REMOTE SENSING APPLIED TO CLASSIFICATION OF LOCAL CLIMATE ZONES

Camila Amaro de Souza (1); Eliane Guaraldo (2); Antonio Conceição Paranhos Filho (3)

(1) PhD, architect and urbanist, arq.camila.amaro@gmail.com, Federal University of Mato Grosso do Sul, rua da Graciosa – 143 – Campo Grande-MS, 67 991832820.

(2) PhD, architect and urbanist, arq.artes@gmail.com, Federal University of Mato Grosso do Sul, rua da Graciosa – 143 – Campo Grande-MS, 67 992138113.

(3) PhD, geologist, toni.paranhos@gmail.com, Federal University of Mato Grosso do Sul, rua da Graciosa – 143 – Campo Grande-MS, 67 992195546.

ABSTRACT

Monitoring of representative intra-urban thermal features is a difficult task due to the complexity of urban terrain (OKE, 2004). The characteristics of urbanized areas can be quantified using different methods, including the classification system of Local Climate Zones (LCZs), which describes the local-scale physical conditions of a given area. It is applied, with universal and relatively easy standardization, based on geometric, thermal and radiative surface properties. This study aims to characterize the urban and rural areas of the municipality of Campo Grande (Midwest region, Brazil) using an adaptation of the LCZ method. Results from the modeling detected the following six built types: 2 - compact midrise, 3 - compact low-rise, 4 - open high-rise, 6 - open low-rise, 8 - large low-rise, 9 - sparsely built. This method can be used in any urban area if the required input data is available.

Key words: climate mapping, thermal comfort, GIS, Brazil.

1. INTRODUCTION

Rapid global urban sprawl has brought a demand for adaptive action in cities. Studies addressing the impact of climate change due to local district warming, characterized by Urban Heat Islands (UHI), are still challenged with difficulties regarding computational and parametric analyses, as well as statistical calculations involving climate models with city-specific characteristics (EMMANUEL; LOCONSOLE, 2015).

This situation is under constant evolution (STEWART, 2011a; HEBBERT and JANKOVIC, 2013), but there is still much to be achieved in order to alleviate the UHI effect and use the UHI mitigation techniques as part of adapting to local climate change.

Urban expansion in the municipality of Campo Grande, located in the center of the state of Mato Grosso do Sul, Midwest region of Brazil (Figure 3), is included in this scenario of spatial, density, metabolic and, consequently, thermal changes.

The different types of land use and occupation associated with the characteristics of relief, presence or absence of water bodies and afforestation, as well as with other factors, cause changes in environmental quality that materialize in different ways, including urban atmosphere (MASSON et al., 2014; MIDDLE, 2014).

In this context, the Local Climate Zone (LCZ) classification system (STEWART, 2011a; STEWART and OKE, 2012) emerges as a method of ordering urban landscape from classes and subclasses, each with the same number of analyzed physical and radiative properties.

Each zone receives a name and an acronym, and is sorted by properties such as height of roughness elements. It is a way to classify the landscape of intra-urban climate environments by measuring the temperature variation between each local climate zone (ΔT LCZ) (STEWART, 2011a).

The urban landscape classification used herein is a simplification of the variety of situations found in urban environments, consisting of arrangements between different urban elements: buildings, roads, vegetation, soils, rock and water, each in different amounts and distribution. This simplification reduces all these arrangements to 17 recognizable patterns: 10 associated with built types and seven with land cover types. The classification also includes a heavy industry zone and four subclasses for variable land cover properties, such as snow cover or wet ground (Figure 1).

