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Analysis of Climate Behavior and Land Use in the City of Rio de Janeiro, RJ, Brazil

Henderson da Silva Neiva [1], Michele Souza da Silva [2] and Cristiane Cardoso [1,*]

[1] Geography, Department of Geography, Multidisciplinary Institute, Federal Rural University of Rio de Janeiro (UFRRJ), Moquetá, Nova Iguaçu RJ, Brazil; hendersonsn@hotmail.com
[2] Geography, Department of Geography, Rio de Janeiro State University (UERJ), Maracanã, Rio de Janeiro RJ, Brazil; michleal@hotmail.com
* Correspondence: cristianecardoso1977@yahoo.com.br; Tel.: +55-21-993-374-335

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Abstract: The city of Rio de Janeiro (Brazil) is located in a tropical zone of the planet, in medium latitude that experiences strong insolation throughout the year. The existence of different geographic factors, and different land uses and covers favor the diversity of existing microclimates. This study aims to analyze the different land uses and covers during the last 30 years that impact the varying climatic conditions in the city of Rio de Janeiro, especially for the development of the urban heat and fresh islands. To accomplish this research, images were used from the satellites Landsat-5 and Landsat-7 to capture the apparent surface temperatures, and land use and land cover maps. Comparing these three decades (1986, 1997 and 2016), an increase in the temperatures of urban areas is noticeable toward the last year, 2016. The neighborhoods located in the West and North zones showed the highest temperatures. The areas near the Pedra Branca, Tijuca and Mendanha massifs showed lower temperatures. Therefore, it is possible to recognize a relationship between land cover and temperature behavior; the greenest areas tend to register lower temperatures, and the urban areas demonstrate higher temperatures.

Keywords: urban climatology; land cover and land use; Rio de Janeiro

1. Introduction

The city of Rio de Janeiro, in Brazil, has climatic diversity due to the diversity of existent geographic factors, such as relief, vegetation and proximity to the ocean. Urban density also favors this diversity by expanding the development of several microclimates in the city. Geiger asserts [1] that humans constantly create microclimates through the modification of the geographical space, especially urban areas, altering the natural thermal and water balance in the region.

Temperatures may reach different records in the city of Rio de Janeiro; the neighborhoods located to the leeward of the Pedra Branca and Tijuca massifs experience the influence of the air warming and tend to become the warmest areas in the city [2]. Other areas that are closer to bodies of water, with the presence of vegetation that are located on higher altitudes, reach the lowest temperature values.

This way, the climate of the city of Rio de Janeiro may vary according to the natural localization of each neighborhood, but it is also influenced by anthropic activities on geographical space. This means that the way the space is developed also affects the formation of microclimates. Consequently, the effects of urbanization influence the climate behavior in the neighborhoods of the city; the higher the urban density is in a determined area, the higher the probability is for the development of heat islands in these areas. Amorim [3] affirms that "the heat islands have become another phenomenon detected in urban environments, resulting in the formation of hot air pockets, due to the differentiated capacity of materials on storing and reflecting the received solar energy." The main reasons for this warming are: the impermeability of building materials, not retaining humidity; the presence of dark materials on buildings and pavements that absorb and store the most solar energy; as well as the removal of natural vegetation, the circulation of automobiles and the increase in urban verticalization [4].

The consequences of this urbanization without proper planning, mainly when discussing climate changes, are the thermal discomfort, temperature increase, irregular air circulation, air quality changes, increases in precipitation, highest risks for flooding and landslides, and many other extreme climate events [5].

Since the Urban Climate System (UCS) theory proposed by Carlos Augusto Monteiro, in 1976 in Brazil, and many other renowned studies on urban climate developed abroad during 20th century [6–8], there has been huge support for the development of new research into the climate of Brazilian cities, similar to the studies completed by Tavares [9], Tarifa [10], Paschoal [11], Leite [12], Lombardo [13] and Brandão [2] that are significant references on urban climate nowadays.

This way, when researching urban climate, it is necessary to understand the specific thermal, hygrometric and rainy aspects of a certain place, so that there is an understanding of the real changes influenced by the urbanization process and different land uses and covers, which are essential for creating new ways of mitigating the consequent damages by the heat island phenomenon.

For this reason, this study aims to analyze and identify the land use and land cover changes over the last 30 years (from 1986 until 2016), through Landsat 5 and 8 satellite images, and how these land cover changes involve different temperature conditions in the city of Rio de Janeiro, especially in connection with the formation of urban heat islands.

2. Materials and Methods

2.1. Study Area

The study area of this research is the city of Rio de Janeiro, capital of the State of Rio de Janeiro, which has a population of 6,476,631 inhabitants, with a territory of 1,197,463 km^2. Its territory is organized by Planning Areas (PA) formed by several neighborhoods. These Neighborhoods are ordered by Administrative Regions (AR) denominated as North, South and West Zones, and Central, as illustrated in Figure 1.

