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GENERAL QUALITY OF URBAN GREENERY AS A CITY INDICATOR IN BRAZIL IN COMPARISON WITH CENTRAL EUROPE

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Abstract. The evidence for climate change and its associated consequences, such as severe droughts, floods, and storms, exposed the need to investigate the ways that countries can cope with them, especially Brazil, which is a continental nation. Moreover, the COVID-19 pandemic contributed to the urgency to consider global uncertainties. To audit it, the Pondělíček method, an indicator of the general quality of urban greenery (IOKZM), was employed. This approach considers four factors to indicate if one city is sustainable: city altitude [m], average annual temperature [°C], average annual precipitation [mm], and the total greenery area [km^2] per inhabitant per year. The outcomes demonstrate that, regardless independently of the Brazilian region, geographic localization, estimated altitude range, or precipitation range may not strongly influence the BIOKZM. The impact measured in the indicator is significantly influenced by the greenery areas in Brazil. Those estimated areas are much smaller than European Union ones. Teresina's F_{kes} demonstrates that if the greenery area is more than 5 (i.e., more than 50 percent), the IOKZM will be a positive outcome. The IOKZM calculated for Brazilian cities is interesting precisely because of their location in the southern hemisphere, as all the evidence of climate change subtly suggests that the climate in the southern hemisphere changes in a different way. Hence, this article can be used as an initial tool to assess whether the chosen Brazilian cities (Belém, São Luís, Guarulhos, Campinas, Porto Alegre, Teresina, and João Pessoa) can be considered "smart cities". It is a step towards guiding mayors and other public figures in charge to create and maintain smart cities in Brazil. In addition, further studies should be conducted to contribute to this collaborative effort.

Keywords: Green cities, climate change, global warming, Brazil, smart cities.

1. Introduction

It is projected that global warming will exceed 1.5 °C during the 21st century, making it harder to limit warming below 2 °C. By 2100, Global Warming will have led to a temperature increase of 2.8 °C [1]. This global event will generate climate impacts which can threaten the culture, infrastructure, and economy of many countries. According to the United Nations Office for Disaster Risk Reduction (UNISDR) [2], seismic events and deep scarcities are continually projected. However, exponential rises in storms and floods have been registered since 1970. The floods and storms are direct climate consequences of this global variation, as opposed to seismic events and deep droughts. UNISDR's estimation shows that extreme events such as heatwaves, heavy precipitation, droughts, and tropical cyclones were provoked by human influence. According to the Intergovernmental Panel on Climate Change (IPCC) [1], human influence has been the main cause of the rise of global sea levels and atmospheric temperatures since at least 1971. This issue is of even more significance due to the global population growing rapidly. It is projected that the population will increase by more than one billion people within the next 15 years, reaching 8.5 billion in 2030, and to rise further to 9.7 billion by 2050 and 11.2 billion by 2100. Roughly 10 % of the global population lives in Europe (738 million) and 9 % in Latin America (634 million). Thus, rapid urbanization, climate change, inadequate maintenance of water infrastructures, and poor solid waste management may lead cities to flooding, water scarcity, water pollution, and adverse health effects. The rehabilitation costs may overwhelm the resilience of cities, and the expenditure of inaction is high. These megatrends highlight the urgent challenges facing cities [3].

The localization of the countries around the globe are determinants for the dangerously escalating climate impacts, such as precipitation. Thus, the ocean level can rise due to its proportionality, which can impact urban systems and the resilience strategies applied in the cities [2]. Approximately 3.3–3.6 billion people live in areas that are highly vulnerable to climate change. And the increasing weather and extreme climate events have exposed millions of people to acute food insecurity, reduced water security, and other impacts [1]. Furthermore, the COVID-19 pandemic has brought into focus the range of challenges faced in responding to a wide range of uncertainties, while also highlighting the need to prioritize local needs in order to facilitate a just and inclusive transition. The pandemic has hit cities around the world and has exposed many vulnerabilities that need to be addressed in order to ensure better resilience to similar future adverse events [4]. The global impacts of both COVID-19 and climate change have caused substantial economic damages, particularly when the two are combined. Climate change has been detected in climate-exposed and affected sectors such as agriculture, forestry, fishing, energy, and tourism. The rising extreme heat events have driven hundreds of local losses of species. Some tropical, coastal, polar, and mountain ecosystems have reached hard adaptation limits. Nevertheless, approaches such as urban greening, wetland restoration, and upstream forest conservation have been effective in reducing flood risk and urban heat [1].

