Urban Cemeteries in Southern Brazil: An Analysis of Planimetric Variations, Vegetation Indices and Temperature

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Abstract: Urban cemeteries have the potential to negatively impact the quality of health of populations in their immediate vicinity. Thus, it becomes important to understand the factors influencing the potential to disperse contamination. This study examined the altimetry, Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) in five urban cemeteries in the City of Passo Fundo/RS, in the south of Brazil, and the possible potential for the proliferation of contaminating agents present in these cemetery spaces in relation to a radius of 300 meters (m). The methodologies used Landsat 8 satellite images to sample the altimetry, NDVI and LST, applied to a regression model, to analyze the dispersion factors of the correlation of collected data. The results showed a trend of contamination of the environment by urban cemeteries in Passo Fundo, in the regions with the highest population density and the lowest vegetative cover.

Key words: Contamination potential, remote sensing, urban cemeteries, urban population.

1. Introduction

The word cemetery is derived from the Latin: coemeterium, meaning dormitory. The practice of using cemeteries first arose around 10,000 BCE when collective burials began to be performed [1, 2]. Several terms were related to cemeteries, such as: necropolis, campo-santo and ram [2, 3].

Different funerary practices have arisen throughout history to prepare bodies for entombment, the most prominent being that of the ancient Egyptians, who used sophisticated forms of preservation, such as mummification [4], for the bodies of select, elite citizens. In the first century CE, the lack of spaces in cemeteries made it possible for people to start burying their relatives on their own land.

In this sense, the apparent problem first encountered in the first century of the lack of cemetery space has led to burial practices ranging from cremation to re-usable graves. With the advent of the conservation movement of the past several decades and sustainable design, an importance has been placed on the need to think about places to meet the demands regarding the storage of bodies, after death [5]. This lack of burial space has persisted as human society has grown and evolved [3]. Historically [5], in addition to being areas for the deposition of bodies, cemeteries were areas for visiting and socializing; however, by the 18th and 19th centuries, cemeteries began to be constructed in
Throughout 19th century Brazil, the custom of burying bodies in churches predominated. A gradual increase in population would put an end to this practice as these sacred spaces were no longer able to accommodate all of the bodies. As the practice of embalming is not commonly used in Brazil, the odor of decay eventually influenced the adoption and use of horizontal cemeteries on the outskirts of densely populated urban areas [3].

Consequently, with the increase in population, there was a higher incidence of mortality, which contributed to the lack of cemetery space. Further study of the effluent that results from mass decay in a limited area in the late 20th and early 21st century has caused a rethinking of cemetery design in order to limit contamination of the environment by dangerous elements [1, 3].

Three cemetery models exist in Brazil [3, 5, 6]: (a) the traditional model, consisting of paved paths with the sequence of semi-buried tombs, mausoleums, chapels, and various grave ornaments such as religious imagery and symbols. The monuments are lined with marble or granite with concrete burial slabs on which bodies are placed. Little to no plant life (trees, grass, shrubs) is present. Most of the land surface in this model is impermeable to water. This model is characterized as museum cemeteries; (b) the park or garden cemetery with bodies located underground and graves covered by lawns, trees and shrubs. The grave is marked only with a plaque above the ground without any adornment; and (c) the vertical cemetery, which consists of a building constructed vertically, above the ground, in which the interment niches have no contact with the ground. The bodies are interred in individual niches through access via stairs, ramps or elevators.

These cemetery models make it possible to identify the various problems related to geographical position, as some are found in populous areas, surrounded by compact and dense residential or commercial structures [1]. Generally, in Brazil, most of the existing cemeteries were not originally built within the urban perimeter, but instead were gradually enveloped by development through the expansion of the city center and resulting urban sprawl [3].

It is important to remember that Passo Fundo, the focal point of this study, is the largest city in the north of the state of Rio Grande do Sul, with an estimated 2021 population of 201,767 [7]. In the urban area of Passo Fundo, there are five cemeteries: Vera Cruz Cemetery, Roselândia Cemetery, Ribeiros Cemetery; Petrópolis Cemetery, and Jardim da Colina Cemetery.

In addition to the negative aesthetics of the urban cemeteries of Passo Fundo, issues related to the entombed bodies must be taken into consideration. Because [1] decomposing bodies undergo biological and chemical changes, cemeteries are characterized as potential source areas for the release of contaminants. Due to the lack of treatment of effluent and gases released by decomposing bodies, the health of those residing within a radius of 500 m of these cemeteries is potentially at risk.

