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Applied Climatology: Porto, Leipzig and Mumbai

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1. Introduction

Applied climatology is not a recent science and over time has become extremely important, due to the comprehensive influence of climate on human actions, offering important insight into climatic behaviour at the local level (Peixoto, 1989). Climate affects human activity, and through climatology we can understand how weather and climate interact at local, regional, and global scales. And thus, applied climatology provides insights into urban planning. In this work, we question what are the existing elements/local specificities that can explain the thermal variability in such a short route as Gondarém street. Considering the relations between economic development and energy peaks (Monteiro, A; 1997), we question what are the differences between Porto (Portugal), Leipzig (Germany) and Mumbai (India).

2. Methodology

For the design of this work and in order to meet the objective initially proposed, comparisons between the cities of Leipzig, Mumbai and Porto were also made.

In the case of the city of Porto, measurements were taken on the street of Gondarem using the text probe 500 in 62 points, chosen by us, these being opposite, (up to 31 correspond to half east and then (32-62) half west of the street). Their choice took into account a wide range of nuances that may condition, either natural or man-made, the climatic comfort of the street. These measurements were taken at 9 AM and 8 PM on Tuesdays and Saturdays every day (except in the case of precipitation). In addition, Flow Plume (for the measurement of NO2, VOC's, PM2.5 and PM10 concentration) and a reference station (GOS IPORTO-133; Elev. 164 ft, 41.16 °N, 8.69 °W - consult (Portfolio_Report_Porto_Dados estação_Localização GosPorto133) were used. With these records, data processing was then performed using statistical and mapping methods.

In order to create the maps of the Digital Surface Model (MDS) and the Sky View Factor, the data provided in the class were used, which include the quoted points, the limits of the streets, through operations carried out in the ArcMap and in QGis. With the Sky View Factor map made, the Sky View Factor was then calculated, referring to the days of the year 2021, in which the Winter Solstices occurred (1/12/2021) and Summer Solstices (21/06/2021) and the day the September Equinox occurred (09/23/2021).

In the case of making surface temperature maps, Landsat 8 images of four days of last year (04/07/2021; 07/28/2021; 09/25/2021 and 11/17/2021) were used. taken from the official page of the United States Geological Survey (USGS). After that, band 10 of each of the days studied was opened in ArcMap and the formula for calculating the surface temperature in degrees Celsius (°C) was applied.

As direct measurements in the cities of Leipzig were not possible, we refer to existing literature and databases in these chapters. On this basis, we have created tables and graphs and used existing maps that helped us to better describe and analyse the individual parameters in order to understand the influence on the climate in these cities.

For the graphs about the weather statistics for Leipzig we have used the dada from the *Weather Station Leipzig Flughafen.* It is located in the Northeast of the city with an altitude of 117 metres. Since there is no weather station with reliable data closer to the city centre, we had to work with the distance to the city centre of about 15 km. These influences have to be taken into account in the following work.

To carry out this work we used information and data taken from articles, websites, news in other forms, which we consider more relevant and which, in some way, respond to the various sub-themes we are going to deal with, in order to allow not only an analysis of Mumbai, but subsequently also a comparison with the other two cities (Mumbain and Leipzig), which we are going to deepen throughout this work.

For the comparison of the three cities, use the information was collected in the sources referred, but is important to consider that in the specific case of temperature, precipitation, and wind speed, we used reconstructions of the climate model of the three cities, using data from 1980 to 2016, using the stations of Weather Spark (Leipzig-Halle Airport, Francisco Sá Carneiro Airport and International Chhatrapati Shivaji), possible to find in the portfolio, Folder Weather Spark Comparation; (Report_Folder Weather Spark Comparation).

3. Bibliographic Review

All systems are complex by nature, created and developed through a complex balance of interaction between various factors, themselves also complex. Climate systems, which climatology is dedicated to studying, are also marked by constant changes and a search for their complex balance, achieved through impulses caused by the resolution processes in the Climate System. In this way, the system does not react immediately to each intrusion, but "results from the accumulation of a set of diverse causes, which makes it difficult to evaluate the representativeness of each action in the final responses" (Monteiro. A; 1997; P.153) But to a climate system that has their state of equilibrium constantly disturbed by human action there are risks associated (Monteiro. A; 1998). This is particularly important in cases of study of urban areas, because the equation of the normal circulation of energy in the climate system is much more complex (Monteiro. A; 1997). Thus, the artificial flow requires more attention, when it comes to understanding urban climate subsystems, since the energy inputs are greater than the outputs in the equation $Qs + Qf + Qi = Ql + Qg + Qe$ (DOUGLAS, 1983, p. 40 in Monteiro. A; 1997). Because this, to urban morphological characteristics the losses by evaporation (Ql) are not facilitated, moreover, "the greater absorption, reflection and dispersion of solar radiation, when crossing the more polluted atmosphere of urban environments, increases the diffuse radiation, affecting the visibility and colour perception of objects" (Monteiro. A; 1997; P. 202). "Favouring a more diversified range of energy inputs and blocking some of the possible ways out of it" ((Monteiro. A; 1997; P. 207).

Another factor of great importance, especially on smaller scales is the influence of trees. Trees are most often valued for their aesthetic aspect, and are undoubtedly great elements for this purpose, but we can consider that trees and other vegetation also help mitigate the effects of an urban heat island (UHI). This is done by increasing latent heat flux through evapotranspiration, preventing near-surface air from warming during the day and providing evaporative cooling at night (Simon et al., 2019). Thus, acting as vegetated "roofs and facades" can help reduce cooling demand in summer and also contribute to insulation in winter, leading to less heat loss to the atmosphere and savings in energy consumption for the immediate environment. As such, vegetation in all its different forms (parks, trees, greenery on the facade, etc.) is the most advised strategy to mitigate the UHI effect and to help improve the urban microclimate (Simon et al., 2019).In addition, they also help reduce wind speed (Georgi & Zafiriadis, 2006).

This last feature is easily explained when we think of trees as obstacles to normal wind circulation. From a broader perspective, we could also talk about the localised effects of trees on the environment as a whole, such as flood prevention, due to the canopy cover of trees, precipitation slows down before it reaches the ground, and the process of evaporating part of the water back into the atmosphere (What is the impact of trees and climate change? | Local Tree, 2021). Another of the most crucial impacts of trees is their ability to trap carbon emitted by human activities (What is the Impact of Trees and Climate Change? | Local Tree, 2021). Yet another advantage would be the capture of these pollutants suspended in the air (Chaudhary & Rathore, 2018). Despite its many advantages, the option to place a tree should be very well considered, considering also its negative factor of accumulating under its crown a large amount of particles with potential contamination and that can cause damage to living beings and materials.

4. Porto city

4.1 Characterization of the study area

Due to the proximity of the sea, it is registered in the street of Gondarem, an influence of the sea-land breeze. On which the buildings can, by the direction of the street, exercise excellent conditions of shelter and protection, reducing, inside the street, this influence (Monteiro. A; 1997). The proximity to the sea is still important, so that it helps to understand the smaller thermal amplitudes, although it is important to remember that this action is, however, very irregular, "depending (...) on the energy available to move the water molecules". (Monteiro. A; 1997; P. 105).

Another important aspect is the morphology of the city, associated with the difficulty of air circulation, but also with diversity in colour, height, density and type of materials used in the construction of buildings, because the urban design creates a greater number he shadow spaces, the arrival of direct solar radiation to ground level is partially prevented, the greater the ratio height of the building / space between buildings (Sky view Factory) (Monteiro. A; 1997). This is also important when we consider the action of trees (Reporte_Porto_Sky View Factor).

The use of the Digital Surface Model (MDS) proves to be important for the execution of this work not only to later develop the Sky View Factor and better represent the surface temperature images; as well as to better understand the representation of the relief of the terrain. In the case of the surrounding area, Rua de Gondarém and the street itself to be studied throughout this work, represent a relief that varies between -12.56 metres, at the lowest point, and 138.41 metres at the highest point (Portfolio_Report_Porto_MDS).