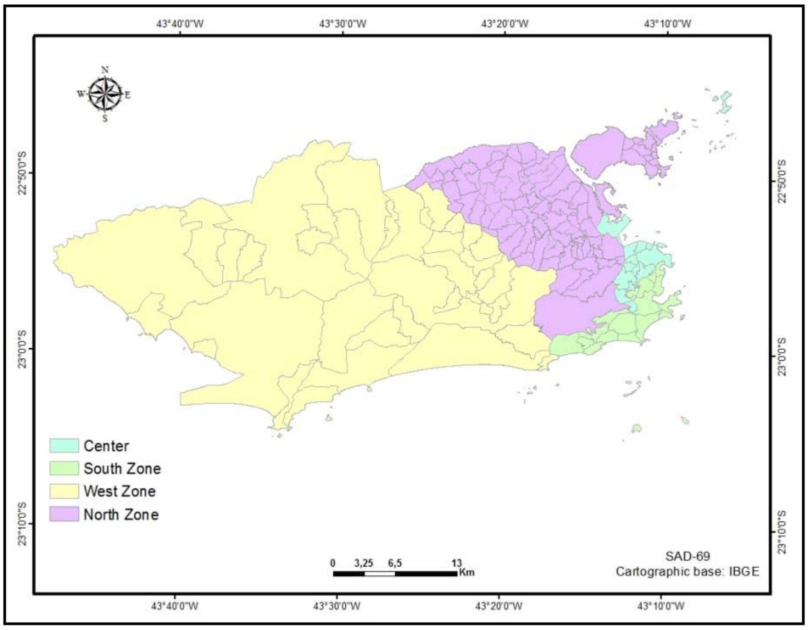

Figure 1. Location map of the areas of the city. Source: Organized by SILVA. Basemap and Shapefile: IBGE [14].

2.2. Thermal Images Processing

In this research, the satellite images are from Landsat-5 that was launched by NASA on March 1, 1984, with TM (Thematic Mapper) and ETM (Enhanced Thematic Mapper) sensors, and with seven spectral bands whose spatial resolution is 30 m each. The band 6, the thermal infrared, has a spectral resolution of 10.4–12.5 µm, and a spatial resolution of 120 m. The other satellite was Landsat-8 that was launched by NASA on February 11, 2016, operating at an altitude of 705 km, with a heliosynchronous circular orbit with a slope of 98.2°. The satellite operates with the Operational Land Imager (OLI) sensor with nine spectral bands whose resolution is 30 m and the Thermal Infrared Sensor (TIRS) owns two infrared spectral bands. The band 10 (10,600–11,190 µm) and band 11 (11,500–12,510 µm) have a spatial resolution of 100 m.

For this study, the band 10 was chosen because, according to the United States Geological Survey (USGS), the usage of band 11 is not recommended due to its anomalies [15].

In order to obtain the results of the apparent surface temperature, it was necessary to go through a few steps until the elaboration of the final product was complete. Firstly, the satellite images of Landsat-5 and Landsat-8 were obtained on the platform of the USGS [15] to the city of Rio de Janeiro, for the period of the summer season. Because of this, three images in the orbit 217 and point 076 were selected for the following dates: January 28, 1986; February 11, 1997 and January 31, 2016.

The steps involved in the image processing until the apparent surface temperature (AST) was obtained, were developed according to the methodology for obtaining the top of the atmospheric temperature [16], as the main objective of this study is to analyze the spatial thermal distribution in the city of Rio de Janeiro. Different than in some studies, such as those developed by Giannini et al. [17], Rajeshwari and Mani [18], and Yu et al. [19], the radiance, emissivity and atmospheric effect corrections were not realized. For obtaining AST, it was necessary to apply formulas in an ArcGis® software raster calculator.

The first step was a conversion of the gray levels to spectral radiance (TOA) for band 6, of Landsat-5, and for band 10, of Landsat-8, and the following radiance conversion to Kelvin temperature. This equation can be observed below.

$$L\lambda = ((\mathrm{Lmax}\ \lambda - \lambda\ \mathrm{Lmin})/(\mathrm{QCALMAX} - \mathrm{QCALMIN})) \times (\mathrm{QCAL} - \mathrm{QCALMIN}) + \lambda \mathrm{Lmin} \quad (1)$$

where:

$L\lambda$ = Espectral radiance ($W/m^2{\cdot}sr{\cdot}\mu m$)
Qcal = Quantized and calibrated gray level pixel value (DN)
Qcal min = Gray level pixel minimum value (DN = 1)
Qcal max = Gray level pixel maximum value (DN = 255)
$L\min\lambda$ = Minimum spectral radiance (3.2 $W/m^2{\cdot}sr{\cdot}\mu m$ = 1.238)
$L\max\lambda$ = Maximum spectral radiance (12.65 $W/m^2{\cdot}sr{\cdot}\mu m$ = 15.303)

Landsat gray level conversion equation—8:

$$L\lambda = M_L \times Q_{CAL} + A_L \quad (2)$$

where:

$L\lambda$ = Espectral radiance ($W/m^2{\cdot}sr{\cdot}\mu m$)
ML = Multiplicative band resizing factor (3.3420 E − 04)
Qcal = Quantized and calibrated gray level pixel value (DN)
AL = Additive band resizing factor (0.1000)

After the conversion to spectral radiance, it was necessary to convert to temperature through the following equation:

$$T = \frac{K2}{Ln\left(\frac{K1}{L} + 1\right)} \tag{3}$$

The last step was the temperature conversion from Kelvin to degrees Celsius (°C) using the following formula: TbKelvin-273.15.

The final layout and elaboration of the apparent surface temperature maps (AST) were made through ArcGis 10.1® software. It was used in the cartographic base, in shapefile format, focusing on the neighborhoods of the city of Rio de Janeiro, so that it could be possible to analyze the surface thermal behavior during the decades of 1980, 1990 and 2010, in the summer seasons.

2.3. Satellite Images Classification Processing and Obtained Weather Data

We developed land use and land cover maps using tQuantum GIS (QGIS) software (Version 2.0.1), through the Semi-Automatic Classification Plugin (SCP), aiming to compare the existing types of land uses and covers in the city Rio de Janeiro and analyze these with the apparent surface temperature maps simultaneously.

For this, the same satellite images used for the development of the AST maps were used for land cover maps, but with different bands. The bands 1, 2, 3, 4, 5 and 7 were used for the years of 1986 and 1997, by Landsat-5 satellite. For the year 2016, obtained by Landsat-8 satellite, the bands 2, 3, 4, 5, 6 and 7 were used.

