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Thermo-hygrometric modeling using ENVI-met® software to an urban park in Cuiabá – Brazil

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Abstract

Climate in urban areas, not under the effect of vegetation, was investigated and its benefits were observed in both vegetated and un-vegetated areas. The objective of this research was to model the air temperature and relative humidity using the Software ENVI-met® in an urban park in Cuiabá. The development of the methodology of this work involved two phases: survey (microclimate) and simulation. The microclimate survey was conducted through a mobile transect, for the periods of January 2014 to March 2014 (hot/wet) and July 2015 to September 2015 (hot/dry). The simulation was developed using ENVI-met® software during these two periods of the year. Generally maximizing the parameters, the ENVI-met® model for microclimate varied in the presence of too much vegetation. Simulations showed an increase in temperature and relative humidity in areas not surrounding the Mãe Bonifacia City Park, and this was particularly apparent in areas laid with asphalt and concrete. Vegetated parks play an important role in how hot climate thermoregulatory agents behave in the city of Cuiabá and the surrounding region.

Keywords: *Urban heat island. Mãe Bonifácia City Park. Air temperature. Relative humidity.*

Resumo

O efeito da vegetação no clima urbano é investigado há algum tempo e seus benefícios podem ser observados não só na área vegetada, mas também no seu entorno. O objetivo geral desta pesquisa é modelar a temperatura do ar e a umidade relativa do ar por Software ENVI-met® em um parque urbano em Cuiabá-MT. A metodologia de desenvolvimento deste trabalho envolve duas fases: Levantamento (microclimático) e Simulação. O levantamento microclimático foi realizado por meio de um transecto móvel, nos períodos de janeiro/2014 a março/2014 (quente/úmido) e julho/2015 a setembro/2015 (quente/seco). A simulação foi desenvolvida pelo software ENVI-met® durante os dois períodos do ano. Em geral, o modelo ENVI-met® maximiza as variáveis microclimáticas na presença demasiada de vegetação. As simulações apresentaram aumento da temperatura do ar e umidade relativa do ar mais baixas no entorno do parque urbano Mãe Bonifácia, acentuadas nas áreas de pavimentação asfálticas e concreto, e nas proximidades de edifício. Atentando ao papel importante dos parques vegetados como agentes termorreguladores do clima quente acentuado como nas cidades de Cuiabá e região.

Palavras-chave: *Ilha de calor. Parque Mãe Bonifácia. Temperatura do ar. Umidade relativa do ar.*

1 introduccíon

Urban areas are characterized by groupings of individuals in natural environments, where the integration of economic and cultural activities results in the modification of the original climate. In the process of urbanization, various changes occur to natural landscapes, especially in cities without adequate planning.

The urban space is a mosaic of different microclimates, such as small islands of heat, pockets of air pollution and local differences in wind flow. The problems related to the urban environment are varied and include excessive noise, emission of pollutants in air and water, scarcity of energy resources and water, lack of adequate waste treatment, changes in rainfall and wind regime, training heat islands, dry islands, cold islands, thermal inversion, and increased energy consumption for artificial conditioning and transport (DUARTE; SERRA, 2003).

Changes in land use and cover, either for agricultural use or urbanization, increase the albedo and surface temperature and reduce vegetation indices and the surface radiation balance (OLIVEIRA et al., 2012; NASCIMENTO et al., 2014).

In most urban areas, much of the existing vegetation is concentrated in parks or playgrounds. Although parks can reduce temperatures in their proximity (BRUSE; FLEER 1998; SANTAMOURIS, 2001), they are thermally incapable of affecting constructive densities where people live, work and spend most of their lives (ROSSETI et al., 2013).

Thus, as a way of evaluating these scenarios, numerical microclimatic models, capable of evaluating these urban scenarios and simulate changes in climate-influencing variables, have been developed. The proposed model in this study is the three-dimensional software ENVI-met® developed by Professor Michael Bruse of the University of Bochum, Germany (BRUSE; FLEER 1998).

ENVI-met® is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics, including simulation of various phenomena such as heat flow and entries in buildings, soil-to-ground and inter-wall steam, turbulence, thermo-hygrometric exchange in vegetation, bioclimatology, and fluid dynamics of small particles and pollutant species (AMBROSINI et al., 2014).

