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CLIMATE CHANGE AND URBAN SUSTAINABILIY OF CHILEAN METROPOLITAN CITIES

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Abstract

Cities are at the same time cause and effect of climate change. Climate Change processes and effects should mainly affect Latin American cities, where most of the population and economic activities are concentrated. Urban climate changes are associated to urban heat island generation and development, and to hydrologic cycle alterations, particularly in terms of Area Total Imperviousness and Runoff Coefficients caused by watershed urbanization. City climate changes are a result of urban sprawl process that affect Chilean Metropolitan Areas (Valparaíso and Santiago). Land use/cover changes related with development of urban heat islands and micro-islands are analyzed in Santiago city on the basis of satellite images and measurement mobile transects. Changes in total imperviousness and runoff coefficients linked to urban sprawl are presented like main outcomes of Valparaiso expansion over hills and streams. Finally, spatial relationships between air temperatures, air pollution and socioeconomic population levels are used to demonstrate that urban climate changes have strong social components and that they are part of the socioenvironmental segregation that characterize Latin American cities.

Introduction

Cities are at the same time cause and effect of climate change. Climate Change processes and effects should mainly affect Latin American cities, where most of the population and economic activities are concentrated. Heat waves, natural hazards and a lack of available drinkable water could be predicted everywhere. Simultaneously, Latin American cities concentrate greenhouse gases sources and their industries and vehicles produce large amounts of Carbon Dioxide, hydrocarbons, methane and other warming pollutants to the atmosphere. Additionally, cities are themselves a relevant heat source due to the continuous functioning of motors that move their industries, transports, and domestic heaters, and specially because the generation of urban heat islands.

Urban spaces are a complex mosaic of heat islands as a consequence of large capacity of built up surfaces for storing direct solar radiation, and latterly, to release it to the urban atmosphere. Urban temperatures are generally higher that rural temperatures, and the origin and diffusion of heat islands is one of the most apparent consequences of urban sprawl that gradually and permanently, substitutes natural land uses and covers by paved ground, altering energy balances and hydrologic cycles. Rainfall is no more infiltrated into soils, runoff increases and cities are increasingly affected by floods. Due to imperviousness, cities are each time more affected by flooding with less rainfall and in a shorter time. Land imperviousness and the substitution of vegetal covers (natural and cultivated) strongly reduce evapotranspiration and atmospheric heat shrinking. This, in turn, strengths urban heat islands and eliminates urban cold islands. The resulting thermal homogenization of the urban atmosphere interrupts air cooling and cleaning functions of local brizes and winds. As a consequence, urban atmosphere concentrates air pollution and in turn, heat accumulation, forcing the use of cooling devices that need electricity, that again, produce more greenhouse gases and air pollution.

Urban climates, like urban environments, should be considered a social construction. The city, its climates and its environments represent the existing social structure and then, a welfare uneven distribution. In Latin America, in general, and in Chile in particular, urban spaces are socially extremely unequal, and the prevailing social segregation is also environmental segregation. In Chilean cities there are urban environments, climates and air qualities that vary according to the economic income of the population. Chilean cities are true examples of social injustice because the poorer and more vulnerable areas suffer disproportionally, the negative effects of natural hazards and air pollution.

Then, climate change effects on urban population should also be socially assessed. Warmer neighbors, where poorer people live, almost always without green areas, concentrate polluted air plumes and, as a result, higher proportion of respiratory diseases. Natural hazards, on other hand, need to be also understood like social risks. Although natural threatens, like heavy rainfall, could cover the whole city, the occurrence of floods, depend from social vulnerability, and then, from socioenvironmental segregation and social lack of justice.

Urban sprawl and urban climate change in Santiago

Since nearly three decades, Santiago, the six million inhabitants Chilean capital city, has experienced an explosive growth of urban land uses, which has increased near thirty thousand hectares, passing from 34.000 in 1975 to 65.000 in year 2005 (ROMERO et al., 2006). Most developed urban land uses correspond to high and low density residential and industrial zones, like could be observed in figure 1. Lower density urbanizations have substituted mainly natural landscapes covered with dense and sparse vegetation located at the eastern part. On contrast, higher density residential areas have mainly occupied previous agricultural lands located at western sides.

