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RESEARCH ARTICLE

Determination of Heat Islands in the Urban Parish of El Coca through a Temperature and Humidity Geodatabase for the Evaluation of Emerging Zones

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Resumen: Uncontrolled urban sprawl leads to the formation of heat islands, urban areas with significantly higher temperatures than the rural areas that surround them, due to the lack of vegetation, the higher concentration of buildings, and higher relative greenhouse gas (GHG) emissions. These heat islands affect thermal comfort, health, and biodiversity, and they aggravate climate change. This study identified heat islands in the urban parish of El Coca, Ecuador, using a temperature and humidity geodatabase to assess emerging zones. Landsat satellite images and ArcGIS software were used to process and analyze the geospatial data. Indices such as Normalized Difference Vegetation Index (NDVI), vegetation index, emissivity, and brightness temperature were calculated to finally obtain a surface temperature map. The results revealed that areas with less vegetation cover have temperatures exceeding 40ºC in approximately 517.70 hectares of urban land use, where conventional architectural infrastructure and low vegetation cover create heat islands, while other areas adjacent to the city with agricultural and forested land use have temperatures ranging from 25ºC to 39ºC during periods of intense heat. In addition, the impact of solar radiation on human health was analyzed. In conclusion, vegetation is important for urban thermal regulation and urban planning strategies that promote greater vegetation cover to mitigate the negative effects of heat islands and protect the health of inhabitants from excessive sun exposure are necessary.

Palabras claves: Turismo comunitario; Resiliencia; COVID-19; Sostenibilidad; Declaración de Otavalo

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1. Introduction

Ever-expanding cities are devouring natural vegetation at an alarming rate, as revealed by a study by the World Resources Institute conducted by Beard et. al. which concluded that global urban area would triple by 2050, yielding a significant impact on vegetation cover [1]. The loss of urban forests affects the capacity of cities to absorb CO2, mitigate climate change, and regulate the microclimate, which directly or indirectly influences environmental quality and human well-being. In this regard, Montoya mentions that urban trees play a vital role in improving air quality, providing shade, moderating temperature, promoting soil infiltration, reducing energy use, and reducing emissions of volatile organic compounds while at the same time increasing the heritage value of cities [2].

Population growth can be interpreted as an urban phenomenon that can lead to the formation of large civilizations and massive consumption of renewable and non-renewable natural resources to meet the needs and development of the population. However, when the population growth limit is exceeded, various environmental, social, economic, and political issues may arise, especially in the absence of adequate land use planning [3].

According to Ferrelli and coworkers., the growth of cities leads to changes in local thermal, hydrographic, and aerodynamic processes, generating an artificial alteration of the climate known as urban climate. These changes are influenced by land use change (LUC), where the replacement of natural areas by buildings reduces evaporative surfaces, water supply, and air quality by reducing green areas in urban environments [4].

In this regard Kennedy et. al. add that urban atmospheric disruption, caused by pollution and LUC, can have serious short-, medium- and long-term impacts on human health and urban wildlife [5].

Another aspect that particularly impacts urban trees is soil, water, and air pollution, which hinders the development of their roots and foliage. This is due to deficient agricultural practices related to the maintenance of urban vegetation, such as pruning, planting, fertilization, and general management [6].

Fernández indicates that urban centers are the most influential social systems in the transformation of the natural landscape and the increase in temperature, creating spaces known as heat islands (HIC). This artificial modification of the climate generates an ecological footprint that exceeds the limits of resilience. Urban areas are responsible for more than 80% of greenhouse gas (GHG) emissions and consume the most natural resources in order to develop [7].

The Ministerio del Ambiente, Agua y Transición Ecológica del Ecuador (MAATE) has implemented a System of Environmental Indicators aimed at evaluating and describing the state of natural resources, including air, climate, soil, water, and ecosystems, either quantitatively or qualitatively. This system is interconnected with society and contributes to the objectives of Sustainable Development. These environmental indicators are presented as essential tools for planning and control in environmental management, thus facilitating decision-making in Environmental Public Policies for Decentralized Autonomous Governments. In addition, they enable the establishment of indicators for sustainable cities, which in turn allows the creation of ordinances for the control and monitoring of green areas within their scope of action [8].

Emerging cities, with their high population densities and impervious building materials, are especially prone to "heat islands," areas with significantly higher temperatures than surrounding rural areas [9]. According to these islands are formed by a combination of the lack of vegetation, the high concentration of buildings, and the high levels of greenhouse gas (GHG) emissions [2].