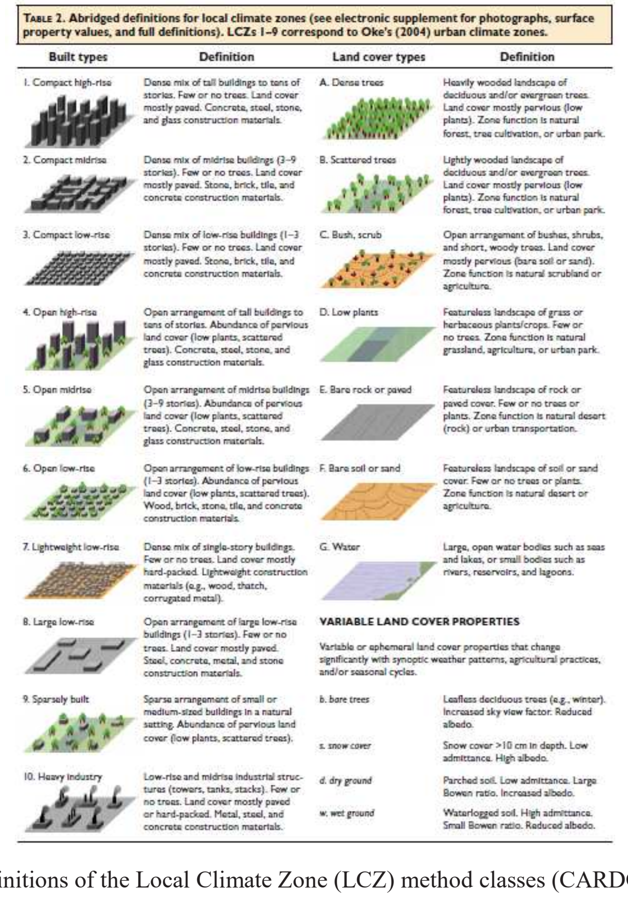

TABLE 2. Abridged definitions for local climate zones (see electronic supplement for photographs, surface property values, and full definitions). LCZs 1–9 correspond to Oke's (2004) urban climate zones.

Built types	Definition	Land cover types	Definition
1. Compact high-rise	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	VARIABLE LAND COVER PROPERTIES Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	*b. bare trees*	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
		s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
10. Heavy industry	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	*d. dry ground*	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Figure 1. Illustrative definitions of the Local Climate Zone (LCZ) method classes (CARDOSO; AMORIM, 2017).

According to its author (STEWART, 2011a), the system scheme is supported by collected and observation data, in addition to numerical relationships, and all classes that emerge from division of the landscape universe are called Local Climate Zones (LCZs), because they are local in the analysis scale, climatic in the nature of the studied properties (physical and radiative), and zonal in the representation of spatial distribution aspects.

The physical (geometric and surface cover) properties of the LCZ method, as numerically described in Table 2.1, are as follows:

1: Ratio of the amount of sky hemisphere visible from ground level to that of an unobstructed hemisphere;

2: Mean height-to-width ratio of street canyons (LCZs 1–7), building spacing (LCZs 8–10), and tree spacing (LCZs A–G);

3: Ratio of building plan area to total plan area (%);

4: Ratio of impervious plan area (paved, rock) to total plan area (%);

5: Ratio of pervious plan area (bare soil, vegetation, water) to total plan area (%)

6: Geometric average of building heights (LCZs 1–10) and tree/plant heights (LCZs A–F) (m);

7: Classification of effective terrain roughness (z0) for city and country landscapes (DAVENPORT et al., 2000). See Table 2.3 for class descriptions.

Table 1 - Values of geometric and surface coverage properties for Local Climate Zones (LCZs). All properties are unitless except height of roughness elements (m). *Adapted from Stewart and Oke (2012)*

Local climate zone (LCZ)	Sky view factor[1]	Aspect ratio[2]	Built surface fraction[3]	Impervious surface fraction[4]	Pervious surface fraction[5]	Height of roughness elements[6]	Terrain roughness class[7]
LCZ 1 - Compact high-rise	.2–0.4	> 2	40–60	40–60	<10	> 25	8
LCZ 2 - Compact midrise	.3–0.6	0.75–2	40–70	30–50	<20	10–25	6-7
LCZ 3 - Compact low-rise	.2–0.6	0.75–1.5	40–70	20–50	<30	3–10	6
LCZ 4 - Open high-rise	.5–0.7	0.75–1.25	20–40	30–40	30–40	> 25	7-8
LCZ 5 - Open midrise	.5–0.8	0.3–0.75	20–40	30–50	20–40	10–25	5-6
LCZ 6 - Open low-rise	.6–0.9	0.3–0.75	20–40	20–50	30-60	3–10	5-6
LCZ 7 - Lightweight low-rise	.2–0.5	1–2	60–90	<20	<30	2–4	4-5
LCZ 8 - Large low-rise	0.7	0.1–0.3	30–50	40–50	<20	3–10	5
LCZ 9 - Sparsely built	0.8	0.1–0.25	10–20	<20	60-80	3–10	5-6
LCZ 10 - Heavy industry	.6–0.9	0.2–0.5	20–30	20–40	40-50	5–15	5-6
LCZ A - Dense trees	0.4	>1	<10	<10	>90	3–30	8
LCZ B - Sparse trees	.5–0.8	0.25–0.75	<10	<10	>90	3–15	5-6
LCZ C - Bush, scrub	.7–0.9	0.25–1.0	<10	<10	>90	<2	4-5
LCZ D - Low plants	0.9	<0.1	<10	<10	>90	<1	3-4
LCZ E - Bare rock or paved	0.9	<0.1	<10	>90	<10	<25	1-2