This research is justified by studying the interference of urban cemeteries in Passo Fundo for the understanding of planimetric variations, vegetation indices and temperature. In this context [8], the planimetric elevation of cities is commonly related to patterns of climate. Furthermore [9], the study of urban vegetation indices allows for the understanding of the dynamics of the type of existing microclimate.

The objective of this manuscript is to analyze the behavior of planimetric variations, vegetation indices and temperature of urban cemeteries in Passo Fundo/RS, in the south of Brazil. The authors focus on a circular area surrounding the center of each cemetery with a radius of 300 m. This area has been identified as potentially contaminated by dangerous elements in the air and soil, due to the lack of treatment of liquids and gases released in urban cemeteries, during the decomposition of human bodies after burial [1].
2. Methods and Materials

The City of Passo Fundo was selected for this study due to the evolution of its urban cemeteries, each of which has been enveloped by urban expansion. Methodologically, data were collected in this research to carry out the analysis of soil altimetry, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), statistical and correlation analysis.

Initially, data collection was performed by attributes and values of the raster layers, using the Point Sampling Tool plugin. For this, a layer of points was created, located at specific distances, starting at the central point of each cemetery, with the radii of 100 m, 200 m and 300 m.

For altimetry analysis, raster images from the Shuttle Radar Topography Mission (SRTM) program with 30 m spatial resolution were used, obtained from the USGS Earth Explorer, obtaining the altimetry dimensions. The image is identified as SRTM1S29W053V3 and the date of acquisition was February 11, 2000 [10].

In this sequence, the NDVI Method was applied to correct emissivity. This calculation refers to the importance of the factor to infer the general condition of the vegetation, using satellite images, referring to Band 4 (RED) and Band 5—Near Infrared (NIR) [11], according to Eq. (1).

\[
NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{1}
\]

Proportion of vegetation \((P_v)\) is calculated according to Eq. (2). This method of calculating \(P_v\) utilizes NDVI values for vegetation and soil [11].

\[
Pv = \frac{Square(NDVI - NDVI_{MIN})}{(NDVI_{MAX} - NDVI_{MIN})} \tag{2}
\]

\(P_v\)—proportion of vegetation;
\(NDVI\)—NDVI raster;
\(NDVI_{MIN}\)—minimum value;
\(NDVI_{MAX}\)—maximum value.

For the analysis of the LST, data from the Landsat 8 satellite were used, with band 10 of the TIRS sensor [10]. The analysis of the climactic dynamics of temperature in the urban cemeteries of Passo Fundo utilized the tools of the QGIS software to insert satellite images provided by the United States Geological Survey (USGS) platform [10], in coordination with National Aeronautics and Space Administration (NASA), which operated and distributed data from the Landsat satellites, providing access to the largest terrestrial remote sensing data file.

For the selection of the satellite image, two criteria were required, a low percentage of cloud cover and the location of the image on path 220 and line 80. A survey was carried out with the Explore Earth portal on March 17, 2020. The image went through the reprojection process of the Datum bands of origin WGS 84 UTM 22 n, for the Datum Sirgas 2000 UTM 22 S. After it was converted into a gray level (NC) image for radiance using Eq. (3) [11, 12].

\[
L\lambda = ML \times Qcal + AL \tag{3}
\]

\(L\lambda\)—spectral radiance of the opening sensor in watts;
\(ML\)—the rescaling factor;
\((0.0003342)\) in the Landsat 8 metadata file.
\(Qcal\)—the image of Band 10;
\(AL\)—the band-specific adaptive value of the scaling factor;
\((0.1)\) in the Landsat 8 metadata file.

For the conversion of radiance to reflectance (brightness temperature—BT), the digital numbers (DN) were converted to reflection. The data of the TIRS band could be converted from the spectral radiance form to reflectance temperature. For this, two constant variables were used in relation to the value of \(K1\) and \(K2\) (Eq. (4)) [11, 12].

\[
BT = \frac{k2}{ln((K1/L\lambda) + 1)} - 273.15 \tag{4}
\]

\(K1\)—(774.89) band-specific constant conversion value in the metadata file;
\(k2\)—(1321.08) band-specific constant conversion value in the metadata file;
\(L\lambda\)—result of the first raster calculation (raster name = TOA);
\[ \ln \]—raster calculator operation;
\[ 273.15 \]—value to convert temperature in degrees Kelvin to degrees Celsius.

