DYNAMICS OF BUILT-UP AREAS OVER THE PAST 30 YEARS ACCORDING TO REMOTE SENSING DATA IN THE CITY OF VALDIVIA, CHILE

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ABSTRACT

The dynamics of built-up areas over the last 30 years in the city of Valdivia was analyzed according to Landsat satellite imagery data. For ETM+/Landsat-7 and OLI/Landsat-8 instrumentation systems, method of automatic satellite image interpretation of build-up areas showed inaccuracy, less than 1%, compared to visual method. For TM/Landsat-5 instrumentation system, method of automatic satellite image interpretation of build-up areas demonstrated unsatisfactory results. Since 1987 and by the year 2017 the city's built-up areas increased by 61% with the population growth of 66% within the same time period.

Index Terms— Valdivia, Chile, urban area, Landsat, remote sensing

1. INTRODUCTION

Urban spaces are among the most quick-changing landscapes and their development (i.e. building construction and infrastructure enhancement) is directly linked to urban population increase. The past 30 years of Chilean urbanization are marked with intensive rise of private building construction on the towns' outskirts [1]. This process is supported by sustained economic and demographic growth.

Remote sensing data have been regularly used in studies of urban environment due to wide spatial coverage of modern satellite sensors, it's frequency of data acquisition and high image resolution. Also, aerospace imagery archives let us analyze the transformations of different parts of landscape throughout decades [2], [3].

Satellite images widely used for detailed and highly accurate topographic and cadastral mapping [4], to define functional areas and urban structure in general [5]; to detect urban heat islands [6].

The useful source of information for such studies is archive of satellite images of Landsat missions, which has been operating since 1979 [7].

In Chile, Landsat imagery have been mostly applied for analyzing dynamics of waterbodies [8], volcano snow coverage [9], specific types of vegetation [10], [11] as well as monitoring large-scale changes of land-use [12], the dynamics of land-use in Santiago-Valparaiso agglomeration [13] and superficial urban heat islands [6].

In this paper, Landsat data were used to study of urban dynamics of the city of Valdivia, which located 800 kilometers south of Santiago, the capital city of Chile.

Extensive research has been carried out into the historical transformations of Valdivia urban area since the city was founded in 1552, and at the moment it is one the oldest cities in Latin America. Several group research due various reasons, were interest in the study of urban structure of Valdivia. Severe damages caused by natural disasters such as city's fires or the 1960 Valdivia earthquake, the most powerful earthquake ever registered, brought about considerable changes in the urban structure of the city [14]. To other experts, the urban area of Valdivia is of particular scientific interest due to its distinct patterns of town layout and street development conditioned by the city's geographic location on the banks of a complicated river system [15].

Borsdorf in 2000 characterized Valdivia as a provincial town of slow urban growth and development. In 2007, the city of Valdivia changed its status and became the capital of Los Rios region. In order to find the effect of this administrative change over built-up areas dynamics in this paper, we will use satellite images obtained over the past 30 years.

2. GEOGRAPHICAL DESCRIPTION OF THE CITY OF VALDIVIA

Valdivia is located in southern Chile in Valdivian Rain Forest Ecoregion [16]; the average annual precipitation is about 2,000 mm [17]. The city has been the capital of Los Rios region since 2007. Its prevailing landscapes are farmlands, forests and wetlands [18]. According to the censuses, between 1982 and 2017 the population of Valdivia grew from 100,046 inhabitants [19] to 166,080 [20].

The transformations of Valdivia built-up area are analyzed within the city administrative boundaries defined by National Institute of Statistics of Chile in 2016. The area of city of Valdivia is 45.6 km^2 [21].

3. METHODS AND DATA

In order to understand the dynamics of Valdivia urban development, analysis based on the satellite imagery archives acquired by Landsat mission over the past 30 years were realized. Spatial resolution for all analyzed spectral bands is 30 m. But for ETM+ and OLI images, after performed pansharpening processing, spatial resolution is 15 m. The information of images used is shown in Table 1.

Table 1. Satellite images used for the analysis.

Date	01-22-1987	02-19-2000	01-13-2007	02-25-2017
Sensor	TM/ Landsat-5	ETM+/ Landsat-7	TM/ Landsat-5	OLI/ Landsat-8

These time intervals, approx. 10 years, are adequate to identify the key processes in urban development. For analysis, only the images taken during summer period were chosen, due to the high amount of cloudy days during other seasons of the year. Cloudiness is the main limiting factor that significantly constraints the application of optical satellite imagery in geographic research.

