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Influence of land use on urban climate of a small town

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ABSTRACT. This study aimed to quantify the influence of anthropogenic activity in changing the microclimate of the urban area of a small town. To this end, the temperature and relative humidity were monitored over six days using a direct-reading thermo-hygrometers placed in mini weather stations. The points where these instruments were installed were spatialized in geographic information system environment using Quickbird satellite imagery. It was defined areas of influence with 450 m radius from each sampling point, which were vectorized and classified according to urban land use. Analysis of Variance indicated a statistically significant difference in temperature and relative humidity between sites under different human activity levels. Later a linear correlation between the temperature and relative humidity with the anthropogenic levels, evidenced that anthropic areas are closely related to local climatic variation. The interference of green areas works inversely, increasing the definition of microclimate throughout the day. The effects of land use on the microclimate are cumulative, i.e, at the end of the day the correlation of the microclimate with land use reached a maximum.

Keywords: microclimate, remote sensing, local climate, Irati.

Análise da influência do uso da terra no clima urbano em cidade de pequeno porte

RESUMO. Este trabalho objetivou quantificar a influência da atividade antrópica na modificação do microclima urbano de uma cidade de pequeno porte. Para tanto, a temperatura e umidade relativa do ar foram monitoradas ao longo de seis dias, utilizando termo-higrômetros de medida direta acondicionados em miniabrigos meteorológicos. Os pontos onde estes instrumentos estavam instalados foram espacializados em ambiente de sistema de informações geográficas com uso de imagens do satélite Quickbird. Foram definidas áreas de influência com 450 m de raio a partir de cada ponto amostral, que foram vetorizadas sobre as imagens e classificadas de acordo com o uso do solo urbano. A análise de variâncias realizada indicou diferença estatisticamente significativa das variáveis temperatura e umidade relativa do ar entre os locais com diferentes níveis de antropização. Procedeu-se ao estudo de correlação linear entre os elementos temperatura e umidade relativa do ar com os níveis de antropização, concluindo-se que áreas mais antropizadas estão altamente relacionadas à variação climática local. As áreas verdes arbóreas atuam de forma inversa, aumentando a definição do microclima ao longo do dia. Os efeitos do uso da terra no microclima são cumulativos, ou seja, no fim do dia a correlação do microclima com o uso da terra atingiu o valor máximo.

Palavras-chave: microclima, sensoriamento remoto, clima local, Irati.

Introduction

The transformation of the landscape by society, with the development of cities and consequent disappearance of native vegetation, has caused sudden climatic changes, such as the urban heat islands, affecting the environment and the quality of life of people. These changes can be identified by the rise in average temperatures of the central zones of an urban area, in comparison to peripheral areas (neighborhood farther from the city center) or peri-urban areas (locations within the urban perimeter, but with occupation and social activities more related to rural environment) or truly rural areas.

Climate changes may arise from the replacement of components of the land surface, from the change in soil roughness and permeability, from the release of greenhouse gases, for example. In this process, the adaptation of the urban environment with the conditions of the local climate is not always considered. The buildings, for example, must comply with the availability of solar energy, because the base temperature is usually associated to the limits of human comfort, and varies from one location to another, especially in tropical countries. All these components are well discussed in works on urban climate (MENDONÇA, 2003; VENDRAMIN et al., 2009).

The land surface, in assessments of dynamics in urban areas, is usually considered as an urban site, treated as a physical basis for building the city, that is, the topographic aspect of the location. This characteristic has a natural roughness, represented by the difference in the altitudes, defining valley bottoms and slope tops, with slope degrees from slight to extremely wavy. In the same way, the natural permeability of the soil is simply intermediated by the vegetation and organic material, which are replaced by the impervious concrete and varied pavements. The natural conditions are gradually altered by the construction and evolution of the city, punctuated by the emerging need of urban structure, resulting in increased release of greenhouse gases and changes in wind direction and speed (LOMBARDO, 1985; MENDONÇA, 1996, 2003; MONTEIRO, 1976, 1990).

According to Gregório and Brandão (2010), climatic variations may occurr due to several materials that compose the urban environments, each with specific characteristics of thermal conductivity, specific heat, density, thermal diffusion rate, and heat capacity. Climatic changes and variability also arise from natural phenomena, such as: volcanic activity; sunspots; alternating cycles in Earth's rotation and translation, and also the capacity of dispersal and accumulation of greenhouse gases. In this way, the combination of natural influences with truly urban activities produces different dynamics for the climate, whether in a local, regional or even global scale.

Currently there are diverse methodologies, providing knowledge and measurement of urbanization factors that influence the climate. A quite used method is interpreting the satellite imagery, obtained from thermal bands. Another option is using high-resolution satellite imagery and field data, measured in repetitive series. The method selection depends on the goal of the research and of the researcher, and usually the climatology expert uses the analysis of thermal bands. However, this is not mandatory, once the evaluation of high-resolution imagery considering the attribute 'land use' or 'urban land use' may provide a satisfactory comparative standard for a higher or lower variability of the climate elements.

The terminology used until the 90's to define the different landscape characteristics, rural or urban, was basically called by 'land use', stressing different purpose and occupation (vegetation, fields, urban lots, water bodies, paved areas, crops etc...). This terminology had been used for a long time, until the beginning of this century when some knowledge areas started to question this procedure, since the concept of land is more specific, especially ascribed to its biological or agricultural value. From these questions, the Brazilian Institute of Geography and Statistics (IBGE) considers that the term 'land use', among the numerous existing definitions, can be considered as a series of activities developed by the human society in order to achieve products and benefits, through using 'nature elements: vegetation (natural and cultivated), water, ice, bare rock, sand, and similar surfaces' (IBGE, 2006).

For geography, in studying the land use dynamics, it is possible to use statistical procedures, emphasizing quantitative analyses, in addition to allow performing qualitative evaluations, and can be considered both in spatial and temporal scales. This procedure ranges from local and some hours to global and several centuries. This trend was considered in this study, where the term 'land use' was chosen as the most adequate to the study, but sometimes just for using a similar language, the term 'urban land use' was also used.

The comparison between desk job (sensory imagery) and field survey (land use and data monitoring) is not always simultaneous, especially for the study on urban climate.

