Analysis of urban heat islands in Monterrey City, México using remote sensing and geographic information systems

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Abstract. Latin America is characterized by the large amount of unplanned cities. This has a significant influence over land surface temperature which rises because of the absence of natural land. Traditional construction materials, air conditioners, atmospheric pollution, human activities, and the lack of green area also contribute to the rise of temperature. The phenomenon is known as Urban Heat Islands. Inhabitants of the Metropolitan Area of Monterrey, Mexico started to live the negative consequences of an accelerated unplanned city growth. This research analyzes the relationship between land surface temperature and land use -land cover for the study area, using Remote Sensing Imagery. Then, social characteristics of the population were included using GIS to know which social stratum is under heat stress. The results provide information to facilitate urban planning and design guidelines for sustainable urban growth. Such analysis stays a basic knowledge of climate behavior of the city and pretends to help planning authorities to take better future decisions and could contribute to an improved use of natural resources, for urban development. The lack of urban planning causes Heat Island formation and because of this it is important to analyze the actual situation in order to be able to delineate correct environmental parameters to achieve sustainable development, reducing the negative effects of urban growth, which will allow better living ways.

Keywords: Land use, land cover, urban planning, urban climate

1. Introduction

The uncontrolled urban expansion of the Metropolitan Area of Monterrey produces an environmental degradation. Traditional types of construction materials, air conditioners, industrial activities, and the lack of greens areas rise the temperature. The phenomenon is known as Urban Heat Island (UHI), and causes health problems, excessive use of resources, such as water and energy. Inhabitants of the Metropolitan Area of Monterrey (MAM) started to suffer the negative consequences of the accelerated unplanned city grow, which comes with an environmental degradation of land surface and deforestation among other consequences, like the alteration of natural hydrologic flows, as a result of these changes. It also has a negative impact on the economy, because the phenomenon increases energy consumption for cooling, among other resources. The lack of urban green areas also reduces the airs' cooling capacity and raises temperature, which cause physical discomfort among inhabitants, among other health problems, such as respiratory diseases, and plagues.

This research analyzes the relationship between land surface temperature and land use - land cover, in the MAM using Remote Sensing Imagery. Social characteristics of the population were included to learn if there is a relationship between social stratum and the effect of heat islands, using Geographical Information Systems. Areas of heat stress were identified. Spatial relationships between land use, land cover and temperature are relevant. Images show not only the distribution and intensity of UHI but also give a more descriptive knowledge about the inhabitants suffering from heat stress. Thus, it is possible to analyze environmental justice, which refers to the degree of suffering because of environmental damage for lower income population.

Such analysis will give a basic knowledge of climate behavior of the city and aims to help planning authorities to take better future decisions and could contribute to an improved use of natural resources, for urban development, and to consider the importance of green areas. It is urgent to elaborate sustainable territorial development plans which seek environmental protection, less harmful human practices, and improve to living standards for the population. The analysis of climate conditions is extremely necessary to take strong planning decisions and formulate design guidelines; every place is unique and should have its own statements. It is also necessary to consider that cities are not independent regions, but that they are inside an ecosystem, so their environmental problems have a relation on a bigger scale, such as global warming. The study UHI of the Metropolitan Area of Monterrey (MAM) will stay a basic knowledge of climate behavior over city. This study intends to help planning authorities to take better decisions that could contribute to sustainable use of natural resources, for urban development, and to consider the importance of green areas.