In this context, urban heat islands not only affect thermal comfort, but also have serious consequences for health, biodiversity, and climate change. According to Harlan and coworkers heat waves amplified by heat islands increase the incidence of respiratory and cardiovascular diseases, especially in vulnerable groups [10]. Habitat loss and the fragmentation of urban vegetation, as described by Grimm et. al. threaten local biodiversity. In addition, heat islands intensify the greenhouse effect, exacerbating climate change [11].

Arellano & Roca highlight the importance of identifying Urban Heat Islands (UHI) in urban environments, as they describe how the existence of urban structures can influence temperature change in specific geographic areas compared to adjacent areas with greater vegetation cover. This temperature change is due to the materials present in the city, such as asphalt and concrete [12].

Faced with these challenges, the creation of a geodatabase, such as the one developed by Simwanda et. al., [13] makes it possible to record the location and intensity of heat islands. Therefore, the objective of this research was to identify heat islands in the urban parish of El Coca, Ecuador, using a temperature and humidity geodatabase to assess emerging zones. This information becomes an invaluable input for urban planning, the design of revegetation strategies, and the evaluation of their impact

2. Methodology

To pursue this research objective, it was crucial to review the available theoretical studies and explore the accumulated scientific knowledge on heat islands. A total of 14 bibliographic references were consulted, along with databases and technical standards, to complement the case study and develop the proposed application using the methodology presented in Figure 1.

First, the United States Geological Survey (USGS) website was accessed to download satellite images from Landsat sensor bands 4, 5 and 10. Subsequently, Quantum Geographic Information System (QGIS) software was downloaded to process and analyze the geospatial data. Once the images and the software were obtained, the bands 4, 5 and 10 previously downloaded were merged into a single file. Then, the study area, i.e., the parish of Puerto Francisco de Orellana, was extracted from the merged bands file.

Next, the Normalized Difference Vegetation Index (NDVI) was calculated from bands 4 and 5 using the raster calculator. This index was used to determine the proportion of vegetation (Pv) using a specific formula in the raster calculator. With the Pv obtained, the surface emissivity was calculated using another formula in the raster calculator. Subsequently, the brightness temperature (TB) was calculated from band 10 and the previously calculated emissivity.

Additionally, the conversion of the values of radiance at the top of the atmosphere (TOA) to brightness temperature was performed using a formula in the raster calculator. Finally, the color ramp in the surface temperature layer (LST) was changed to green and red for better visualization, thus obtaining the temperature map of the parish of Puerto Francisco de Orellana.