After this, the first stage was the conversion of the DN radiation to the top atmosphere reflectance (TOA), through the atmospheric DOS1 correction, according to the method proposed by Congedo [20]. With these procedures, the bands start emitting the ideal spectral radiation measured by the sensors, considering the atmospheric influences, for the following stages of classification of the satellite image pixels.

The classes *Urban, Vegetation, Dryland and Irrigated Croplands/Rocks and Water Bodies* were collected as samples and denominated as *regions of interest* (ROI). This procedure aims to exemplify areas in the image for each corresponding class. This way, the software is trained to identify which areas should be classified as a Water Body, Urban, Vegetation or Dryland and Irrigated Croplands/Rocks, thus characterizing the software as a semi-automatic supervised method for satellite image classification.

The last step was the choice of the classification algorithm, which was the *Minimum Distance* that combines the spectral radiation of each pixel of the satellite image with each of the collected pixels' spectral radiation, in the ROI, collected in the previous step. The *Minimum Distance* algorithm was chosen because among the three available options in the plugin, this algorithm was the one with the highest precision in the land cover classification process.

The Kappa index showed accuracy higher than 88% to the three land cover maps with the *Minimum Distance* algorithm; however, the other algorithms, such as *Maximum Likelihood* and *Spectral Angle Mapping* provided accuracies lower than 70% during the classification process. Therefore, *Minimum Distance* obtained the best outcome, which is the reason for using this method.

At the end, there is the combination of what was trained as a spectrum of a specific class with the real pixel spectral emission, resulting in, for the entire satellite image, the land cover maps fitting into the four suggested classifications in the first step.

The weather data were obtained from the National Institute of Meteorology (INMET/GeoRio) [21,22] and then analyzed to create the climatograms and tables with the temperature and rainfall data of the city through the software Excel (2010).

3. Results and Discussion

3.1. The Climate of the City of Rio de Janeiro, RJ

The comprehension of the climate dynamic of the city of Rio de Janeiro (CRJ) must be attentive to multiple factors, and among them, the natural aspects of its geographical space.

The capital of Rio de Janeiro is located between latitudes 22°74′58′′ S and 23°7′34′′ S, and between longitudes 43°10′36′′ W and 43°74′65′′ W. Such coordinates show that the city is in the tropical zone of the planet, in medium latitude, which experiences strong insolation throughout the year. Thus, according to the Köppen climate classification, the climate of the city is considered as *Tropical Aw* [23].

In terms of this classification, the city of Rio de Janeiro is inside the group called the "Rainy tropical climates" and is in the "Savannah climate" subgroup. The first letter—**A**—corresponds to the temperature, the coldest month having an average temperature above 18 °C. The second letter—**w**—corresponds to the distribution of rainfall throughout the seasons, which for this case, is more concentrated during the summer season. This means that there is a higher rainfall period during the warmer months, which are those months between November and March.

These characteristics are evidenced when observing the climatogram in Figure 2. According to this graphic, it is possible to observe that between the months of November and April there are maximum average temperatures (MAT) above 27 °C and minimum average temperatures (MIT) around 23 °C; on the other hand, from May until September, MAT is around 25 °C and MIT is around 18 °C.

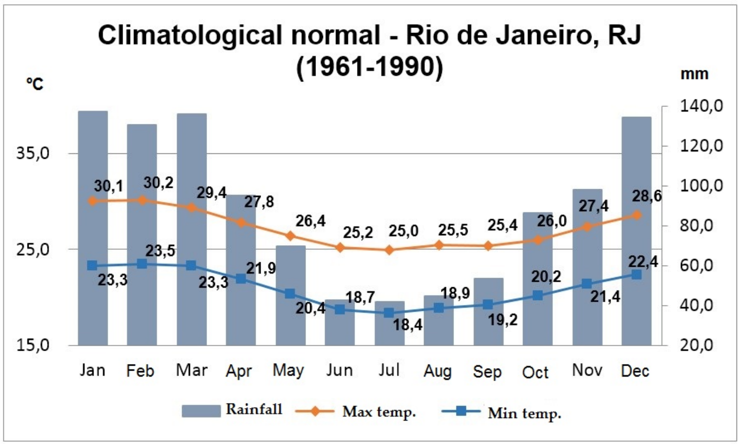

Figure 2. Average maximum and minimum temperatures and total rainfall for the city of Rio de Janeiro. Data source: Instituto Nacional de Meteorologia—INMET [21]. Organized by NEIVA [24].

This illustrates that there is not a large thermal amplitude across the seasons. There is a decrease from May to September, but the biggest amplitude in the climatogram reaches the value of 11.8 °C, when comparing the maximum average of February (summer) with the minimum average temperature in July (winter).

Regarding rainfall, the concentration of rain occurs during the hottest months. For this reason, between November and March there are accumulations of more than 100.00 mm; from April to August, there is a decrease, reaching accumulations of around 41.00 mm monthly.

However, despite these general characteristics of the city, there are some particularities of each neighborhood, which are associated with the formation of microclimates within the dynamic climate of the city.

Several factors will influence the development of microclimates in the city of Rio de Janeiro; they are motivated by natural factors within the city, such as geographical relief, proximity to the ocean, general and secondary atmospheric circulation, among others, as well as anthropogenic factors, resulting in the development of heat islands.

Regarding the geographical relief, the city has three large massifs, which are the Tijuca, Pedra Branca and Marapicú-Gericino-Mendanha massifs, as shown in Figure 3. These orographic formations have an important influence on the microclimatic characteristics in some areas of the city. About this, Serra [25] affirms the following.

