

# Analysis of urban expansion and its relationship with climate change in Huancayo 1969-2019

Kiara Chihuan<sup>1\*</sup>, Michelle Mollehuara<sup>1</sup>, Cristhian Quispe<sup>1</sup>, Jennifer Condori<sup>1</sup>, and Jose Cornejo<sup>1</sup>

<sup>1</sup>School of Environmental Engineering, Faculty of Engineering, Universidad Continental, Huancayo, Peru

**Abstract.** In recent decades urban expansion has indicated changes in the atmosphere and land. This article aims to analyze the relationship between urban expansion and climate change in the city of Huancayo in the period 1969-2019. Annual meteorological data from SENAMHI, demographic data from INEI for urban and rural population, and satellite images for land use change were used, and the Pearson correlation model was applied. From this, it was obtained that the average temperature suffered an increase of 1.87 °C, and the accumulated annual precipitation remained at constant peaks. In the case of the population, the urban zone presented an increase of 37.12% and in the rural zone a decrease of 50.57%. On the other hand, the change in land use was categorised into 6 classes, resulting in the following growth rates for the urban zone 2% and the agricultural zone 0.2%, in contrast to the forest zone, which showed a decrease of 0.7%. Finally, the analysis shows a strong direct correlation between the variables of mean temperature-urban and agricultural expansion ( $r= 0.646$  and  $r= 0.278$ ) with a significance of ( $\alpha= 0.05$ ). Therefore, it is necessary to implement urban planning measures in a context of climate change.

## 1 Introduction

In recent years, rapid urbanisation has been observed on planet Earth, although this only accounts for less than 3% of the entire global land surface [1]. Urbanisation is known to be a process of alteration from a rural society to a life of urban civilisation [2] and the world's urban population is predicted to reach 6.68 billion by 2050 and the land is expected to expand by 0.36 to 0.74 million km between 2015 and 2100 [3].

Urbanisation has had a detrimental impact on the regional climate, soil, and vegetation growth, reducing vegetation cover and decreasing carbon sequestration capacity, thus making the locality more vulnerable to the effects of climate change.

The Intergovernmental Panel on Climate Change (IPCC) [4] predicts that if temperatures rise above 1.5°C, climate change impacts will become more frequent, more difficult for society and biodiversity to cope with and adapt to. These effects of climate change have been observed to a greater extent in cities around the world, which have had to declare a climate

---

\* Corresponding author: [73605415@continental.edu.pe](mailto:73605415@continental.edu.pe)

emergency due to increased heat waves, strong winds, frost, floods and other events [5]. In addition, one of the main sources of greenhouse gases comes from urban areas, as they generate higher carbon (fossil energy) emissions due to the increase in land used for urban purposes.

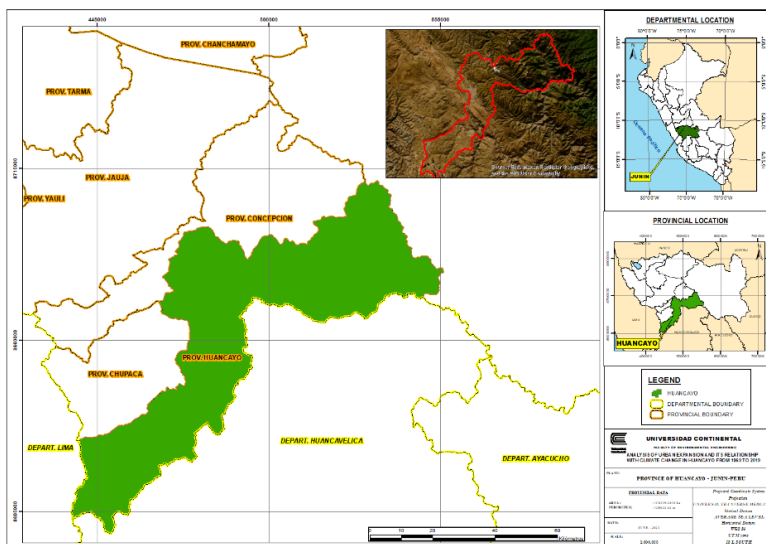
According to the Ministry of the Environment [6], Peru is positioned as the third most vulnerable country to climate change, and has suffered serious consequences in recent years. Although there are regulations for adaptation and mitigation in the face of this climate emergency, these strategies are focused on the energy, agriculture, fisheries, water, forestry, health and aquaculture sectors [7,8], as none of them are centred on urban growth. In recent years, low temperature risk scenarios have been observed in the provinces of the department of Junín, one of the most affected is its capital, the city of Huancayo, known as "The Incontrastable City [9], which is home to the largest number of inhabitants with 545,615 people, accounting for 43.6%, according to the National Institute of Statistics and Informatics (INEI). Currently, it continues to increase at an annual rate of 1.6% [10], which causes open areas and forests in rural areas to be replaced by housing and socio-economic activities without any planning by the Regional Governments, mainly damaging the loss of vegetation cover, causing higher temperatures known as the urban heat island effect and increasing rainwater runoff that causes flooding [11].