The program can be used as a tool in the urban planning process to compare different scenarios with variations in urban morphology, constructive typology, constructive density, soil permeability, and vegetation index (BRUSE; FLEER 1998; PEZZUTO, 2007; AMBROSINI et al., 2014). This study sought to analyze the behavior of the microclimatic variables in a widely vegetated area, thus making this research the inverse to the one performed in urban centers using ENVI-met® software.

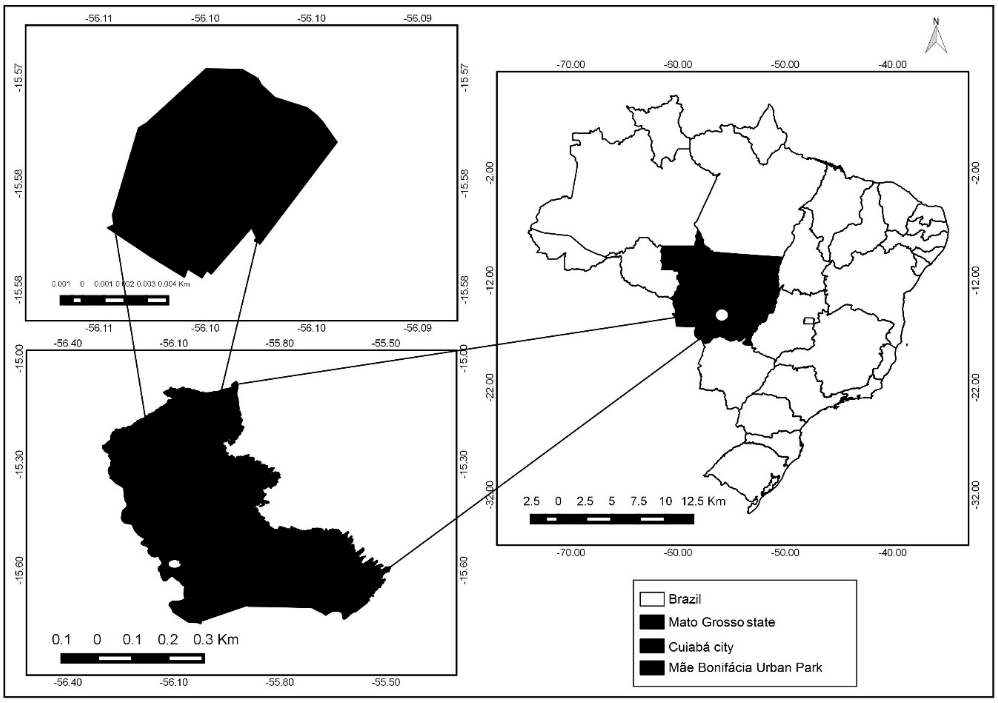
ENVI-met® offers several data output options, analyzing the behavior of the variables air temperature (°C) and relative humidity (%), and allowing for comparisons to be made between actual and simulated data.

Thus, the general objective of this research was to model the air temperature and the relative humidity of the air using ENVI-met® Software in an urban park of Cuiabá-MT.

2 Materials and Methods

2.1 Experiment location

Figure 1. Location of the Mãe Bonifácia City Park in Cuiabá-MT, Brazil



The city of Cuiabá, the capital of the state of Mato Grosso, is in west-central Brazil, and has geographical coordinates of 15.3556° S, 56.0601° W. The municipality has an area of 3,224.68km², and can be divided into 254.57 km² (7.89%) of urban area and 2,970.11 km² (92.1%) of rural area (NOVAIS et al., 2014), figure 1.

Mãe Bonifácia City Park is in western Cuiabá, Mato Grosso, between the geographic coordinates of 15.3444° S, 56.0501° W, and is 77.16 hectares in area. The city park area was first a designated Local Interest Conservation Unit under Complementary Urban Management Law n. 004 on December 24, 1992 (CUIABÁ, 1992). Decree no. 1,470, dated June 9, 2000, created the Mãe Bonifácia City Park.