The main massifs are Pedra Branca to the west (W), with 1024 m of maximum height. There is also Tijuca to the east €, with 1025 m. The respective slopes delimit the lowlands of Sepetiba, Guanabara and Jacarépaguá. To the north (N) is the Mendanha mountain range. In its extension to the southeast (SE), the Guanabara shoreline constitutes the North and South Zones of the city, separated by the carioca mountain range, Tijuca.

These massifs affect the wind circulation in the city, because the neighborhoods that are without the orographic barrier (to the windward) in relation to the Atlantic Ocean receive the greater fresh air coming from the maritime breeze. Those who are located behind the massifs (to the leeward) receive the air originating from the ocean in a warmer and drier way than those in the windward position. This phenomenon results in a natural variation of air temperature among the neighborhoods [26]. Therefore, the neighborhoods that are located at the beachfront have temperature mitigation in comparison to those located in the North Zone and part of the West Zone of the city.

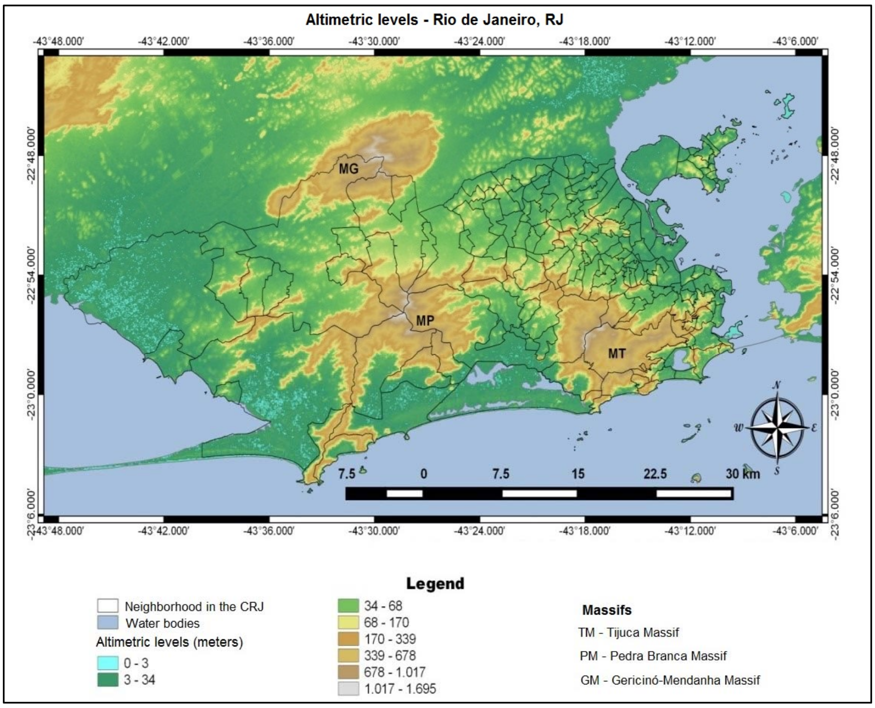

Figure 3. Map of altimetric levels in the city Rio de Janeiro, RJ. Basemap and shapefile: Prefeitura da Cidade do Rio de Janeiro—Instituto Pereira Passos, IBGE and EMBRAPA [27–29]. Organized by NEIVA [24].

Another aspect that is affected by the massifs is the altitude of some neighborhoods, like Alto da Boa Vista; in this case, the influence is on the lower temperatures.

According to Figure 3, it is possible to observe that in the intermediate areas of the massifs there are altimetric levels that reach the interval of 678 m to 1017 m, and in the peaks, reaching the range of 1696 m.

The Alto da Boa Vista neighborhood is situated on the Tijuca massif, in the range of 678–1017 m, which gives this district lower temperature values and higher values of total rainfall. This greater concentration of rain in this neighborhood is associated with the fönh effect, causing the wind dynamics and resulting in windward and leeward phenomena because of the slopes of the massifs and the sea breeze.

This way, when the sea breeze crosses the top area of Tijuca massif, large orographic origin rains occur, which is exactly where the neighborhood Alto da Boa Vista is located.

Besides this air circulation, there is the shading that the massifs provide throughout the daytime period in the South Zone of the CRJ, due to the position of the sun throughout the year. This favors the greater heating in the areas to the north of the massifs (to leeward); on the other hand, the areas to the south of the slopes (to windward) receive a greater amenity in the air temperature, because of the shading during part of the day [26].

Therefore, when taking into account the relief of the city, it is important to take into account the altitude, as well as the position of the slopes [26–30].

Another climatic element that will be highly influenced by the proximity to the ocean is the relative humidity, because the coast on which Rio de Janeiro is located is that of the Atlantic Ocean, and it is a region bathed by warm sea currents, which favors the humid climate. This way, the city obtains a high relative humidity value of air, reaching an annual average of around 80%, precisely because of the proximity to the ocean and due to the tropical latitude [26].

In order to exemplify these characteristics, Tables 1 and 2 represent the comparison for 4 years between four neighborhoods of the city located in different zones, which are the neighborhoods Centro/Praça Mauá, Realengo and Alto da Boa Vista (North Zone) and Santa Cruz (West Zone).

Table 1. Average maximum and minimum temperatures (2010–2013).

Neighborhoods	Maximum Average Temperature	Minimum Average Temperature
Praça Mauá	30.2 °C	21.6 °C
Realengo	30.0 °C	20.7 °C
Santa Cruz	29.7 °C	20.2 °C
Alto da Boa Vista	26.4 °C	18.1 °C

Data source: Portal GeoRio [22]. Organized by NEIVA [24].

Table 2. Average precipitation (2010–2013).