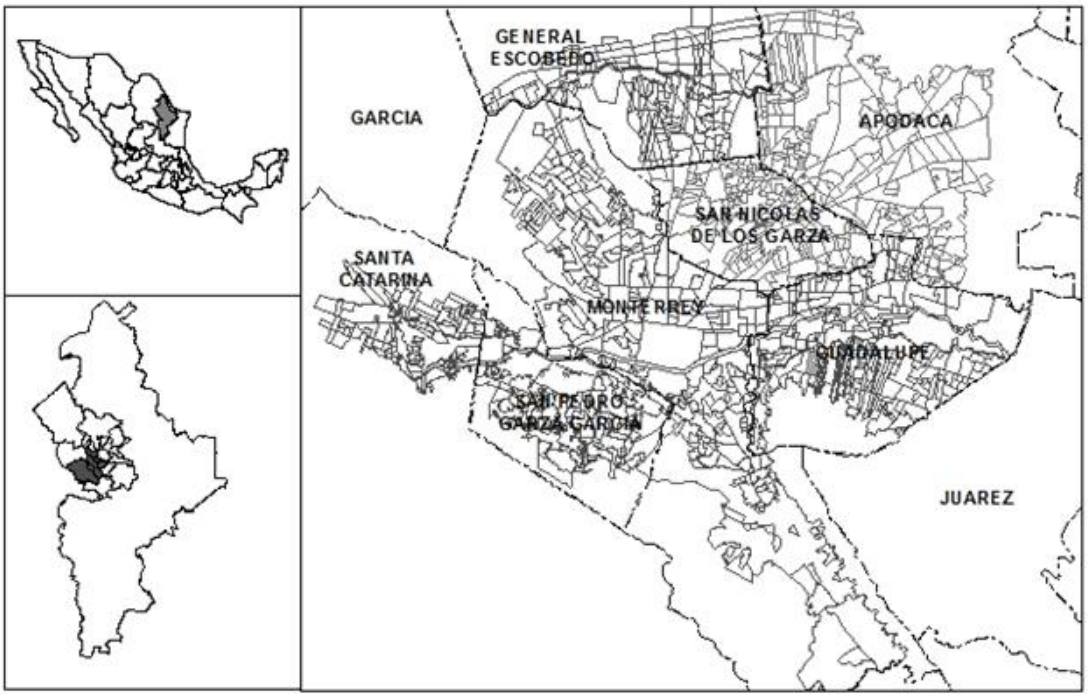

Figure 1. Location of the Metropolitan Area of Monterrey, México

2. Methodology

Heat Islands will be characterized using socioeconomic data, climate conditions, and land use/land cover. Using this information it will be evident which strata are under severe heat stress and their conditions. Having a geographical view of the problem it will be easier to establish more effective Mitigation Strategies for the MAM.

2.1 Urban heat islands

The historical analysis of the distribution of temperature over the study area will lead to the quantification of climatic changes. Pre-treatment was completed before calculating temperature for ASTER 2003 image and LANDSAT TM 2009. Digital number (DN) will be transformed to Absolute Radiant Brightness. This Spectral Radiance is then transformed to brightness temperature in Kelvin. The last step considers change in units from Kelvin to Celsius. The same steps but with different formulas will be consider for each sensor. Finally a Heat Island map will be produced.

2.2 Climatic analysis

Climatic data will help to give a better description of the phenomenon of Heat Islands. The conditions that will be taken into consideration are: Temperature, Rainfall, Wind Patterns, and Solar Radiation Temperature to determine the driest areas in the MAM. Data temperature and rainfall will be used to produce a climograph which it is a representation of the monthly average temperature and precipitation, used for a quick view to identify weather trends for each year. Finally, wind patterns will help to determine temperature dissipation over the MAM. The final product of this analysis will be a Climate Characterization.

2.3 Urban environment

Remote sensing data from SPOT 5 will be used to perform a Land Cover classification. In addition, official Land Use shape will be analyzed using GIS. The major factor contributing to the formation of heat islands are the land use and land cover transformations. The land change often includes replacements of natural surfaces with concrete and asphalts, which affects the thermal environment in cities. Also, high density built up spaces, vegetation, water bodies, and land use types (commercial, industrial or residential) contributes to the variation in temperature.

2.4 Social composition

The census data will be interpreted to characterize the social strata of the study area. Variables that will be taken into consideration to build a deprivation index are: lack of access to education and health care, residence in poor housing and lack of basic necessities.

AGEBS defined as urban units of study, with higher percentage of population and houses without a basic need or service (Education, Health, Basic Housing Services, and Assets) are considered with a high deprivation index. Heat Islands will be characterized using socioeconomic data, climate conditions, and land use/land cover. Using this information, it will be evident which strata are under severe heat stress and their conditions. Having a geographical view of the problem it will be easier to establish more effective Mitigation Strategies for the MAM.

3. Results

Areas of heat stress were identified. Images show not only the distribution and intensity of UHI but also give a more descriptive knowledge about the inhabitants and establish a correlation of land use/land cover and UHI. Spatial relationships between land use, land cover and air temperatures in the city are relevant. However, urban heat islands develop over industrial zones, reaching the hottest temperatures. Also, topographical variations inside the MAM generate urban heat sink formation, especially in Santa Catarina. It is then to be said that there is a high socio-spatial segregation, among the inhabitants of the MAM, who suffer from Heat Stress.

3.1 Urban heat islands

The results show that the geographical aspects of the MAM, conditions the climatic behaviour. Remote Sensing analysis for Urban Heat Islands shows that, in a historical comparison, maximum temperatures had risen almost 3.8°C. Images show that not only has increase in °C but also in area due to land use and land cover change. The next table shows a comparison of the three images. Minimum was not taken into consideration due to the negative minimum temperatures that are registered on the original statistics, due to cloudiness.