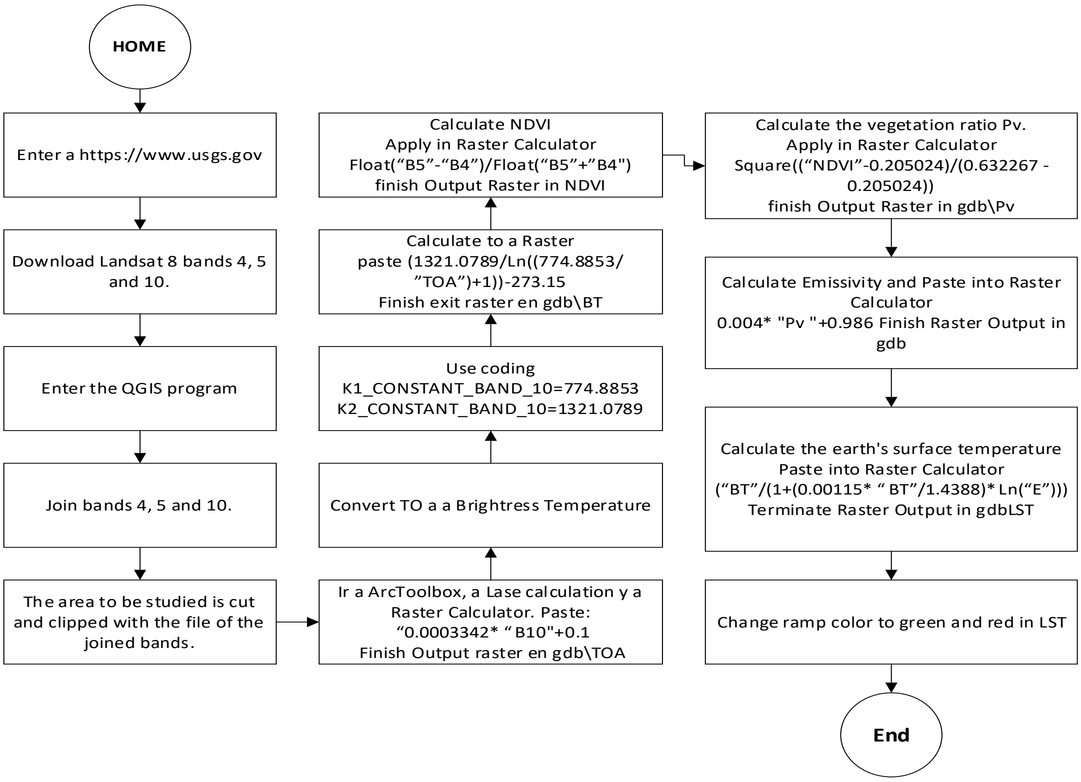

Figure 1. Process diagram for the creation of the temperature map of the parish of Puerto Francisco de Orellana

The software selected for the simulation of the proposal is QGIS, a tool that integrates data to capture, manage, analyze, and represent all geographically referenced information, allowing for researchers to visualize, understand, question, and interpret data so that it is possible to identify patterns, relationships, and trends in the form of maps, globes, reports, and graphs. In short, it is an essential tool for analyzing spatial information and modeling processes in various fields by integrating geographic data from different sources for analysis and visualization.

3. Results

3.1. QGIS Geodatabase

Within QGIS, a Geodatabase was created taking satellite maps of the province of Orellana, focused on the Canton of Puerto Francisco de Orellana, and taking into account the maximum and minimum temperatures present in the city of El Coca, creating heat islands, as shown in Figure 2. Here red color temperatures correspond to 40ºC - 45ºC, orange color to those from 35ºC to 39ºC, mustard color to those from 30ªC to 34ºC and finally green color for temperatures ranging from 18ºC to 24ºC; water bodies and wetlands are represented by the blue color and carry temperature values between 7ºC and 11ºC.

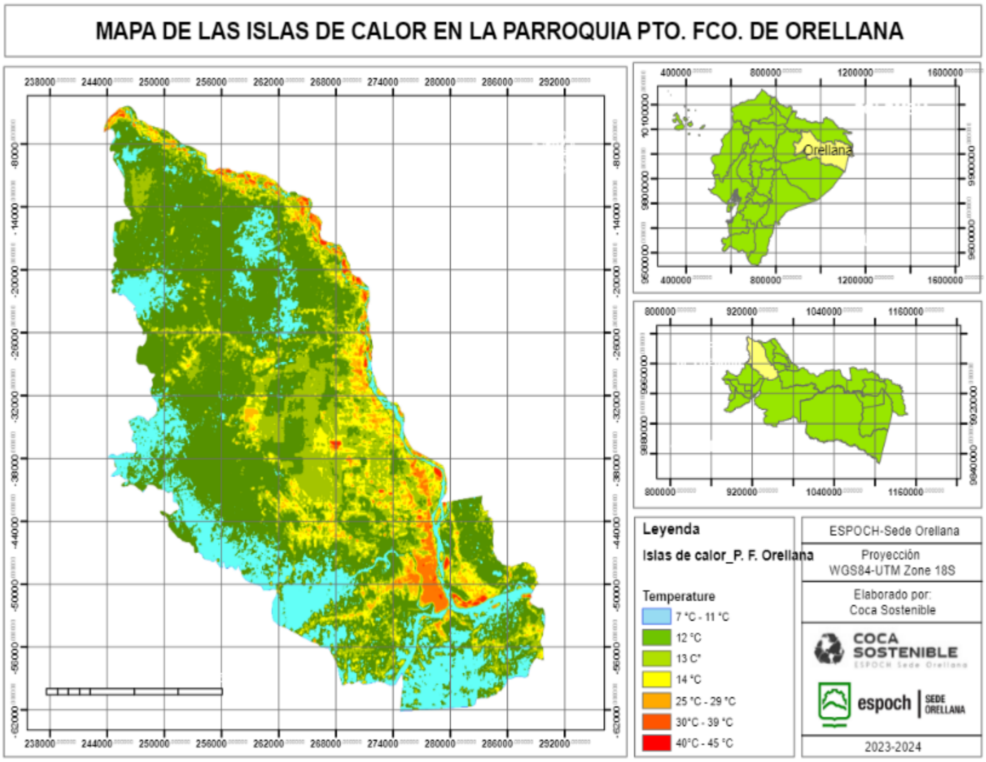

Figure 2. Heat Island Map of the urban parish of El Coca.