LCZ F - Bare soil or sand	0.9	<0.1	<10	<10	>90	<25	1-2
LCZ G – Water	0.9	<0.1	<10	<10	>90	-	1

Values of thermal, radiative and metabolic properties for LCZs (Table 2) are as follows:

1: Ability of surface to accept or release heat (J m– 2 s– 1/2 K– 1). It varies with soil wetness and material density;

2: Ratio of the amount of solar radiation reflected by a surface to the amount received by it. It varies with surface color, wetness, and roughness.

3: Mean annual heat flux density (W m– 2) from fuel combustion and human activity (transport, space cooling/heating, industrial processing, human metabolism). It varies significantly with latitude, season, and population density.

Table 2 - Values of thermal, radiative and metabolic properties for Local Climate Zones (LCZs). All values are representative of the local scale. *Adapted from Stewart and Oke (2012).*

Local climate zone (LCZ)	**Surface admittance[1]**	**Surface albedo[2]**	**Anthropogenic heat output[3]**
LCZ 1 - Compact high-rise	1,500–1,800	0.10-0.20	50-300
LCZ 2 - Compact midrise	1,500–2,200	0.10-0.20	<75
LCZ 3 –Compact low-rise	1,200–1,800	0.10-0.20	<75
LCZ 4 - Open high-rise	1,400–1,800	0.12-0.25	<50
LCZ 5 – Open midrise	1,400–2,000	0.12-0.25	<25
LCZ 6 – Open low-rise	1,200–1,800	0.12-0.25	<25
LCZ 7 - Lightweight low-rise	800–1,500	0.15-0.35	<35
LCZ 8 - Large low-rise	1,200–1,800	0.15-0.25	<50
LCZ 9 - Sparsely built	1,000–1,800	0.12-0.25	<10
LCZ 10 – Heavy industry	1,000–2,500	0.12-0.20	> 300
LCZ A - Dense trees	unknown	0.10-0.20	0
LCZ B - Sparse trees	1,000–1,800	0.15-0.25	0
LCZ C – Bush, scrub	700–1,500	0.15-0.30	0
LCZ D – Low plants	1,200–1,600	0.15-0.25	0
LCZ E - Bare rock or paved	1,200–2,500	0.15-0.30	0
LCZ F - Bare soil or sand	600–1,400	0.20-0.35	0
LCZ G – Water	1,500	0.02-0.10	0

Large roughness in urban areas decreases the average regional wind speed, and the wind flow is directed to the lower pressure zone (OKE, 1987). Thus, surface roughness1 is an important concept in descriptive and predictive studies addressing wind behavior on a given surface.

Grimmond and Oke (1999) determined roughness in different types of cities. One of their references was the Davenport's methodology (1960; 1967). Stewart and Oke (2012) used Davenport et al. (2000) in their correspondence analysis with LCZs, as shown in Table 3.

[1] "Roughness length is the physical property that describes the action of the Earth's surface in reducing momentum and absorbing wind impact (Martins et. al, 2008). Terrain roughness controls the shear stress value ($\tau 0$) and, therefore, the friction speed ($u*$). The rougher the surface, the greater the shear stress near it and the greater the flow in the atmospheric boundary layer (ABL)" (REIS, 2016, p.17).