4.2 Sky View Factor (SVF)

Sky View Factor is the designation used to indicate the limit of the visible sky at a given point of observation and that varies between 0 and 1. For our work it was also necessary to use it to help us with the final conclusions, being therefore the first map that appears . It should be noted that Rua de Gondarém has values between 0 and 1 along its length, and the lowest values represented in blue are located at the foot of the places where trees are inserted (Portfolio_Report_Porto_Sky View Factor_Sky View Factor).

Moving now to the maps representing solar radiation, starting with the summer solstice map (Portfolio_Report_Porto_Sky View Factor_RS2106Wh), we can say that Gondarém street is not the hottest in that area, showing the average values of our scale (3001-5500 wh/ m²). These values are represented with shades of yellow and orange. With regard to solar radiation in September (Portfolio_Report_Porto_Sky View Factor_RS2309Wh) on Rua de Gondarém, we noticed that there is a decrease in temperature, that is, the values are now between 501-2000 wh / m², represented between the shades of dark and light blue, so we noticed that the amount of energy is less than in summer.

To finish the maps relating to solar radiation, the last one we drew up is of solar radiation at the Winter Solstice (Portfolio_Report_Porto_Sky View Factor_RS2112Wh), the time of year when the street in Gondarém is the coldest. Our measurements took place between October and November, which is the time of autumn, but we can say with certainty that there were mornings and nights when we felt very uncomfortable due to the thermal sensation, also because the same trees that do not let the sun's rays pass in the summer they provide shade, in the winter they end up not allowing the little radiation that passes through that street to pass through.

After evaluating the solar radiation on Rua de Gondarém, we added to our work the number of solar hours that the street has on the Summer Solstice (Portfolio_Report_Porto_Sky View Factor_HSol2106), the September Equinox (Portfolio_Report_Porto_Sky View Factor_HSol2309) and the Winter Solstice (Portfolio_Report_Porto_Sky View Factor_HSol2112). As previously mentioned, Rua de Gondarém does not have many hours of sunlight from September to December and from January to June the radiation increases.

4.3 Climatic context

The perception of the behaviour of the climatic elements on a broader scale is important for the perception of the thermal behaviour recorded in the street, so we used the daily records of temperature and precipitation at the station mentioned earlier in the methodology (Portfolio_Report_Porto_Dados estação).

In the month of October the temperature varied from 23.9 ºC to 11.9 ºC, the average temperature recorded being 17.1 ºC. Regarding precipitation it appears that the total was accumulated throughout the month 199.64 mm, and until October 15 there is no accumulated precipitation and from October 25 to October 30, recorded a more intense precipitation, corresponding to the highest accumulated precipitation on day 28 (44.7 mm). The increase in rainfall values recorded are explained by the influence of extratropical cyclones Armand and Beatrice. This factor also explains the wind gusts that reached 124.9 km/h. In addition, there was an average humidity of 86% (maximum 98% and minimum 48%).

Relatively to November, we verified a decrease in temperatures, ranging between 21.8ºC and 7.7ºC, with an average temperature of 14.7ºC. At the same time we see higher values of precipitation of 236.53 mm (an increase of 18.5%). This situation is the result of "humidity rivers", i.e. extremely long and narrow bands in the atmosphere that carry most of the water vapor (about 90%) in the lower layers of the atmosphere, from the subtropical regions to the northern regions, to the so-called medium latitudes, where Portugal is located (National Oceanic and Atmospheric Administration (US)). It is also important to note that the maximum value of wind gusts is lower this month, corresponding to 91.7 km / h (November 21) and is associated with the passage of frontal swells coming from the Atlantic.

4.4. Surface Temperature using Landsat 8

To determine the surface temperature, we used information corresponding to Landsat 8 taken from the official page of the United States Geological Survey (USGS), referring to our study area, using information from four days of the year 2021, in which there were no clouds interfering in the study area and they were the closest to the days when the Solstices and Equinoxes occurred last year. After pulling out the Landsat information, it was then worked into ArcMap and superimposed on the hillshade created from the MDS.

On all the maps in the southwest corner, we can see the presence of the sea with a temperature variation between 12°C and 17°C and which gradually increases as you approach the land.

Looking at the surface temperature map on April 7 (Portfolio_Report_Porto_Surface Temperature_Surface temperature on April 7th and September 25th.) , 2021, we can see that the temperature on land varies almost entirely between 24 ° and 25°C, with some exceptions in the North, in the East corner, in the Southeast corner and to the along Avenida do Brasil where the temperature varies between 22° and 25° Celsius. In the case of September 25th (Portfolio_Report_Porto_Surface Temperature_Surface temperature on April 7th and September 25th.), the temperature varies between 22°C and 23°C, in the area connecting the sea to land, varying between 24°C and 27°C on the earth's surface. We start to observe the surface temperature, on November 17 (Portfolio_Report_Porto_Surface Temperature_Surface temperature on November 17th and July 28th), at a time when temperatures are lower as the days get progressively shorter, as well as the angle of incidence of the sun's rays, which is smaller and smaller. Therefore, currently, the temperature in the area closer to the coast varies between 20°C and 21°C, while further inland the temperature varies between 22°C and 23°C.

On the 28th of July 2021 (Portfolio_Report_Porto_Surface Temperature_Surface temperature on November 17th and July 28th), a typical summer day, we were able to see that the lowest surface temperatures are seen closer to the coast, along Avenida do Brasil, where the temperature varies between 22°C and 27°C, increasing progressively as we move away from the sea. Leaving Avenida do Brasil we can see that the temperature varies mostly between 28° and 29°C with some exceptions where the temperature reached 31°C. These areas where the temperature reaches 31°C are located mainly in the south of the map, normally being areas that are not perpendicularly crossed by streets oriented in the southwest-northeast direction and that suffer the direct influence of the sea.

In addition, the highest surface temperatures can be found inside building blocks, as well as in streets that are completely exposed to solar radiation where there are no tall buildings or physical obstacles that prohibit the passage of rays. buildings, such as at the southeast end of Rua de Gondarém, where there are no more trees, the sidewalks become wider and the existing buildings have few floors.

4.3 Itinerant Measurements

The itinerant measurements performed on the street of Gondarém were made throughout the month of October and November. Are presented the 8 days on which measurements were made being that on October 15th we only have the data from the morning, on October 8th and 25th no measurements were taken due to rainfall. In addition, on November 5 we took measurements, but the data were lost. (Portefólio_report_porto_plume_measurePoints_Gondarém).

As already explained in the methodology, the measurements were performed through a set of pre-selected points. Each of these has its own characteristics that can be important factors in explaining the climatological differences along the street. Thus, we will apprest those with special features, the rest can be seen in the attached table.

4.4 Selection of and analysis of standard examples

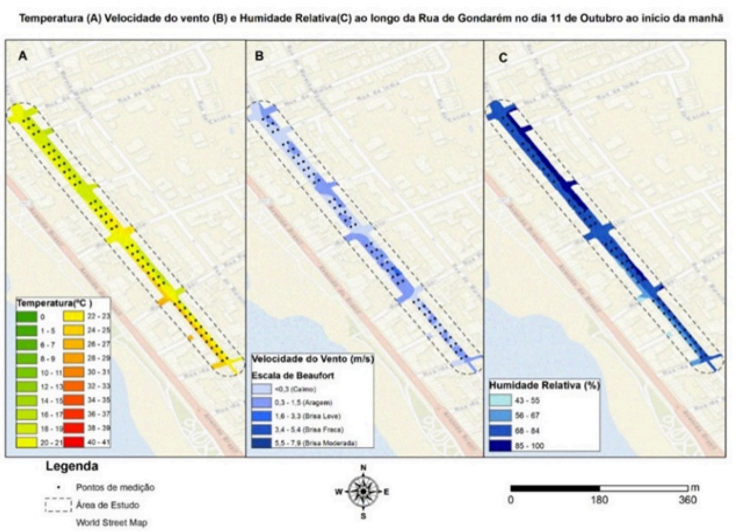
After carrying out the cartographic representation of the collected data (attached), through the text probe 500 and analysing the data presented, two days were selected to be analyzed in this chapter, since the analysis of their particularities presents a complete explanation of the elements and factors that help to understand the complexity of the climatic system of Rua de Gondarém.
Thus, we will analyze the temperature, wind speed and relative humidity in the mornings and afternoons of October 11th and November 1st, and the remaining maps can be consulted in the portfolio (Report_Porto_Climate characterization).