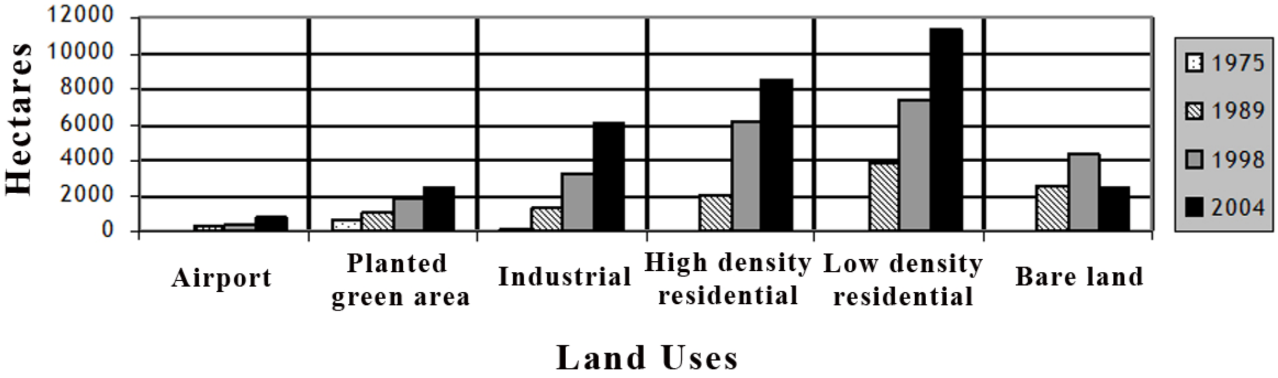


Figure 1: Santiago city urban land uses changes between 1975 and 2005

Natural covers substitution by urban land uses strongly affect the city environment (PICKETT et al., 2001; WITHFORD et al, 2001). One of the most relevant modifications corresponds to urban climate alterations (PEÑA Y ROMERO, 2006; ROMERO and SARRICOLEA, 2006), that are a direct result of the disappearance of natural landscapes and vegetation covers that regulate surface and air temperatures in the city, producing a warming process that locate heat islands at the western city border in early morning, which migrate to the historical centre of Santiago during midday and specially, at nights (Figure 2).

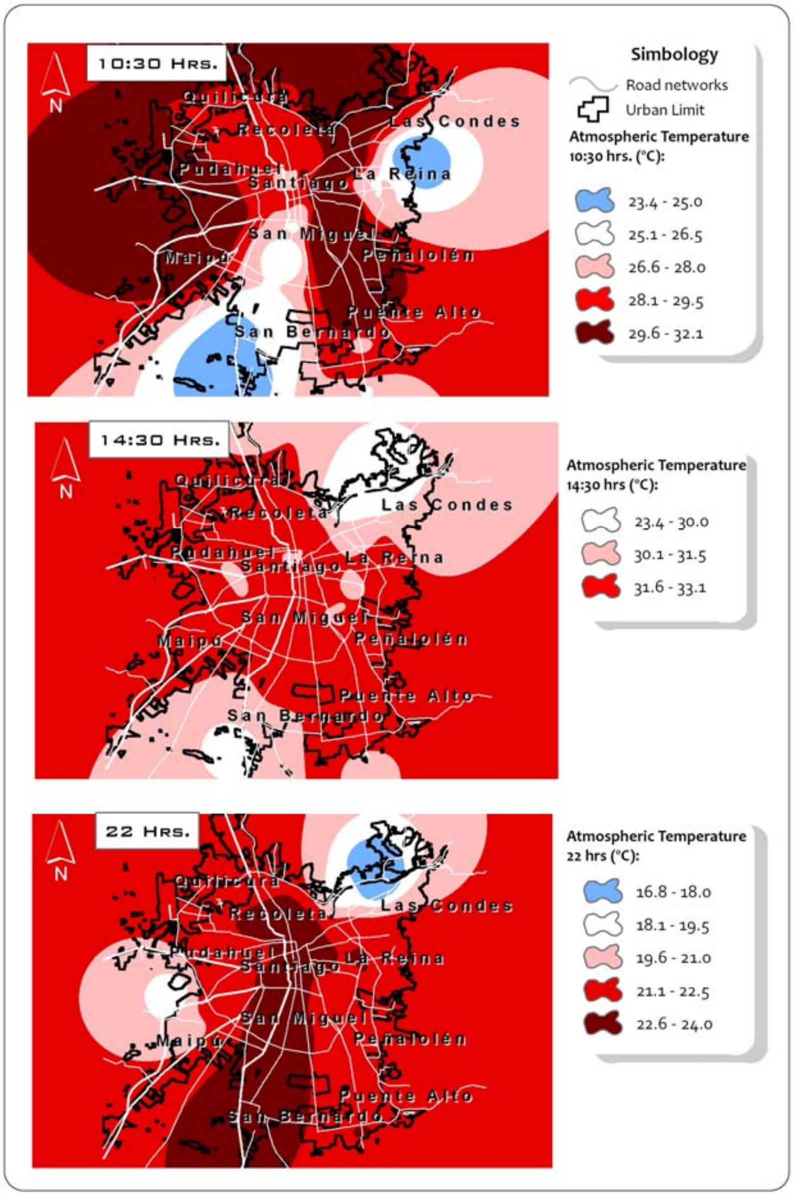


Figure 2: Air temperatures in Santiago and its daily evolution.

Morning warmer temperatures are mainly recorded in the Nonwestern communes (Quilicura, Colina, Pudahuel and Maipú), while in the southern border, San Bernardo and Calera de Tango communes, maintain lower temperatures that are transferred towards the city center trough a climate corridor formed by the Cerrillos airport approaching cone. The rest of the city, and specially the areas near the center, remain cooler during mornings. Figure 2 shows that the urban temperatures distribution begins to change at midday, when they equal and overpass the rural ones. Urban heat islands are located now near the historical center and the surrounding commercial zones. Finally the typical urban heat island centered at historical sites and at the Central Business District could be observed during summer nights.