So far, there is not enough research or studies in Peru on the consequences of urban sprawl on climate change on a regional scale. Therefore, the main objective of this research is to analyze the relationship between urban sprawl and climate change in the city of Huancayo in the period 1969-2019, with this research can encourage local, regional and national governments to take action on adaptation and mitigation of cities to the effects of climate change, and promote the creation of public policies and urban development plans for the construction of environmentally healthy and sustainable cities, which is of utmost importance.

## **2 Methods**

### **2.1 Study area**

The case study was carried out in the province of Huancayo, located in the department of Junín which is situated in the central highland region of the country, on the Andes mountain range, between latitude South 12° 4' 5" and longitude West 75° 12' 38" with a total surface area of 373359.25 hectares, with an average altitude of 3300 m above sea level [12], see Fig. 1. Its geography is shaped by the Mantaro River and constitutes one of the widest valleys in the Peruvian Andes, classified as having five types of climates which are: semi-dry with abundant humidity all seasons of the year (temperate), semi-dry with dry autumn and winter (cold) and rainy with dry autumn and winter (cold), semi-arid with dry winter (temperate), semi-dry with dry winter (temperate). Thanks to this, there is a variety of plants, wild animals, watersheds, and natural Andean grasslands. It is also the most developed in terms of urbanisation and occupies 90% of the population of the department of Junín.



**Fig 1.** Location of the Province of Huancayo

## 2.2 Compilation of climate information

The information collected from annual meteorological data was obtained from the National Service of Meteorology and Hydrology of Peru (SENAMHI) from the Huayao station in the period of 1969-2019 for a total of 50 years. The climatic parameters: average temperature and precipitation were chosen to compile the annual data of the province of Huancayo and its change in climate, these data were worked in Microsoft Excel and their respective correction was made in this system, in addition to the elaboration of graphs corresponding to precipitation and average temperature for their subsequent analysis.

## 2.3 Demographic data

The demographic data were obtained from the National Institute of Statistics and Informatics (INEI) in charge of population censuses, population estimates and projections, the results of the Basic Demographic Indicators at the municipal level are published several months after the end of the year [13,14]. We worked with urban and rural population variables, which were analysed in Microsoft Excel software from 1981 to 2017, calculating projections for each year based on the growth rate of each census (Table 1) to obtain more accurate data.

**Table 1.** Population Growth from 1981-2017.[14]

| YEAR | URBAN  | % URBAN GROWTH RATE | RURAL | % RURAL GROWTH RATE |
|------|--------|---------------------|-------|---------------------|
| 1981 | 230711 | 71.70%              | 90838 | 28.30%              |
| 1993 | 342843 | 78.40%              | 94548 | 21.60%              |
| 2007 | 399741 | 85.70%              | 66605 | 14.3%               |
| 2017 | 503674 | 92.30%              | 41941 | 7.7%                |

## 2.4 Satellite image data

The satellite images were obtained from the USGS Science for a changing World Platform, from Landsat 5, 7 and 8 satellites [15]. To select the Landsat images, some characteristics were considered such as: Minimum cloud cover (<10%), dry season in the Junin Region (May to November), from the years 1990, 1999, 2007, 2014, 2018 (Table 2). To obtain more realistic data, a radiometric correction was performed on the satellite images using the calibration coefficients in order to eliminate distortions detected by the sensor [16]. Satellite image processing and radiometric corrections were performed in ArcGis software.