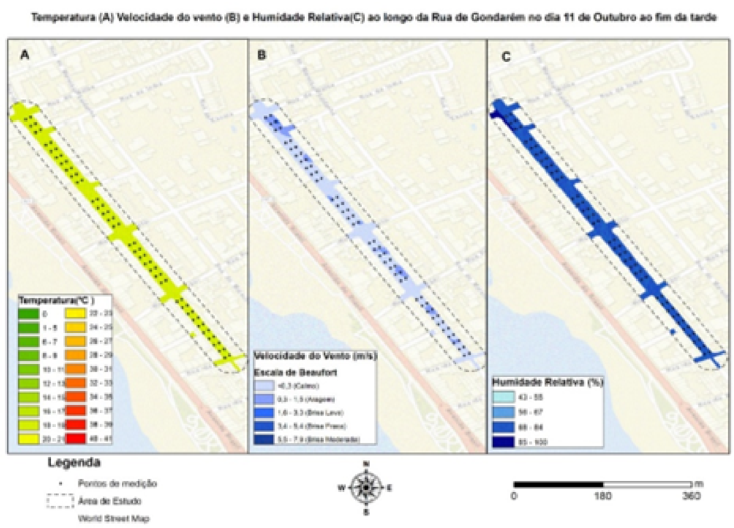
Between 9.30 am and 10 am, there are maximum temperatures of 25.7ºC (October 1st) and minimum temperatures of 15.1ºC (October 4th). In the measurements recorded between 8:00 pm and 8:30 pm, the anthropic influence is greater, reflected in a greater homogeneity of temperatures, with the maximum recorded temperature of 18.4ºC and the minimum of 14.2ºC, with measurements at the end of the day generally showing a smaller thermal variation.

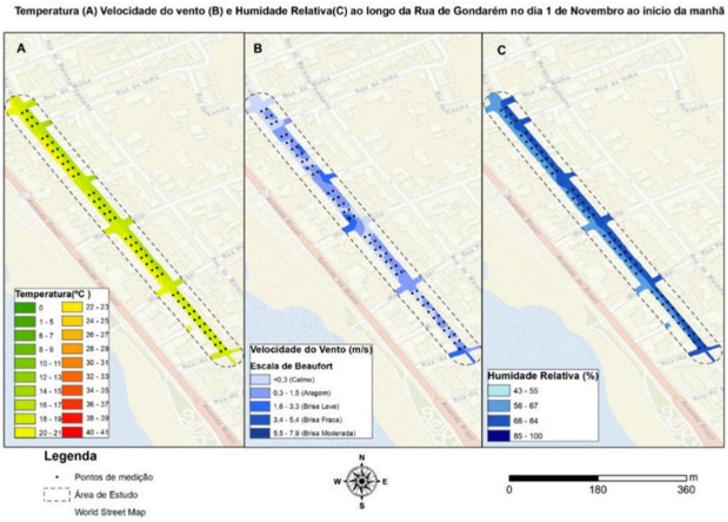
The wind speed did not exceed 7.9 m/s, classified as a moderate breeze. The places with the highest values are characterised by the intersection of Rua Gondarém with Rua Molhe, Rua Castro, Rua Padrão and Rua Agra, in an east-northeast direction and directly perpendicular to the sea. Despite this, they distinguish some exceptions, whose particularity of the higher wind speed in these places is explained by the direction of the wind on these days.

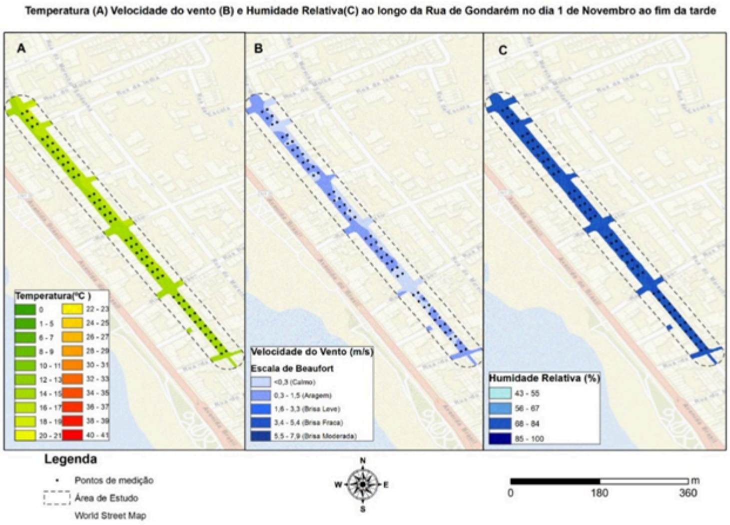
Furthermore, humidity is a natural influence of precipitation and solar exposure visible in the data represented along the maps, reflected for example in the data retained after heavy precipitation or in the side of the street that receives first sun rays. Furthermore, humidity is important for us to understand what is the climatic behaviour of the street and the discomfort that the population may feel along this street.

Throughout Chapter 7 (7.1) - Discussion and Results, we will develop a specific analysis of the variables and contrasts along the street.









4.5 Air quality on the route taken (Plume)

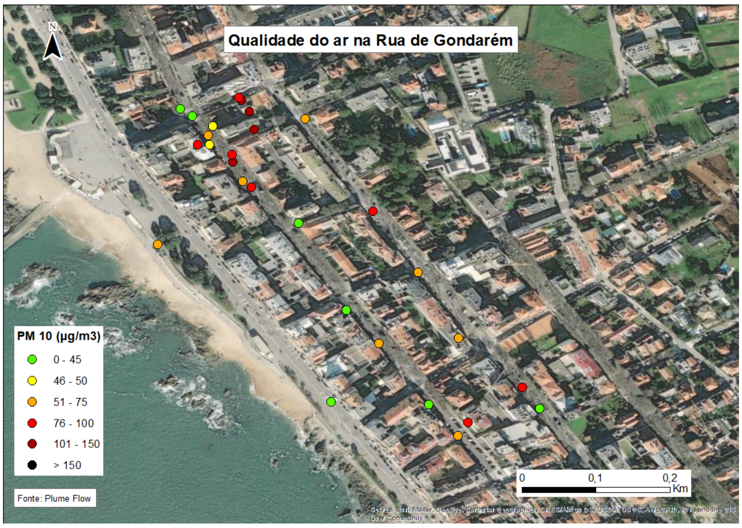
4.5.1 Characterization of particles and pollutants

As a result of our work with Plume, it was possible for us to understand the behavior of pollution in an urban context. Following the values of provisional targets and the air quality guidelines of the World Health Organization, it was possible to perceive that PM10 and Nitrogen Dioxide are the pollutants that present the most worrying values for health in an urban context.

4.5.2 Results

The main conclusion drawn from the work carried out on air quality is that the ventilation of indoor and outdoor spaces is essential to understand air pollution in urban contexts. Since pollution essentially has two ways of being cleaned, through air flows that move the pollution away from the emission sites and through rains that clean the surfaces of the pollution but take it to the groundwater and to the soils, this means that it is not uncommon to find reduced air quality in places where the sources of pollution are not significant but which, due to ventilation, end up establishing themselves there, usually in places where there are trees or other obstacles. In fact the most noticeable fact was that higher pollution values were usually observed in narrower streets and even more in those with trees, since the possibility of ventilation in these streets is generally lower. Meanwhile, in interiors with less ventilation capacity, such as buses or closed rooms, higher values of particles and pollutants are also perceived than those with better ventilation, making it possible to notice that inside the train the air quality is superior to that of the bus for example.