Among the researches undertaken without using remote sensors, but with automatic data collection stations, stands out the study of Xavier et al. (2009), where it was used the transect measures method, measuring temperature and air relative humidity in three different environments of the city of Cuiabá (State of Mato Grosso). This procedure, carried out in areas under different levels of urbanization and vegetation density, allowed diagnosing the spatial and temporal evolution of the urban climate in that city.

Lombardo (1985) and Mendonça (1996), in turn, employed NOAA-6 and NOAA-7 satellite imagery, associated with thermal band of LANDSAT. These studies have characterized minutely the urban site and urban land use, aiming at data collection for sampling through small-weather shelters, with tools that evaluated the temperature, air humidity, wind direction and speed. The results were used in doctoral theses and proved the hypothesis of heat islands in cities with different sizes, linked to land use.

From this standpoint, the present study verified the influence of human activity and of some landscapes components on the modification of urban and peri-urban climate of Irati (State of Paraná). To this end, it was used data from mini weather stations (climatic elements) and high-resolution orbital imagery (land use). This method did not aimed to compare the heating levels monitored by different sensors (remote and local), but rather to associate the land use (evaluated on the field, but confirmed by using remote sensing) with the variability of climatic elements, taken at 1.5 m above the ground.

Importantly, the occurrence of heat or cool islands, strictly speaking, was not the main goal of this study, even though incidentally the data allow identifying this phenomenon. The variability of climatic elements, from the central area of the city to the boundary of urban perimeter, herein called peri-urban[1], once it is influenced by both urban and rural activities, pointing out that the vegetation (natural or cultivated) plays important role on microclimate control. Moreover, this study was significant given that Irati, despite of being a small town, it already presents characteristics similar to larger urban centers.

Material and methods

The study area is located in the municipality of Irati, South-Central region of the State of Paraná (Figure 1). The average altitude is 812 meters and the climate, according to Köppen classification, is Cfb, i.e., temperate climate, with frequent frosts during the winter, and maximum mean temperature of 24.2°C; and minimum of 11.0°C, monthly mean rainfall of 194 mm and monthly mean relative air humidity of 79.6% (PREFEITURA MUNICIPAL DE IRATI, 2008). The coldest month is August, but the meteorological conditions tend to present climatic extremes in June and July as well. Temperatures below zero are common, with long-lasting rainfall, and strong gusts of wind, which provide a thermal sensation typical of temperate regions.

The winter season between June and August is the less rainy period, since it usually concentrates 50% of occurrences of months with no rain. After, the autumn (March to May) totaling 31.25% of the less rainy months, with 23.44% of total rainfall. The spring (September to November) comes next with 12.5% of the less rainy months, and 28.97% of total rainfall. At last, comes the summer (December, January and February) with 6.25% of the less rainy months and 29.05% of the rainfall. Associated with thermal dynamics, the coldest and driest month is August. Thus this month features average temperatures around 10ºC, but with absolute temperatures commonly below 0ºC. The relative air humidity decreases, being around 77%, while in the other seasons (especially autumn) this index is usually close to 90%.

Andrade et al. (2010) emphasized that the urban site of Irati is located on concave relief, once the highest altitudes are along the boundaries of the urban perimeter, but some isolated points, with fairly high altitudes, are located within it. The lots with one end on tops and another on valley bottoms have the same type of land use and occupation, according to the logic of urban planning, whenever existing. The slopes are mostly oriented to the West and Northwest, indicating a good availability of solar radiation.

The land, i.e., the physical basis of the Irati town, has limitations to its use and partially explains the fact that less than 50% of its perimeter is completely urbanized, even after 101 years of political emancipation. The physical attributes (direction of the slopes, slope and altimetry) are important in defining how and when the town grows, even not being the only explanation for its evolution. The urban structure is still under process of construction and the difficulties found, mainly those related to the aspects of the urban site, impedes a faster growth.

The population of Irati in 2009 was estimated at about 56,483 inhabitants by the IBGE, the main economic activity is agriculture, followed by timber industry and commerce. The census of 2010 showed that 79.95% of its population lives in the urban area, and only 20.05% in rural area. This demonstrates that despite being an essentially agricultural area, most of the population is in the urban area (IBGE, 2010).

Temperature and relative air humidity data were gathered in mini-weather stations, with thermo-hygrometers, following a standard for construction and appropriate installation for monitoring climatological conditions at the surface (Figure 2).

The thermo-hygrometers used are direct-reading devices with mercury columns, accurate to 3% (more or less), INCOTERM brand. Before installing, the instruments were placed in a closed environment with ‘data loggers’, Perceptec brand, model DHT 1020. Later, systematic measurements were made in all devices for seven days. By the end, it was possible to observe that the thermo-hygrometers provided a very best accuracy, with errors not exceeding 0.5ºC among devices, while the ‘data loggers’ had errors close to 1.0ºC.

[1]"peri-urban areas are transition zones between city and field, with a mix of rural and urban activites in the race of land use. Hence, many authors of studies on peri-urban areas consider them as multifunctional, undergoing major and rapid economic, social and physical changes,..." (VALE; GERARDI, 2006, p. 237).