According to Andrade et al. (2016), the Mãe Bonifácia City Park is a savanna fragment that remains in its natural form and has not undergone relevant anthropic actions to alter its biophysical characteristics. Among the most abundant species are *Curatella americana, Albizia niopoides, Anadenanthera colubrina, Samanea Tubulosa, Stryphnodendron barbatimão, Inga Vera and Bowdichia virgilioides.*

2.2 Measurement variables

Climatological normals were used from a database of a historical series published by (INMET 2016), and refer to the weather station at the Marechal Rondon airport in Cuiabá - MT, which belongs to the network of the National Institute of Meteorology.

2.3 Collection period

Measurements were carried out on days with solar incidence on the savanna fragment, without cloud interception. Measurements were taken on days with no rain and no or minimal cloud cover.

According to the classification of Koppën, the climate is type Aw2, Semi-humid Tropical, and is characterized by high temperatures throughout the year, with annual averages between 28ºC and 32ºC (ALVARES el al., 2013). The area's climate alternates between two well-defined season: a hot/dry season (autumn-winter) and a hot/wet season (spring-summer). Precipitation is concentrated in the months of October to April, whereas during the rest of the year, from May to September, dry air masses over central Brazil inhibit rainfall (NOVAIS el al., 2014). Almeida et al. (2011) affirm based on a series of 15 years, that 86% of the area's precipitation occurs between the months of October and April.

Measurements were taken between October 2014 and September 2015, averaging the microclimate fr each period, establishing the hot/wet period (January, February and March) and hot/dry period (July, August and September).

2.4 Modeling of air temperature and relative humidity

The software ENVI-met®, model 3.1, was used for the thermohygrometric modeling and the software *Leonardo* 2014 beta (E.T.) build 3.100.2 was used to make the maps. The area has been rendered with a 140 x 140 x 20(x, y, z) grid, keeping the following spacing: dx=2; dy=2; dz=2. The resolution is an average within the suggested values (minimum 0.5 m – maximum 10 m), and is a reasonable compromise between accuracy and calculation time. A more accurate resolution would imply a larger model, considering that the maximum dimensions allowed by the software are 250 × 250 × 30 cells (AMBROSINI et al., 2014).

For the vegetation modeling, three different plant types have been employed: grass, 50cm, aver, dense; tree, light, 15m; tree, 10m, very dense. The soil has been modeled with asphalt road, pavement (concrete) and loamy soil.

In this work the simulation elapsed time is 48h, being presented the results of the last 24 hours. Climatic data was fed to the ENVI-met® software configuration file for model processing for each climatic period, and included the following required information: simulation start day, format (DD.MM.YYYY), (HH: MM: SS), total simulation period in hours, model state data recording frequency in minutes, wind speed at 10 m in m/s, direction of the wind in degrees relative to North, surface roughness at the reference point, initial temperature of the atmosphere in K, specific humidity at 2500 m in gH2O/kg air, and relative humidity at 2 m above ground level in %.