Although we noticed that in streets with trees the pollution was usually higher we do not say that the trees should get out of the urban landscape, since they are not a source of pollution. The primary source of pollution identified throughout this work was the use of cars and the release of associated pollutants in the exterior while in interiors the quality of furniture and paint of them and walls might contribute to the air quality in the rooms we've been in. However for the results of PM 10 and PM2.5 there is always the possibility of the values being influenced by non-pollutant particles. It's the case of Rua de Gondarém where we noticed that some higher records might have an influence from salinity, given the proximity to the sea. In this street, these two factors combined with the existence of trees in a large part of the street and the fact that the street is parallel to the sea affect the existing ventilation there, explaining the values found there.



5. Comparative Study - Leipzig, Mumbai and Porto

5.1 Overview

It is really important to understand what are the characteristics of the cities that will be worked before being presented, so we will proceed to a short presentation of each of them.

The city of Porto is confirmed by 214 349, this number referring to 2016, which is the most recent year that Google assumes.Its population density: 5,165 inhabitants per km2 in total, with an urban area consisting of 41.42 km 2. The city of Porto, whose climate is Mediterranean type Csb, was considered a Unesco heritage.

In other way, Leipzig is located in the state of Saxony and thus in the eastern part of Germany, which has 84.1 million inhabitants at the current date. At the 31 of December 2021, the city had a population of 601,866 people and an area of 297.80 square kilometres (Statistisches Bundesamt, 2022).

Mumbai (Portfolio_Report_Mumbai_Annexes_Localização de Mumbai), formerly called Bombay, is the capital of the state of Maharashtra, located in Southwest India, with a Latitude - 18° 53' North and a Longitude - 72° 50' East. Being the most populous city in the country and the fourth most populous city in the world. It has an area, which spans about 619 sq. km. Mumbai currently has 20,961,000 inhabitants, showing an increase of 1.42% over the previous year (2021) and with a population density of approximately 73,000 per Km². (Mumbai Population 2022, 22 C.E.).

5.2 Characterization of Climatic Characteristics

5.2.1 Köppen-Geiger Climate Classification

The three cities are different climatically, so to get a better idea of the differences between the three, we will consider the Köppen-Geiger climate classification. We will see that Leipzig has a climate classification (Köppen-Geiger) of Ddb corresponding to a cold climate with no dry season and hot summers, while Mumbai has a very different type of climate, with a humid and dry tropical climate, Savanna (Aw). Porto at the other extreme, being in southern Europe, is closer to the climate found in Leipzig than in Mumbai. However, there are obvious differences with Porto having a Csb climate, agreed with Köpppen-Geiger, which is known as a Mediterranean climate with cool summers.

Based on the Köppen-Geiger Climate Classification (Beck, H. et al., 2018), Germany is located in 3 different climate zones (period 1980 - 2016). The northwest is predominantly characterised by a Cfb climate. This means that moderate temperatures prevail, there are no dry seasons and hot summers. In the middle of Germany there is a small area that is characterised by the Bsk climate. Here the climate is greatly influenced by the low mountain range in Germany called Harz. The climate there is steppe-like, arid and cold. This is because it is in the rain shadow of the mountains. Less than 100 km southeast of this area is Leipzig. Here, as in southern and northeastern Germany, the climate is characterised by a Dfb climate defined according to Köppen-Geiger. Leipzig thus lies, on average, in a rather cool climate with no dry season and hot summers. The difference between northwest and southeast Germany can be attributed to the warm Gulf Stream in the Atlantic Ocean. This still influences the climate somewhat in the northwestern part of Germany, due to its closer location to the Ocean. In the Leipzig area, however, it no longer has such a strong influence. The influence of the Harz mountains in central Germany also does not have a significant effect on the climate in Leipzig. For the future (2071 - 2100), Köppen-Geiger predicts a trend towards an increasingly arid, dry and hot climate. Consequently, Leipzig will be characterised by a Cfa or BSk climate in the future. This is similar to the climate that already exists in the Mediterranean in Barcelona, Spain, for example.

On the other hand, Mumbai (Portfolio_Report_Mumbai_Annexes_classificação do clima Mumbai) has a tropical wet and dry, savanna climate (Köppen-Geiger classification: Aw) with a pronounced dry season in the low sun months with no cold season, the wet season occurs in the high sun months. In the Köppen-Geiger AW classification (Mukherjee, 2005), the winter months are drier, with low precipitation, where in the driest month precipitation can reach less than 60 mm. In this type of climate classification during the winter months, due to low precipitation levels, the water balance is in deficit, while during the summer months, the water balance is generally in deficit. The summer months, on the other hand, are more humid, with high precipitation and there is an excess of water coming from the rains.

The climate of mainland Portugal, according to Koppen's classification, is divided into two regions: a temperate climate with rainy winter and dry and hot summer (Csa) and another temperate climate with rainy winter and dry and not very hot summer (Csb), consult Portfolio (Report_Porto_Climate characterization_"Koppen (IPMA)"), the city of Porto being included in the latter classification (IPMA). In this case, temperature variations are not usually of great order neither during the days nor during the year.

5.2.2 Climate Variation

Leipzig is located in the northern hemisphere. Summer begins here in June and ends in September. The average temperatures for the years from 1991 to 2021 (Portfolio folder Report_Leipzig_Annexes, Figure 1) range from 0.9°C in January to 19.7°C in July. Precipitation totals 723 mm per year. The most precipitation falls on average in July with 80 mm per year and the least in February with 44 mm per year. The lowest relative humidity (Portfolio folder Report_Leipzig_Annexes, Figure 2) over the year is in July (65.68 %). The month with the highest humidity is November (84.03 %). September has the fewest rainy days (10.23 rainy days), while December has the most rainy days (13.43 rainy days). The duration of sunshine hours per year was measured from 1999 to 2019 (Portfolio folder Report_Leipzig_Annexes, Figure 3). The month with the most sunshine hours per day is July with 11.1 hours and the month with the least sunshine hours is December with 3.1 hours per day. (Climate Data, 2022)

If we look at the average values for Leipzig last year (December 2021 to November 2022), we can see some trends (Portfolio folder Report_Leipzig_Annexes, Figure 4). The average highest temperature was 21.1°C in August and the lowest was 2.7°C in December. This is one month later and 1.4°C warmer compared to the annual average (1991 - 2021). The coldest month is one month earlier and 1.8°C warmer than the annual average. In addition, it

can be seen that the temperature fluctuations between the highest and lowest temperatures during the day are more distinctive in the summer months than in the winter months.
The total rainfall was drastically less last year compared to the annual average (Portfolio folder Report_Leipzig_Annexes, Figure 5). The total between December 2021 to November 2022 was 317, which is 405 mm less than the annual average. Even in July, where the most precipitation falls, it was 24.2 mm less than the annual average last year. In addition, a trend of the months with the least precipitation can be observed in the direction of the summer months. The lowest precipitation was in March, April and May with an average of 6.67 mm. This is 37.3 mm less than the annual average (Deutscher Wetterdienst, 2022).