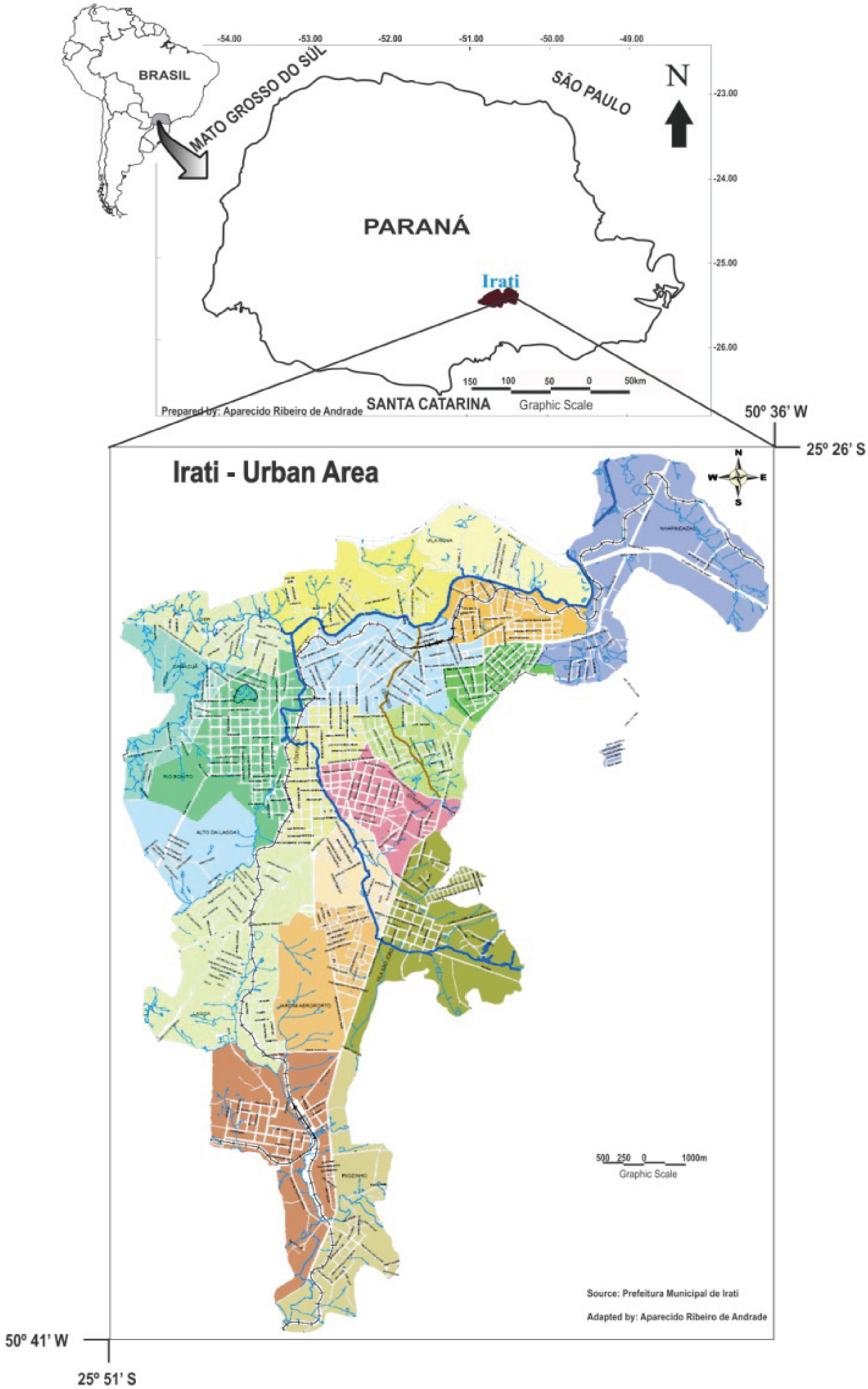

Figure 1. Irati, State of Paraná: geographical location.

Figure 2. Mini weather station.

Besides the procedure above, once it is chosen the direct-reading devices, it was necessary to recruit and train a staff of volunteers to perform the periodical and simultaneous readings. Mendonça (1996) and Andrade et al. (2010) used these procedures and emphasized the need of the staff to be at the researcher's disposal for the work that will be performed in specific dates and times, once the lack of commitment of these volunteers may cast doubt on the data collected and undermine all the work. Thus, the volunteers were selected among undergraduates, master's students, and residents near the areas where the equipments were assembled. All were duly trained through a minicourse lasting 10 hours, covering using and maintenance of the equipments.

The choice of the sites for data collection was based on two main criteria: relief structure (altitude and morphology) and land use and occupation. The relief structure considered allowed the installation of the collection stations on the slope top and on the valley bottom, both in the central area of the town and in peripheral neighborhoods, all with the same direction (South quadrant). This procedure did not aim to find thermohygrometric differences, but rather to homogenize the data for similar land use and occupation (central dense area and peripheral area with less buildings, on the top and on the valley with the same direction), providing a more representative dataset for statistical analyses. Even finding the influence of the altitude, in the present study the land use was the evaluation pattern chosen for the analyses. This technique and discussions inherent to the altitude influence in relation to the land use is discussed in detail by Andrade et al. (2010).

In this way, the selected sites were located in areas that covered different realities, either peripheral areas to the urban center, with dense vegetation, or central areas with greater urban density. The sites were distributed as follow: two sites in the central area of the town; two sites in more peripheral areas, and one site in the rural area, i.e., on the boundary of urban perimeter, so-called peri-urban site. These sites were all georeferenced using GPS (Table 1).

After six monitoring days, encompassing the period from 1st to 6th August, 2008, the obtained data were those listed in Table 2.

To test possible differences in the mean values of temperature and humidity, considering the spatial or temporal differences, we used an analysis of variance for multiple factors. Later it was applied the complementary test of ANOVA of multiple intervals, with confidence levels of 85% (LSD - *Least Significant Difference*) of Fisher, aiming to evaluate which factor had statistically significant difference (FERREIRA, 2009).

Then, we implemented a spatial data model in SPRING 5.1.5 (CÂMARA et al., 1996), with fused multispectral orthoimages of the Quickbird satellite from 2008, with spatial resolution of 61 cm. In this data model, the sampling sites were spatialized on the images and from each site were defined the catchment areas (*buffers*) around the sites, with 450 meters radius, totaling an area about 63.62 ha for each sample (Figure 3). This area was defined as a function of the distance between the sites 3 and 4, and also by covering a good variety of land use in urban and rural area in each sample, and between samples, without being too large, which would hamper the work of detailed vectorizing on the images.

Table 1. Location of the sites for data collection.

	Longitude	Latitude	Altitude (m)	Location
Site 01	-50º38'53"	-25º31'23"	822	Transition area (peri-urban)
Site 02	-50º40'00"	-25º29'50"	847	Peripheral area (high)
Site 03	-50º39'23"	-25º28'30"	771	Peripheral area (low)
Site 04	-50º39'06"	-25º28'15"	813	Central area (high)
Site 05	-50º38'41"	-25º27'41"	763	Central area (low)

Table 2. Data of air temperature and air relative humidity of Irati, State of Paraná.