Spatial relationships between land use, land covers and air temperatures in the city and its daily evolution are presented in figure 3. Rural areas are warmer than urban areas during early morning (non urban heat islands). However, at midday micro urban heat islands begun to be developed over more built up and impervious areas, such as airports and industrial zones, that reach the hottest temperatures (32,5ºC). At night, these urban heat islands are spatially consolidated at industrial zones, airports and high density urbanizations. A difference of 2ºC is found between residential higher and lower density areas, as a consequence of different percentages of vegetation covers and imperviousness. Cooler or warmer urban neighbors are the result of socioeconomic controls and from urban planning and design, i.e. from human made decisions.

HONJO et al. (2003) and ELIASSON (1999), have emphasized the role that vegetation and imperviousness play in terms of the climatic performance of the cities. Both factors not only control the spatial distribution of temperatures but also explain micro scale differences between urban zones of similar density or similar land uses (figure 4). In the case of Santiago, vegetation covers up to 40% explain relevant heat reductions in urban spaces.

Urban planners and managers share important responsibilities on present and future climate changes in the cities. Present situations of poor living quality that suffer most of the urban population –climate discomfort, air pollution, natural hazards, respiratory and environmental diseases- reveal permanent and severe fails in urban planning and management in Latin America, and constitute an urgent plea to solve these accumulative issues.

Imperviousness rates and vegetation covers -both dependent from politic decisions-, must be considered in decision making about land use allocations, urban densities, nature and location of urban parks, green belts and ecologic corridors, thinking in terms of climate control, improving living quality and getting social equity. Like at global scale, urban climate change is not a pure biophysical phenomena but a social, cultural and political issue.

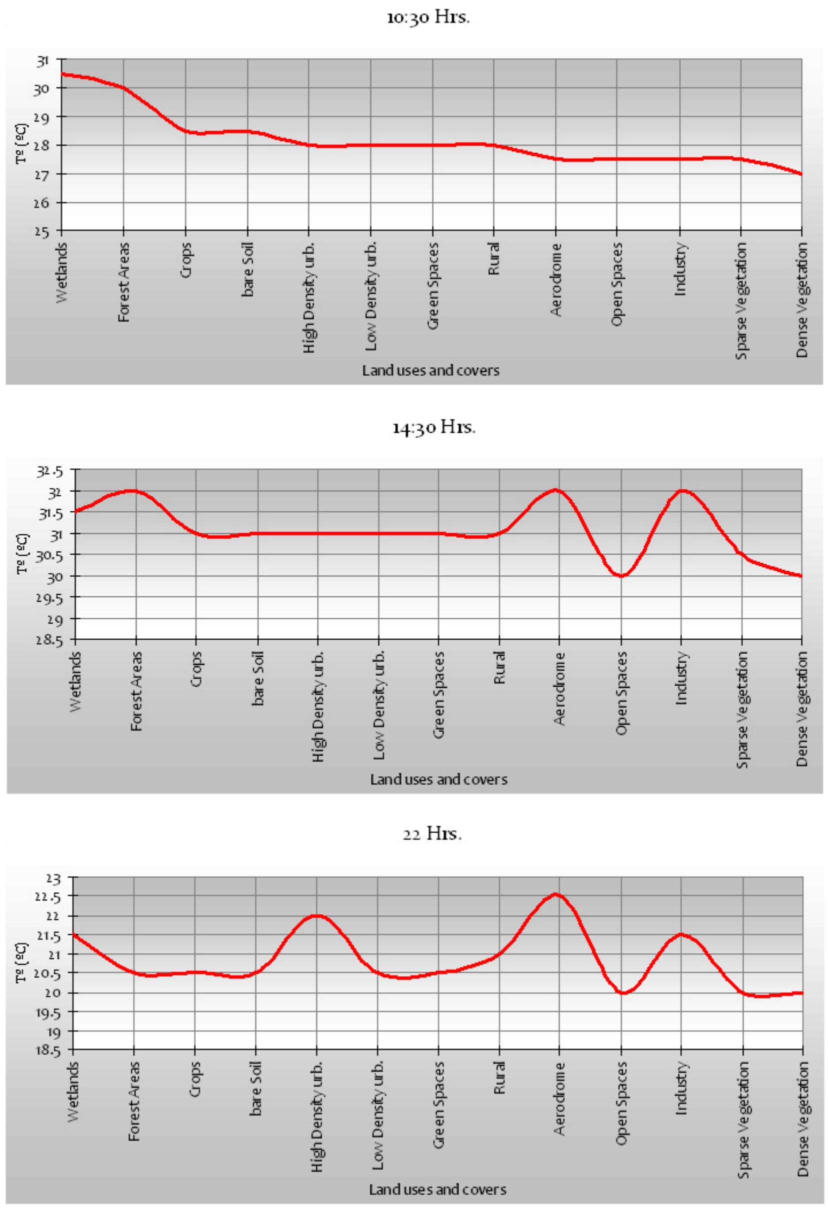


Figure 3: Spatial relationships between land use, land covers and air temperatures in the city and its daily evolution at Santiago de Chile.