In case, the climate of Mumbai (Portfolio_Report_Mumbai_Annexes_Temperatura) is hot and humid. There are four seasons. Cool weather prevails from December to February and hot weather from March to May. The rainy season, brought on by the monsoon winds from the southwest, runs from June to September, the so-called monsoon, and is followed by the post-monsoon season, which lasts until October and November, when the weather becomes warmer again. In Mumbai, the rainy season is oppressive, characterised by strong winds and overcast skies; the dry season is sultry and cloudless, But throughout the year, the climate is hot. Throughout the year, in general the temperature ranges from 19 °C to 34 °C and is rarely below 16 °C or above 36 °C. The warm season lasts for 1.4 months, from 13 October to 24 November, with an average daily maximum temperature above 34 °C. The cool season remains for 2.4 months, from July 3 to September 15, with average daily maximum temperature below, or at most 30 °C. The coldest month of the year in Mumbai is January, with a maximum of 19 °C and a minimum of 30 °C on average .
In Mumbai, the average percentage of cloudy sky (Portfolio_Report_Mumbai_Annexes_overcast sky Mumbai) suffers extreme seasonal variation throughout the year. The least cloudy season of the year starts around October 13 and lasts for 7.4 months, ending around May 25. The least cloudy month of the year in Mumbai is February, during which, on average, the sky is cloudless, near cloudless or partly cloudy 85% of the time. The most overcast time of the year starts around May 25 and lasts for 4.6 months, ending around October 13. The most overcast month of the year is July, during which, on average, the sky is cloudy or almost cloudy 84% of the time.

In contrast, Leipzig stands out for its drastically different temperatures, with a range of 26ºC between the minimum and maximum temperatures of the year and a variation of 11ºC of maximum temperatures recorded in each month and 12ºC of the minimum temperatures of each month. Finally, Porto is in a balance between these two cities, with a variation throughout the year of 18ºC and between months a variation of maximum and minimum temperatures, respectively, of 10ºC and 9ºC. Furthermore, it is worth noting that the maximum temperature recorded in Mumbai is 30ºC, in Leipzig 24º C and in Porto 24ºC, contrasting with a minimum temperature of all months of 19ºC, 6ºC and -2ºC, respectively. Porto also stands out for being the city with the most regular temperature range throughout the year.

5.2.3 Precipitacion

Of precipitation, Mumbai (Portfolio_Report_Mumbai_Annexes_Temperatura) stands out, with a maximum 593.5 mm of precipitation in July, and high values from June through September. Leipzig has the lowest precipitation values, with a maximum of 51.9 mm, but could have snow within 4 months (December through May). In addition, Porto has the highest precipitation values in October through May, with the first four months registering values above 112 mm of accumulated precipitation.

In Leipzig, when we have a look at the daily precipitation and temperature values in the months of October 2022 and November 2022 in Leipzig (Portfolio folder Report_Leipzig_Annexes, Figure 6), we can see a decreasing trend in temperature. The lowest daily average temperature was on 19.11.2022 with -3.6°C. The highest daily average temperature was 18.9°C on 17.10.2022.

No trend over the time period in precipitation can be determined (Portfolio folder Report_Leipzig_Annexes, Figure 7). However, a rain peak is clearly visible on 18.10.2022. It is the only rain peak with 18.9 mm precipitation on this day. All other days between October and November had rainfall below 8 mm per day. The day of the rain peak is only one day after the day with the highest average temperature (Deutscher Wetterdienst, 2022). A correlation can be seen between these two parameters. Due to the increased air temperature, the air was able to absorb and hold more water. Then, on 18.10.2022, the forces that could hold the water particles on the aerosols in the air collapsed and the strongest precipitation event of the two months occurred. This also resulted in a cooling of the surrounding air masses, as can be seen in the Figure 8 (Portfolio folder Report_Leipzig_Annexes).

In other away, in Mumbai the peak rainfall season lasts for 4 months, from June 5 to October 4, with a probability of rainfall occurrence, above 39%. The month with the highest number of days with rainfall in Mumbai is July, with an average of 23.1 days of the month where rainfall occurred and an average of 594 millimetres of rainfall per day, reached on July 16. The rainless period of the year lasts for 5 to 6 months, from November 11 to May 7, where the month with the fewest number of days with precipitation is January, averaging 0.2 days of precipitation. Across western India, extreme precipitation events have tripled from 1950 to 2015 due to increased atmospheric moisture thanks to the warming Arabian Sea(Chandrashekhar, 2022).

5.3 Characterization and Analysation of Geographic Characteristics

5.3.1 Geographic History of Surface Mines and Lakes

This topic is exclusively for Leipzig.

The *Leipziger Tieflandsbucht* (Lowland Bay of Leipzig) was formed in the Tertiary period. It is a basin in which weathering material was deposited. The warmer, wetter climate in the Tertiary period created forests that were regularly destroyed by floods. In the process, their wood was covered with sediments, which prevented decomposition. Due to the mountain pressure, lignite was formed from the wood. Loess deposits, which is drifting sand, from the Pleistocene were deposited in the foreland of the glaciations and are also widespread in the Lowland Bay of Leipzig. (Renneke, S., 2005)

It is mainly lignite and its surface mining that has strongly shaped Leipzig's landscape. There are 23 open-cast lignite mines in the vicinity of the city of Leipzig, some of which are still active today. Mining of lignite began in 1850 and was greatly intensified around 1930. In the period between 1945 and 1989, the open-cast mines moved towards the Leipzig city region from the south (Leibniz-Institut für Länderkunde, 2015). This had many consequences for the landscape and the climate. At times of very active mining, air pollution was very high. In addition, many ecosystems were partially or completely destroyed, such as parts of the Leipzig floodplain forest. Rivers and roads were rerouted and entire villages were resettled. In addition, there was also a high level of noise pollution due to the work in the opencast mines and a lowering of the groundwater level.

After the opencast mines were closed down, the holes were flooded from 1995 onwards. An extensive lake landscape was created. That is why Leipzig's surrounding area is also called *Neuseenland* (that means New-Lake-Area). There have been many renaturation measures and now a leisure and recreation area is being created around Leipzig. This also has an influence on the surrounding area. Air pollution is less, there are more water areas and more vegetation and animals. New healthy ecosystems are being created. At the same time, the probably largest solar park in Europe is being built in the region with an output of 650 megawatts (Leibniz-Institut für Länderkunde, 2015). It is being built only a few kilometres from Leipzig on recultivation areas of the disused open-cast mine.

These changes in the landscape have positive influences on the climate of the city of Leipzig. The loess deposits from the Tertiary period lead to high agricultural yields and good plant growth. This is why there are many large open spaces and a lot of vegetation in the area surrounding Leipzig. These influence the city climate. On the large open spaces, the air can flow freely and the temperatures at night can cool down better. In addition, the air quality is improved by the emergence of new ecosystems with more vegetation. They absorb CO_2 and donate oxygen and cool the surrounding air through evaporative cooling.

In the vicinity of the bodies of water created by the open-cast mines, the temperature rises more slowly, the wind is stronger, which results in good ventilation, and there is more precipitation in specific areas near to the lakes, which purifies the air of pollutants.

5.3.2 Analysis of Geographic Parameters

5.3.2.1 Hydrography

In the maps of watercourses in and around Leipzig, one can see a clear difference between the years 1850 and 2010 (Portfolio Report_Leipzig_Annexes folder, Figure 9). In 1850, the only major water occurrences in and around the city of Leipzig were rivers. The city lies in the middle of the confluence of the Weiße Elster, Pleiße and Parthe rivers (Stadt Leipzig, 2022). With the emergence of the lakes, due to the flooding of the residual holes that were created due to the open-pit mines, there is an expansion of the water network. Among others, the following lakes were created: Markkleeberger See, Cospudener See, Zwenkauer See, Störmthaler See and Kulkwitzer See (Wirth, C. et. al., 2020), as can also be seen in figure 10 from 2016 (Portfolio folder Report_Leipzig_ Annexes).