To interpret the Landsat images and classify land use types, the Corine Land Cover classification system [17] (cultivation area, urban areas, forest, water bodies, wet areas, snowy and little or no vegetation), and current Google Earth images and the ecological and economic zoning map (ZEE) of the Junin Region of the Ministry of Environment were used for the accuracy of the land use classification.

**Table 2.** Data from the satellite images [15]

| Year | Satellite Image           | Date of Acquisition | Image ID              |
|------|---------------------------|---------------------|-----------------------|
| 1990 | Landsat 4-5 TM C1 Level-1 | 13/08/1990          | LT50060691990225CUB00 |
| 1990 | Landsat 4-5 TM C1 Level-1 | 13/08/1990          | LT50060681990225CUB00 |
| 1999 | Landsat 4-5 TM C1 Level-1 | 06/08/1999          | LT50060681999218CUB00 |
| 1999 | Landsat 4-5 TM C1 Level-1 | 07/09/1999          | LT50060691999250COA03 |
| 2007 | Landsat 4-5 TM C1 Level-1 | 09/07/2007          | LT50060682007160CUB00 |
| 2007 | Landsat 4-5 TM C1 Level-1 | 09/07/2007          | LT50060692007160CUB00 |
| 2014 | Landsat 8 TM C1 Level-1   | 14/07/2014          | LC80060682014195LGN01 |
| 2014 | Landsat 8 TM C1 Level-1   | 14/07/2014          | LC80060692014195LGN01 |
| 2018 | Landsat 8 TM C1 Level-1   | 23/06/2018          | LC80060692018174LGN00 |
| 2018 | Landsat 8 TM C1 Level-1   | 27/06/2018          | LC80060682018158LGN00 |

## 2.5 Statistical analysis

The statistical analysis was elaborated in the IBM Statistical Package for Social Sciences (SPSS) version 25 under a correlation model between the variables: climate (average temperature and precipitation), and demographic data (urban-rural population, and agricultural area-urban area) to find the relationship between them. The correlation model used was Pearson's correlation because the variables have a normal distribution. In addition, Microsoft Excel software was used to verify the results obtained in the IBM Statistical Package for Social Sciences (SPSS).

## 3 Results and Discussion

### 3.1 Climatological data

#### 3.1.1. Temperature

Fig. 2 shows the average temperature data (°C) obtained from the National Service of Meteorology and Hydrology of Peru (SENAMHI), showing proportional variations over the years with a linear adjustment with a positive slope for the temperature. In the year 1998 the

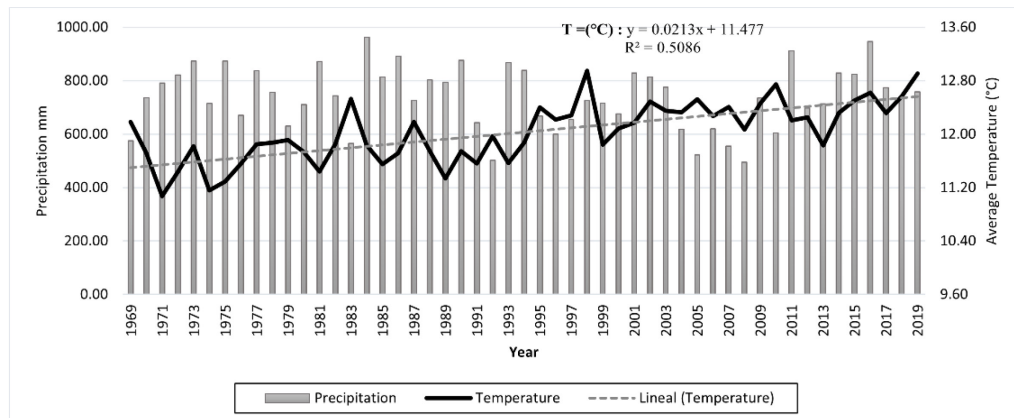
highest temperature recorded was 12.95 °C, while in 1971 the lowest temperature was 11.07 °C.

### 3.1.2. Precipitation

Fig. 2 shows the annual accumulated precipitation data, in the time periods 1973, 1975, 1981, 1984, 1990, 1993, 2011 and 2016 there were a greater number of precipitation events compared to other years. The year 1984 recorded the highest incidence of precipitation with an average of 961.90 mm, while the year with the lowest incidence was 2008 with an average of 493.90 mm.