3 Results and Discussions

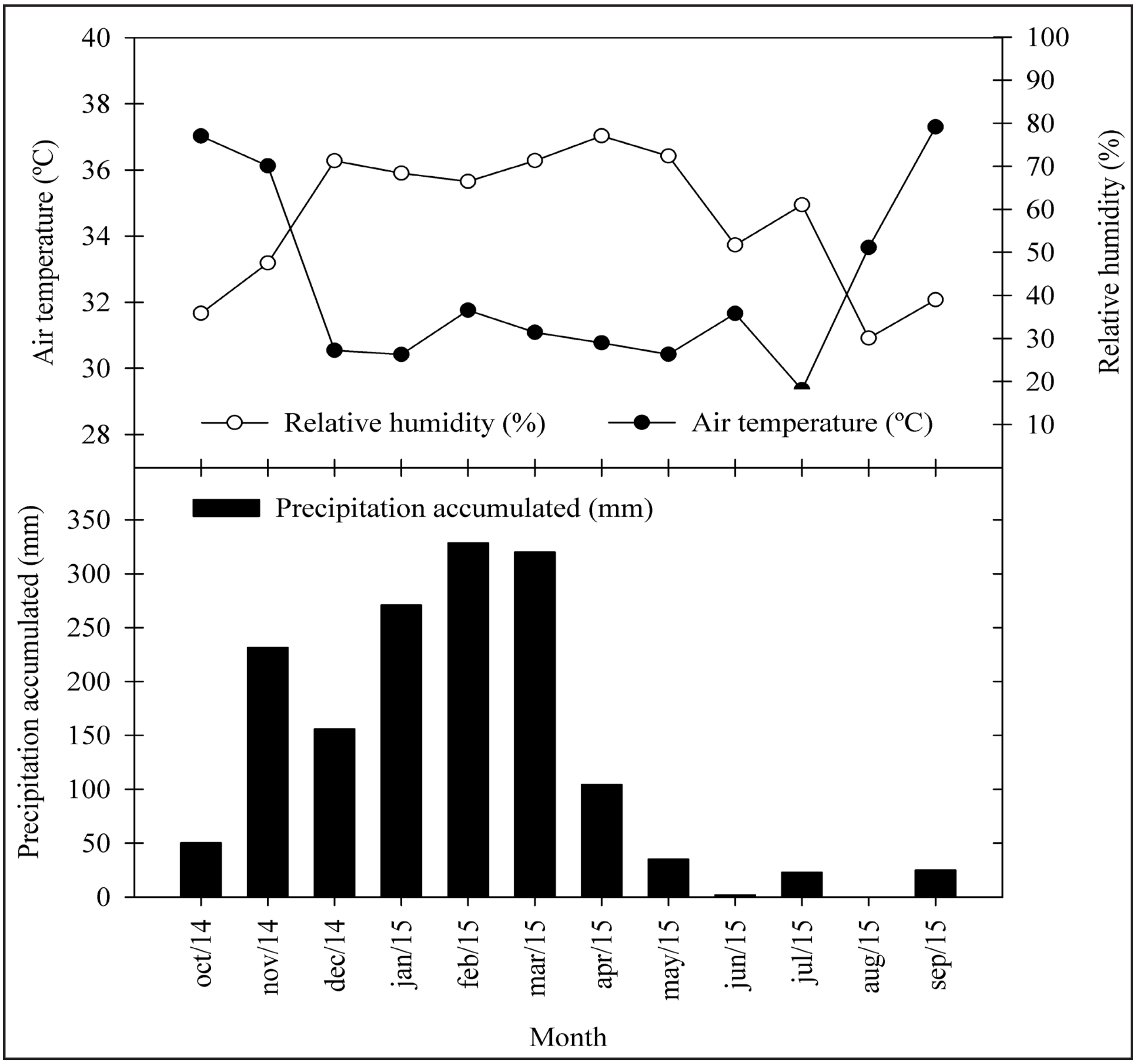
3.1 Characterization of the microclimate

The behavior of micrometeorological variables in this region is distinct over the of the year, thus justifying a seasonal division according to the rainfall regime (NOVAIS et al., 2016; NOVAIS et al., 2017).

According to (PIAIA, 1997), the average annual rainfall is about 1500 mm, and is concentrated during the rainy season of spring-summer, when the area is dominated by the presence of a mass of hot and humid continental equatorial air. In contrast, during the dry season, this station is influenced by a mass of continental tropical air that sets in the region, driving hot and dry winds.

It can be seen in Figure 2 the behavior of the microclimatic variables throughout the year, including air temperature, relative humidity and precipitation, at the station in the city of Cuiabá-MT, (INMET, 2016).

Figure 2. Microclimatic variables from the year 2014 to 2015 for the city of Cuiabá-MT



The highest rainfall occurred in February 2015, with 328mm, whereas in the months of June, July and August of 2015 it hardly rained. The highest relative humidity occurred in April 2015, with 77%. In August of 2015 the lowest relative humidity occurred, 30%. In September 2015 there was the highest air temperature, 37.3ºC, while in July it was the lowest, 29.35. It is noteworthy that the measurements of air temperature and relative humidity are below the vegetative canopy.