Mumbai, on the other hand, lies on the westernmost coastal outskirts of the state of Maharashtra in India (Portfolio_Report_Mumbai_Annexes_Temperatura). Surrounded by the western arm of the Indian Ocean, the Arabian Sea, on its three sides can be referred to as a mini peninsula, the city with an extreme coastal zone, is home to a large expanse of mangrove forests on its east and west coasts, 149 km long, with Thane District to the east, Palghar to the west and Raigad to the southwest. (Ramesh & Iqbal, 2022). The normal annual rainfall in the district ranges from about 1800 to about 2400 mm. It is minimum in the central part of the district around Kurla (1804.9 mm). It gradually increases northward and reaches a maximum around Santacruze (2382.0 mm). The area is drained by the Mahim, Mithi, Dahisar and Polsar rivers. These small rivers near the coast form small streams that mix with each other, resulting in swamps and mud flats in the lower areas.

Finally, we have, situated between the banks of the Douro and a short distance from the sea, Porto, presenting itself as a platform slightly inclined towards the Atlantic Ocean, limiting the city respectively to W and S the Atlantic Ocean (3. 6 km) and the Douro river (9.6 km), by E and N meets other municipalities of the metropolitan area of Porto (OLIVEIRA, 1973 in Monteiro. A; 1997). In addition, the proximity of the river Leça and the river Homem also stands out. Another interesting aspect is that the city of Oporto is located close to the embedded valley of the Douro, which is not usually found near the mouth.

In relation to the water bodies in or around the cities, the three studied have quite different characteristics, being Leipzig "cut" to several rivers and the presence of lakes and is located far from the sea, something very different from Mumbai and Oporto, since both cities are located by the sea. The former is almost surrounded by water from the Arabian Sea having some lakes and rivers entering the city, and Porto is located by the Atlantic Ocean and has the Douro River crossing its southern border. This reveals a great diversity of the relationship between our cities and water, and the climatic variations are produced by this relationship.

5.3.2.2 Hypsometry

In general, Leipzig is a city that sits above sea level at least 90 metres with altitudes of over 180 metres. The low-lying areas follow the courses of the rivers with the highest areas located in the north and southeast of the city. Mumbai, at the other extreme, being in contact with the sea, has very low areas with land at sea level, and the highest point rises to 55 metres above sea level. Porto shares some similarities with Mumbai, as both are coastal cities and have land at sea level, but in Porto the heights rise from west to east, reaching 180 metres above sea level. We will now perform a more detailed analysis. In the digital terrain model of the city of Leipzig (Portfolio folder Report_Leipzig_ Annexes, Figure 11), you can see that it lies between 90 m and 180 m above sea level. The low areas (blue) are due to runoff and calm waters in the surrounding area. The highest areas (brown) are the Seehausen embankment in northern Leipzig and the Monarchenhügel and Galgenberg hills in the southeast. In addition to the Seehausen embankment, the Fockeberg, the Möckern embankment and the Kleinzschocher embankment also have isolated elevations (Stadt Leipzig, 2019).

Mumbai consists of a low plain, which is flanked on the east and west by two parallel ranges of low hills. Colaba Point, is the promontory formed at the southern end by the largest of these ranges. The western ridge ends at Mount Malabar, which rises 55 metres above sea level, and is one of the highest points in Mumbai. Being an archipelago of islands, the relief and terrain was historically composed of coastal cliffs, hills and ridges with swamps in between, it had a total of 22 hills before the era of rapid development that has now left Mumbai with only three hills which are the Ghatkopar hills in the northern district, the Trombay hills, located in the southeastern part of the area in the middle of the dense built-up region and the highest Powai range, are found in the northern part of the city in the Borivali/Sanjay Gandhi National Park. From the elevation map of Greater Mumbai, it can be clearly interpreted that the study area is dominated by very low to low areas with elevations ranging from 0 to 35 m above mean sea level.

Porto, in turn, is territorially characterised by being a territory that slopes gently down to the W, towards the sea, with a strong embedding, to the South, of the Douro River valley and its tributaries, which exerts a striking action on the city by its embedded valley that gives it unexpected characteristics (PDM Porto, 2 revision; 2018), see map in the Portfolio (Report_Porto_Climate characterization_ Hipsometria_Porto (PDM)).

5.3.2.3 Wind Speed

Considering the aspects studied, it is safe to say that Leipzig's urban morphology shapes the way the wind blows through the city. It's a particularly important feature here since the other two cities have a strong sea influence on the wind pattern.
Wind speed within the urban area is influenced by the geometry of buildings and the slope of the land, as well as open spaces, trees and forests. Air temperatures, which cause areas of low and high pressure, play a decisive role here. In Leipzig, a wind field as shown in Figure 12 (Portfolio Report_Leipzig_Annexes folder) can be observed 2 m above the ground at 4 am (Stadt Leipzig, 2019). Relatively low wind speeds are noticeable near the rivers, in the city centre and at the highest point of the Seehausen embankment hill. These can be explained by various conditions. The alluvial forest is located near the river. This poses an obstacle (just like tall buildings in the city centre) and slows down the wind speed a bit. Also, high wind speeds occur at night, particularly in sloping areas. From a slope of one to two degrees, downdrafts settle after sunset. This phenomenon is determined by the temperature deficit of the surrounding air and the slope of the terrain.
The hourly average wind speed in Mumbai experiences significant seasonal variation over the course of the year. The windier time of year lasts for 2.9 months, from June 1 to August 30, with average wind speeds greater than 17.0 kilometres per hour. The windiest month in Mumbai is July where it was reached on 25th July 2022 where the wind was at its strongest reaching 23.1 kilometres per hour average speed. The calmer time of year lasts for around 9 months, from August 30 to June 1. The calmest wind month in Mumbai is October, with an average wind speed of 10.7 kilometres per hour.
The average hourly predominant wind direction in Mumbai varies throughout the year. The wind is most often from the West for 6.5 months, from March 22 to October 5, with a peak percentage of 96% on August 5. The wind is most often from the North for 2.3 weeks, from October 5 to October 21, and for 3.2 months from December 17 to March 22, with a peak

percentage of 40% on October 14. The wind is most often from the east for 1.9 months, from October 21 to December 17, with a peak percentage of 50% on November 7.
Completing the comparison, the port city stands out for the low wind gust speeds, revealed in Leipzig and Mumbai. Mumbai has the highest wind speed variation with values close to or above 20 km/h, the highest of the three countries. Finally, Leipzig records higher values than Porto, but assumes a more constant similar behaviour, with a maximum of 18.9 km/h in January.

5.3.2.4 Land Use

The land use is one of the important ways to understand the changes that humans did to the territories and these decisions affect the climate in the cities. In Leipzig it's possible to understand that urbanisation takes the city centre space with buildings, roads and rail tracks while the surrounding areas are destined to greener spaces, both natural or man made. Mumbai on the other side has a great part of its territory urbanised although with some green spaces in the southwest shore and in the north having the National Park Kanheri Caves. Porto has its bigger green space close to the sea, in the west, as Mumbai, and has other little green spaces sparse through the city, making the great majority of its land use being buildings and roads, with great impermeabilization of the territory.

Leipzig's land use is described via 16 different structure types, each of which has different physical characteristics. Accordingly, the land use classification for the city of Leipzig corresponds to the status as of 2017 (Portfolio folder Report_Leipzig_Annexes, Figure 13). In the city centre, the largest area is taken up by construction (industry, housing, retail) and road and rail traffic. If you look a bit into the surrounding area, you can increasingly see the use of green spaces (sports fields, forests, parks) as well as the rivers that run through the city. Particularly worthy of mention is the Leipzig floodplain forest, which covers an area of 5,900 ha near the river. This is the largest landscape conservation area in the vicinity (Engelmann, R., 2013). Further inland, the land use then increasingly changes to more open land and still waters. (Stadt Leipzig, 2019)

In the case of Mumbai, the dominant soil groups are Coastal Alluvium and Vertic Halaquepts (Soil-Inceptisols Group). These soils are shallow, poorly drained and thin soils on very gentle slopes on residual hills with slight erosion and slight traces of high salinity (Ramesh & Iqbal, 2022).Mumbai lies on a land dug out of the water. In the 18th and 19th centuries, British settlers levelled the hills of the small islands, mentioned earlier, which gave rise to what is now called the Mithi River estuary, using the resulting debris to unite the archipelago into a narrow peninsula on the northwest coast of India.