The implementation of eco-technologies can upgrade the discussions of management tools such as indicators, standards, budgets, and rating systems, which incentivizes cities to make an effort to achieve their green objectives [5]. That growth of the global population contributes to the importance of smart cities, which involve natural elements. As highlighted by JÓŹWIK and JÓŹWIK [6], sustainable development largely encompasses ecological, physical, and visual or aesthetic issues. The United Nations Sustainable Development Goals, particularly Goal 11, emphasize the need to take urgent actions in cities to address multiple social, economic, and environmental concerns [4]. According to ISO/FDIS 37122:2019 [7], smart cities provide social, economic, and environmental sustainability outcomes and respond to challenges such as climate change and rapid population growth. This type of city uses data information and modern technologies to deliver better services and quality of life to the residents, businesses, and visitors of the city without disadvantages for others and natural environmental degradation. Smart city is a term that encompasses the following topics: sustainability, technology, urban mobility, transport, planning, digitalization, innovation, resilience, climate change, urbanization, artificial intelligence, big data analytics, public health, remote sensing, social media, information technology, deep learning, internet of things (IoT), energy demand, cloud computing, efficiency, renewable energy, energy management, optimization, blockchain, wireless sensor networks, security, and privacy [4].

Data sources from different cities can vary depending on them [7]. Nowadays, all of these matters remain to integrate public and private services using technological innovation, which typically involves information and communication technologies (ICT) in planning, governance, transportation, water treatment, electricity distribution, and public oversight areas. They can draw people with different cultures and qualifications to exchange their abilities and expertise. Besides, they can lead the world to a new era of sustainability by reducing the high levels of carbon in the atmosphere, potentializing the mobility and energy sectors, and adapting to climate change [5]. In this context, the global smart cities market is expected to exceed \$2 trillion (USD) by 2025 [8]. Smart cities are treated as countries' progress strategies [5], because their structures prevent attitudes to avoid the interruption, incapacitation, or destruction of networks and infrastructure, which can result in serious social problems, waste treatment issues, and economic consequences. They can be applied as a strategy in stage two of the Diagnostic and Evaluation of cities' risk, especially approach number 6, which involves analyzing the environment and engaging with local stakeholders [2]. As such, this article proposes to analyze seven Brazilian cities using the Pondělíček method as a step to offer assistance to mayors and public in creating and maintaining smart cities in Brazil.

2. Research Methods

From the 18$^{\text{th}}$ of February until April, a literature review was conducted and encountered in Google Scholar, SpringerLink, and ScienceDirect databases based on this article. Likewise, the Pondělíček method for calculating the indicator of the general quality of urban greenery (IOKZM) the method will be applied in Brazilian cities. The IOKZM indicator is important and based on an understanding of environmental gradients (biotic and abiotic nature, even their intra and inter actions) for the predominant types of urban greenery, and these are also considered to be predominantly euryvalent species and dated to urban conditions (ecologically less demanding and tolerant) and not stenovalent (ecologically intolerant). Therefore, quantities describing the basic factors for generally conceived greenery in cities are part of the construction of the indicator. Briefly, the IOKZM indicator, according to Equation (1), is a constructed indicator that is then a real composite indicator of the level of general quality of greenery in cities in the Czech Republic and has across-the-board information based on geographic and meteorological data. The indicator mathematically creates an area between four axes, according to Figure 1, on which logarithmized values of individual components of the indicator are plotted. The total and target value of the indicator is therefore given by the area of the resulting quadrilateral, formed inside by four right triangles.

$$\begin{aligned} IOKZM = \frac{1}{2}[\,&(\log F_{kes} \cdot \log F_{prt}) \\ &+ (\log F_{prt} \cdot \log F_{prs}) \\ &+ (\log F_{prs} \cdot \log F_{nmv}) \\ &+ (\log F_{nmv} \cdot \log F_{kes})], \end{aligned} \tag{1}$$