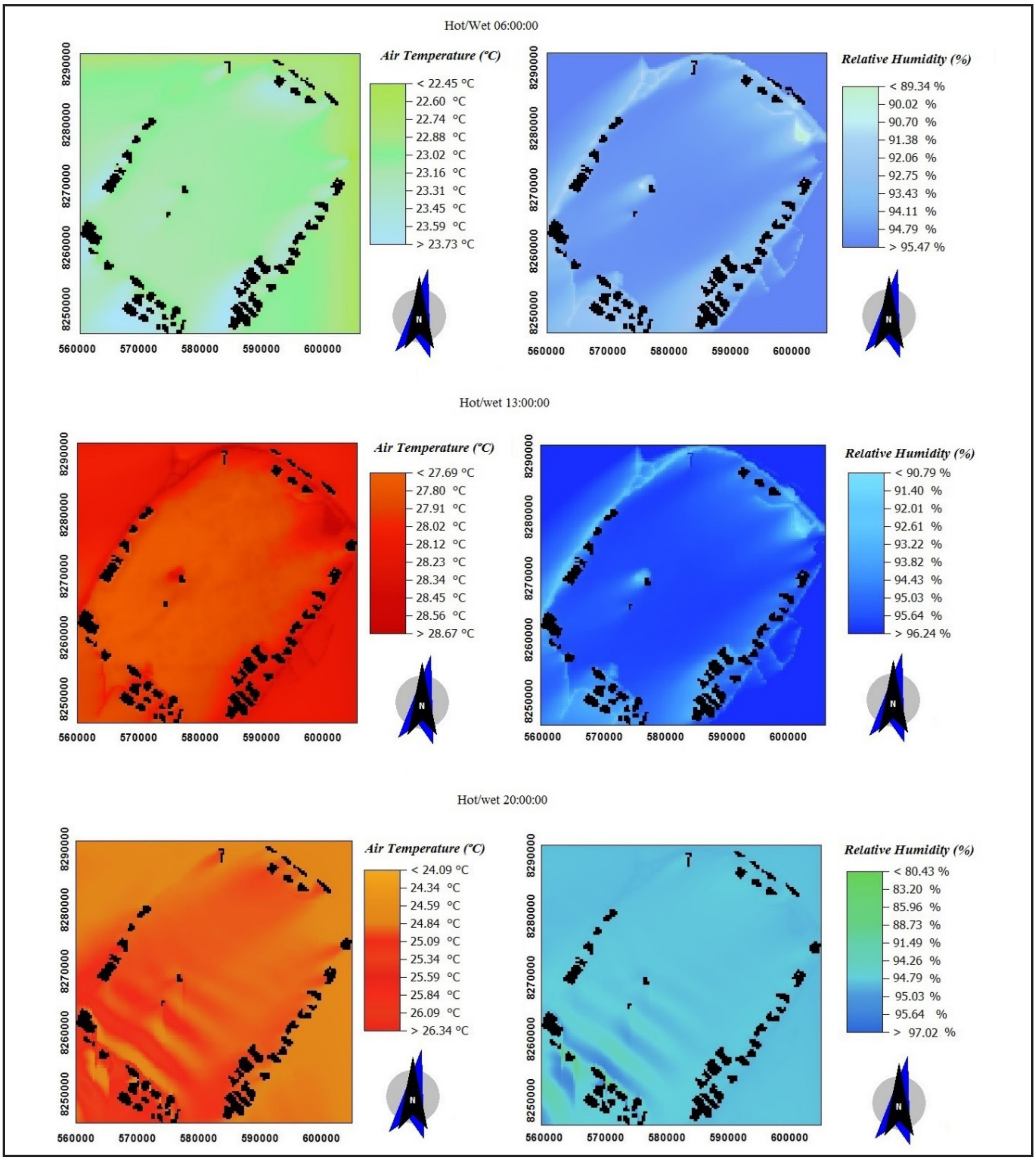
3.2 Hot/wet period maps for air temperature and relative humidity

For the hot/wet period in the three schedules previously described, it is relevant to note the differences between the schedules and the correlation between the air temperature variable and relative humidity, and also to verify the relationships of the variables with the surroundings of the Mãe Bonifácia City Park, as shown in Figure 3.

In the morning (6h), during the hot/wet period, was observed in the air temperature map a minimum of 22.45ºC and a maximum of 23.73ºC. These low values occur due to the incidence of solar radiation on the surface being low during the early hours of the day. It is worth noting that the park has a concentration of lower air temperatures, but with larger alterations in the environment nearby including constructed areas, an average difference of 1 ºC was noted when compared to the vegetated city park.