Table 1: Statistics Comparison in C°

Year	Maximum	Mean	Median	Mode	St. Dev.
2003	48.4988	33.2195	32.1727	33.4286	4.06
2009	50.1478	34.6184	35.7935	35.4892	8.89

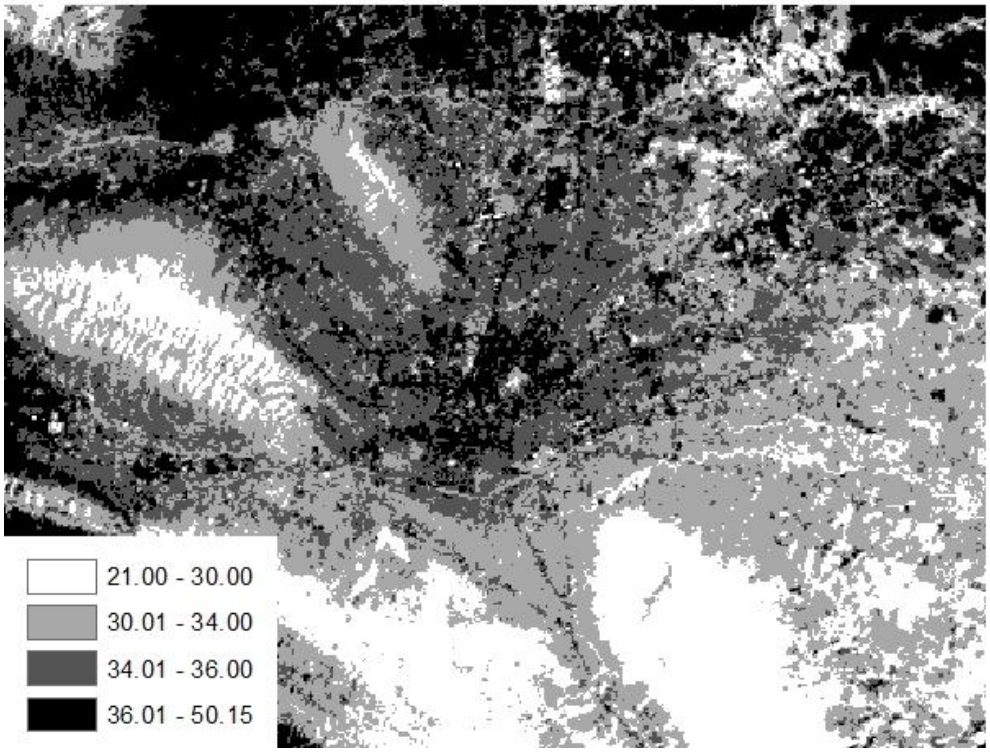

Figure 2. Aster image, May 15, 2003

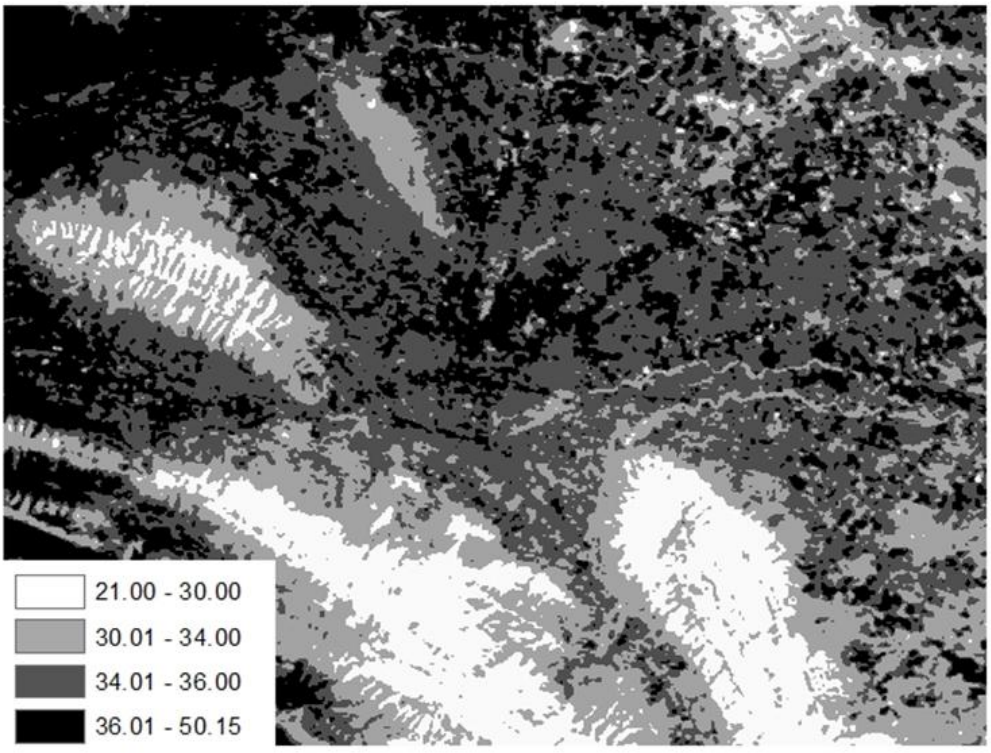

Figure 3. Landsat TM, May 07, 2009

3.2 Climatic analysis

The isotherm map shows that the highest temperature is located north of the MAM and extends east to Guadalupe and Juarez municipalities. The lowest temperature is registered south up the Sierra Madre. Isohyets map shows the highest rainfall south the MAM, and northwest areas are the driest, west Monterrey to García. Months with high precipitation are the months of June and September.

The north center heat island formation phenomena can be explained by the isotherm map which defines that the highest medium temperature (22°C) is set along east-north and extends north Monterrey municipality through Guadalupe. The isohyets map can explain the heat island formation west Santa Catarina, due to the lowest rainfall value. In the same way wind patterns can help determine the heat island formation north the MAM. Heat is driven north by south winds. On the other hand, it is a fact that temperatures are getting extremer (cooler winters, warmer summers), drier months with rain in unusual months. Maybe it is not a strong datum, but an operation to determine where temperature has raised shows that areas like east Monterrey in its way to García, south Santa Catarina, Guadalupe in its way south Monterrey had an increase in temperature. There is no surprise in this statement because land cover has been changed dramatically by real estate developers.

3.3 Urban environment