According to Figure 3, the areas with the highest temperatures above 40 ˚C are those with the lowest vegetation cover. The zones with temperatures above 40 ˚C (Table 1) within the urban area can be observed in Figure 3.

Table 1. Targets imaged with QGIS and with temperatures in the range of 40 to 45ºC.

'arget	ırea (m^2)
4820	8372,84
4832	·8603,33
5020	4624,81
5014	:6487,44
5182	8959,097
5467	:1654,22
5706	:2989,16
5076	0886,696

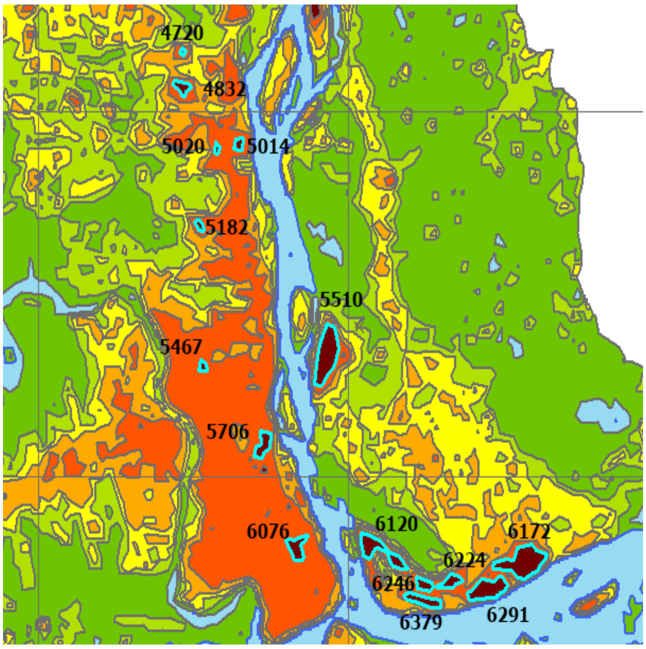

Figure 3. Codification and identification of areas in the parish of Puerto Francisco de Orellana (El Coca) with temperatures above 40 °C (Heat Islands).

Thus, the heat island map was obtained (Figures 2 and 3) and the areas with the highest temperatures within the urban sector and its surrounding parish, Francisco de Orellana, city of El Coca, were identified. In other urban areas with little vegetation or presence of tree species that provide shade, such as the orange areas belonging to agricultural land use and pastures, people are exposed to high temperatures above 35 °C and below 39 °C and in infrastructure areas where green areas are scarce the temperature can exceed 39ºC to 45ºC during periods of intense heat. However, areas with temperatures of 7 to 28 °C correspond to areas with wooded vegetation cover, which are ideal for the development of many species and as providers of environmental services.

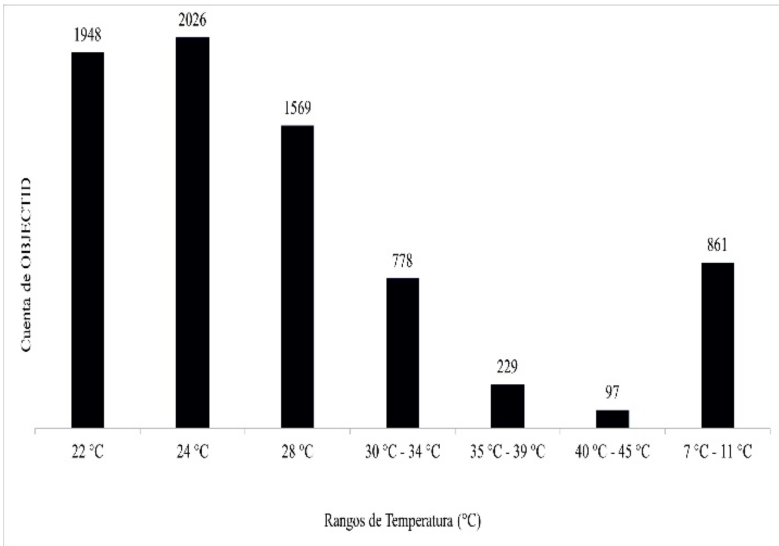

Figure 4. Temperature behavior with respect to urban and rural areas.