Date/time	Air temperature (ºC)					Air relative humidity (%)				
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 1	Site 2	Site 3	Site 4	Site 5
1/8/2008 (6:00)	3.0	4.5	8.0	9.0	4.0	83.0	68.0	75.0	70.0	83.0
1/8/2008 (9:00)	11.5	13.0	17.5	17.0	12.0	88.0	77.0	71.0	62.0	84.0
1/8/2008 (15:00)	24.0	26.0	24.0	23.0	24.0	46.0	36.0	43.0	45.0	47.0
1/8/2008 (21:00)	10.5	13.0	16.0	18.0	12.0	87.0	77.0	79.0	80.0	88.0
2/8/2008 (6:00)	9.0	10.5	7.0	7.0	10.0	75.0	87.0	80.0	60.0	87.0
2/8/2008 (9:00)	13.0	17.0	16.5	15.0	11.0	78.0	72.0	75.0	55.0	88.0
2/8/2008 (15:00)	22.0	24.0	26.0	21.0	25.0	58.0	46.0	41.0	50.0	54.0
2/8/2008 (21:00)	14.5	16.0	15.0	17.0	15.0	89.0	79.0	78.0	65.0	89.0
3/8/2008 (6:00)	12.0	13.5	9.0	11.0	8.0	88.0	89.0	74.0	58.0	82.0
3/8/2008 (9:00)	17.0	16.0	20.5	17.0	13.0	90.0	79.0	65.0	65.0	89.0
3/8/2008 (15:00)	16.0	16.5	28.0	20.0	16.0	89.0	79.0	54.0	62.0	79.0
3/8/2008 (21:00)	9.5	11.0	17.5	12.0	12.0	87.0	88.0	71.0	70.0	80.0
4/8/2008 (6:00)	8.5	12.0	14.0	11.0	9.0	87.0	65.0	80.0	75.0	87.0
4/8/2008 (9:00)	15.0	16.0	21.0	21.0	19.0	78.0	59.0	65.0	50.0	56.0
4/8/2008 (15:00)	16.5	16.5	18.0	29.0	28.0	90.0	79.0	80.0	45.0	48.0
4/8/2008 (21:00)	14.5	14.5	16.0	18.0	26.0	89.0	89.0	89.0	72.0	78.0
5/8/2008 (6:00)	15.0	14.0	14.5	14.0	12.0	89.0	89.0	80.0	85.0	89.0
5/8/2008 (9:00)	18.0	18.0	16.5	16.0	15.0	90.0	80.0	80.0	82.0	90.0
5/8/2008 (15:00)	17.0	19.0	18.0	18.0	16.0	80.0	80.0	81.0	84.0	89.0
5/8/2008 (21:00)	12.0	15.0	15.0	15.0	13.0	88.0	78.0	78.0	84.0	87.0
6/8/2008 (6:00)	12.0	12.0	12.0	14.0	12.0	88.0	76.0	76.0	82.0	87.0
6/8/2008 (9:00)	12.0	12.0	18.0	16.0	13.0	88.0	76.0	78.0	85.0	88.0
6/8/2008 (15:00)	14.0	14.0	21.0	18.0	15.0	89.0	78.0	68.0	72.0	78.0
6/8/2008 (21:00)	13.0	13.0	19.0	16.0	14.0	88.0	77.0	74.0	80.0	82.0

Source: Field data, monitored by volunteers in the research.

The sampling sites were spatialized on the images, since the goal of the study was to explain the influence of land use strictly around each sampling site. In relation to the choice of the dimension of each area, the area of 63.62 ha for each site is justified by forming a reasonable surface for the urban area of Irati, not being too small. In this case, the sampling site could be influenced by the eventually different surroundings, nor being too large, to accurately represent the local characteristic of interest.

The areas defined by the *buffers* from each sampling site were then overlapped to the image and classified by the process of interpretation and vectorization on screen. Later, the polygons generated were associated with the corresponding classes, predefined according to the Table 3, which allowed knowing the sampled areas per class of land use.

Table 3. Classification of land use.

Class	Description
Bare soil	Area free of vegetation and urban buildings
Green areas	Fields, pastures, and areas with isolated trees
Arboreal areas	Areas covered by groups of trees
Built-up areas	Areas occupied by buildings and paved
Water bodies	Rivers, Lakes

After applying Multi-Factor Analyses of Variances, we examined the diverse features of the classified areas, representing higher or lower levels of urbanization (Figure 3).

The data obtained were exported to a spreadsheet, where we used the Pearson Correlation Coefficient to measure the correlation between the different land uses (values of area of each class) and the variables Humidity and Temperature, separately (obtained in four times throughout the day, simultaneously). Also, it was individually calculated the correlations between Humidity and Temperature (four times throughout the day) and the variables of land use (made up by the values of area of each class).

Results and discussion

The Table 4 presents the mean values of temperature for the different sites and times, duly added the confidence intervals, enabling a more judicious statistical treatment on the absolute data. These results were extremely important to validate the gathered data.

The results of the Table 4 indicated that the assumptions of the ANOVA were reached: independent and homoscedastic residual variance, and Gaussian, evaluated by using graphic analysis and Kolmogorov-Smirnov test.

The analysis of variance in Table 5 resulted in p-values lower than 5%, evidencing significant difference among the mean values of temperature for the different variables Site and Time, at confidence level of 95%. Interactions between the factors (site and time) had no statistical significance, given the non-significant F-test, i.e., p-value above 5%, thus being withdrawn of the analysis.

