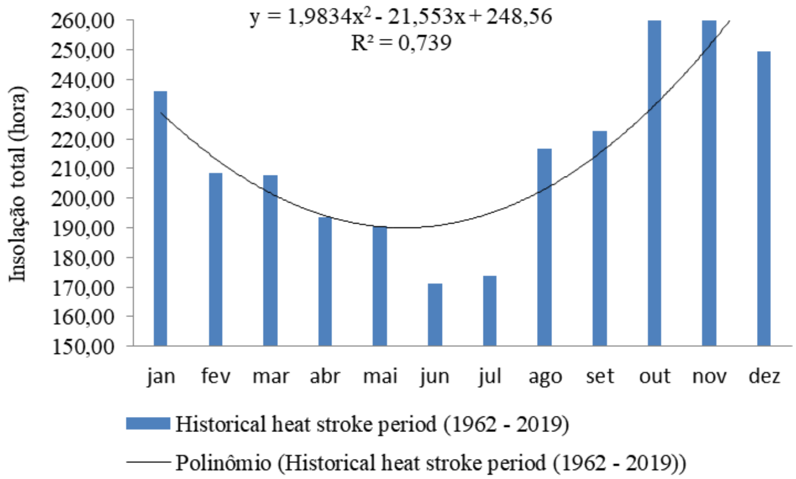

Figure No. 18: Histogram of the historical average heat stroke and polynomial trend for the period 1962 to 2019 in the area of the hydrographic area of the Ipojuca River. Source: Medeiros (2021).

Table 3 shows the statistical parameters of total sunshine for the area of the hydrographic area of the Ipojuca River Basin. It is observed an annual average of 2590.8 hours and tenths and its monthly fluctuations between 171 tenths hours in the month of June and 260.3 hours and tenths in the month of October. The annual median of 2860.6 hours and tenths, with monthly fluctuations between 217.7 in April and 263.5 in August with hours and tenths. The probability of occurrences of the median values is of low significance, given its dispersion. The average values with the increase or reduction of the standard deviations may be registered or happen as stated by the authors Katz (1991) and Katz *et al*. (1992) with the relative frequencies of extreme events depend on changes in the deviation and not on the mean.

Table No. 3: Statistical parameters of total sunshine (hour and tenth) for the area of the hydrographic area of the Ipojuca River. Source: Medeiros (2021).

Months	Statistical parameters					
	Average	Median	Detour Pattern	Variance Coefficient (%)	Maximum Absolute	Minimum Absolute
January	236,1	238,5	9,1	0,039	249,6	213,8
February	208,5	217,4	6,9	0,033	220,3	191,4
March	207,6	224,4	8,5	0,041	227,8	194,3
April	193,5	217,7	11,6	0,060	217,7	175,1
May	190,5	232,0	15,1	0,080	232,0	162,1
June	171,0	221,4	17,9	0,105	221,4	140,3
July	173,9	233,5	21,9	0,126	233,5	141,5
August	216,7	263,5	26,1	0,121	263,5	162,1
September	222,7	263,1	22,2	0,100	263,1	183,6
October	260,3	257,5	14,1	0,054	294,0	230,2
November	260,2	253,7	6,7	0,026	278,9	245,6
December	249,6	237,9	5,2	0,021	258,8	236,5
Yearly	2590,8	2860,6	147,0	0,057	2860,6	2289,7

The maximum and minimum absolute values have a payback time between 3 and 5.5 years of being repeated. These variabilities are linked to the meso and micro scale transient systems in the studied area.

According to Galvani (2011) the standard deviation is important to have information on the "degree of dispersion of values in relation to the average value". The coefficient of variance is used to make comparisons in relative terms and expresses "the variability of each data set normalized in relation to the average, in percentage."

The extreme events of high magnitude and a short time interval are expected, as stated by Marengo *et al*. (2015). These results are in accordance with the presente study.

In panoramas of future changes caused by the increase in gas concentrations in the atmosphere, it is assumed that only the average can change, with the standard deviation remaining unchanged (Galvani, 2011).

CONCLUSION:

Total sunstroke is greater than the cloud coverage in the period from August to March, totaling 1861.8 hours and tenths, while in the same period the cloud coverage is 0.45 tenths. These incidences of insolation rates above normal are conditioned by low cloud cover, temperature fluctuations and low or no ground cover.

The heatstroke has importance for purposes of applicability in the agricultural sectors, generations of energy aiming to help industrial parks, energy distributors, and climatic studies that are scarce or widespread.

The deviations are positive, showing increases in the monthly and annual values, even though the straight line trends show insignificant reductions for the period studied.

The study provides a tool for planning and actions that aim the best way to implement solar parks using the systems that influence the high and low values of insolation registered.

The trend lines of the respective 12 months are negative and without significance, which agrees with the calculations of the moving averages stating that there has been a reduction in insolation in the next nine years and after ten years the insolation rates return to the historical average level.

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