### 3.1.3. Average temperature vs. annual cumulative precipitation

Fig. 2 shows a positive relationship according to their degree of correlation, on the side of the average temperature a moderate growth trend is observed, reaching a maximum of 12.91°C in 2019, while on the side of the annual accumulated precipitation a slow and long-term trend is observed with a total of 758.40 mm for the same year.



**Fig. 2.** Annual cumulative rainfall vs average temperature data from 1969 to 2019.

## 3.2 Urban and rural

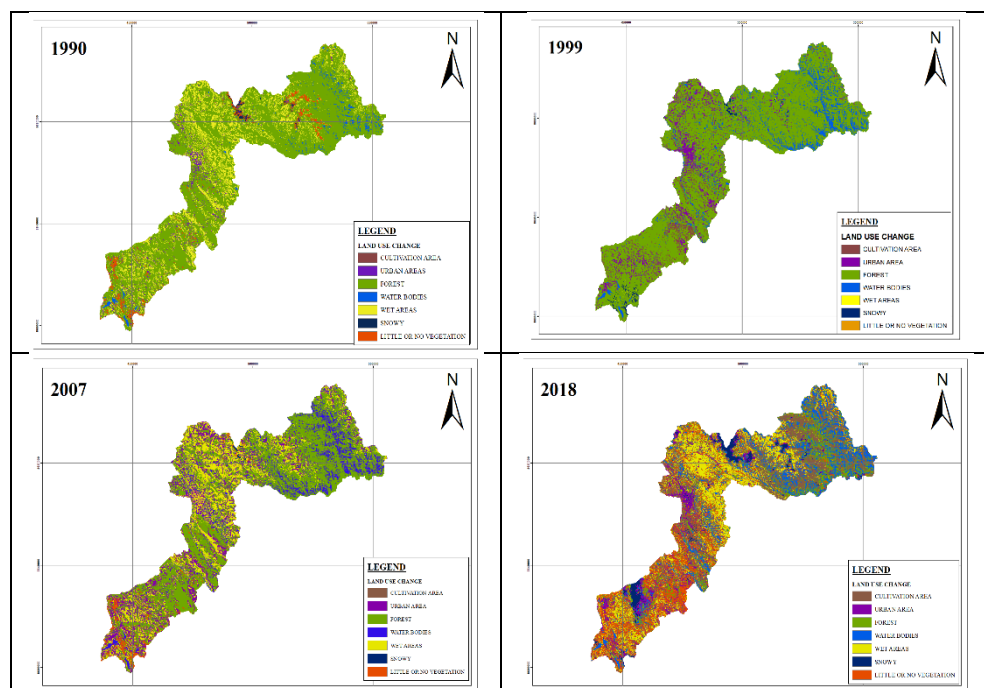
Regarding the population growth in the city of Huancayo from 1972 to 2017, it has been categorised into urban areas (industries, commerce, constructions) and rural areas (agricultural areas, communities, population centres), the general trend for the urban area shows a linear increase over the years representing an increase of 37.12%, the smallest amount was 186976 people in 1972 compared to the year 2017 in which a higher population was obtained, with 503674 inhabitants. On the other hand, the variation of change in the rural area shows a slight decrease in the period 1972 - 2017 representing a loss of 50.57%.

## 3.3 Spatio-temporal variation in land use change area

The classified Landsat images of the years 1990, 1990, 2007, 2014 and 2018 were represented in 6 classes (cultivation area, urban areas, forest, water bodies, wet areas, snowy and little or no vegetation), indicating an acceptable accuracy. The areas of urban expansion found in this period were: 6036.52, 6810.2793, 7306.65, 7949.34, 8060.33 in ha, it could be

observed that the highest growth rate was recorded in 2008 with 2% and the lowest in 2018. Regarding the cultivated areas were: 172202.5713, 176389.6655, 179200.9778, 180305.9982, 180826.8103 in ha, for this case, the year 1999 represented the highest growth rate with 0.2%, compared to 2014 which recorded the lowest rate with 0.05%.

In relation to forest areas, the results obtained were: 178788.7059, 172476.0846, 168897.1625, 166827.4723, 166107.7552 in ha, showing that the rate decreased by 0.7%. The change of land use and vegetation cover in Fig. 3 shows that urban expansion has been increasing in a higher percentage than cultivated and forest areas, centred in the provinces of Huancayo and Chupaca. Likewise, Fig. 3 illustrates that the areas destined to forests in the period 1987-2012 were replaced by cultivated areas in 2018.