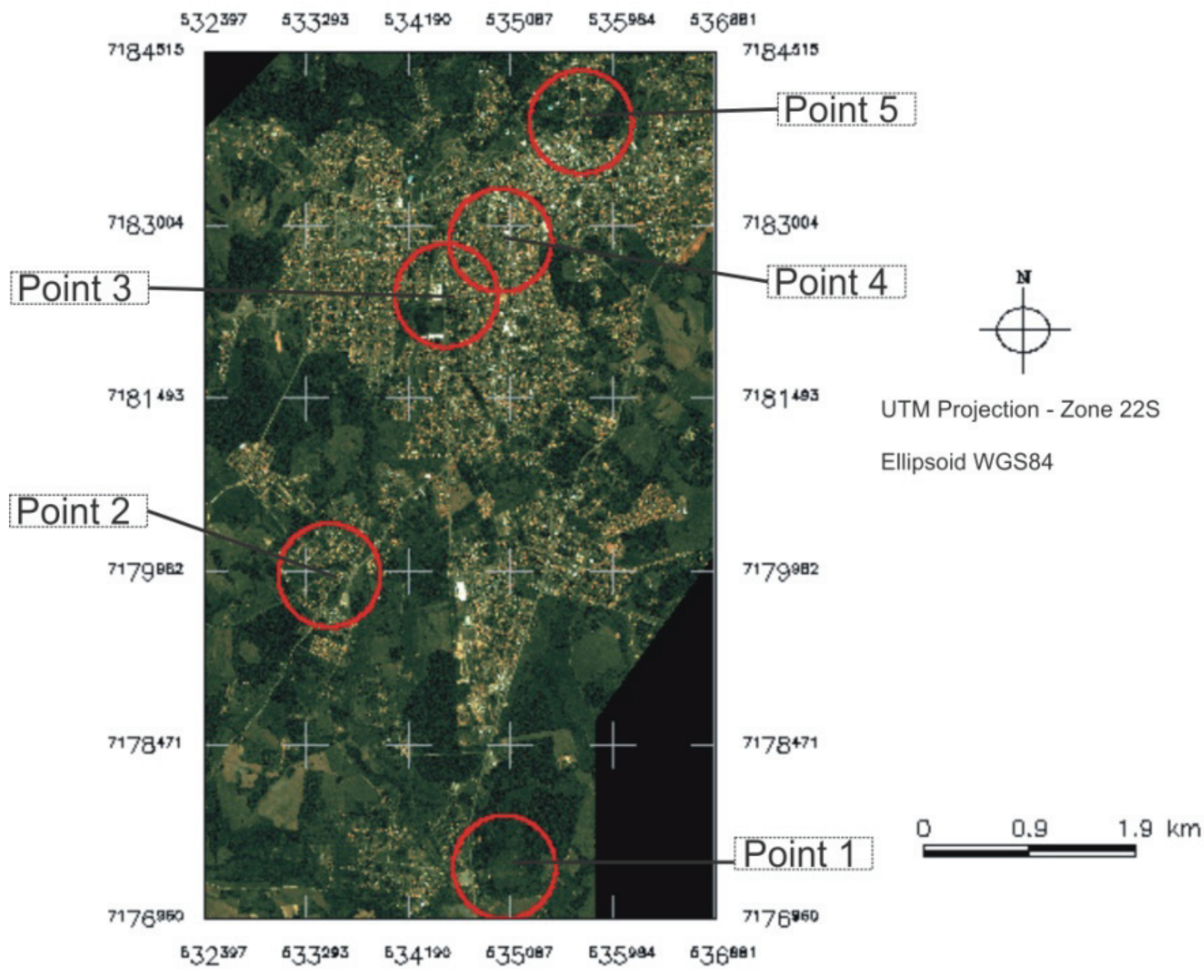

Figure 3. Distribution of the sampled areas on the Quickbird image.

Table 4. Means and Confidence Intervals (95%) for the air temperature.

Level	N	Mean	Standard error	Lower Limit	Upper Limit
Grand mean	120	15.3458			
Site					
1	24	13.7292	0.676609	12.3885	15.0698
2	24	14.8750	0.676609	13.5344	16.2156
3	24	17.0000	0.676609	15.6594	18.3406
4	24	16.3750	0.676609	15.0344	17.7156
5	24	14.7500	0.676609	13.4094	16.0906
Time					
6	30	10.3833	0.605178	9.18425	11.5824
9	30	15.7833	0.605178	14.5842	16.9824
15	30	20.4500	0.605178	19.2509	21.6491
21	30	14.7667	0.605178	13.5676	15.9658

Table 5. Analysis of Variance for the variable Temperature.

Source of variation	Sum of Squares	D.F.	Mean Square	F	p-value
Effects: Site	167.658	4	41.9146	3.81	0.0060
Time	1536.170	3	512.0580	46.60	0.0000
Residual	1230.570	112	10.9872		
TOTAL (corrected)	2934.400	119			

To identify which mean values are significantly different, we used the multiple interval test complement of ANOVA with confidence intervals of 95% LSD of Fisher (Table 6). The Fisher's test was chosen since it is less conservative than Tukey's test, motivated by the origin of temperature data during the winter. Even though, only differences of 2ºC or above were statistically significant.

Four contrasts (or differences) of means between sites had been statistically significant, standing out the first two contrasts: 3.3 and 2.6ºC. The site 3 is present in all these contrasts and, on average its temperatures are the highest during the observation period. In this way, this site had the most significant contrast, evidencing that the low peripheral neighborhood is the most heated and with the highest variability.

The site 3 belongs to the homogeneous group 'c', with a small statistical similarity with the site 4, which may also fit to the group 'b'. These two sites have larger built-up areas and are most influenced by human activities.

The Figure 4 corroborates, through the Fisher's test, the significant incidence of highest temperatures for the site 3.

The Table 7 shows that the contrast is not significant only for the pair of times of 9 and 21 hours. Considering the variability between the sampling times, it was possible to identify the following homogeneous groups: group a) 6:00 hours; group b) 21:00 and 9:00 hours; group c) 15:00 hours. The greatest contrasts occurred between the times of 6:00 and 15:00 hours, 15:00 and 21:00 hours, and 6:00 and 9:00 hours, with 10, 5.7 and 5.4ºC, respectively.

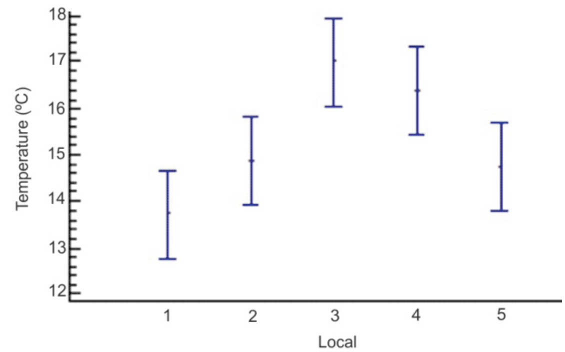

Figure 4. Mean values and 95% Fisher's LSD confidence intervals for the variable Temperature.

Despite the remarkable influence of the land use for the contrasts between the sites (Table 6), for the factor time, this correlation is poorly significant, since the time of minimum temperatures (6 hours) diverges more evidently from the time of maximum temperatures (15 hours). This interaction takes place regardless the sampling site, defining a relatively homogeneous heating pattern for all these sites.

Table 6. Multiple interval test for the variable Temperature and factor site.