Table 3 - Davenport classification of effective terrain roughness and its correspondence with LCZs. *Adapted from Stewart and Oke (2012)*

Davenport Class	Roughness length, z_0 (m)	Landscape description	LCZ correspondence
1. Sea	0.0002	Open water, snow-covered flat plain, featureless desert, tarmac, and concrete, with a free fetch of several kilometers.	E, F, G
2. Smooth	0.005	Featureless landscape with no obstacles and little if any vegetation (e.g., marsh, snow-covered or fallow open country).	E, F
3. Open	0.03	Level country with low vegetation and isolated obstacles separated by 50 obstacle heights (e.g., grass, tundra, airport runway).	D
4. Roughly open	0.1	Low crops or plant covers; moderately open country with occasional obstacles (e.g., isolated trees, low buildings) separated by 20 obstacle heights.	7, C, D
5. Rough	0.25	High crops, or crops of varying height; scattered obstacles separated by 8 to 15 obstacle heights, depending on porosity (e.g., buildings, tree belts).	5-10, B, C
6. Very rough	0.5	Intensely cultivated landscape with large farms and forest clumps separated by 8 obstacle heights; bushland, orchards. Urban areas with low buildings interspaced by 3 to 7 building heights; no high trees.	2, 3, 5, 6, 9, 10, B
7. Skimming	1	Landscape covered with large, similar-height obstacles, separated by 1 obstacle height (e.g., mature forests). Dense urban areas without significant building-height variation.	2, 4
8. Chaotic	≥2	Landscape with irregularly distributed large obstacles (e.g., dense urban areas with mix of low and high-rise buildings, large forests with many clearings).	1, 4, A

The first stage of this classification consisted in preparing sample datasheets describing the physical and radiative characteristics of the different intra-urban environments based on an adaptation of Stewart and Oke (2012).

2. OBJECTIVE

This article aims to analyze the different Local Climatic Zones (LCZs) of the municipality of Campo Grande from an adaptation of the Stewart methodology (2011a).

The specific objectives are: systematize the data, adapting them to the situation of the municipality where the study was conducted; identify the LCZs of the municipality of Campo Grande, state of Mato Grosso do Sul, Brazil; prepare new datasheets for each LCZ of the municipality using the same analysis criteria (physical and radiative) for each of them with the intention to provide a tool for urban and environmental management in the Midwest region.

3. METHOD

Rapid global urban sprawl has brought a demand for adaptive action in cities. Studies addressing the impact of climate change due to local district warming, characterized by Urban Heat Islands (UHI), are still challenged with difficulties regarding computational and parametric analyses, as well as statistical calculations involving climate models with city-specific characteristics (EMMANUEL; LOCONSOLE, 2015).

This situation is under constant evolution (STEWART, 2011a; HEBBERT and JANKOVIC, 2013), but there is still much to be achieved to alleviate the UHI effect and use the UHI mitigation techniques as part of adapting to local climate change.

The municipality of Campo Grande, located in the center of the state of Mato Grosso do Sul, Brazil (Figure 2), has an urban area of 155 km² and a population of approximately 874,210 inhabitants (IBGE, 2017), is also inserted in this current context of changes within the scope of channeling of water bodies, increased impervious areas, and imbalance in the energy released from solar radiation.

The study area comprises the urban and rural areas of the municipality. The initial analysis scale is the same as that of the Campo Grande Urban Regions, and can be detailed to the number of neighborhoods overlapping in their boundary maps.

A selection of the Local Climate Zone (LCZ) model criteria that fit the municipality of Campo Grande was made having the Stewart methodology (2011a) as the starting point.

Various image classification methods have previously been applied to identify LCZs: the methodologies proposed by (BECHTEL et al., 2015) using free SAGA-GIS software and the World Urban Database and Access Portal Tools Project (WUDAPT) online support platform, by (BECHTEL et al., 2016) comparing the LCZ classification scheme, and the Global Human Settlement Layer (GHSL LABEL) developed by the Joint Research Center (JRC); the method developed by (GELETIC; LEHNERT, 2016) with algorithms for pixel decisions for each LCZ with nine sequential equations; the classification from pattern analysis with the preparation of attribute table created by (CARDOSO; AMORIM, 2017) using ArcGIS software. Comparison between the aforementioned methods also allowed interpretation of the decision making for each of the adopted procedures.