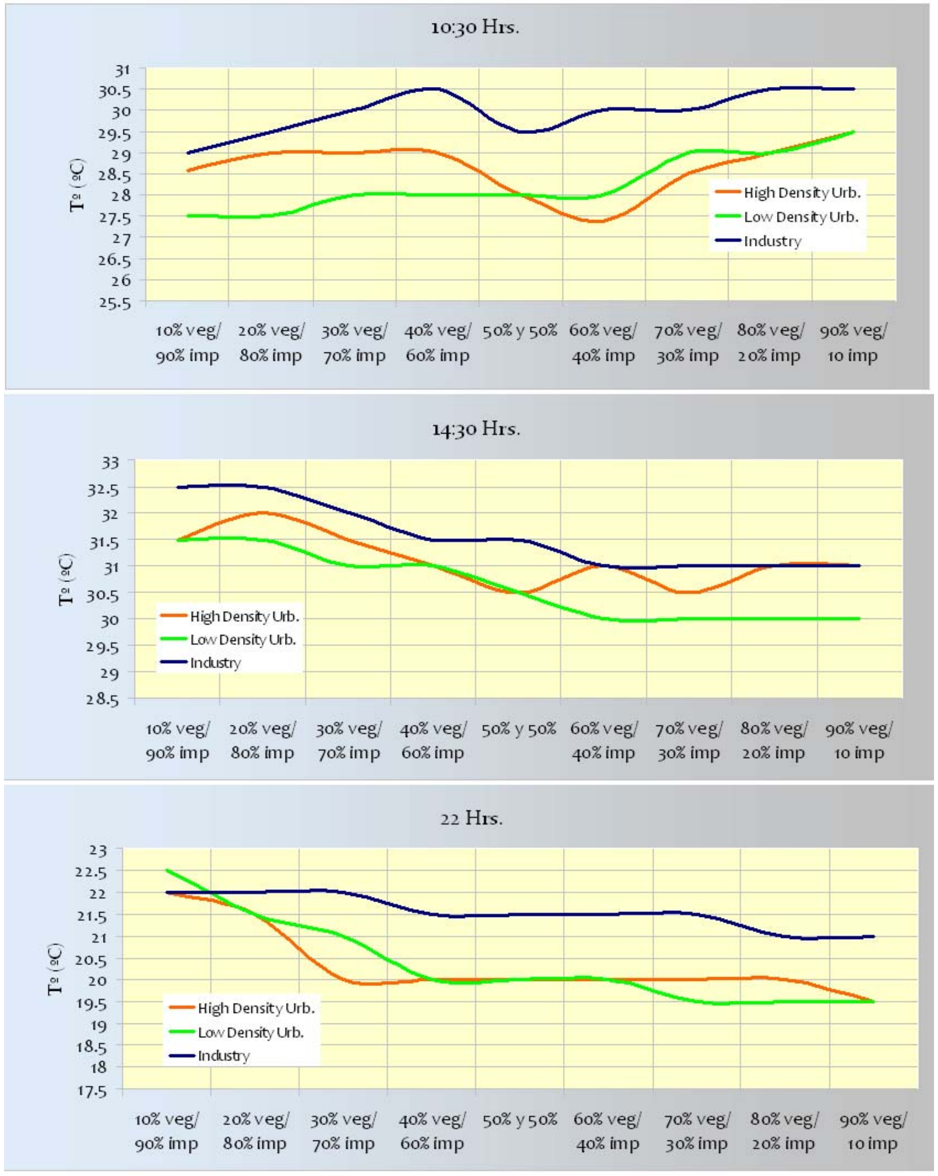


Figure 4: Air temperatures distribution according to land uses, urban densities, vegetation covers and imperviousness rates at Santiago de Chile.

Urban sprawl effects on imperviousness total areas and runoff coefficients at Valparaiso .

Due to a complex topography, Valparaiso Pacific Ocean port city, reaches extreme levels of urban landscapes heterogeneity. Such complex landscape mosaic is also explained by the continuous human occupation of a series of watershed that are formed by very steep slopes and numerous streams that drain several and successive marine abrasion terraces that could reach up 500 m above sea level, towards a vey narrow flat sedimentation plain.

Watershed urbanization modifies the Total Imperviousness Areas (TIA) or the percentage of watershed surface that has been effectively ceiled by urban land uses, that, finally determines the proportion of rainfall that it is on site infiltrated or runoff down water. Imperviousness rates vary substantially among such lands that are completely covered by vegetation, that infiltrate near 100% of rainfall, and those lands occupied by commercial zones or covered by buildings and high density residential areas where infiltration is almost nothing and water must drain down water.

Imperviousness rates of different land uses and covers determine runoff coefficients, or the amount of water that descend from the slopes. Increasing TIAs and Runoff Coefficients (RC) have depth effects in respect to climate change in the cities. Under most concentrated and seasonally irregular rainfalls, they increase natural hazards in terms of debris flow, floods and landslides, decrease ground water recharges and increase available heat because evaporation reduction. Additionally, because watershed urbanization consist mainly in the substitution of green covers by paved areas, home roofs and walls, disappear several vegetation environmental services that control urban heat island development, filtrate polluted air, and offer wildlife habitats and recreational sites for urban society.