Site	Number of observations	Mean (Least Squares)	Standard deviation (Least Squares)	Homogeneous groups	Groups
1	24	13.7292	0.676609	X	a
5	24	14.7500	0.676609	XX	a b
2	24	14.8750	0.676609	XX	a b
4	24	16.3750	0.676609	XX	b c
3	24	17.0000	0.676609	X	c

Contrast	Significance	Difference	+/- Limits
1 - 2		-1.14583	1.89592
1 - 3	*	-3.27083	1.89592
1 - 4	*	-2.64583	1.89592
1 - 5		-1.02083	1.89592
2 - 3	*	-2.125	1.89592
2 - 4		-1.5	1.89592
2 - 5		0.125	1.89592
3 - 4		0.625	1.89592
3 - 5	*	2.25	1.89592
4 - 5		1.625	1.89592

*Statistically significant difference.

Table 7. Multiple interval test for the variable Temperature and factor time.

Time	Number of observations	Mean (Least Squares)	Standard deviation (Least Squares)	Homogeneous groups	Groups
6	30	10.3833	0.605178	X	a
21	30	14.7667	0.605178	X	b
9	30	15.7833	0.605178	X	b
15	30	20.4500	0.605178	X	c

Contrast	Significance	Difference	+/- Limits
6 - 9	*	-5.4	1.69576
6 - 15	*	-10.0667	1.69576
6 - 21	*	-4.38333	1.69576
9 - 15	*	-4.66667	1.69576
9 - 21		1.01667	1.69576
15 - 21	*	5.68333	1.69576

*Statistically significant difference.

The Table 8 lists the correlations between the values of air relative humidity with the factors site and time. A significant difference was detected between the means of humidity for the different levels of the factors site and time, at 95% confidence level. Interactions were not significant and were withdrawn from the model.

Table 8. Analysis of Variance for the variable Humidity.

Source of variation	Sum of Squares	D.F.	Mean Square	F	p-value
Effects: Site	3402.05	4	850.513	7.16	0.0000
Time	4481.09	3	1493.700	12.57	0.0000
Residual	13308.80	112	118.828		
Total (corrected)	21191.90	119			

In the Table 9, the multiple intervals for the variable humidity enabled to identify four groups of sites for which eventual differences of humidity were not significant: a) 3 and 4; b) 3 and 2; c) 2 and 5; d) 5 and 1.

Besides that, six contrasts of mean values between sites have been statistically significant: 1-2, 1-3, 1-4, 2-4, 3-5 and 4-5.

The Table 10 presents the mean values for the variable humidity, for the factors site and time, besides the confidence intervals set by the Fisher LSD method.

The mean values and confidence intervals are represented in the Figure 5.

From the interpretation and vectorization followed by the association to the predetermined classes, we obtained the results in percentage presented in the Figure 6. This figure shows the different compositions of urban land use in the sampled areas.

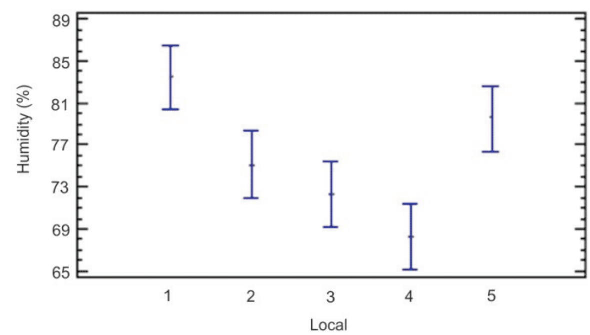

Figure 5. Mean values and 95% Fisher's LSD confidence intervals for the variable Humidity.

After identified which interactions and means were most significant among the climatic elements (Tables 4-10), besides defining the composition of land use in the catchment areas of the five sampling sites (Figure 6), it is clear that the Circle 3 (site 3) is the one with smaller area of bare soil and no water body, even outside the most central area of the town. The greatest contrast of temperature, especially at 15 hours, is explained by the lack or reduction of moderating factors of land use, herein identified as being the soil and water, although the built-up area is also a significant factor, because it is only smaller than the central area of the town.

Table 9. Multiple interval test for the variable Humidity and factor site.

Site	Number of observations	Mean (Least Squares)	Standard deviation (Least Squares)	Homogeneous groups	Groups
4	24	68.25	2.22513	X	A
3	24	72.2917	2.22513	XX	a b
2	24	75.125	2.22513	XX	b c
5	24	79.5417	2.22513	XX	c d
1	24	83.4167	2.22513	X	d

Contrast	Significance	Difference	+/- Limits
1 - 2	*	8.29167	6.235
1 - 3	*	11.125	6.235
1 - 4	*	15.1667	6.235
1 - 5		3.875	6.235
2 - 3		2.83333	6.235
2 - 4	*	6.875	6.235
2 - 5		-4.41667	6.235
3 - 4		4.04167	6.235
3 - 5	*	-7.25	6.235
4 - 5	*	-11.2917	6.235

*Statistically significant difference.

Table 10. Mean values and 95% Confidence Intervals for the variable humidity.

Level		N	Mean	Standard error	Lower Limit	Upper Limit
Grand Mean		120	75.725			
Site	1	24	83.4167	2.22513	79.0079	87.8255
	2	24	75.125	2.22513	70.7162	79.5338
	3	24	72.2917	2.22513	67.8829	76.7005
	4	24	68.25	2.22513	63.8412	72.6588
	5	24	79.5417	2.22513	75.1329	83.9505
Time	6	30	79.8	1.99021	75.8566	83.7434
	9	30	76.1	1.99021	72.1566	80.0434
	15	30	65.6667	1.99021	61.7233	69.61
	21	30	81.3333	1.99021	77.39	85.2767

In turn, the correlations between the climatic elements humidity and temperature with the classes of land use, presented in Table 11 and 12, evidenced that regardless site and sampling time, the anthropized areas had most significant contrasts in relation to the arboreal areas, primarily when considered the Air Relative Humidity.

Between 9:00 and 15:00 hours, the effect of arboreal areas on the humidity is reduced, possibly due to the stomatal closure of arboreal plants, and consequent decrease in evapotranspiration. Larger green areas may be considered influential only at 21:00 hours, as well as arboreal areas at 9:00 hours, presenting significant negative correlations with the temperature.

In the Figure 7 it is possible to confirm visually the composition of the urban land use in the different sampled sites.