A map with the distribution of LCZs within the urban perimeter, that is, up to 17 classes (as illustrated in Figure 1) was prepared using the QGIS 3.4.5 - Madero software (QGIS DEVELOPMENT TEAM, 2015) and the SAGA 7.0 software (Automated Geoscientific Analysis System) following the tutorial of the World Urban Database and Access Portal Tools Project (WUDAPT) online support platform and the Stewart's (2011a) theoretical and mathematical background for reading the output data generated by the software.

Finally, standardized datasheets were developed to systematize the data of each LCZ analyzed in the study as illustrated in Figure 2. The datasheets include acronym, name, function (commercial, residential, mixed-use, green area), location, characteristics (morphology, land cover, anthropogenic flux) and illustration of the class, and properties (Tables 1, 2 and 3).

The physical properties previously listed using the GIS methods were analyzed from vector-based and raster databases using, mainly, remote sensing information. These calculations were made for circular areas centered at temperature measurement points (obtained from mobile transects of winter 2018 and summer 2019) with a radius of 250 m. This size was used because a typically upstream search of 200-500 m is required so that the air, at the time of measurement, becomes fully adjusted to the underlying surface and relatively homogeneous (STEWART and OKE, 2012).

Surface admittance and albedo (Table 2, items 1 and 2) were analyzed from surface temperature maps using thermal bands 10 and 11 of LANDSAT-8 satellite images obtained from Earth Explorer of the United States Geological Service (USGS) (http://earthexplorer.usgs.gov/), Google Earth, orbit and period: 225/74, transition date: 26 April 2015, local time: 09:45.

Anthropogenic heat output (Table 2, item 3) was predicted from the analysis of population density of the samples of each LCZ and the number of circulating vehicles (analysis based on the city's zoning, verifying the existing collecting road axis and corridors).

The ratio of the amount of sky hemisphere visible from ground level was measured using a Samsung Galaxy A8 mobile phone camera with a fisheye lens pointing upwards at ground level under clear sky conditions, and further treated using the RayMan PRO 2.3 Beta software according to Matzarakis et al. (2007; 2010).

The ratio of building plan area to total plan area (%) was measured within a 250 m radius of each selected sample in each LCZ identified in the city. For buildings located on the border of the circle, only the intersection area was considered.

The ratios of impervious plan area (paved, rock) to total plan area (%) and of pervious plan area (bare soil, vegetation, water) to total plan area (%) were analyzed from a map generated using LANDSAT-8 satellite imagery obtained from Earth Explorer of the USGS (http://earthexplorer.usgs.gov/), Google Earth with vegetation cover analysis from the Normalized Difference Vegetation Index (NDVI) for 2015 image as initial observation basis for the study area, orbit and point: 225/74, transition date: 26 April 2015, local time: 09:45.

Effective terrain roughness (z0) for city landscapes was classified according to Davenport et al. (2000) (Table 3). The circles were classified through visual interpretation of aerial photographs, topographic maps, and building database.

4. RESULTS

A minimum of five samples of the Local Climate Zones (LCZs) detected in the urban and rural areas were collected (Figure 2). Sampling was conducted through the preparation of polygons using Google Earth PRO, which were exported in KML format and used for map processing in the SAGA-GIS 7.0 software from the step-by-step of the WUDAPT online platform.

Figure 2. Sampling for landscape classification of the urban and rural areas in the municipality of Campo Grande, state of Mato Grosso do Sul (20 km) using the LCZ method. Spatial resolution: 20 Km. The map was drawn from Google Earth PRO, Maxar Technologies (2018).

The following classes were selected from the modeling: 2 - Compact midrise, 3 - Compact low-rise, 4 - Open high-rise, 6 - Open low-rise, 8 - Large low-rise, 9 - Sparsely built, A - Dense trees, B - Scattered trees, D - Low plants, E - Bare rock or paved, F - Bare soil or sand.