**Fig. 3.** Land use change from 1990 to 2017.

### 3.4 Correlation between urban expansion and climate change

#### 3.4.1. Correlation between population growth and climatological variables

Pearson's correlation between the variables of population growth and mean temperature showed a direct correlation with a p-value of 0.00001 at a confidence level of 95% and a high coefficient of determination ( $r = 0.646$  and  $R^2 = 0.45$ ). On the other hand, there was no relationship between precipitation and population growth, because a p-value of 0.155 was obtained, being higher than the confidence level ( $p\text{-value} > \alpha$ ) with a determination coefficient ( $R^2 = 0.1261$  and  $r = 0.0159$ ).

#### 3.4.2. Correlation between land use change and climatological variables

First, we worked with the variables of forest, agricultural area, and urban expansion, obtaining an indirect ratio relationship with a p-value of less than 0.1, presenting a semi-perfect coefficient of determination ( $r = -0.998$  and  $R^2 = 0.996$ ). In the case of urban

expansion, we worked with Spearman's test because it was a non-parametric correlation, in which we obtained a ratio indirectly and a p-value of less than 0.1 at a confidence level of 99%, presenting a perfect relationship, with a coefficient of determination ( $r=-1$  and  $R^2 = 1$ ).

Cano et al identified potential urban expansion zones from Landsat images from 2000 to 2014, from which they obtained two cartographic maps, one of urban coverage distribution and the other of the municipalities with the greatest expansion, resulting in an increase of 72.3 km<sup>2</sup> with an average growth rate of 1.8% per year in the state of Hidalgo [17]. Costa et al. (2022) conducted an analysis with satellite images from 1985, 1993, 2006 and 2015 where they used a Maximum Likelihood Supervision classification and worked with the population from 1960 to 2010, obtaining as a result that the urban area tripled in Macapá, since in 1985 it occupied 18.92km<sup>2</sup> and in 2015 it already represented 65.87km<sup>2</sup> [18] Mendes et al. (2020) used satellite images from 2000 to 2019 to verify the increase in the temperature of the ground surface in a large part of the city of Santiago, especially on bare ground, which reached a temperature of 50°C [19]. In our study, the results obtained demonstrate the increase in average temperature, due to urban and agricultural expansion, and the decrease in forests, since a significant correlation between the variables was obtained. Which coincides with the article of Mansouri et al. (2019) used a correlation test to statistically evidence the effect of urban expansion on climate for this they employed a relationship between four climate parameters (surface temperature, surface longwave flux, total ozone and black carbon density) and urban expansion based on three time sequences in the study area with this they obtained a positive relationship with result where R ranges from 0.827 to 0.981 [20].

At the research level, it contributes to the socio-environmental sector to promote and establish lines of mitigation and adaptation to the climate crisis [21, 22], mentions the importance of rational allocation of population and natural resources to contribute to the potential for economic and social development at a regional level under appropriate political systems. Indicating that the concept of "Territorial Planning" has not been correctly established worldwide and that there are no climate-related planning regulations in Peru, Krishnan S.'s study focused on long-term urban planning proposals for climate uncertainty in two case studies in Amsterdam and Mumbai, resulting in four propositions that should be taken into account for a better understanding of urban planning [23].

## 4 Conclusions

For the period 1969 - 2019, an analysis of meteorological variables such as precipitation and average temperature was carried out in the province of Huancayo. In the case of precipitation, the results showed a slow trend of increase throughout the period, obtaining a total annual accumulated precipitation of 758.40 mm, while the average temperature showed an increase of 1.87°C throughout the period, with an average linear trend. On the other hand, the demographic data obtained show an increase of 37.12% in the urban population, while the rural population showed a decrease rate of around 20%. Satellite images for the years 1990, 1997, 2007, 2014 and 2018 indicated a higher urban and agricultural growth.

Correlation and determination analyses also showed a strong link between temperature and urban growth variables ( $r= 0.646$  and  $R^2=0.45$ ). In recent years, the migration of the rural population to urban areas has led to increased housing construction, higher greenhouse gas emissions and land degradation. Without any urban development plan or regulations to regulate urban expansion and include adaptation and mitigation of cities to the problems we are experiencing, the effects of climate change will be more severe and detrimental to the entire region in social, environmental, and economic terms.