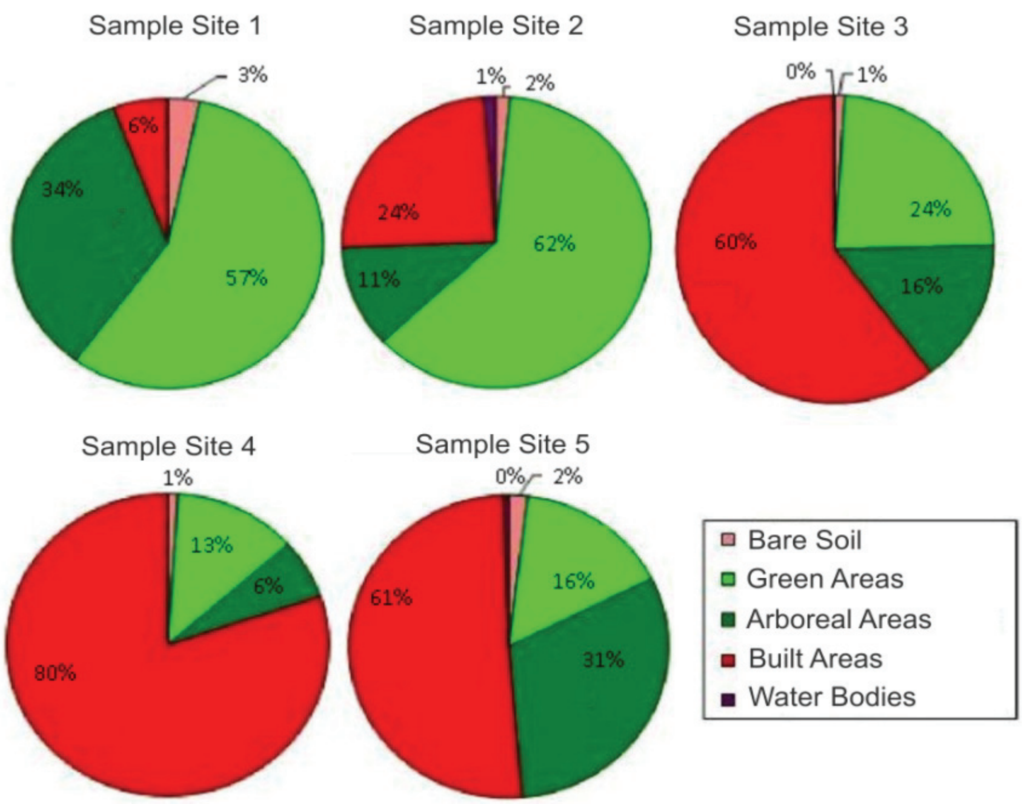

Figure 6. Composition of land use in the different sampled sites.

Table 11. Correlations between the variable humidity and classes of land use.

Time	Anthropized areas	Green areas	Arboreal areas	Water bodies
6:00	-0.412157	0.204906	0.565506	0.035772
	(p = 0.024)	(p = 0.277)	(p = 0.001)	(p = 0.851)
9:00	-0.439093	0.229866	0.584145	0.024713
	(p = 0.015)	(p = 0.222)	(p = 0.001)	(p = 0.897)
15:00	-0.289518	0.224916	0.245620	0.021998
	(p = 0.121)	(p = 0.232)	(p = 0.191)	(p = 0.908)
21:00	-0.581262	0.387989	0.612054	0.091483
	(p = 0.001)	(p = 0.034)	(p = 0.000)	(p = 0.631)

Obs.: p-values < 0.05 indicate statistical significance. P-values in parentheses.

Table 12. Correlations between the variable temperature and classes of land use.

Time	Anthropized areas	Green areas	Arboreal areas	Water bodies
6:00	0.055334	0.042256	0.042256	0.035772
	(p = 0.771)	(p = 0.825)	(p = 0.825)	(p = 0.851)
9:00	0.360559	-0.209310	-0.433627	-0.194638
	(p = 0.050)	(p = 0.267)	(p = 0.017)	(p = 0.303)
15:00	0.305406	-0.278279	-0.177925	-0.106091
	(p = 0.101)	(p = 0.136)	(p = 0.347)	(p = 0.577)
21:00	0.459763	-0.424375	-0.259061	-0.121138
	(p = 0.011)	(p = 0.019)	(p = 0.167)	(p = 0.524)

Obs.: p-values < 0.05 indicate statistical significance. P-values in parentheses.