	1st Semester	2nd Semester	Annual Total
Alto da Boa Vista	1354.2 mm	1058.4 mm	2412.6 mm
Santa Cruz	893.9 mm	474.8 mm	1368.7 mm
Praça Mauá	764 mm	450.15 mm	1214.15 mm
Realengo	769.3 mm	395.35 mm	1164.6 mm

Data source: Portal GeoRio [22]. Organized by NEIVA [24].

The thermal behavior is analyzed so that the meteorological station corresponding to Centro neighborhood (central area) presents the highest values of maximum and minimum average temperatures. This is mainly due to the modification of the previous natural geographical space by the constant introduction of low albedo materials, resulting in strong accumulations of solar radiation, along with the great flow of vehicles and people daily in this area of the city, characterized as a business and commercial center. In this way, this neighborhood is considered to be one of the urban heat islands in the city of Rio de Janeiro.

The neighborhood Realengo is situated between the Pedra Branca and Gericinó-Mendanha massifs, and experiences the effects of warmer and drier air due to the föhn phenomenon because of its position to leeward of the slope. The neighborhood of Santa Cruz experiences a softened climate in relation to the first two, due to its space with great air circulation because it is not located between two massifs, favoring the circulation of fresh and humid air. In addition, this neighborhood still has a greater presence of green areas than Centro/Praça Mauá and Realengo.

In relation to Alto da Boa Vista, this presents the lowest values of average maximum and minimum temperatures. This fact is explained by its altitude and its high presence of vegetation that provides great shading throughout the year, thus, a decrease in temperature.

However, when discussing the precipitation, the Alto da Boa Vista neighborhood has the highest annual accumulation, exceeding the average of 2000 mm, while the other neighborhoods have an average of less than 1500 mm per year. The justification for this rainfall behavior is the high orographic origin of the rainfall in this neighborhood.

Regarding this, Serra and Ratisbonna [26] affirm that the cause of the intense precipitation in this neighborhood has a "frankly orographic origin, connected to the secondary disturbances to the south of Tijuca massif," obtaining "an orographic effect to windward, and the föhn effect to leeward of Tijuca massif." This characteristic emphasizes the importance of understanding the climatic dynamics of the city of Rio de Janeiro through its land use and cover, geographical relief, and atmospheric circulation, among other factors.

Both neighborhoods (Praça Mauá and Realengo), identified in Table 1, are the ones with the highest temperature values and the lowest rainfall values.

Another aspect of the analyzed rainfall behavior is that the first semester experiences the largest rainfall values compared to the second semester (Table 2). This is motivated by the fact that there are larger intakes of air masses with high humidity in the city during the months of higher temperatures, which are from November to March [31].

As the first semester presents the highest temperature averages, there is also a lot of rain formation by convective development during this period. Therefore, the second semester ends up experiencing a decrease in precipitation.

For this reason, in order to recognize the climates within the city of Rio de Janeiro, whose climatic mesoscale classification is the *Tropical Aw*, it is necessary to be attentive to the diversity of natural factors and on the anthropic influence that results in microclimatic differences among its neighborhoods. Both affect temperature and rainfall behaviors, as well as the wind circulation and the relative humidity of the air.

3.2. Thermal Field in the City of Rio de Janeiro, RJ

The use of remote sensing through the thermal band allowed for a better observation of temperature spatialization, but it also enabled the use of older images to analyze the thermal field and the land cover changes during the decades.

The thermal band provided the apparent surface temperature, including vegetation, water bodies, urban constructions, dryland and irrigated croplands, and rocks' heat emissions. Voogt and Oke [32] emphasize that thermal remote sensing is a special case for observing the surface temperature that varies according to the energy balance response. The resulting surface temperature incorporates the effects of surface and thermodynamic radiations, including surface humidity and surface emissivity, and radiation input from the sun, and the effects of the surface near the atmosphere. In this way, the use of remote sensing can allow for the analysis of the development of the urban heat islands in urban centers such as the city of Rio de Janeiro.

Stathopoulou et al. [33], through surface temperature maps, have shown that the intensity of the heat islands is not related to the size of the city but to the intensity and type of urban development of the city, observing a strong relationship between the surface temperature and the land cover.

According to the analysis of the surface temperature maps, considering the season of the year where the incidence of solar rays increases, in the summer, different results can be observed in the period of 1986, 1997 and 2016, and the temperature varies among the neighborhoods of the city of Rio de Janeiro.

In Figure 4, to the year of 1986, the AST shows a variation from 10 °C to 35 °C. The neighborhoods located in the West Zone of the city showed records ranging from 30 °C to 35 °C, emphasizing the neighborhoods of Campo Grande, Guaratiba and Bangu as those with the highest temperatures. The areas near the massifs recorded lower temperatures.

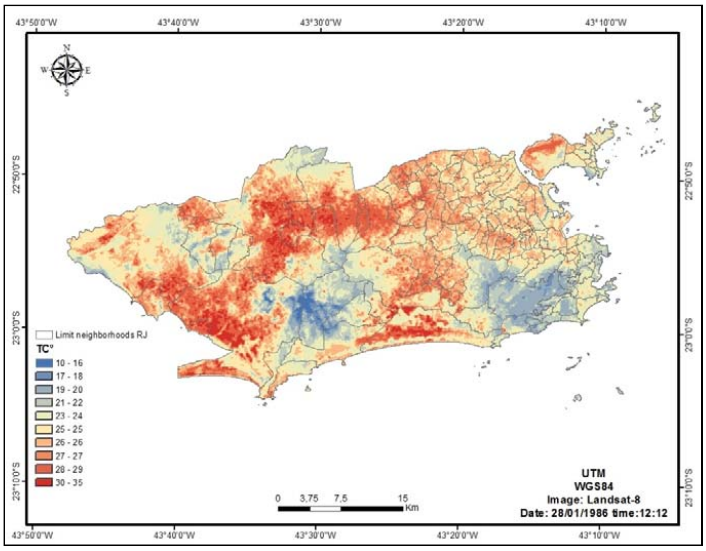

Figure 4. Apparent Surface Temperature Map—1986, city of Rio de Janeiro (CRJ).