In addition, considering the complete targeting obtained through QGIS, a total of 7,508 targets were obtained for the entire province of Orellana, as shown in the Table 2. It can be seen that the lowest number of targets with respect to temperature are found in the urban zone where the temperature ranges from 40 to 45 °C, as shown in the graph below.

Temperature range ºC	Target count
40 - 45	97
35 -39	229
30 - 34	778
7 -11	861
28	1569
22	1948
24	2026
Grand total	7508

Table 2. Temperature and total targets obtained from the areas of Puerto Francisco de Orellana (El Coca)

3.2. Soil analysis from QGIS database

Taking into account the results obtained regarding the temperature in the urban area (Figure 2), a comparative analysis was made with both urban and rural land use, and it was found that the highest temperatures, which range from 30ºC to 45ºC, correspond to urban areas where green areas are scarce, as shown in Figure 5.

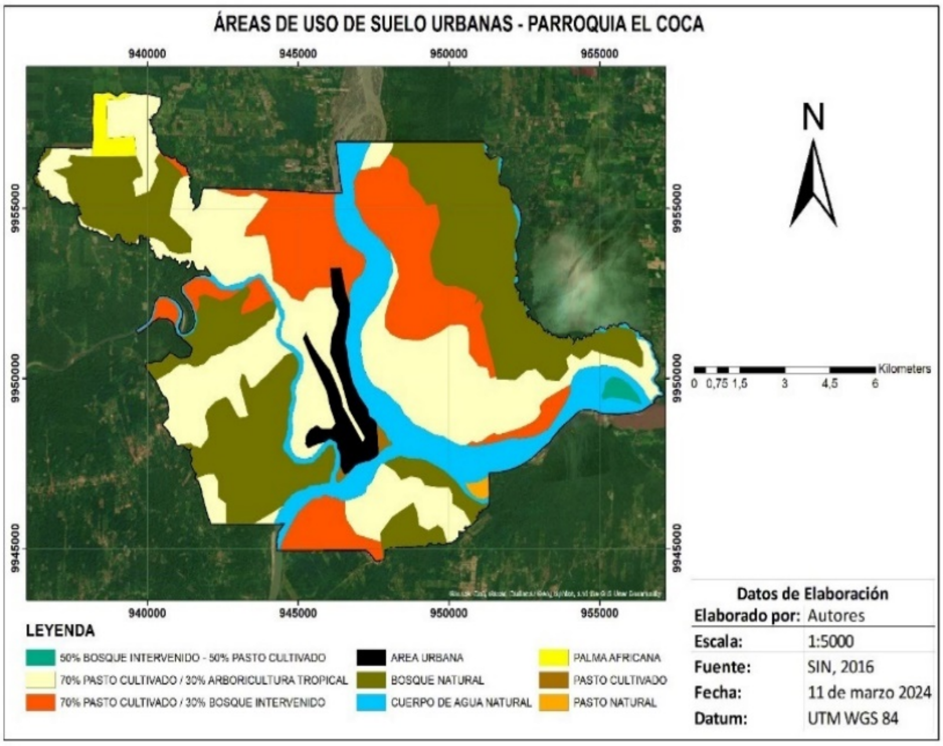

Figure 5. Urban land use areas in the urban parish El Coca.

It is observed that land use in the urban parish of El Coca has an impact on the formation of "Heat Islands" due to agricultural activities in the territory. Some of the most relevant land uses are forests which have been converted into agricultural land and large extensions of pastures, occupying 16 %, and urban areas, occupying 10 %; these differ considerably with respect to the 36 % of the total surface area made up of forest remnants. However, there is concern about population growth and how this could lead to socio-environmental problems without proper land-use planning. The main environmental concerns are the loss of vegetation cover, the loss of ecosystem connectivity, and the formation of heat islands as shown in Figure 5.

A study in the Brazilian Amazon found that conversion from forest to grassland increased surface temperature by 1.5°C on average, while urbanisation raised temperatures by up to 3°C. These data suggest that the situation in El Coca, with 26% of its territory converted to urban and agricultural areas, could be experiencing similar temperature increases [14].

Another study carried out in Uruapan, Michoacán, Mexico, using satellite remote sensing to determine urban heat islands (UHI), recorded temperature data for the period 2013 -2021, where they identified areas that had exceeded 1º C of the average temperature value, giving a total of 23 points covering an area of 146.8 hectares, concentrating 95.6% of heat islands in the urban center of Uruapan with a significant increase between 1 and 3.9ºC [15].