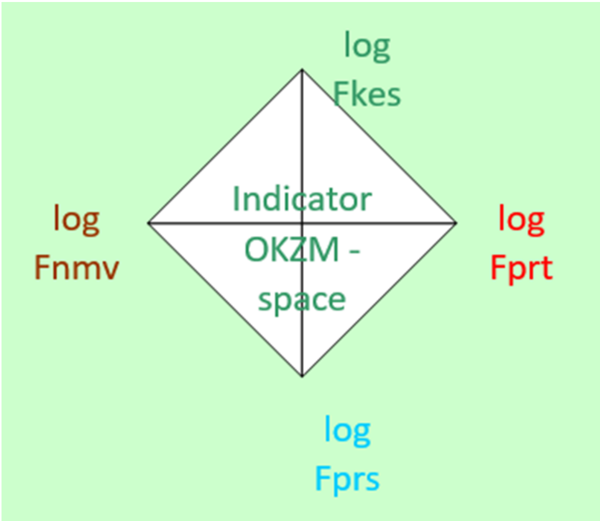

Figure 1. Construction of the OKZM indicator.

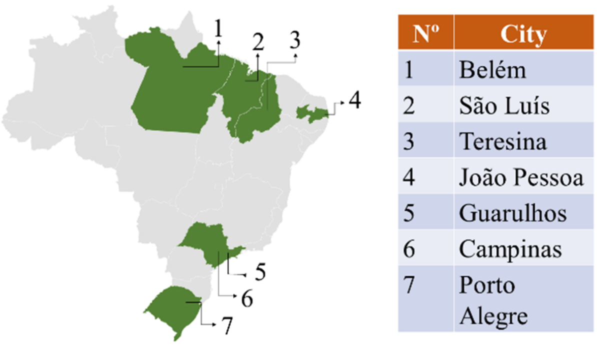

Figure 2. Localization of Selected Cities in Brazil.

where F_{nmv} is the city's altitude data [m], F_{prt} is the average annual temperature in the city [°C], and F_{prs} is the average annual precipitation in the city [mm]. To apply this indicator in Brazilian cities (BIOKZM), seven cities were chosen strategically to analyze the IOKZM influence in different Brazilian regions (North, Northeast, South, and Southeast), as seen in Figure 2 and Table 1. These have around one million inhabitants, according to the 2022 Brazilian Geography and Statistic Institute (IBGE) [9] census (Table 1), and they were elected because they can represent the variety of influence of the factors according to their regions. Moreover, the factor F_{kes} corresponds to the percentage of the total of greenery areas calculated in square km per inhabitant annually. Brazilian greenery area data was registered in IBGE's database in square meters (F_{kes}). Those were converted into square km and transformed in percentage to be applied in Pondělíček's calculus. In addition, the IBGE computes the F_{kes} in different years, according to Table 2. All data were taken from the Climate Data [10], Sustainable Cities Institute [11], `https://topographic-map.com` [12], and IBGE [9, 13] databases, according to Table 3, and the IOKZM variables were calculated in consonance with them, according to Table 3.

City	Brazilian region	Inhabitants
1	North	1 367 336
2	Northeast	1 061 374
3	Northeast	868 523
4	Northeast	889 618
5	Southeast	1 383 272
6	Southeast	1 170 247
7	South	1 404 269

Table 1. Brazilian cities data according to the 2022 census from the Brazilian Geography and Statistic Institute (IBGE) database.

City	F_{kes}	Census Year
1	23.1761	2008
2	1 014 837	2015
3	184 359 971	2013
4	83.3303	2012
5	44.6744	2012
6	9.8843	2015
7	47.11	2014

Table 2. Brazilian greenery areas data registered in IBGE's database in square meters (F_{kes}).

3. Results

The BIOKZMs were calculated according to the aforementioned databases and the results are shown in Table 3.