The result shows the urban morphology map of 2019 for the LCZs, according to the methodology previously described, with a spatial resolution of 100 m. Visual comparison with Google Earth images (2018 and 2019) showed good correspondence to the main morphologies, but some uncertainties were verified in the classification.

The main uncertainty was the incorrect classification of areas of a sparse tree or brush vegetation in rural areas, which are classified as Local Climate Zone (LCZ) 9 (LCZ 9) (Sparsely Built). Even with alteration of the training areas, the problem persisted. Ferreira et al. (2016) discussed this error and suggested that the amount of river bank pavement and the high pollution levels could be the cause of misclassification.

A manual correction of these areas was considered; however, given the pixel dimensions (100 m), these areas should be classified either as Scattered Trees (LCZ B) or Low plants (LCZ D), depending on the participation percentage of tree vegetation in the pixel area. This process would have to be carried out visually, which would demand long processing time. In addition, this misclassification would impact mainly the measurement of surface (Tsurf) or air (Tair) temperatures by LCZ class, which was not performed in the entire rural area, but only in a correctly classified sampling.

Approximation of the map for the rural area showed both good correspondence to the main morphological features at the local scale (Figure 3) and some of the main confusions found in all LCZ classes. The surrounding of the area considered as LCZ A (Dense trees) was predominantly classified as LCZ 9 (Sparsely built), but it should have been classified as LCZ B (Scattered trees) or LCZ D (Low plants).

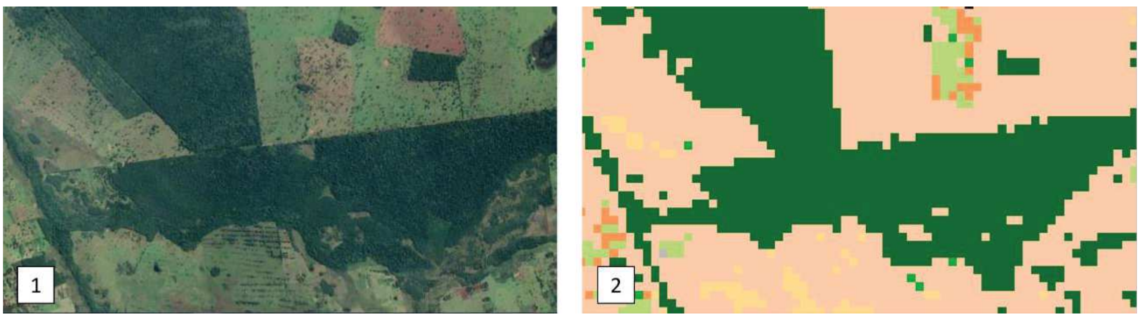

Figure 3. 1) Imagery: Google Earth (2019). 2) Map of LCZ (2019). Rural area. Source: 1) Google (2019). 2) Prepared based on the algorithm of the SAGA-GIS 7.0 software and classified in the QGIS 3.4.5 software.

Figure 4 shows that the surrounding of the area considered as LCZ A (Dense trees) was correctly classified as LCZ B (Scattered trees) and LCZ D (Low plants), with some undue distribution of LCZ 9 (Sparsely built).

Figure 4. 1) Imagery: Google Earth (2019). 2) Map of LCZ (2019). Rural area. Source: 1) Imagery: Google Earth (2019). 2) Prepared based on the algorithm of the SAGA-GIS 7.0 software and classified using the QGIS 3.4.5 software.

Some road axes were classified as LCZ 2 (Compact midrise) and LCZ 8 (Large low-rise). The large number of paved areas in LCZ 8 possibly explains the misclassification of some major avenues (Figure 5).