In Figure 5, we can verify the land use and cover for this same period. In order to elaborate this map, we used four categories of land use and land cover, which we consider fundamental for comparing temperature data: Urban and Built-up, Vegetation, Dryland and Irrigated Croplands/rocks, and finally, Water Bodies.

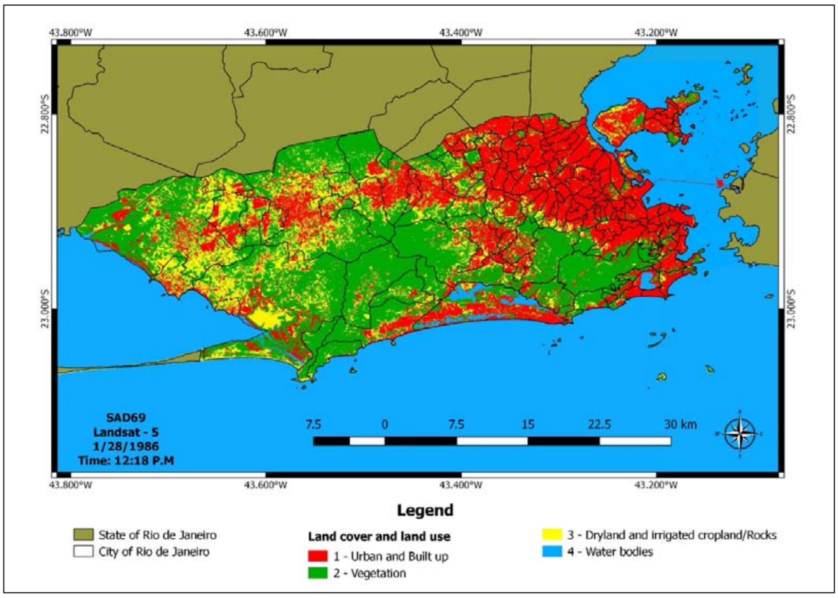

Figure 5. Land cover and land use map—1986, CRJ.

The North and Central Zone of Rio de Janeiro have the highest occupancy rates, with emphasis on urban and built areas; when we compare with Figure 4, we find the highest surface temperature rates in these areas. The West Zone presents a high AST, but there is also a great predominance of land use and cover by Dryland and Irrigated Croplands/Rock areas (the region is surrounded by the

Gericinó-Mendanha and Pedra Branca massifs). In the South Zone, there is the biggest presence of water bodies. Therefore, in Figure 4, we observe an amenity to the AST in this area.

Analyzing the land use and cover of this period (1986), it is possible to verify (Table 3) that 21.45% of the surface is classified as Urban (Urban and Built-up), 32.57% corresponds to the Vegetation class, 12.40% has Dryland and Irrigated Croplands/Rocks and 33.48% corresponds to Water Bodies.

Table 3. Variation of land cover classes over the years.

Land Cover and Land Use Variation—1986, 1997 and 2016			
Years Classes	**1986**	**1997**	**2016**
1—Urban and Built-up	21.45%	27.71%	32.64%
2—Vegetation	32.57%	34.77%	28.85%
3—Dryland and Irrigated Croplands/Rocks	12.40%	3.71%	5.09%
4—Water Bodies	33.48%	33.71%	33.32%

Figure 6 shows a variation in temperature, with a minimum of 16 °C and a maximum of 37 °C. The neighborhoods located in the West Zone showed temperatures between 26 °C and 30 °C, while the ones located in the North Zone obtained temperatures around 37 °C; in the massifs, the temperature becomes lower, between 16 °C and 21 °C.

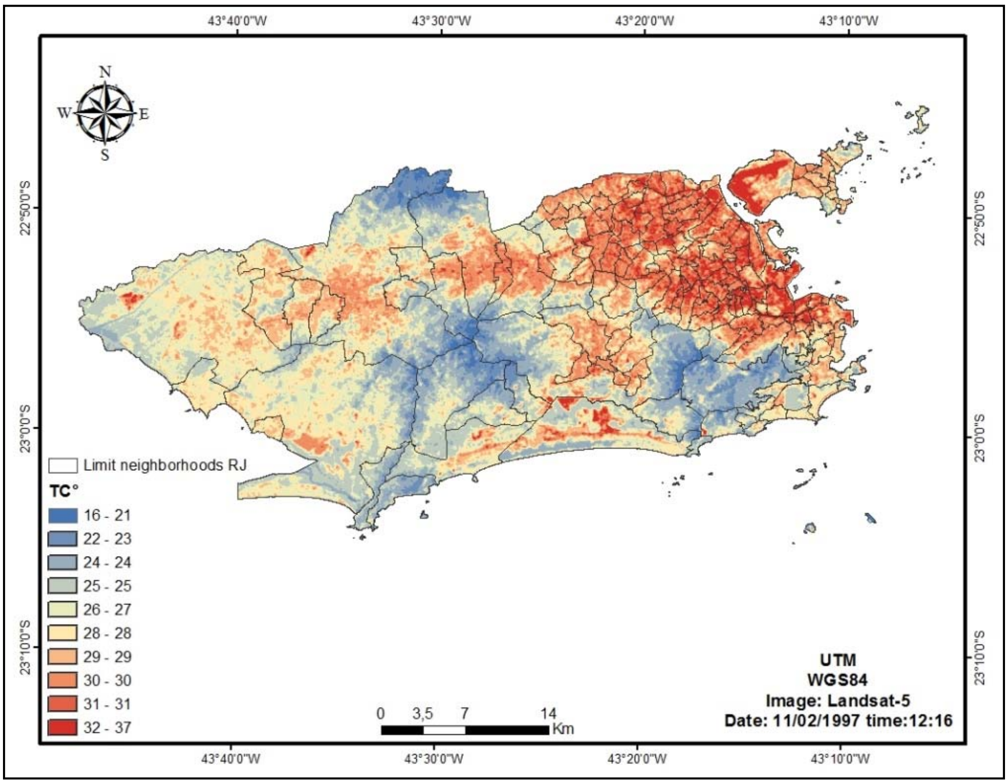

Figure 6. Apparent Surface Temperature—1997, CRJ.