3.3. Effects of solar radiation on the people of Puerto Francisco de Orellana parish.

Caloric and UV radiation from the sun, although it is true that it allows the development of several vital functions on earth [3], can also be destructive due to the intensity it emits on the surrounding bodies, as is the case when part of the spectrum of electromagnetic radiation reaches the earth's surface, 5% for UVA rays and 0.5% for UVB [16].

On the other hand, solar radiation is classified into three types according to its wavelength: UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm), with UVA and UVB rays mainly reaching the earth's surface [17]. UVA radiation has the ability to penetrate the inner layers of the skin, with approximately 39 % of this radiation reaching the dermis, resulting in direct skin pigmentation and immediate short-term tanning. On the other hand, UVB is less able to penetrate the skin, but is responsible for sunburn and indirect pigmentation (melanin) following skin reddening, which in the long term contributes to premature skin ageing [18]. It is important to note that melanin, although traditionally considered a protective factor against UV-induced DNA damage and the development of skin cancer, may also have carcinogenic effects [19].

Environmental and public health impacts, in addition, overexposure to ultraviolet radiation (UVR) during childhood and adolescence increases the risk of sunburn and is a risk factor for the development of basal cell carcinomas and malignant melanomas [20].

Therefore, a fundamental strategy for the care of children is photoprotection, which involves improving habits to avoid excessive exposure to the sun. Among these practices, the recommendation to reduce the time of sun exposure during the hours of greatest intensity, from 12:00 to 16:00 hours, stands out [20]. In addition, it is suggested to physically protect the skin by wearing appropriate clothing, hats, and sunglasses, the latter being the most effective and economical strategies for photoprotection [21].

Moreover, according to Li et. al. [22] and Yeager [23], it is essential to apply sunscreen regularly to both children and adults, as it acts as a protective agent against ultraviolet rays (UVR), thus reducing skin damage. However, it is important to note that the use of sunscreen does not safely prolong sun exposure.

In this context, the harmful effects of radiation can become even more synergistic for human beings when the formation of heat islands reaches temperatures ranging from 40º to 45ºC due to cancerous skin diseases, critical dehydration, among others, which is why local governments must implement adaptation and mitigation measures, such as the creation of urban green corridors that minimize urban temperatures, in addition to proper land use planning, as reported by [24].

Considering that there are not enough urban green areas in the parish, suggest that urban patterns and ecosystems should be efficiently planned to maintain a balance between urban development and the preservation of natural ecosystems, as environmental and social problems could arise in the future if corrective measures are not taken [25].

Other study on urban climatology, agree that the replacement of natural surfaces by urban materials alters the energy balance, increasing heat absorption and retention, and that the population has excessive energy consumption in air conditioning, which in turn emits CO and Chlorofluorocarbons directly into the atmosphere, contributing to the acceleration of climate change [26].

4. Conclusión

The creation of a geodatabase in QGIS made it possible to identify the heat islands in the urban parish of the city of El Coca, revealing that the areas with urban land use without green areas and with a conventional architectural structure present the highest temperatures, exceeding 40 °C. While in peri-urban or adjacent areas with little vegetation of the tree stratum and with a pasture or agricultural land use, temperatures reach between 35 °C and 39 °C during periods of intense heat, in contrast to areas with forest cover and urban green areas that provide or provide environmental services of climate regulation. These findings highlight the importance of vegetation in urban thermal regulation and reducing people's exposure to extreme temperatures.

In addition, the impact of solar radiation on human health was discussed, highlighting the risks associated with excessive exposure to UVA and UVB rays, which can cause everything from sunburn to serious skin diseases such as basal cell carcinoma and malignant melanoma.

In conclusion, this research highlights the relevance of urban heat islands and their relationship with vegetation, as well as the detrimental effects of solar radiation on human populations.

These results underline the need for urban planning strategies that promote increased vegetation cover to mitigate the negative effects of urban heat and protect the health of inhabitants from excessive solar exposure. Such is the case of the city of Riobamba, where, under a socio-environmental analysis and determination of the environmental services provided by urban trees, a municipal ordinance was designed for the control and protection of natural vegetative heritage species in parks, pavements and streams, in order to help decontaminate the air, provide oxygen, reduce heat islands, and beautify the urban landscape, among other environmental services.

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Conflicts of interest: The authors declare that they have no conflicts of interest.

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