Urban watersheds are a complex mixture of different land covers and land uses. Although their urbanization needs to be carefully planned and managed, most of Valparaiso watershed urbanization has been the result of unplanned and spontaneous occupation, mainly by poorer and more vulnerable social groups. Some quantitative indicators are required to facilitate decision making and to monitor the performance of these urban spaces, particularly under great climate uncertainties. TIAs allow the consideration of different land uses management because they weight the imperviousness rates of housing, roads, parks and other urban lands, according to the surface that they occupy in the watershed. An intensification caused water up by social housing construction could be compensated by infiltration green areas located down water.

In Valparaiso, there are still large natural vegetation covers in the watersheds. However, the continuous urban sprawl process is progressing slope up, increasing TIAs and RCs (DIETZ & CLAUSEN, 2007), like could be observed in figure 5, which corresponds to the evolution of Subida de Yolanda neighborhood, an urban area overlapping the older natural stream.

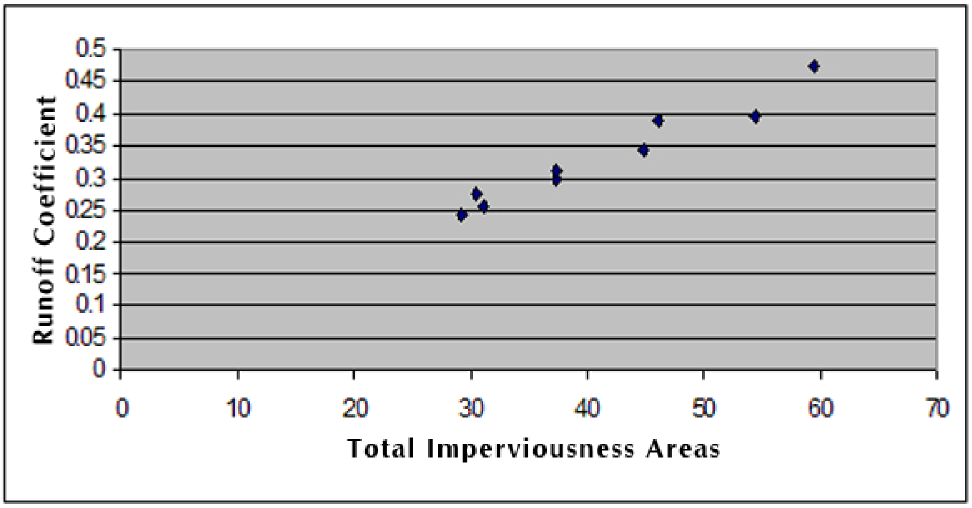
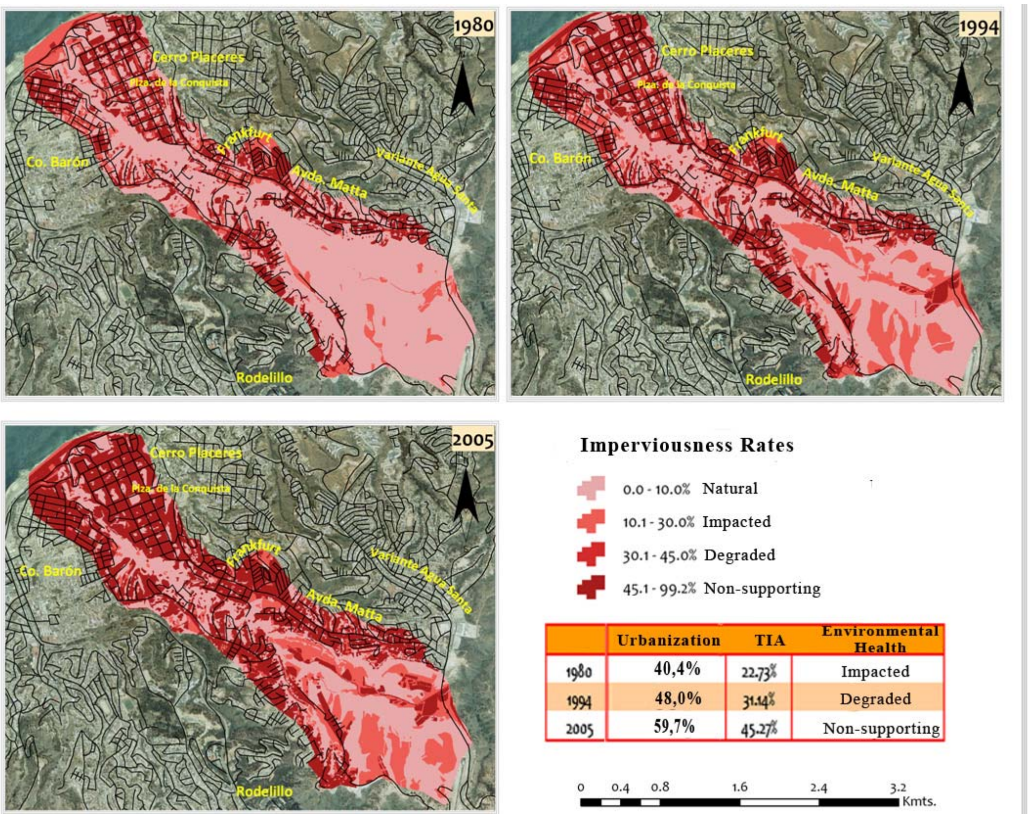


Figure 5: Correlation between Total Impervious Areas and Runoff Coefficients at Subida de Yolanda neighborhood at Valparaiso in 2005.