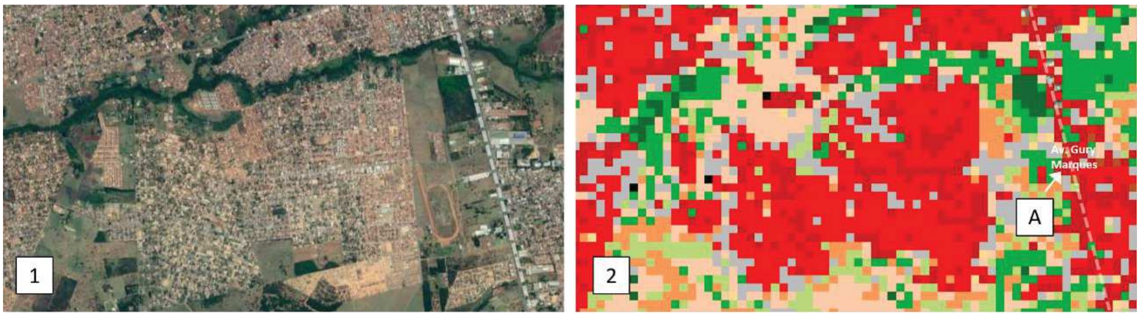

Figure 5. 1) Imagery: Google Earth (2019). 2) Map of LCZ (2019). Av. Gury Marques Axis Source: 1) Imagery: Google Earth (2019). 2) Prepared based on the algorithm of the SAGA-GIS 7.0 software and classified in the QGIS 3.4.5 software.

The LCZs of the municipality of Campo Grande were organized and described according to the Stewart's (2011a) datasheets, which were input with data observed in the city and in the regression models, with illustrations corresponding to the LCZs and aerial photographs.

LCZ 2 - Compact midrise is composed of a dense mix (residential and commercial) of midrise (3-9 stories) buildings with albedo from facade surfaces of stone, concrete and brick, and from roofs of concrete, tile and steel.

Predominant land cover is impervious, with few or no trees. The LCZ 2 is located mainly in the urban center of Campo Grande and distributed along the Afonso Pena and Ernesto Geisel avenues, where anthropogenic flux (calculated from vehicle traffic) is considered high.

LCZ 3 - Compact low-rise is characterized by dense mix of low-rise (1-3 stories) buildings. Surface albedo includes construction materials such as ceramic block, fiber cement, and tile roofs.

Most of the land cover is impervious with tarmac pavement and few trees throughout the zone, which is inserted in the central urban region, in residential neighborhoods with some local commerce, also concentrated in popular neighborhoods in the south (Moreninhas I, II, III and IV), west (Santo Amaro), southwest (Aero Rancho), northeast (Nova Lima, Campo Campo Belo) and east (Marçal de Souza) districts.

LCZ 4 - Open high-rise is represented by in an open geometric arrangement of tall buildings to tens of stories. Buildings are uniform in height, width, and spacing. Sky view from ground level is significantly restricted. There are heavy construction materials and thick roofs and walls, and typically flat slab roofs. There is abundance of pervious land cover (low plants, scattered trees) and moderate-to-low demand for space heating/cooling. Vehicle traffic flow is moderate. Zone function is residential, with apartment blocks and high-rise developments located in some main avenues (Afonso Pena, Ernesto Geisel and Joaquim Murtinho).

LCZ 6 - Open low-rise is represented by open arrangement of low-rise buildings (1-3 stories) in orthogonal distribution, in rows, or randomly dispersed. Sky view from ground level is slightly restricted.

Various light and heavy construction materials (wood, stone, concrete, brick) are used. There is abundance of pervious land cover (low plants, scattered tress) and low demand for space heating/cooling. Vehicle traffic flow is low. Zone function is mainly residential (single - or multi-family) with interspersed local commerce. In the municipality of Campo Grande, this LCZ occurs in the urban areas (outskirts of the city); this climate zone is also common in cities considered rural.

LCZ 8 - Large low-rise shows open arrangement of large low-rise buildings, with scattered warehouses or clusters. The construction materials used are varied (wood, stone, concrete, brick), and the roofs are made of fiber cement and tile. These are regions with consolidated infrastructure, poor pervious land cover, with few or no trees between buildings, and presence of bare soil. Vehicle flow is low to medium. In this LCZ, there is presence of light industry (modern warehouses), commercial establishments (shopping malls, storage facilities), and transportation sites (airport, bus station, train station, truck parking lots). It occurs in the urban areas (outskirts of the city), ring roads, and along urban corridors such as the avenues Ernesto Geisel, Afonso Pena and Duque de Caxias.