The calculation of the emissivity of the terrestrial surface must be known to estimate the LST, since the emissivity of the terrestrial surface is a proportionality factor of the brightness of the blackbody (Planck’s law) to predict the emitted brightness, for the efficiency of transmitting thermal energy over the surface in the atmosphere. This determination of soil emissivity is calculated conditionally. \( \varepsilon \) consists of the emissivity of vegetation and soil, respectively, and \( C \) represents the surface roughness (\( C = 0 \) for homogeneous and flat surfaces) taken as a constant value of 0.005 [11], according to Eq. (5).

\[
\varepsilon_\lambda = \varepsilon_v \lambda + \varepsilon_s \lambda (1 - \varepsilon_v) + C \lambda \quad (5)
\]

\( \varepsilon_\lambda \)—calculated emissivity;
\( \varepsilon_v \lambda \)—emissivity of vegetation;
\( \varepsilon_s \lambda \)—emissivity of the soil;
\( C \lambda \)—surface roughness;
\( \varepsilon_v \)—proportion of vegetation.

Error correction is represented by Eq. (6) [11].

\[
p = h \left( \frac{c}{\sigma} \right) \quad (6)
\]

\( \sigma \)—Boltzmann constant \((1.38 \times 10^{-23} \text{ J/K})\).
\( h \)—Plank’s constant \((6.626 \times 10^{-34})\).
\( c \)—the speed of light \((2.998 \times 10^8 \text{ m/s})\).

The LST was calculated with Eq. (7) [11, 13].

\[
LST = BT / \left( 1 + [ (\lambda^*BT/\rho) * \ln * \varepsilon_\lambda ] \right) \quad (7)
\]

\( LST \)—surface temperature of the land area;
\( Ts \)—emissivity correlation (unit degrees C);
\( BT \)—the at-sensor raster (degrees C unit);
\( \lambda \)—(10.985) the wavelength of the emitted radiance;
\( \varepsilon_\lambda \)—calculated emissivity (item 6);
\( \ln \)—raster calculator operation;
\( \rho \)—(1.4388).

The analysis of the mean was performed from the tabulation of the quantitative data acquired in the satellite images, based on altimetry, NDVI and LST, with the aid of the JASP software, version 0.13.01, and using descriptive statistics, generated in a spreadsheet. Thus, Pearson’s correlation analysis was performed, with values for “\( r \)” between 1 and -1. Values close to zero signify null correlation. As for the interpretation, the correlation 0.00 to 0.19 was considered very weak; 0.20 to 0.39 is weak; 0.40 to 0.69 becomes moderate; 0.70 to 0.89 is strong; and 0.90 to 1 is very strong, which demonstrates a greater reliability of the research.

3. Results and Discussions

3.1 Analysis of Altimetry around Cemeteries

The analysis of altimetry in relation to the intra-urban scale shows that the cemeteries of Vera Cruz (a) and Petrópolis (b) are located at higher elevations, and the cemeteries of Ribeiros (c), Jardim da Colina (d) and Roselândia (e) are at lower elevation levels (Fig. 1). In fact, the central points of the Vera Cruz and Petrópolis cemeteries are the highest points in their respective areas, at 691 m. The area surrounding Vera Cruz Cemetery exhibits extreme urban density.

The Jardim da Colina cemetery is located at an elevation of 650 m and the Roselândia cemetery is located at 656 m, for the 100 m radius the difference in height is 2 m, with a 15 m difference in the 300 m radius.

The altimetric profiles of each of the cemeteries have the ability to influence the urban microclimate by impacting wind patterns and temperature [14]. This can influence the movement of microorganisms present in the cemeteries within a radius of 500 m [1, 3], leading to negative effects on the health of the resident population. Thus, Vera Cruz and Petrópolis cemeteries have a greater capacity to spread odors, bacteria and fungi to buildings in the neighboring areas.

3.2 Normalized Difference Vegetation Index (NDVI)

The normalized difference vegetation index (NDVI) is an indicator of the amount of vegetation present in an area (reflection of chlorophyll). The Vera Cruz and
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Fig. 1 Altimetry maps of the urban cemeteries of Passo Fundo/RS: (a) Vera Cruz Cemetery; (b) Petrópolis Cemetery; (c) Ribeiros Cemetery; (d) Jardim da Colina Cemetery; (e) Roselândia Cemetery. Source: use of the USGS database [10].

Petrópolis cemeteries exhibit a lower incidence of NDVI, due to the high level of urbanization around these two cemeteries (Figs. 2a and 2b). In contrast, the Jardim de Colina and Roselândia cemeteries (Figs. 2d and 2e) are located in less dense areas with a greater presence of vegetation, including the presence of native forest.