Land Uses and Covers	Imperviousness Rate (%)
Planted green area	4.6
Bare land	19.8
High density residential	89.2
Low density residential	66.4
Commercial	81.1
Industrial	80.8
Primary roads	99.2
Secondary roads	85.6
Dense natural vegetation	0.7
Sparse natural vegetation	4.1
Cleared spaces	17.1
Streams	0.0

Table 1: Imperviousness rates and land uses and covers in Subida de Yolanda neighborhood at Valparaiso

Table 1 indicates imperviousness rates for each land use and land cover that occupied at 2005 the Subida de Yolanda neighbor, following the model proposed by STANUIKYNAS & VAN ABS (2000). Figure 6 illustrates about land uses and cover changes that have taken place in this Valparaiso urban watershed between 1980 and 2005, and the State of the Urban Watershed Environmental Health, according to ARNOLD & GIBSON (1996) classification.



	Urbanization	TIA	Environmental Health
1980	40,4%	22.73%	Impacted
1994	48,0%	31.14%	Degraded
2005	59,7%	45.27%	Non-supporting

Figure 6: Environmental Health of Valparaiso Subida de Yolanda neighbor changes between 1980 and 2005

Subida de Yolanda watershed urbanization has systematically increased impervious total areas. In 1980 they covered 22,73% of the watershed surface. In 1994, urbanization reached 31,14% and in 2005, 45,27% of the watershed the total surface was impervious, demonstrating large difficulties to get a real sustainable urban development along this typical and emblematic urban landscape of Valparaiso and many other coastal cities, either in Chile and Brazil (MENDOÇA y LOMBARDO, 2008; MENDOÇA e ROMERO, 2008). Some urbanizations have been installed at slopes higher than 60º, meaning an important social risk, especially in respect to landslides and avalanches that have always occurred, killing many people and destroying homes and urban infrastructure. It is important to take into consideration that climate change predicts a large rainfall concentration for this part of the country. In Valparaiso, under Mediterranean climate types, annual average rainfall is around 400 mm that precipitate in 30 days, recorded only between May and August.

Extraordinary daily rainfall concentration should be considered for the estimation of runoff coefficients, following the Curve Number Method proposed by TORRES (2004). Mean maximum storm precipitation for Valparaiso in 24 hours is estimated in 82.7mm. Table 2 shows the runoff coefficients for each of the main land uses and covers at one representative Valparaiso´s urban watershed.

Land Use and Cover	RC
Planted green areas	0.143
Bare land	0.249
High density residential	0.738
Low density residential	0.554
Commercial	0.738
Industrial	0.628
Primary roads	0.928
Secondary roads	0.738
Dense natural vegetation	0.082
Sparse natural vegetation	0.110
Cleared spaces	0.206
Streams	1.000

Table 2: Runoff coefficients for different land uses and covers in Subida Yolanda neighborhood at Valparaiso in year 2005.

Again, unplanned and mismanaged watershed urbanization has caused a relevant increase in runoff, passing from 0,23% in 1980, to 0,29% in 1994 and 0,38% in 2005 (figure 7) . Reasons to understand why Valparaiso is suffering more frequent and rapid floods could be related with increasing runoff coefficients caused by uncontrolled watershed urbanization.

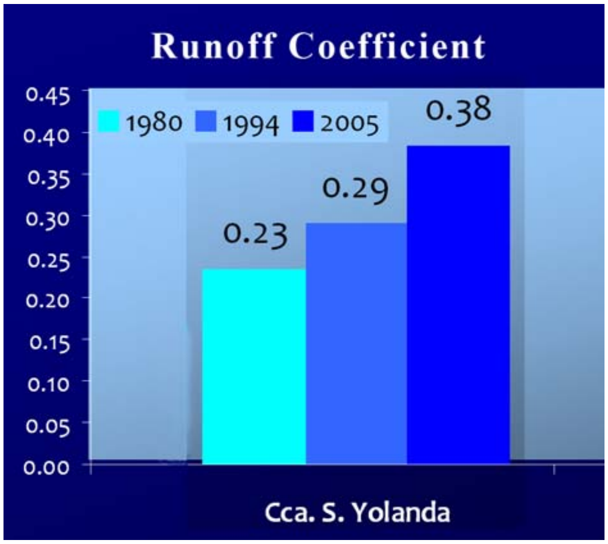


Figure 7: Runoff coefficient changes between 1980 and 2005 in Valparaiso Subida de Yolanda neighborhood.