There is a high percentage of impervious material. High density can be observed North West Monterrey. Taking out of consideration the natural in the surrounding, there are few urban vegetated areas. Also, agricultural land represents a small portion of the MAM. It is important to notice the Industrial Land, which had a different spectral response, which can correspond to a contaminated soil. Isolated roof classification inside the Huajuco and Chipinque can explain how the urban expansion is now over high slopes, and how impervious materials replace natural vegetation.

The relation between Temperature and Land Use is strong. The result expresses that industry is a powerful source for the formation of Urban Heat Islands. The R^2 estimated is 0.9831. On the other side, the relation between Temperature and Land Use is also strong. The result expresses that artificial land cover, and industrial lands have a direct effect over the formation and intensity of Heat Islands. The resulted R^2 is 0.9581.

3.4 Social composition

The unit area of analysis was an Area Geoestadística Básica (AGEB). The goal was the definition of an indicator, which could localized areas with high poverty concentration, and be able to identify susceptible population groups to have a better geographic reference of where and which public policies should be taken in place. A map was generated for each variable, and at the end there was an integrated map. Variables were: 1) Population density; 2) House Quality based on infrastructure; 3) Population without health service.

Results show that there are 130 AGEBS considered as “LOW WELL-BEING”, meaning lack of house services and public health, representing 435, 721 inhabitants of the MAM. Of the total AGEBS of the MAM, 849 do not consider Public Green Area, according to official records, which contains 1, 923, 839 inhabitants. Finally, without Public Green Area and living in a precarious, unsanitary situation 111 AGEBS containing 366, 573 inhabitants. It is a must to consider that without these factors health problems and environmental degradation are more common, and without a public health service this population is very vulnerable.