The presence of vegetation around the cemeteries brings benefits that go beyond improving the appearance of cities, but rather, in terms of influence, from a sanitary and hygienic point of view. The vegetation purifies the environment, oxygenating the soil and the subsoil, aiding in the degradation and alteration of organic matter [15]. Thus, it is possible to verify some interesting issues in the urban cemeteries of Passo Fundo: in these cemeteries the NDVI indices did not yield high values, as it is expected that the cemeteries have higher thermal amplitudes in relation to the surroundings. Vegetative barriers next to houses can intercept and filter air flow and winds that come from the cemeteries to a certain degree. In the vicinity of cemeteries surrounded by dense urban construction, where the NDVI values are closer to zero, such as Vera Cruz and Petrópolis (Figs. 2a and 2b), the air flow and winds instead pass directly onto and into residential structures with neither interception nor filtration.

Additionally, these two cemeteries are located close to the Passo Fundo River.

Fig. 2 NDVI maps of the urban cemeteries of Passo Fundo/RS: (a) Vera Cruz Cemetery; (b) Petrópolis Cemetery; (c) Ribeiros Cemetery; (d) Jardim da Colina Cemetery; (e) Roselândia Cemetery. Source: use of the USGS database [10].
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3.3 Land Surface Temperature—LST of the Areas Directly Adjacent to the Urban Cemeteries of Passo Fundo

On LST maps, reddish tones highlight higher temperatures whereas bluish tones correspond to lower surface temperatures [11]. Fig. 3 presents the varying LSTs of the cemeteries examined (with a radius of 300 m). Overall, the densely concentrated urban areas presented higher surface temperatures, whereas those areas with higher NDVI and areas close to water resources display lower surface temperatures. Also, the presence of monoculture agricultural cultivation areas is observed (Figs. 3c and 3d), which have higher surface temperatures than areas surrounded with native forest (Fig. 3e).

The temperature spikes related to the Vera Cruz, Petrópolis and Ribeiros cemeteries demonstrate that the extent of urbanization is related to the increase in LST. In this context, the Ribeiros, Vera Cruz and Petrópolis cemeteries have LSTs of 28.6 °C, 28.2 °C and 28.5 °C, respectively. This is due to the widely heterogeneous characteristics of reflectance capacity of the construction materials within and surrounding these cemeteries, resulting in different heating capacities in the analyzed terrestrial surface. Certain areas of the Jardim da Colina and Roselândia cemeteries also exhibited areas of high temperature, demonstrating a high localized reflectance capacity. However, the surroundings of these two cemeteries are homogeneous due to the presence of cultivated agricultural areas and portions of native forest, resulting in cooler overall LSTs. This helps to demonstrate the importance of urban vegetation on the maintenance and quality of the urban microclimate [9].

3.4 Correlation Analysis

Fig. 4 represents altimetry, NDVI and the influence on surface temperature (LST). NDVI has a negative relationship, that is, the higher the NDVI index, the lower the surface temperature [11, 13]. The relationship between NDVI and LST shows the concentration of the data and the correlation between the two variables, where the \( r \) index yielded a value of -0.47, which demonstrates a moderate correlation. When analyzing the correlation between altimetry and LST, the data show that the sampling error is greater in this relationship. While there are factors that influence the rise in temperature, an \( r \) index of 0.277 means that it is of weak correlation.

For the analysis, the significance of the \( p \)-value must be less than 0.05. The correlation between NDVI and LST in the cemetery points is strong, with an \( r \) index of 0.874, demonstrating that inside the cemeteries, as the NDVI decreases, the surface temperature also decreases. This is due to the different characteristics...
of the construction materials in the urban cemeteries of Passo Fundo.

4. Conclusions

The altitude of the examined cemeteries showed potential for dispersing viruses, fungi and bacteria via wind from the cemeteries to the surrounding neighborhood areas. This potential air transport presents health risks to the local population surrounding the urban cemeteries of Passo Fundo.

The vegetation index that plays a fundamental role in the urban microclimate influences not only localized winds but also surface temperature. The Vera Cruz and Petrópolis cemeteries, surrounded by dense urban development, have a scarcity of vegetation in several sections analyzed. This absence of vegetation yielded higher overall LST values in the cemeteries located in the areas of greater urban density.

Therefore, the authors suggest active monitoring of these urban cemeteries, as this manuscript demonstrates the dispersion capability of contaminants by urban cemeteries within an analysis radius of 300 m in relation to altimetry, NDVI and LST [1, 3].

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