Analyzing the established classes for this study (Table 3 and Figure 7), we noticed an urbanization increase. In 1997 the Urban and Built-up class corresponds to 27.71% of the area. The Vegetation area corresponds to 34.77%. However, Dryland and Irrigated Croplands/Rocks obtain 3.71% and Water Bodies correspond to 33.71% of the area.

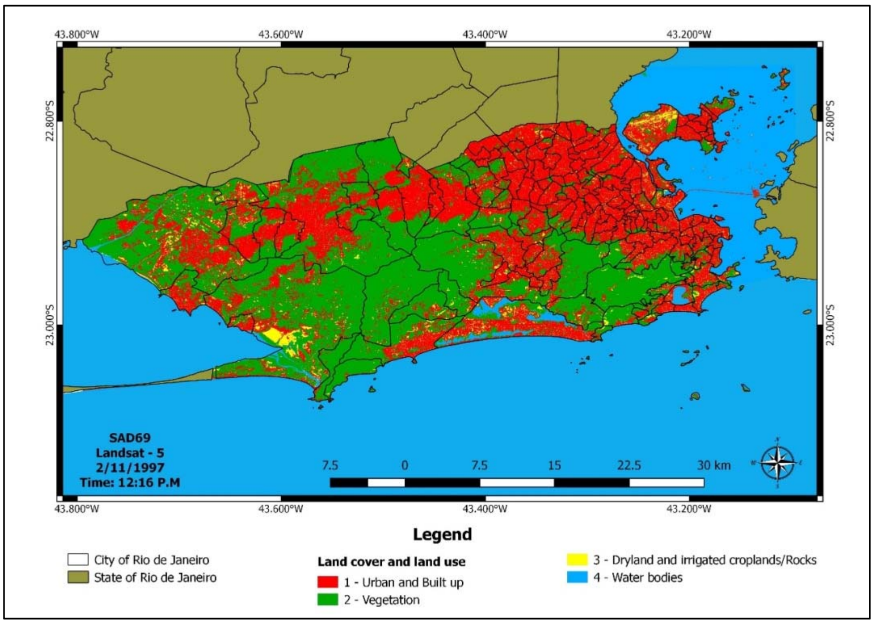

Figure 7. Land cover and land use map—1997, CRJ.

Figure 8, for the year 2016, shows a temperature variation between 12 °C minimum and 44 °C maximum. The neighborhoods located in the West Zone, such as Campo Grande and Bangu, registered temperatures between 36 °C and 44 °C, highlighting the central areas of these neighborhoods where the urbanization is larger. The neighborhoods located in the North Zone also show temperatures between 36 °C and 44 °C.

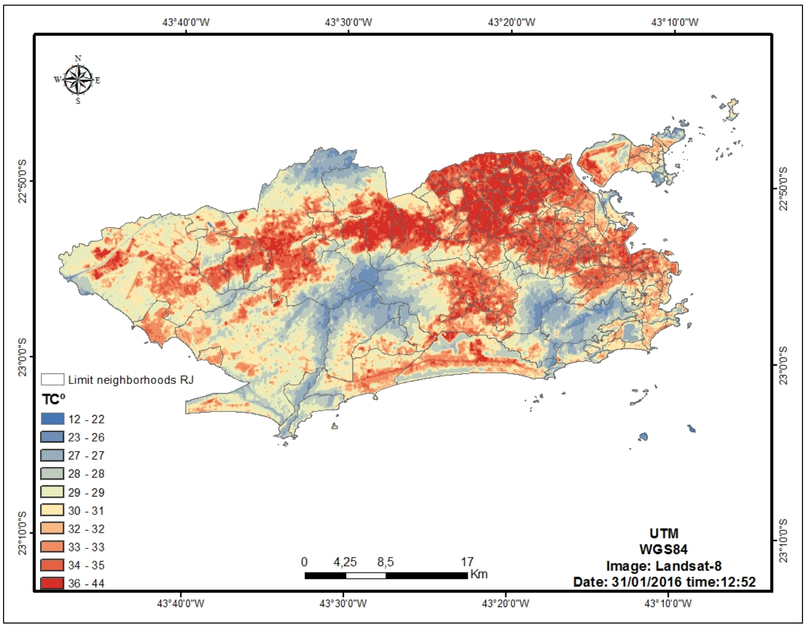

Figure 8. Apparent Surface Temperature—2016, CRJ.

In Figure 9, referring to land use and cover in 2016, we can see that great change occurred in the occupied urban spaces of the city of Rio de Janeiro. It is important to notice the huge growth of the Urban and Built-up areas in the West Zone of the city. The North Zone continued to grow/urbanize.