## References

1. Z. Qin, Z. Sha, *Modeling the impact of urbanization and climate changes on terrestrial vegetation productivity in China by a neighborhood substitution analysis*, *Ecol, Modell* **482**, 110405 (2023)
2. M. R. Mansouri Daneshvar, G. Rabbani, S. Shirvani, *Assessment of urban sprawl effects on regional climate change using a hybrid model of factor analysis and analytical network process in the Mashhad city, Iran*, *Environ. Syst. Res* **8**, 1 (2019)
3. Y. Zhou, M. Chen, Z. Tang, Z. Mei, *Urbanization, land use change, and carbon emissions: Quantitative assessments for city-level carbon emissions in Beijing-Tianjin-Hebei region*, *Sustain. Cities Soc* **66**, 102701 (2021)
4. Intergovernmental Panel on Climate Change, *La acción climática urgente puede garantizar un futuro habitable para todos* (2021)
5. Organización de las Naciones Unidas, *Las ciudades, 'causa y solución' del cambio climático*, Noticias ONU (2019)
6. Ministerio del Ambiente, *Cambio climático y Desarrollo Sostenible en el Perú* (2018)
7. Ministerio del Ambiente, *Catálogo de medidas de mitigación* (2018)
8. Ministerio del Ambiente, *Plan Nacional De Adaptación Al Cambio Climático* (2012)
9. Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres. *Escenario de riesgo por bajas temperaturas del departamento de Junin* (2022)
10. Instituto Nacional de Estadística e Informática, *Resultados Definitivos*. (2018)
11. Q. Yu, L. Xie, L. Dong, N. Cheng, Y. Liu, *A conceptual framework for riparian green space planning in mountainous cities*, *Energy Reports* **9**, 499–513 (2023)
12. Municipalidad de Huancayo, *Huancayo en la region de Junín - Municipio y municipalidad de Perú* (2017)
13. Instituto Nacional de Estadística, *Indicadores Demográficos Básicos Metodología Índice* (2021)
14. Instituto Nacional de Estadística e Informática, *Perfil Sociodemográfico*, **4** (1993).
15. G. Chander, B. L. Markham, D. L. Helder, *Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors*, *Remote Sens. Environ* **113**, 893–903 (2009)
16. Copernicus, *CORINE Land Cover — Copernicus Land Monitoring Service*, Land Monitoring Service-COPERNICUS, (2018)
17. L. Cano Salinas, R. Rodríguez Laguna, J. R. Valdez Lazalde, O. A. Acevedo Sandoval, R. I. Beltrán Hernández, *Detección del crecimiento urbano en el estado de Hidalgo mediante imágenes Landsat*, *Investig. Geogr* **92**, 1–2 (2017)
18. P. Loge, E. Fonseca, A. Silveira, *The urban expansion process and its impact on the vegetation cover of Macapá*, *Rev. Bras. Geogr* **1**, 758–769 (2021)
19. F. H. Mendes, H. Romero, D. Ferreira da Silva Filho, *Cambio Climático adverso provocado por la urbanización sin planificación ni evaluación ambiental en Santiago de Chile*, *Rev. Geogr. Norte Gd* **210**, 191–210 (2020)
20. Y. Yan, C. Wu, Y. Wen, *Determining the impacts of climate change and urban expansion on net primary productivity using the spatio-temporal fusion of remote sensing data*, *Ecol. Indic* **127**, 107737 (2021)
21. C. Wu, A. D. Jiang, W. Zheng, *Study on the Measures for Optimizing China's Provincial Territorial Space Based on the Perspective of Resource and Environmental Carrying Capacity in the New Situation*, *Sustain* **14**, 1–21 (2022)



22. M. Suppala *et al.*, *Climate and land-use change drive population decline in a red-listed plant species*, *Glob. Ecol. Conserv* **45** (2023)
23. S. Krishnan, N. Y. Aydin, T. Comes, *RISE-UP: Resilience in urban planning for climate uncertainty-empirical insights and theoretical reflections from case studies in Amsterdam and Mumbai*, *Cities* **141**, 104464 (2023)