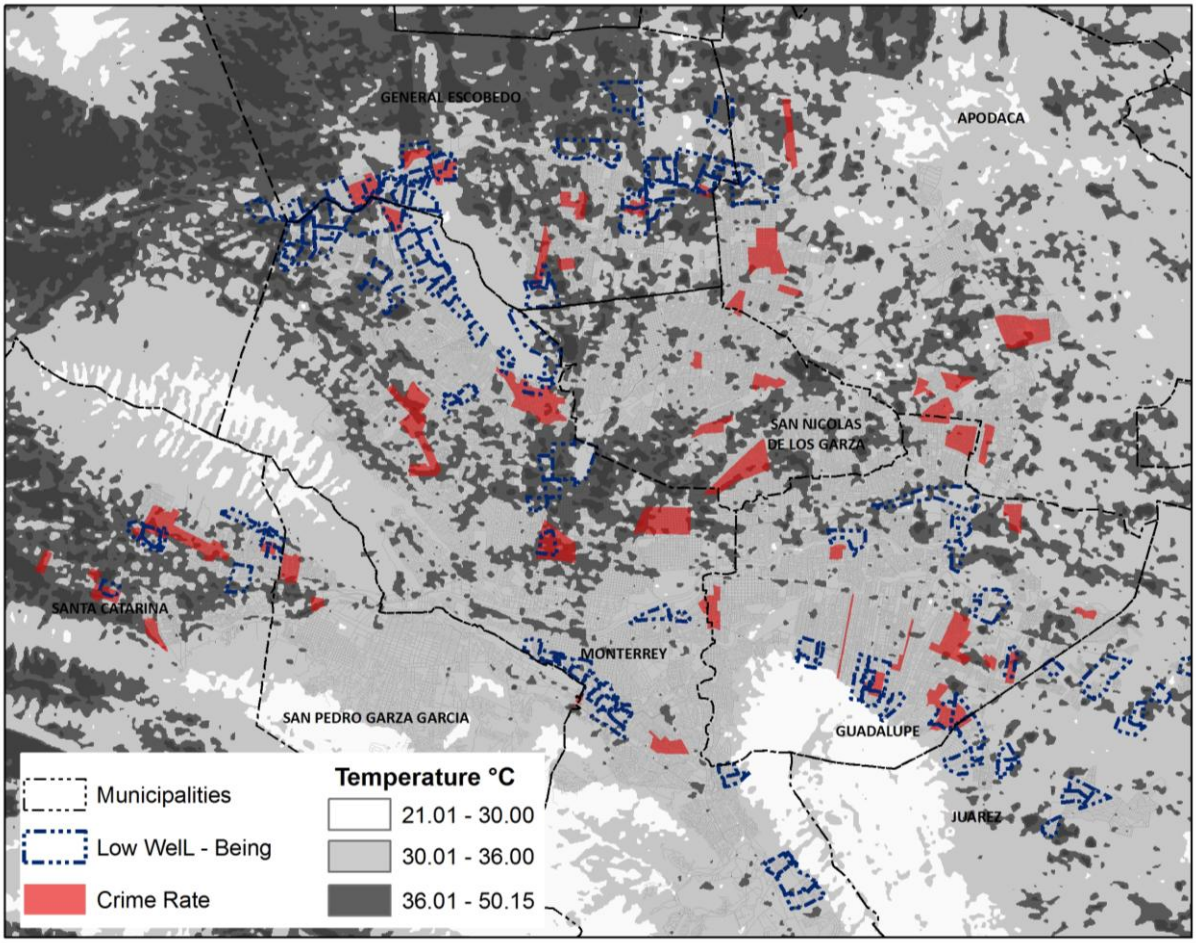

Figure 4. Areas of heat stress and Low Well-Being.

4. Conclusions

Changes in land cover and urbanization affect local temperatures and climate. Moreover, urban marginalization highlight the importance of strengthening social development programs to improve the habitat of the urban population in areas with high levels of poverty, and promote housing basic services accessible to people with low income to contribute to equitable growth, orderly and sustainable cities and population centers.

Remote Sensing and GIS assist in the analyses and visualization of urban heat islands growth in the MAM. The produced information is helpful to design better urban planning policies, alternative analysis and mitigation strategies. Urban Heat Island is a complex problem that can be mitigated with different approaches. Anyway, with such information, better decisions could be made or be considered, which could give a real solution to the problems of the population. Mapping the low income population areas, with adverse temperatures and social problems will represent an effective mechanism to evaluate government decision impacts.

Geographic Information Systems (GIS) is a very useful planning tool to obtain existing urban conditions. Using demographic data from the census and from federal guidelines aids to determine the affected population's localization. This type of study allows architects, planners, decision makers and different government departments to visualize how sustainable a city proposal or public policy will be, for better urban management.

Urban heat island mitigation measures must be adopted when planning further development in the cities. Mitigation measures should not involve individual measures but a change in the way of making city. The use of technology and software should be employed to study the natural and social characteristics of the concerned area to carry out effective measures. Updated data (census, cadastre, risk analysis, meteorological data acquisition) is fundamental to carry out any technical study, which could allow a simulation as a window to the future, evaluating the possibilities of a mitigation strategy. And the most important, already considered, go from research to policy implementation. For the creation and implementation of public policies, it is necessary to have analytical tools to synthesize the complexity of urban problems in a high resolution scale measure to sort and differentiate between each other priority problems affecting population. Decision-makers must find a way to utilize the scientific knowledge and ask policy-relevant questions about potential impacts, without demanding particular answers.

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