Both automatic and visual methods of image interpretation were used. The quality of visual interpretation mainly depends on spatial resolution, image quality (contrast), as well as on interpreter's experience. Automatic processing of satellite images provides more accurate quantitative descriptions as each pixel is being thoroughly examined. As a result, all quantitative characteristics, such as area, can be measured with pixel-precision.

All objects, which are located in Valdivia, can be divided into three groups - water, built-up areas and territories covered by vegetation. The following spectral bands were chosen for automatic satellite image interpretation: green (0.53-0.59μm), red (0.64-0.67μm) and near infrared (0.76-0.90μm), spectral bands are presented for OLI/Landsat-8 sensor. The differences between selected groups of objects are most strong in these spectral bands.

Fig. 1 shows spectral reflectance curves of the selected groups for the spectral bands. Objects brightness differs most clearly in near infrared zone, where the vegetation has the maximum reflection of solar radiation, and waterbodies has the maximum absorption of solar radiation.

Automatic satellite image interpretation based on the unsupervised classification by the ISODATA [22] method was performed and 36 classes were divided which then were grouped in two larger ones: 1) urban areas and 2) natural objects.

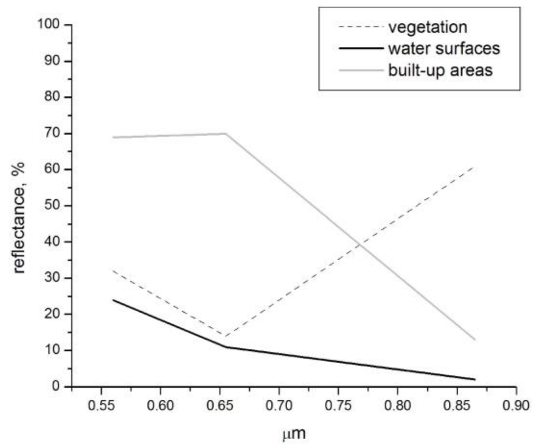

Figure 1. Spectral reflectance curves.

4. RESULTS AND DISCUSSION

The area of urban territories in the city of Valdivia was calculated (Table 2) based on results of visual and automatic interpretation of satellite images. The undertaken research revealed that some anthropogenic and natural objects are distributed into the same classes when image classified into a smaller number of classes, e.g. 5, 10 or 20. By the end, 36 classes were singled out with only 6 of them including pixels of anthropogenic objects.

Automatic classification of the TM/Landsat-5 images made in 1987 and 2007 turned out to be inefficient, even when they were grouped in a larger number of classes. It might be explained with a rather low TM spatial resolution of 30m compared to 15m of ETM+ and OLI.

Most of the residential area of the city is characterized by single-family houses with backyard, which is significantly bigger than the building. Since the size of each pixel is 30 by 30 meters, the brightness value is considerably averaged; as a result, automatic classification fails to identification of class of the pixels accurately.

Table 2. Measured areas of urban territories in city of Valdivia.

Year	1987	2000	2007	2017
Automatic interpretation	—	22.2km^2	—	26.1km^2
Visual interpretation	16.1km^2	22.1km^2	24.5km^2	25.9km^2

Therefore, visual interpretation of the four satellite images was performed and at the same time compared the results of the built-up areas in the years 2000 and 2017 obtained by automatic and visual interpretation.

Table 2 demonstrates the measured urban territories in the selected periods. No significant difference was observed between visual and automatic interpretation methods.

Fig. 2 shows the changes in Valdivian population and city's built-up areas according to the results obtained through visual interpretation. The city was losing its population density from 6,956 people per square kilometer of built-up area in 1987 to 6,080 in 2007. These changes have been produced by constant increase of the number and area of single-family houses with backyards, built in the periphery part of the city during these 20 years. Besides, the shantytowns with high population concentration have been diminishing as well [14].

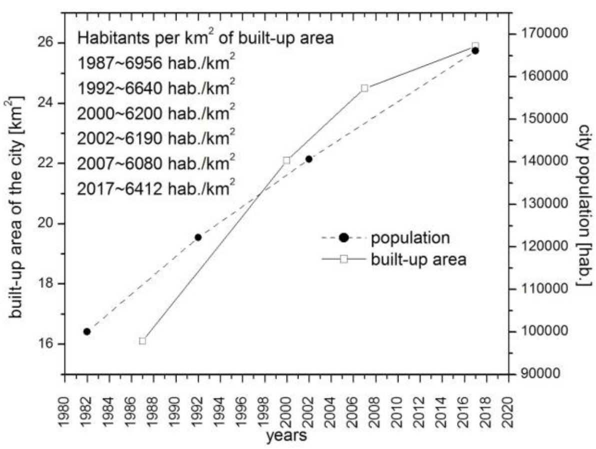

Figure 2. Changes in Valdivia built-up areas and city population.