In the relative humidity map at the same time, the minimum was 89.34% and the maximum was 95.47%. Humidity in

Figure 3. Air temperature (° C) and relative humidity (%) maps for the hot/wet period in Mãe Bonifácia City Park in Cuiabá –MT



vegetated areas was higher than in built and paved areas where the percentage was lower.

According to (MASCARÓ, 1996), vegetation interferes with solar radiation, wind and humidity. In some tree groups air temperature can be 3°C to 4°C lower than in areas exposed to solar radiation, with this difference varying according to the stratification of the air and the extent of the vegetation.

At 13 h, when the solar radiation is maximum, the air temperature map shows the highest values of this microclimatic variable, with a minimum of 27.69 ºC and a maximum of 28.67 ºC. It can be seen in the map that the park registered lower temperatures, except in some areas such as the asphalt parking lot, and a constructed area next to the center of the park.

The high air temperatures for this time were recorded in the area surrounding the park, which is influenced by built areas, such as the residential buildings concentrated in the lower part of the map. Nearby residential areas and asphalt paved areas such as the AV. Miguel Sutil also obtained the highest values, as found by Andrade et al. (2016).

At the same time of the afternoon, the highest relative humidity is concentrated in the vegetated areas, similar to the morning period, with a minimum of 90.79% in the built and paved areas and a maximum of 96.24%.

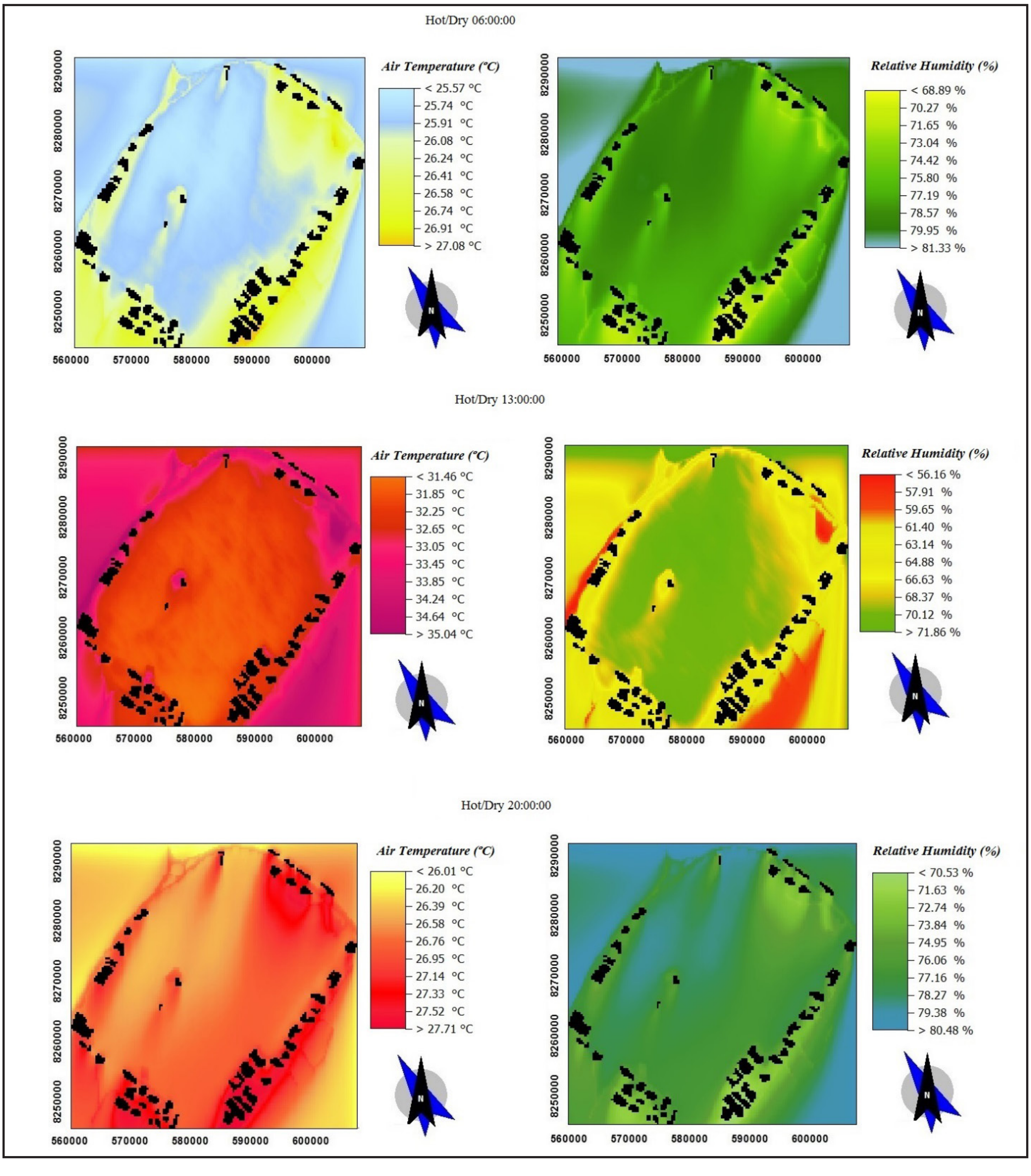
At night (20 h), where there is no influence of solar radiation on the surface, there are gradually lower microclimatic variables. For this period, as seen in the air temperature map, minimum was 24.09 ºC and the maximum was 26.34 ºC, following the same parameters of the locations where the lower and higher means were concentrated.