Spatial relationships between urban temperatures, air pollution and socioeconomic indicators.

It has been already mentioned that urban Santiago´s heat islands and air temperatures demonstrate a daily distribution. Air temperature are higher at the western border of the city during early morning and cooler at night. Conversely, the centre of the city is cooler at the morning and warmer at night time. Comparing both locations, temperatures daily oscillations are higher at the western side of the city. Temperatures spatial distribution is also correlated with air pollution. Figure 8a shows that a logarithmic model explains 86% of their variance. Nigh time concentrations of Micro Particulate Matter (PM10 or particulates >10um), increases with temperature, particularly between 19 and 22ºC. It means that air pollution is concentrated in the centre of the city during night and in the western border during earlier mornings.

Figure 8b relates urban temperatures with the population socioeconomic distribution in the city. A R^2=0,819 indicates that both variables strongly correlate. Higher income population reaches lower urban temperatures because their homes are mainly lower density and have numerous green areas around. The upper class (ABC1) is the only social group that can get moderate temperatures during summer nights as a result of the concentration of urban amenities at their exclusive and segregated neighborhoods. Other social classes (medium C2 and C3) have intermediate temperatures and do not show large variations. The used logarithmic correlation model has overestimated temperature in areas occupied by lower social classes.

Air quality, represented by micro particulate matter distribution, is also meaningfully related to socioeconomic distribution in Santiago, either in summer and winter season nights (R2=0.842 y 0.791, respectively). In summer night (figure 8c), when air quality is good in the entire city, micro particulate matter is even lower in areas where richer people (ABC1) live. Such better environmental quality at urban zones where live the most affluent people, is also corroborated on winter season, when air pollution is the most relevant environmental issue in Santiago (figure 8d). At winter nights, only the urban areas where richer people reside could have a good quality air. The rest of the city presents a fair quality where medium classes live, or definitively, a bad quality where lower middle class and poor people live.

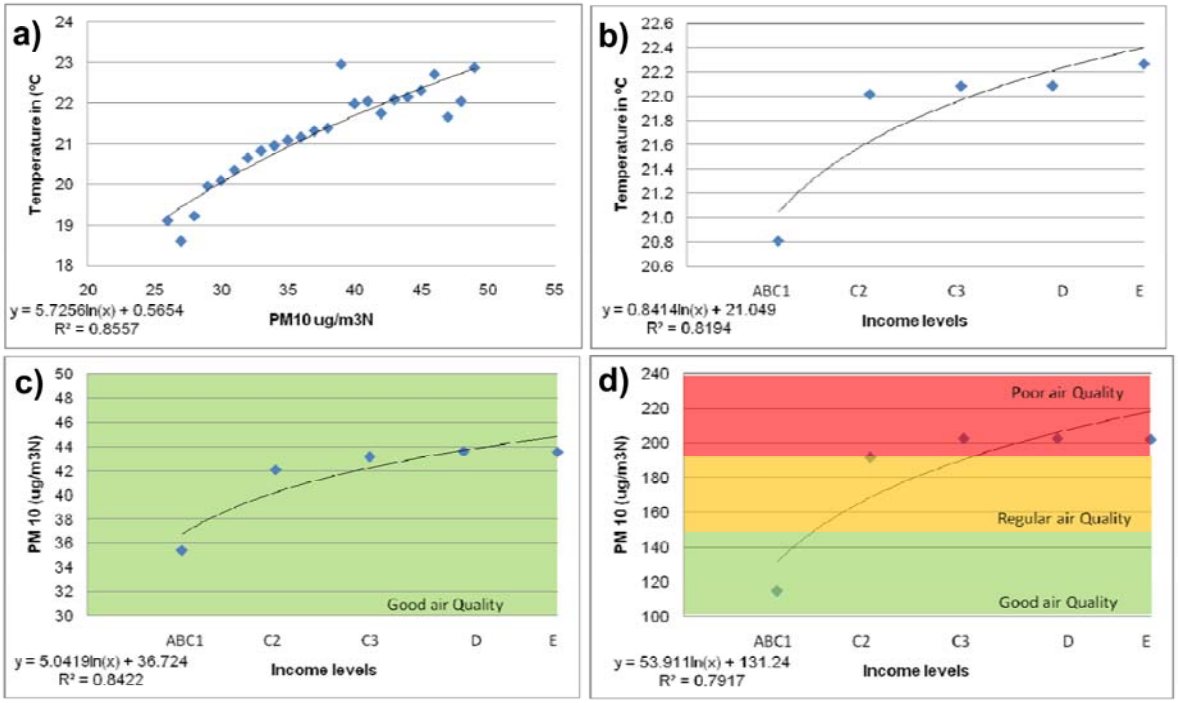


Figure 8: Relationships between air temperatures, Particulate Matter and Socioeconomic levels at Santiago de Chile

Figure 9a represents the socioeconomic distribution of Santiago's population. Santiago is a very socially segregated city since different social classes tend to occupy very specific urban areas. Richer people (ABC1 groups) are concentrated at eastern and northeastern areas, and the poorest sectors in the nonwestern sectors. Upper middle class groups are extending in axes towards the western and southern sectors, showing a new trend of spatial diffusion since 1990. Higher land values and scarce available lands in the eastern side, seems to explain this new spatial behavior.