4. Discussion

The measured impact of Brazilian greenery areas on the indicator was found to be significant, despite the fact that these estimated areas are much smaller than those in the European Union. Thus, greenery areas which do not represent a high significant number in square km, results in F_{kes} that are close to zero. According to Table 3, independently of the Brazilian region, these outcomes indicate that geographic localization, estimated altitude range, or precipitation range result in low values in Table 4, which make it difficult to compare BIOKZM with European Region IOKZM. The Brazilian IOKZM and European Region IOKZM are shown in the Table 5. It is important to establish which Brazilian outcomes exposed a situation based on archaic data for greenery areas. It was not possible to find city censuses on recent greenery areas. If it was possible to calculate the recent Brazilian IOKZM, these BIOKZM might possibly decrease too much. The human growth and fast urbanization with insufficient environmental management plan for those cities indicate that a decrease is provoked in the indicator [14, 15], and these issues had happened in Brazil. The correlation between F_{kes} and temperature (F_{prt}) is directly evidenced by the IOKZM, with deforestation in Brazilian cities contributing to higher temperatures [16]. The range of temperature

City	log 1 × log 2	log 2 × log 4	log 3 × log 4	log 3 × log 1	BIOKZM
1	1.109	0.684	1.593	2.582	2.984
2	1.54	-2.457	-5.736	3.596	-1.528
3	3.073	1.141	2.497	6.723	6.717
4	1.947	-2.277	-4.854	4.151	-0.516
5	3.751	-1.669	-4.111	9.239	3.605
6	3.747	-2.46	-5.862	8.928	2.176
7	1.829	-1.432	-3.54	4.521	0.689

Table 3. Variables of BIOKZM equation.

Brazil		European Region	
City	F_{prs}	City	F_{prs}
Belém	2,085	Prague	480
São Luís	2,156	Munich	938
Teresina	1,447	Vienna	675
João Pessoa	1,462	Budapest	563
Guarulhos	1,580	Berlin	535
Campinas	1,451	Krakow	675
Porto Alegre	1,019		

Table 4. Comparison of Brazilian and European Union precipitation range.

Brazil		European Region	
City	F_{prt}	City	F_{prt}
Belém	26.7	Prague	13
São Luís	26.8	Munich	13
Teresina	19.2	Vienna	9,5
João Pessoa	21.3	Budapest	11.2
Guarulhos	19.7	Berlin	12
Campinas	27.9	Krakow	9.2
Porto Alegre	25.8		

Table 6. Comparison of Brazilian and European Union temperatures range.

Brazil		European Region	
City	IOKZM	City	IOKZM
Belém	2.984	Prague	7.3776
São Luís	-1.528	Munich	8.9197
Teresina	6.717	Vienna	7.3308
João Pessoa	-0.516	Budapest	6.7725
Guarulhos	3.605	Berlin	6.0678
Campinas	2.176	Krakow	7.6091
Porto Alegre	0.689		

Table 5. Comparison of Brazilian and the European Union IOKZM.

in Teresina is almost like other cities in the European Union, according to Table 3 and Table 6. Even with the higher temperature range of Brazilian cities, the BIOKZM of some cities was maintained in negative outcomes.

GOMES (2022) demonstrated that deforestation disrupts the balance of hydrological systems, especially the flow of rivers in the Amazon rainforest and the Cerrado. As a consequence, the water flow was reduced because of the decrease in water recharge in the soil [17]. This hydrological disturbance affects the temperature range and the plumiometric range. According to the results in Table 3, the pluviometrics can reduce the IOKZM. However, comparing these outcomes within Table 6, the European Union has cities with lower grades in pluviometric terms, and their IOKZM are positive. Even considering São Luis, which has the top F_{prs}, the BIOKZM are not positive. According to Table 3, F_{prt}, F_{prs}, and F_{mnv} combined were not sufficient to turn the IOKZM to a high number. On the other hand, the precipitation indicator that is correlated with negatives BIOKZM influences this indicator directly, as can be observed in the outcomes from cities number 4 and 6 from Table 3. The altitude above sea level slightly influences the IOKZM when applied in different countries. This is clear in the Pondělíček study, where the cities selected from the European Union have altitudes slightly similar (47, 127, 200, 233, 239, 520 m) compared to the Brazilian ones (6, 12, 24, 26, 134, 665, 841 m). According to Table 3, Teresina is the highest city analyzed, and this associated outcome caused a positive BIOKZM. Compared to the Pondělíček method for calculating the IOKZM of the European Union, we can observe that all five European Union cities selected for this study exposed higher grades compared to Brazilian IOKZM, according to Table 3. BIOKZM revealed the influence of the temperature of the cities investigated. The five cities inspected from the IOKZM of the European Union have temperatures under 13 °C, which is the maximum measured between the European Union sample. In contrast, the Brazilian minimum and maximum average temperatures analyzed are 19.2 °C and 27 °C, respectively.