5.3.2.5 Number of hours with sun

Another aspect is the number of hours of sunshine received, both have the maximum reached in June and the minimum in December. Mumbai (Portfolio_Report_Mumbai_Annexes_Número de horas de sol) has the least amplitude in the number of hours received throughout the year (2h 30 minutes), and in 2022, the shortest day is December 22, with 10 hours and 59 minutes of sunlight. The longest day is June 21st, with 13 hours and 17 minutes of sunlight. In the case of Porto a range of 5h 8 minutes, and Leipzig stands out with a range of 8h 7 minutes (Report_Weather Spark Comparison).

5.3.3 Influence on the Temperatures

The regulatory equivalent temperature (PET) is based on the Munich Energy Balance Model for Individuals (MEMI), which models the thermal conditions of the human body in a physiologically relevant way, is a index that is most widely applied for several climatic conditions as well as serving varied practical thermal bioclimatic assessment needs (Matzarakiset al., 2010). Thus, it performs a balance of human body heat balance with the same core and skin temperature under the complex external conditions to be evaluated. Thus, even without extensive knowledge, it is possible to understand the integral effects of external thermal conditions on human comfort (P. Höppe; 1999).

The parameters mentioned above have a significant influence on the temperatures in the city of Leipzig. Temperatures vary significantly between day and night and the location within the city. In the following figures, the temperatures were taken 1.1 m above the ground at 2 pm (Portfolio folder Report_Leipzig_Annexes, Figure 14) and 4 am (Portfolio folder Report_Leipzig_Annexes, Figure 15). The temperature at day also refers to the physiologically equivalent temperature (PET). This is a thermal index to indicate heat stress. It is based on transferring the current climate values of the environment to a comparable indoor climate characterised by the same thermophysiological load. During the day, it can be seen that there is less heat stress in the area of flowing and still waters and in the area of the alluvial forest. In contrast, in the city centre, especially in the vicinity of the market square and the railway station, very high temperatures and thus high PET values occur. In addition, the temperature increases with increasing terrain height. At night, the surrounding area with its open spaces cools down considerably. However, the city centre maintains warm temperatures due to the built-up area, road traffic, industry and low winds. Especially near the main roads, the railway station, in densely built-up areas and the market place in the city centre, there is only a moderate exchange of air and little cooling. This can be explained by the phenomenon of the heat island city (Stadt Leipzig, 2019).

Mumbai's (Portfolio_Report_Mumbai_Annexes_Humidade Mumbai) high humidity in the summer season and temperature rather than radiation heat were factors causing high heat stress. In the monsoon season though temperature remains a dominant factor. However, during the monsoon in both seasons, radiant heat and sensible heat were formative in significant PET growth. Furthermore, despite the growth of urban centres, the population of these cities is exposed to increased thermal stress, which can deteriorate healthy living conditions and affect human performance (Desai; M; Et al; 2021).

More than observing the individual behaviour of each of the climatic elements in Porto, it is important to assess what the bioclimatic comfort conditions are. PET shows that the most common thermal discomfort is due to cold, although heat is also significant (31%). In addition, 22% of the days had comfortable conditions, and it is the period between November and February that has the highest percentage of days of discomfort because of could and August presenting the highest percentage of days of discomfort due to heat (PDM Porto, 2º Edição; 2018, p.20).

5.4 Vulnerabilities

Cities don't have the same problems, but there are some that are common. In the following subchapters, we will present some "urban evils", because we know that in the geography of climate risk, some places are more vulnerable than others, coastal megacities like Mumbai face the combined threat of rising sea levels and increased probability of events extreme climatic conditions, and it is important to also take into account the vulnerabilities.

5.4.1 Air Quality

The air quality in the cities are quite different between the two European cities and Mumbai, having the first two a similar moderate air quality through the year, although slightly better in Porto, where Mumbai shows a poor air quality, with the PM10 being a great worry to the city.
The rapid growth of cities like Mumbai in India in the 21st century can be largely attributed to rural-urban migration. Urbanisation or population growth has a major negative impact on air, water and soil quality.

Mumbai’s air pollution (Portfolio_Report_Mumbai_Annexes_Qualidade do ar) problem has a plethora of contributing factors such as emissions from vehicles or industry. However, Mumbai’s location helped keep the air relatively clean due to the strong winds from the sea sweeping the pollutants away (Sinha, 2022). So despite having a coastline, the deteriorating air quality has been linked to increasing pollutants from emissions, adverse weather conditions, and rapid construction. The level of PM 2.5 - fine particulate matter that can clog

lungs and cause a host of diseases - was recorded at 308 in December, 2022 ("Mumbai AQI: Air in India's Financial Capital Getting Worse Than Smog-Filled Delhi," 2022). In studies on air quality in Mumbai, it has been determined that maximum concentrations of all pollutants are mainly found during the months of December, January and February, i.e. before the monsoon season, while minimum concentrations can be found during the monsoon months of June, July and August (Kumar et al., 2016). This is not surprising since rainfall carries pollutants with it. The months after the monsoon period, on the other hand, denote a gradual increase in pollution levels. As can be seen in (Portwhich shows the Air Quality Index per day in Mumbai in 2022.
Since November of 2022, Mumbai has witnessed a significant drop in air quality where, towards the end of the month, the AQI stood at 215. For context, an AQI between 0 and 50 is considered "good"; 51 to 100 is "satisfactory", 101 to 200 "moderate", 201 to 300 "poor", 301 to 400 "very poor" and 401 to 500 "severe" ("Mumbai Air Quality Becomes Poor—Worse Than Delhi's | Weather. com," 2022).

The air quality in Leipzig is given as the Air Quality Index (AQI) per day. It is mostly classified in the "Good" category throughout the year 2022. The PM2.5 value is only in the "Moderate" category on 8 days per year and the PM10 value falls below the threshold for good air quality on only 6 days per year. year (Leipzig Mitte Air Quality Index, 2022). If you look at the distribution within the city, you will only see small differences within the city. The AQI ranges from 10 to 20 AQI (PlumeLabs, 2022).

In case of Porto, the AQI is moderate, being around 20-30 AQI (PlumeLabs, 2022), it is therefore higher than the maximum limit established for one year by the WHO. Throughout the year, this category generally remains, with two exceptions: better and worse air quality. And although there were days with worst air quality, these were fewer than those with better quality.

5.4.2 Flood problem

Flood problems are common in Mumbai. As their populations expand, paving permeable soil for houses and roads further increases the risk of flooding. As the number of cyclones coming from the Arabian Sea increases, the sea level will also increase and the city continues to spread over floodplains and hills. For example between 1991 to 2018, the city lost 58% of its already limited open space (Chandrashekhar, 2022). Especially during the monsoon period (Ramesh & Iqbal, 2022) due to the heavy rainfall that occurs during this time period, climate change is already affecting the central belt of India from Mumbai to

Bhubaneshwar, as demonstrated by the three-fold increase in heavy rainfall events from 1901 to 2015. Sometimes these can last for 2-3 days and paralyse cities even longer. This is due to antiquated drainage systems, as Mumbai's storm drainage was installed in the early 1900s with a maximum flow rate of 25 millimetres per hour. Which is insufficient at certain times, to cope with the amount of rain that hits the surface (Mulhern, 2020).

5.4.3 Water pollution

This topic is exclusively for Mumbai.

Pollution of groundwater as well as surface water is a major problem in Mumbai. Groundwater is of such poor quality that the government prohibits its use for personal and domestic consumption. Rivers in the region are often used as a dumping ground for sewage and industrial effluents.
The Maharashtra Pollution Control Board (MPCB) data indicates concentration of Mercury (Hg) higher than the permissible limit as well as other health hazardous metals like Arsenic (As) observed in fish from Thane and Chembur, lead and copper (SOURABH GUPTA, 213 C.E.) was also found in the river waters.