Relative humidity was a minimum of 80.43% and a maximum of 97.02% for the same points during other periods of the day.

3.3 Hot/dry period maps for air temperature (ºC) and relative humidity (%)

The air temperature (°C) and relative humidity (%) maps for the hot/dry period in the three schedules previously described are shown in Figure 4.

Figure 4. Air temperature (° C) and relative humidity (%) maps for the hot/dry period in Mãe Bonifácia City Park in Cuiabá –MT



During the morning (06h), the air temperature was a minimum of 25.57 ºC in the part of the park where there is the highest concentration of vegetation. According to (BARROS et al., 2010), the Mãe Bonifácia City Park is an island of freshness for the region and its thermal environment is favored due to its configuration maintaining the original savanna of the region, producing narrow tracks where the tree canopy minimizes the entrance of solar radiation.

Due to the low solar radiation, the effect of the wind on the behavior of this variable can also be observed, and it was determined that within the Mãe Bonifácia City Park the places with the lower temperatures were areas of ventilation. In low-ventilation areas, the air temperature was higher, possibly because of the concentration of heated air with no ventilation.

The maximum temperature for the morning and afternoon time (13h) was mainly concentrated in areas of residential buildings in the lower part of the park, influenced by the asphalt streets. This was also observed along the Av. Miguel Sutil and in the vicinity of the commercial area, both of which have asphalt. According to (MACIEL, 2011) this effect can be explained by the low albedo value of asphalt, which results in great absorption of thermal energy from solar radiation.

The ambient air temperature profiles show that the cooling effect of the park is on average 2°C compared to the open square with peaks up to 6°C. Compared to the canyon, the temperature of the park is about 2.5°C lower around noon.

The difference between the built-up area and the interior of the park may be related to the composition of the vegetation on the site, and the local relief and the angle of incidence of solar rays, such that the presence of buildings near the measuring points shades the area, slowing the time of arrival of the solar rays. This causes the energy transfer processes to be delayed both with respect to the sensible heat, which is capable of directly modifying the air temperature, and the latent heat, which is capable of directly modifying the relative humidity of the air.

According to (CORBELLA, 2003), in urban centers buildings, which have grown in height and in mass, increasing the thermal inertia, and are associated with a greater number of asphalted streets, absorb more solar energy and convey this energy with the same intensity to the immediate space.

In the evening (20h), temperatures declined in relation to the period of the day, noting that in urban areas such as the buildings around the park and in the built area in the center of the park, in the parking lot, the temperatures did not fall significantly. Oke et al. (1999) conducted measurements of the energy balance in Mexico City during the dry season in a constructed area. The results showed an environment dominated by sensible heat and that stores large amounts of heat in the constructed space during the day, releasing it at night.