Figure 9b shows that air pollution distribution follows socioeconomic distribution. Concentrations of micro particulate matter are lower at northeastern areas, exactly where richer people live, and higher at the western side of the city, where inhabit most of the poorer people.

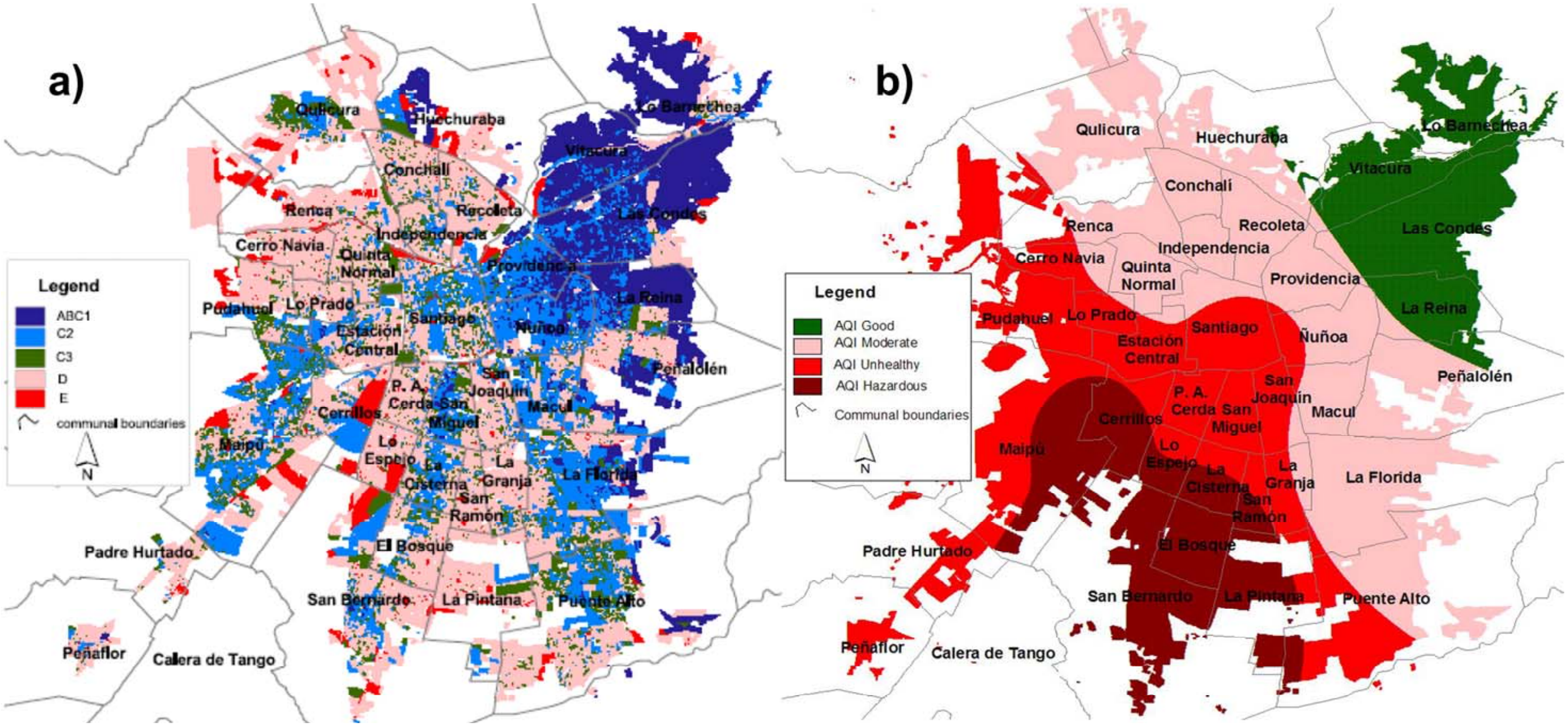


Figure 9: a) Socioeconomic and b) Particulate Matter distribution at 21 hours in winter at Santiago

Conclusions

Climate change is evident in the Chilean large cities. Urban sprawl promotes the generation of heat islands and gradually eliminates cool islands, homogenize land surface and reduce local winds and brizes. Urban climate change is caused by heat accumulation on impervious surfaces that are a result of the continuous urbanization of natural and agricultural land uses and covers. Heat islands can cause thermal discomfort, secondary pollutants and heat weaves, and in turn, they promote air pollution because the use of cooling devices to reduce heat in urban spaces. Urban planning and management are not taking into consideration climate change in urban climates programs. On the contrary, lack of urban planning and management are allowing an uncared watershed urbanization on such complex topography of coastal cities, like is represented by Valparaiso. Uncontrolled urbanization is changing imperviousness rates and runoff coefficients, increasing the occurrence of natural hazards, such as floods, landslides and avalanches. Natural threatens are exacerbated by social vulnerabilities and the lack of institutional commitment with environmental perturbations.

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