In LCZ 9 - Sparsely built, there is predominance of sparse arrangement of small or medium-sized buildings in a natural setting. Sky view from ground level is complete. Construction materials vary widely. There is abundance of pervious land cover, with presence of trees between the buildings and near surroundings with scattered or dense trees and low plants. It is characterized by low traffic flow, and zone function is mainly residential (single- or multi-family), locally commercial, institutional (research/business clusters), and agricultural (farms). It occurs in the north and northeast districts and in some neighborhoods of the city where there are remaining farms (east district and east rural areas).

LCZ A shows a synthesis of dense trees, whose shape consists of heavily wooded landscapes and scattered trees in mostly pervious land cover with low plants. There are few or no buildings or roads with low or no traffic flow. It comprises areas with natural forest remnants and has the function of urban recreation, with some wooded parks. It occurs from small fragments in the intra-urban space to rural areas near the city and wooded valley bottoms.

LCZ B - Scattered trees shows lightly wooded landscape of scattered trees with pervious areas covered by low plants. There is presence of roads and buildings near this LCZ, thus presenting moderate-to-high traffic flow. It consists of areas of natural forest or reforested remnants, and it has the function of urban recreation (parks and green areas). It can be found in intra-urban spaces, but is mostly concentrated in the near rural areas.

LCZ D - Low plants is located in the urban and rural areas. It presents featureless landscape of grass or herbaceous plants/crops, with few or no trees, highways or buildings. Sky view from ground level is complete. Vehicle traffic is low. They are characterized by natural grassland or reforested areas, and zone function is urban recreation (parks, green areas).

LCZ E - Bare rock or paved presents surface albedo of tarmac and bare rock. It shows featureless impervious landscape of rock or paved cover. Its land cover is varied (tarmac, concrete, gravel). There are few or no trees, low plants or buildings. Sky view from ground level is complete. There is little or no vehicle traffic. It presents no demand for space heating/cooling. Zone function is natural desert (rock), geological shield, and urban transportation (vehicle and container parking lots, bus and train terminals, and airport). It occurs both in urban and rural areas.

LCZ F - Bare soil or sand is characterized by bare soil and sand, both defining the surface albedo of this class. Featureless landscape of impervious soil and sand cover is predominant. There are few or no trees, plants, highways or buildings. Sky view from ground level is complete. There is little or no vehicle traffic. There is no demand for space heating/cooling. Zone function is natural desert (heat), agriculture (plowed or fallow fields), and barren land. It occurs both in urban and rural areas.

Despite the existence of the LCZ G - Water in the urban and rural areas of the municipality of Campo Grande, the SAGA-GIS software processor did not identify this LCZ. This class is representative of large water bodies such as lakes and sea bays, and small bodies such as rivers, lagoons and reservoirs. There is little or no terrain roughness. Sky view from ground level is complete. The main function of this zone is natural water systems, recreation, transportation, and industry. This LCZ occurs both in urban (artificial lakes and rivers and streams) and rural areas.

The organization of the LCZs and their respective information in technical datasheets enabled visualization of the elements that distinguish them and knowledge about the factors that most affect the air temperature near the surface represented by each LCZ (built type, construction materials, land cover type, and traffic flow).

5. CONCLUSIONS

Regarding thermal changes and Urban Heat Island(UHI) formation, the simplification of the analysis methods widely adopted since the 1950s can mask the real scenario by using hygrothermal data from weather stations away from the analysis points; in addition, traditional classification methods, such as those that adopt only land use and land cover characteristics, are not considered sufficient to describe the characteristics of intra-urban climate environments, and establish a relationship only between urban and rural areas.

The identification and characterization of the Local Climate Zones (LCZs) in the urban and rural areas allowed a descriptive representation of the situation in the municipality of Campo Grande. The creation of scenarios for each surface analyzed was the basis for the formation of an updated database for research and studies that could be extended to similar cities and to the Midwest region of Brazil.

An UHI has a direct effect on the thermal comfort and health of the population, and the identification of urban morphologies, following the pattern pre-established by Stewart & Oke (2012), as well as of land cover, make these areas eligible for continuous collection of climate data, thus assisting with characterizing the UHI distribution in the municipality of Campo Grande, state of Mato Grosso do Sul, Brazil.

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