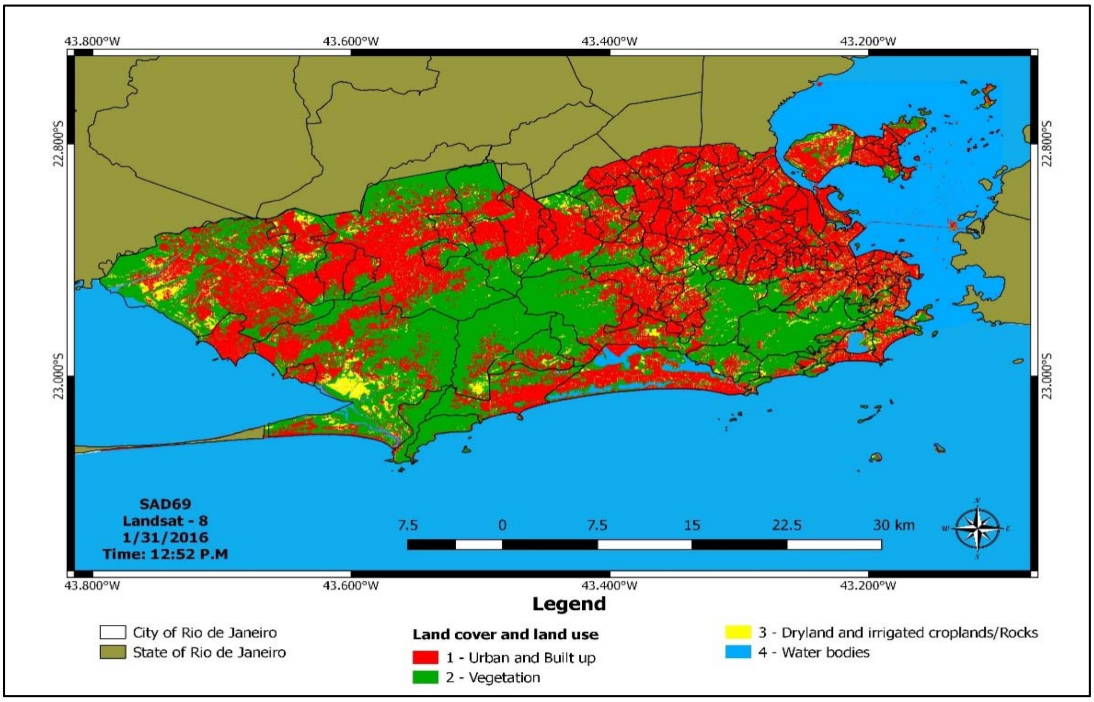

Figure 9. Land use and land cover—2016, CRJ.

Comparing Figures 8 and 9, we observe that the AST in this period remains high in the North Zone and expands to the West Zone. The low AST values remain in the massifs (due to altitude, presence of vegetation and the wind and humidity circulation) and in the South Zone of the city.

Comparing these decades (1986 to 2016) we notice temperature increases towards the last year, in 2016, and the neighborhoods located in the West and North Zones presented the highest temperatures. The areas near the Pedra Branca, Tijuca and Mendanha massifs showed lower temperatures. This way, it is possible to realize the relationship between the temperature increase and the land cover change due to the constant occupation, where the localities with presence of vegetation tend to register lower temperatures; those with a predominance of urban occupancies favor the increase in temperature.

In terms of land use, we have noticed a significant increase in the Urban and Built-up classification. In 1986, there was a total of 21.45%, and in 2016, there is 32.64% for this class, in the city of Rio de Jeneiro. Observing the map, it is noticeable that this growth directly influenced the results of apparent surface temperatures (AST). The areas with the highest growth were the North and West Zone.

Accompanying this pattern, there was a very large deforestation, probably to be substituted by new areas of residence, commerce and service provision. In 1986, the city of Rio de Janeiro had 32.57% of the area with vegetation, but in 2016 it presented a decrease to 28.85%. This demonstrates one of the reasons for the AST to have increased in areas and intensity.

There was an expansion of urbanization toward the West Zone and this is clearly visible when comparing the images. The West Zone of Rio de Janeiro has a new urban expansion as we see in these images. During a period of 30 years, we can observe the land use and cover changes, a fact that happened because of the incentive made by the government to occupy these areas and also due to a constant process of expulsion of poor people from the most valued areas of the city.

When comparing the Dryland and Irrigated Croplands/Rocks, we noticed that there was a significant decrease in these areas of the city. In 1986, there was a total area of 12.40% in this condition. However, in 2016, this area was reduced to 5.09%. This data is important because the areas of Dryland and Irrigated Croplands/Rocks were transformed into urban areas.

Heat islands are developed exactly in those areas with the highest concentration of urbanization. The maps already highlighted these higher temperatures, and the ASTs are almost double in the more urbanized areas, such as the West and North Zones, when compared to the areas in high altitudes and with a huge presence of vegetation in the massifs and in the South Zone of the city.

The importance of vegetation is noticeable, as altitude and dynamic air masses from the oceans provide a significant decrease in ASTs and in air temperature. This happens mainly in the South Zone of the city of Rio de Janeiro, which provides a valuation of the real estate in this area because of this climate amenity that results in a better quality of life for the population. Therefore, the South Zone was becoming a residential area for middle and upper classes, while some areas of the North Zone, West Zone and periphery of the central area were allocated to the poorest people.

4. Conclusions

During the development of this study, we realized that human activities modifying the environment may bring serious problems for survival. Nowadays, there are many discussions about floods, global climate changes, landslides caused by intense rainfall and other extreme natural phenomena. These events look to happen sporadically, without a specific apparent cause, as if they were results of good or bad luck of a certain population. However, when the climatic dynamics are understood for a determined place, and how these climate aspects may affect the societies and a geographical space (mainly in urban areas), we realize how the constant transformation made by humans can cause these conditions (urban heat islands, intense and concentrated precipitation, too high or too low relative humidity). In this way, the consequences suffered by the population are felt at many scales.

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