This article and thesis aims to look at the geographical and climatic conditions of cities differently and to obtain an overview of the quality of selected Central European cities in terms of conditions for developing green infrastructure within cities. The selected Indicator of the General Quality of Green Cities (OKZM Indicator) was used to determine the relative potential of selected cities for further support of green infrastructure of the city (the indicator works similarly to IQ, with the comparison of values among themselves). To measure the potential of the need to care for urban vegetation in Europe, the cities closest to Prague with populations of more than 1 million in absolute numbers and linked to the Central European area were selected: Munich, Vienna, Budapest, Krakow, and Berlin (Berlin and Krakow are peripheral cities, but subject to similar development patterns as the others, and their influence on the development of Central Europe is obvious). Similarly, in Brazil, selected cities from different zones, from the equator to the temperate zone in the southern hemisphere, were chosen for the BIOKZM: Belém, Campinas, Guarulhos, Joao Pessoa, Porto Alegre, Sao Luiz, and Teresina. In Central Europe, Munich and Krakow dominated, taking into account the number of local inhabitants and thus the density of inhabitants in cities. The best in terms of BIOKZM in Brazil were the southern hemisphere cities of Campinas, Porto Alegre, and Teresina, which are practically in similar conditions as cities in the northern hemisphere and in Europe. Based on a comparison of the results of IOKZM and BIOKZM, we conclude that cities in the temperate zone are practically suitable and comparable for assessment thanks to IOKZM and its calculation, whereas cities on the equator have extreme conditions and their vegetation within the city cannot be evaluated similarly. In principle, calculations have proven that IOKZM works at this level [18–21].

This comparison between IOKZM and BIOKZM from temperate zones signifies a significant advance of international collaboration efforts to minimize global warming and climate change impacts. Thus, EU and Brazilian temperate zones can be studied with more accuracy in these terms. Moreover, this paper gives the scientific community resources to investigate some countries which are in temperate zones as well as to discover if the OKZM indicator can be used on them too. Countries in the southern hemisphere, such as South Africa, the south of Australia, New Zealand, Chile, Argentina, and countries in the northern hemisphere, such as the USA, Canada, Morocco, China, Mongolia, North Korea, and South Korea are in the temperate zones and represent an important part of the global economy. And this fact is related to sustainability. In addition, the aggregation of data from these countries could propose to the scientific community and the governments an OKZM network which reflects international cooperation. Some secondary data could be created from these preliminary country-specific data, correlating OKZM with specific issues such as the influence on continents, the economy, the relationship with the country's position in the world (north or south), global demographics, climate change per hemisphere, and governments' efforts to attain a state of environmental well-being combined with societal cooperation.

5. Conclusions

IOKZM calculated for Brazilian cities is interesting precisely because of their location in the southern hemisphere, as all the evidence of climate change subtly suggests that the climate in the southern hemisphere changes in a different way. According to some authors, this is due to the Pacific Ocean and also Antarctica as a land mass with a large glaciation, which cools South America more. The purpose of the BIOKZM calculation is now mainly to identify trends in the cities, and when comparing data from five years ago to the current data, it can indicate how the geomorphological and climatic conditions are changing. The final use of BIOKZM is in the field of vegetation care and maintenance in cities. According to BIOKZM, we can assess the level of care required for vegetation and predict its demands based on the influence of the climate. In particular, financial demands are costs that are important to the care of urban vegetation. High-quality vegetation and functional trees fulfil their role in improving the microclimate of the city better and dampening all extremes. The main role of BIOKZM is therefore to look for trends in the care of urban vegetation and to help find a trend where it is possible to reduce or increase investments in greenery, depending on the city's population density.

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