As seen in the relative humidity map at 06h in the morning the maximum of 80.33% is similar to the maximum of the night period 20h of 80.48%. Areas of large vegetation tended to have lower temperatures and a higher percentage of relative humidity due to the absence of solar radiation.

During the hot/dry period the average temperature difference was 4°C when compared to the hot/humid period during the morning time, and 7°C for the afternoon, and 1°C for the night, respectively. This difference in the maximum relative humidity between the same periods was 14% for the morning, 23% for the afternoon and 15% for the night. The differences occurred in the set of points near the paved areas.

The higher air temperature in the region near the asphalt of the park may be associated with the interactions that this fragment has with its surroundings, in this case the extensive pavement.

The paved areas result in an increase in the emission of long waves and a consequent effect on microclimate. An increase in the incidence of long waves in the region results in effects an increase in the temperature of the air as part of this energy flow constitutes as sensible heat, that is, it can change the temperature of the air in the region of its incidence.

During the wet period there was sufficient water available to level the air temperature. We were not able to perceive the spatial influences of the environment during the dry period for this same reason, but rather the inverse occurred, there was not enough water for the occurrence of thermoregulation, the spatial differences were leveled from below; it is as if the vegetation of the innermost area of the park was not able to significantly reduce the temperature of the air.

3.4 Model validation

For the validation of the ENVI-met® software model, the average data of the hot/wet and hot/dry periods were compared, with the mean data for the same period and time of the National Institute of Meteorology – INMET station and the surveys completed in the Mãe Bonifácia City Park.

Analyzing the differences of the variables of the map simulated by the model and with other authors it did not maintain an average pattern of the two proposed microclimatic variables, table 1.

Data from the INMET (National Institute of Meteorology) were collected in an open space, justifying their greatest differences with the park data. This comparison was necessary to compare the data within an urban park with data for open space. Comparing the microclimatic variables of the INMET database and the ENVI-met® simulation, a difference of 2.2°C and 10.1% of air temperature and relative humidity of the air, respectively, occurred during the hot/wet period and for the hot/dry period a difference of 6.2 ºC and 1.6%, respectively, was noted.

Comparing the results of ENVI-met® with other authors results who studied the park, it is noted that for the hot/wet period the model overestimated the relative humidity and underestimated the air temperature. The lowest differences between the

Table 1 - Mean values of air temperature and relative humidity to the Mãe Bonifácia City Park in Cuiabá-MT

Period	Hot/Wet	
	Air temperature (°C)	Relative humidity (%)
INMET (2016)	26.5	80.8
ANDRADE et al. (2016)	31.1	68.7
ANNUNCIAÇÃO (2016)	29.1	79
BARROS et al. (2010)	30.6	74.9
ENVI-met®	28.2	90.9

Period	Hot/Dry	
	Air temperature (°C)	Relative humidity (%)
INMET (2016)	24.7	68.2
ANDRADE et al. (2016)	33.4	44.3
ANNUNCIAÇÃO (2016)	28.8	63
BARROS et al. (2010)	27.8	72.8
ENVI-met®	30.9	69.8

relative humidity and air temperatures encountered in the hot/dry period occurred. In contrast, ENVI-met provides an overestimation of about 20% for the same climatic conditions – that can lead to differences as high as 20ºC.

These results suggest that improvements can be made in the model when there is a greater amount of water in the place, probably because the species used in the model do not represent the local species, which are mostly deciduous trees, directly influencing the evapotranspiration and the microclimate below of the vegetative canopy.

4 Conclusions

The model was successful in thermohygrometric modeling of the site, especially in the hot/dry period. Adjustments are required in relation to the species bank of the model, to optimize the results, especially in the hot/wet period. There was seasonality in the results found, where the air temperature in the hot / dry period was 2.7 ºC warmer than the hot/wet period. Regarding relative humidity, the hot/wet period with a mean of 90.9% was 21% wetter than the hot/dry period. It was also observed that in both periods there was a higher air temperature and lower relative humidity in the vicinity of the buildings and paved surfaces.

Considering the results of this study, the study of the urban climate in the state of Mato Grosso and the Central-West region was enriched. It is key to consider the important role of vegetated parks as thermoregulatory agents of the hot climate as accentuated in the cities of Cuiabá and the region.

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