5.4.4 Heat islands

The analyses have shown that the city of Leipzig is strongly affected by both climate change and the heat island phenomenon and will remain like this in the near future. This has negative impacts on people, animals and plants. On this basis, a climate emergency was declared by the city council of Leipzig in 2020 and a plan with immediate measures was drawn up (Stadt Leipzig, 2020). In addition to political measures, there are also many initiatives and small organizations that want to improve and protect the city's climate. These include many small student associations, climate activists as private individuals, but also the projects of a cycling city (Stadtradeln, 2020) and Ökolöwe (Umweltbund Leipzig, 2022) for example.
Porto, like show for Ana Monteiro in “O clima urbano do porto”, is other example of city that apresent a urban heat island, there is a type of interdependence existing between the intensification of the urbanization phenomenon and the local and regional climate, modification of the final result of the energy balance equation.

7. Discussion of the results obtained

7.1 Porto

The best way to understand the influence of the winds is to analyze the situation recorded on October 11 (Map. 1 e 2), the weather station records on that day, from 9 am until 9.30 am winds that evolved from NE to NW, and as is noticeable the streets described here present a higher speed of air flow. However, reflecting the change in wind direction to NW, a significant air flow is already present, in places that are "protected" to the west by buildings. In the evening, with winds in the NNW and NW direction, it can be seen that despite the low wind speed, a greater velocity is perceptible along the street. Furthermore, if we think of the street as an air channel, with NW winds, we would see a similar air circulation along the entire street. However, as the flow advances along the street it will encounter obstacles, such as the trees located in the northwestern part of the street act as obstacles, so it is common to see air flows with higher velocity on one side of the street. And you will also find intersections between streets, places where the airflows are "attracted" and diverted from their normal flow, resulting in air leaks and often an increase in velocity. This factor explains, among other things, that after the intersection with the standard street there is no regularity in the flow.

It is also important to note that in a path characterised by a highly impermeable and highly artificial soil, energy retention and consequent temperature increases are processes that occur much more easily, as described by Ana Monteiros, 1997. As such, higher temperature values are recorded in the late afternoon, because the street is under the influence of the release of accumulated heat, visible more easily consulted the values of each point (portfolio_Report_Porto_Measurements) comparing the part of the street under the influence of the shade of trees and the measurements recorded at points 22 to 40. That way, the trees prove to be important in the microclimate of this street, since it is essentially at the end of the street, where there are no trees, that the temperatures are higher, as they absorb or do not allow solar radiation to pass through.

In terms of the colours of the buildings, light colours such as beige, blue or white dominate with small exceptions, thus favouring larger albes along the street that guarantee a high reflection of the energy that arrives there.

Finally, a constant that was verified is that points 1, 2 and 3 in the measurement at the end of the afternoon always had higher temperatures, which is due to the sky view factor of that location and the position of the sun at that time, since the buildings of the Sea side are lower and the sun shines from the west which allows reaching those points with direct solar radiation, being that every day it is the last place on the street to receive solar radiation.

It is also important to consider that the west side of the street registers, in the morning, the highest values because it also receives the first sun rays of the day, perceptible if we consider the natural movement of the sun, the orientation of the street and the incidence of sun rays.

7.2 Leipzig

The city of Leipzig and its surrounding area are affected by both climate change and the phenomenon of the urban heat island. The comparison of climate parameters between today and the long-term average shows a strong tendency towards a drier and warmer climate. In addition, we have seen that the warm temperatures in the city centre cannot cool down sufficiently even overnight. There are many reasons for this. Among other things, it is due to the dense development in the city centre, which prevents wind circulation, too much traffic from motor vehicles on the main roads, the large railway station in the city centre and not enough forest and water areas to compensate.

The city of Leipzig and its residents are aware of these problems and are formulating measures to sustainably protect the city's climate.

7.3 Mumbai

Considering the climate of Mumbai, the biggest hurdle the city faces is withstanding the effects of floods during the wetter season. Studies have shown a trend of rising temperatures over a century in the summer months and an increase in annual mean precipitation by 1.5mm/decade (Mohammad & Goswami, 2019). Apart from flooding, air pollution is also something that the city has to immediately rectify. Normally, the city was at an advantage, being a coastal city, that the sea breeze would sweep away all the pollutants away from the city and usually stagnant air would only stay for a day or two. However, in recent years, one can notice the trend of stagnation lasting for a week instead. Recent studies show that this is due to changing wind patterns and rising emissions (Sinha, 2022).

Wind speeds have declined significantly this year and this phenomenon merits further investigation. The cyclical pattern of wind moving from the sea to land and vice versa has been altered and has resulted in pollutants remaining in the air over the city for over a month. Vehicular emissions and rapid construction are major contributors to PM 2.5 and PM10 pollutants (Sinha, 2022). Unfortunately, these high levels of pollution already have shown adverse effects on human health and doctors in the city have advised people to wear a mask to filter out the pollution. Local hospitals have seen a spike in cases coming in for breathing difficulties and this has forced the civic body to issue a statement about taking urgent steps to improve air quality ("Mumbai AQI: Air in India's Financial Capital Getting Worse Than Smog-Filled Delhi," 2022).

Relative humidity in Mumbai is about 75% although it varies from 62% in December to 89% in July. They're both the least and most humid months of the year respectively (*Relative Humidity Data of Mumbai*). Now, we have established that the city is next to the Arabian Sea and witnesses the South West Monsoon so it's safe to conclude that humidity is consistently high in the city regardless of the time of year.

The government has initiated the Mumbai Climate Action Plan with the chief aims of setting tangible emission reduction goals for the city, creating a 'climate profile', and defining ecological features of the city. The plan also aims to identify vulnerable communities that are most impacted by the effects of climate change and to increase resilience by introducing sector-specific strategies for mitigation and adaptation. It outlines specific activities that can be undertaken to meet emission goals of the Paris Agreement. It is India's first climate action plan to set net zero targets for 2050 (*MCAP*).

8. Limitations and future developments of the work

In this work, the limitations can be divided into two groups, the first for the study of Porto and the street and the second related to the study of Leipzig and Mumbai.

In the first, the limitations were related to the fact that the measurements performed only reflect a few moments of the day, and we felt that, in order to better understand the climate system, we missed measurements performed, for example, at noon and mid-afternoon. Another limitation are the days of precipitation, in a relatively short period of time, they significantly reduced the data we had available to work with, even if in many cases we went outside and waited for a moment with no rain, the humidity was too high to use the devices without risking damage. In addition, in the future we would like to understand what would be the climatic behaviour of a busier street or a street farther from the ocean, with more time to understand patterns and anomalies.

The second group of limitations are related to the difficulty of access to information from Leipzig and Mumbai, making it impossible to perform a proper cartographic representation or even a more localised study of the phenomenon. In comparison of the 3 cities de datas taken for the same period of time is another difficulty. Naturally, in the future we would like to make a study similar to the one carried out in Gondarem street in the spaces of these cities.

9. Conclusion

In this work, three cities are presented that are very different from each other, and it is normal to see many climatic disparities, relations, and similarities. As we saw in the first chapter, it is necessary to understand that the existing variability is natural within the cycle of irregularity intrinsic to the climate system. Furthermore, the climatic characteristics of these cities see an impact of the pressures on the environmental components, both in terms of the direct exploitation of natural resources, and in terms of the degradation of their quality. It is important to emphasise here that the manifestations of Global Warming are felt particularly in temperate latitudes, exerting different influences on these three cities.

Thus, each city presents its own characteristics, and in the specific case of Porto, it is remarkable that even on a smaller scale (Gondarem Street) one can feel the impacts of relations and the different impact of factors on the stability and conditions of the Climate System.

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