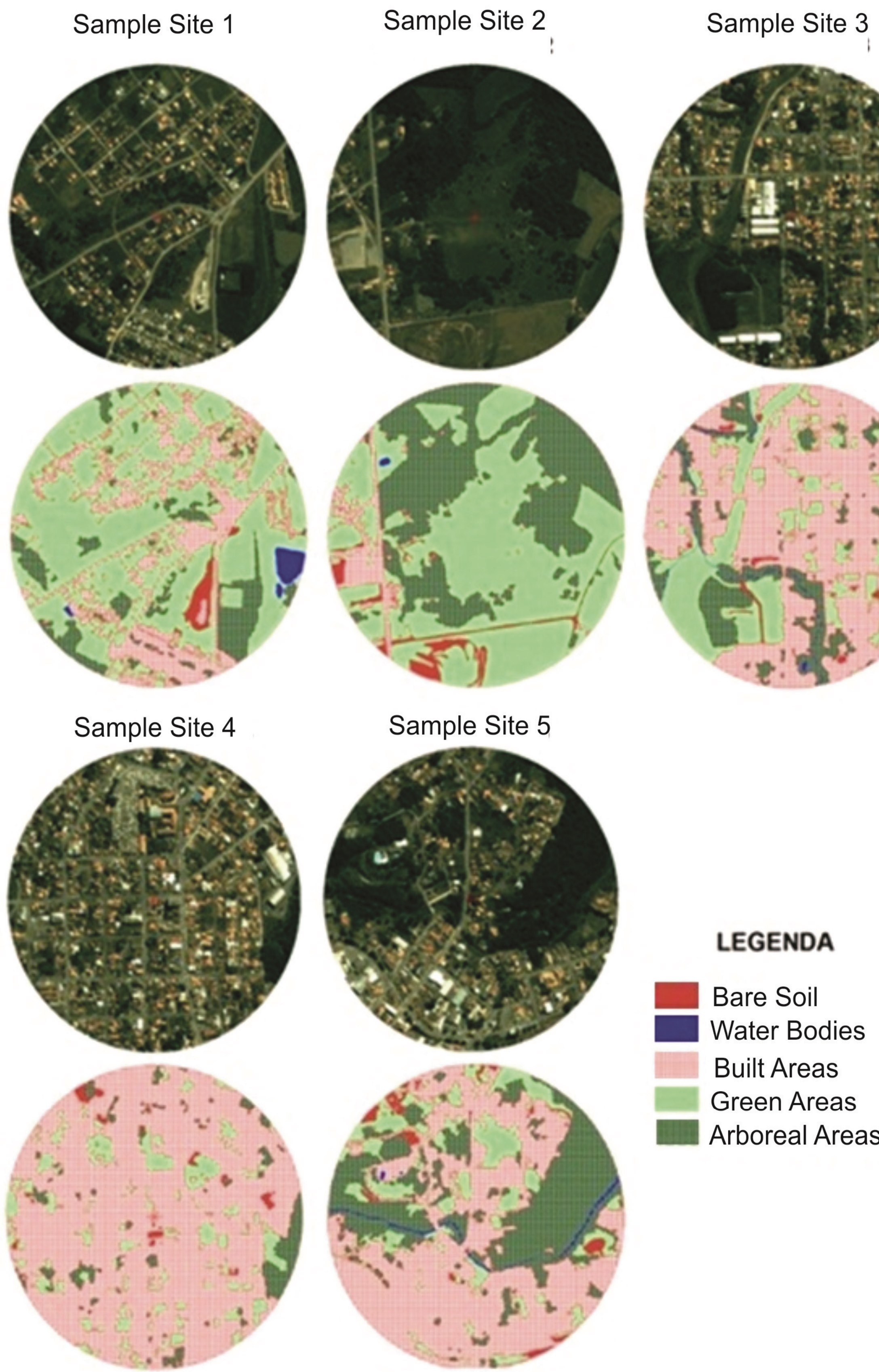

Figure 7. Sampling areas and respective results of visual interpretation.

The correlations between humidity and the variables anthropized areas (built-up area) and arboreal areas were statistically significant (p-value < 0.05), except for the time 15:00 hours. For green areas, the correlations were significant only for the time 21:00 hours, while for the water bodies, no significant correlation was found. The observed correlations were moderate (between 0.4 and 0.7) and with upward trend along the day. For anthropized areas, the correlation was negative, whereas for green areas and arboreal areas, the correlations pointed out positive influence from the humidity levels, that is, attenuate the trend of reducing humidity along the day. The graphic of the Figure 8 shows the moderate positive correlations between humidity and arboreal areas. For 15:00 hours, the correlation between humidity and arboreal areas decreased and had no statistical significance. This is also explained by the plants phenology, where during the hottest time of day, the plants tend to close their stomata and decrease the contribution for increasing air humidity. In relation to green areas and water bodies, the correlation was low and null, respectively, without significance, although the non-tree vegetation maintained or increased its evapotranspiration rate at higher temperatures. Due to the low frequency of water bodies, the correlation was kept low, with small effect on the humidity.

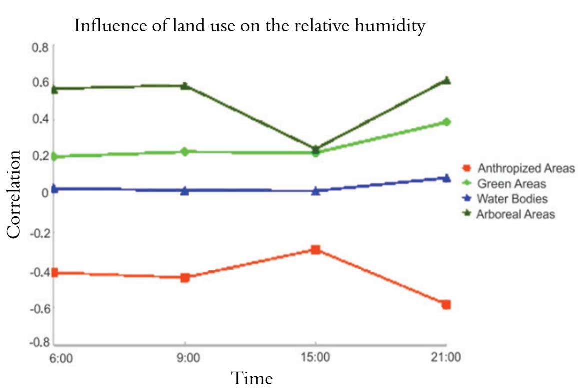

Figure 8. Correlation between the variables land use and air relative humidity on different times.

The Figure 9 illustrates the influence of land use on the temperature.

The Tables 11 and 12, as well as the Figures 8 and 9, evidenced that the effect of anthropized areas on the climate of Irati is moderate, increasing along the day. The green areas and arboreal areas were negatively correlated with temperature. The affirmation that the microclimatic effect increases along the day, can be explained by the direct correlation between the anthropized areas with the temperature, and the inverse correlation with the humidity. The variables of land use had null correlations with temperature, especially at 6:00 hours. In this way, a difference was observed between this variable and the humidity, which presented almost the same pattern of correlation for the different times. By being inversely correlated, the variables temperature and humidity are influenced in opposite ways by the several components of land use.

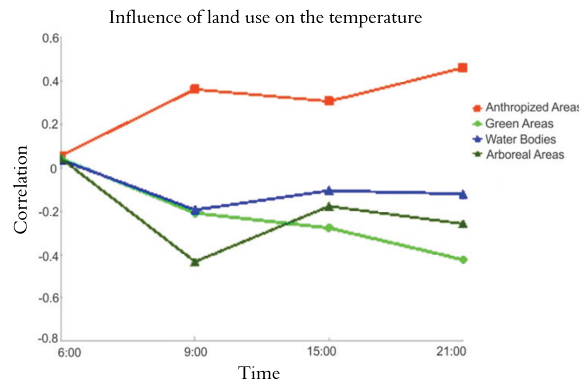

Figure 9. Correlation between the variables land use and temperature on different times.

Conclusion

It was possible to relate the effects of land use on the local microclimate. This conclusion was proved by the significant correlation between the several types of land use, based on the spectral reflectance of satellite imagery, and also on the data of air temperature and relative humidity. The humidity was correlated with the variables of land use, with a similar pattern along the day, also verified for temperature, except at 6:00 hours, which can be considered independent of variables of land use.

In summary, the methodology used proved to be satisfactory, given the identification of catchment areas for the 5 observation sites, arealmente distributed. The combination of in situ monitoring data with remote information, enabled to know the temporal and spatial dynamics of the urban microclimate of Irati. These methods, if used separately, would provide unsatisfactory results.

The town of Irati, despite being considered of small size, has microclimatic characteristics similar to more dense urban centers. This is completely proved by the highly significant correlation between anthropized areas and the highest spatial and temporal variability of the climatic elements.

Another conclusive finding is that in Irati, the lack of bare soil and water bodies in the catchment area of the site 3 (low peripheral neighborhood) was responsible for the greatest climatic contrasts. This result allow affirming that in the other areas, these factors minimize the human intervention (built-up area), especially when associated with a larger vegetal cover.

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