Transformation of a provincial town into the region capital facilitated vertical urbanization. Construction of high-rises and social housing units led to an increase in population density, and in 2017 it rose to 6,412 people per square kilometer of built-up area.

Fig. 3 illustrates built-up area spreading over the past 30 and 10 years respectively. Between 1987 and 2017 the built-up areas increased by 61%, and between 1987 and 2007, 52, yet, urban sprawl have been slowing down for the past 10 years. Most areas under construction are located in southern, south-eastern, western and northern parts of the city, right along the main transport routes.

Locher-Krause et al. in 2017 looked into the land-use dynamics in the southern part of Los Rios region and in the northern sectors of Los Lagos region. This study area covers all urban surfaces, including the cities of Valdivia and Osorno. The research revealed that between the years of 1985-2011 the built-up areas expanded by 26%.

Figure 3. Change in built-up areas over the past 30 and 10 years.

In our study the values of built-up areas transformation are higher, which is perfectly in line with the results mentioned, since we analyzed only the capital city of the region with intensive urban development compared to other towns of the region.

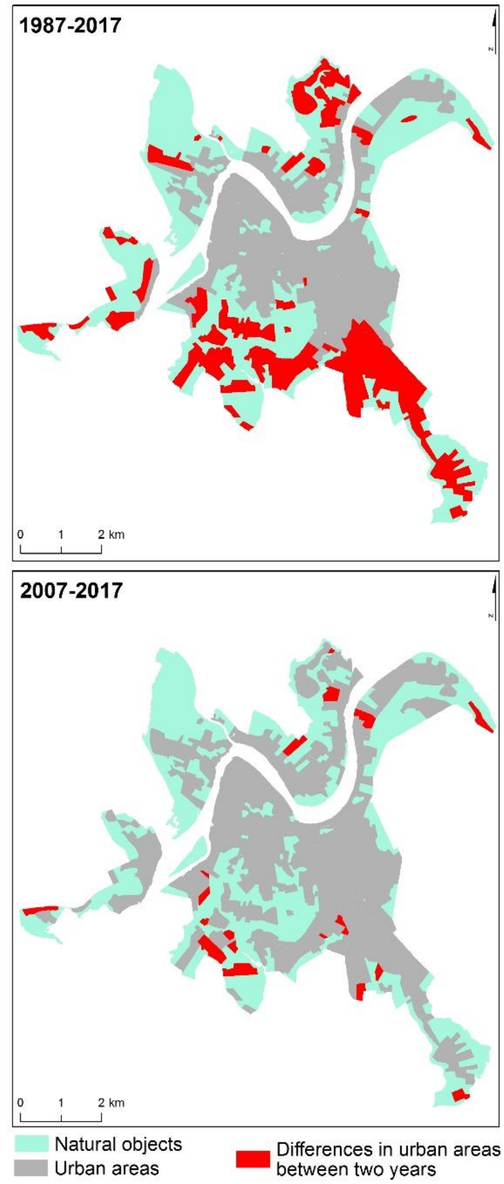

Figure 3. Change in built-up areas over the past 30 and 10 years.

5. CONCLUSIONS

The quantitative assessment of built-up areas dynamics in the city of Valdivia over the last 30 years based on Landsat satellite imagery was performed. Method of automatic interpretation (unsupervised classification by the method of ISODATA) showed results that are in concordance, agreement, with the results of the visual interpretation of satellite images.

It was found that by the year 1987, the built-up areas occupied 35.5% of the total modern urban area. By 2017 this number increased up to 56.8%. In study of Silva et al. in 2015 mentioned that urban green territories covered 41.8% of the total city area. Therefore, the data obtained by our study can be considered adequate.

Our findings based on the analysis of both satellite image interpretation and demographic statistics proved the fact that the change of Valdivia administrative status in 2007, transformed the of urbanization and housing development processes over the past decade due to increase of construction of high-rise buildings; the rate of expansion of built-up areas in Valdivia in its current administrative boundaries has decreased presently. This decrease is also due to economic factors (a rise in prices per square meter of land within the boundaries of the city).

6. ACKNOWLEDGMENTS

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