LAND USE DATA IN THE MIDDLE MAULE RIVER SUB-BASIN: CLASSIFICATION AND COMPARISON BETWEEN 1999 AND 2019

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ABSTRACT:

The use of satellite images is a modern strategy for the evaluation and prediction of various weather scenarios. In addition, this is a key tool for the development of environmental sciences. Since the end of the last decade, Chile has been suffering from a megadrought associated with climate change. In this context, this study proposes to evaluate the role of land use change in the Middle Maule River sub-basin, located in the Maule Region, Chile. This is an important sector characterized by a significant agricultural and hydroelectric contribution. To do so, this study performs a supervised classification of land cover through the usage of QGIS software and Landsat images for the years 1999 and 2019. The results show the growth of areas without vegetation due to a great drought facing the Central Zone of the country. Additionally, there is a decrease in available bodies of water. This article leaves open future research on the impact of the main economic activities of the region.

1. INTRODUCTION

1.1 General Instructions

Human activities change the land cover and use, since it alters the natural surfaces and thermal (Kalnay and Cai, 2003), radiative (Morais et al., 2018), and physical properties (Huntra and Keener, 2017), influencing in the atmosphere (Pielke et al., 2011). Besides, anthropogenic and natural changes in the soil involve several environmental problems such as the impact on biodiversity through degradation or destruction of habitats, it also degrades the soil, pollutes water bodies as a result of the removal of forests (Newbold et al., 2015). It also produces changes in atmospheric temperature due to the emission of greenhouse gases. From another perspective, it also generates alterations to the hydrological cycle (Legesse et al., 2003; Li et al., 2007; Rudke et al., 2019). The change in land use through the monoculture of exotic species is contributing both to the loss of habitat and biodiversity and the species extinction (Fierro et al., 2016). The monitoring of biodiversity and the environmental impact resulting from human activities is essential since it helps to design mitigation and adaptation activities to prevent higher losses of biological diversity. At this point, the evaluation of space-time changes in ecosystems is critical (Pettorelli et al., 2014).

In recent years, remote sensing has become an essential tool in understanding the role of Land Use and Land Cover (LULC) change in the climate of a region, especially with the aid of numerical modeling of the atmosphere (Fan et al., 2014; Morais et al., 2017; Solecki and Oliveri, 2004). In addition, the use of satellite imagery has become fundamental in urban planning, agriculture, energy, among other activities (Csiszár et al., 2019; Ho et al., 2001; Kar and Liou, 2019; Li et al., 2019; Wilson et al., 2019; Xiao et al., 2006). In recent times, research on LULC mapping has increased considerably with 87.9% of publications in the 21st century (Yu et al., 2014). In this sense, various satellite products have emerged in recent years for the entire globe, which increases the available mappings (Grekousis et al., 2015). Several authors have studied and compared different global mapping products on land use and have concluded that they have discrepancies in terms of results and databases, consequently, several products have been developed at regional level (Capucim et al., 2015; Congalton et al., 2014; Congalton, 1991; Herold et al., 2008; Rudke et al., 2019).

In South America, the study of LULC is quite diverse. Hansen et al., (2013), for example, shows that, between 2000 and 2012, South America suffered deforestation of approximately 542,000 km^2. In Chile, many studies for multiple application has been done. Echeverria et al., (2006), showed the deforestation of 67% of Chilean temperate forests between 1975 and 2000 for the south-central region. For the same region, Nahuelhual et al. (2012) showed that this deforestation is related to plantation expansion. Zhao et al. (2016) produced a multi-seasonal and dynamic series of LULC maps using Landsat 8 imagery for 2013 and 2014. Using LULC, Rojas et al., (2019) quantified the urban growth over the wetland for the metropolitan area of Concepción, in south Chile. Building scenarios of LULC, Manuschevich et al., (2019), discuss the forest policy, transitions and environmental outcomes linking political and economic processes. Curtis et al. (2019) show that southern Chile is the region with the most suitable condition for the presence of non-native pine plantations. Liu et al. (2019) studied the environmental impact of lithium mining in the Atacama Salt Flat using Landsat imagery and MODIS land products. Martínez Martínez et al., (2019) studies the effect on the effects of the land use changes on the net primary product for south-central Chile from 2000 to 2014.

Despite the various LULC studies for Chile, there is a gap in understanding their changes and the impact on the hydrological

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cycle and climate, just as the country is experiencing a megadrought that began a decade ago (Garreaud et al., 2019). In this context, this study aims to analyze the changes in LULC in the Middle Maule River sub-basin, which is important for the power generation and water supply of the Maule region in south-central Chile, between the years 1999 and 2019.

2. DATA AND METHODOLOGY

2.1 Characteristics of the study region

The Maule River Basin is located in the Central Zone of Chile (Figure 1), has an area of 20,300 km^2, and has an average flow of 467 m^3/s (BCN, 2017). The basin has an installed hydroelectric power of 1,368 MW, approximately 9% of national production(Generadoras de Chile, 2017). In the Maule Region, there are 17.2% of the national silvoagropecuary production with activities such as forest plantations, cereals, fruit trees, viticulture, among others. On the other hand, in the region, there is 18% of the total national livestock (ODEPA, 2018).

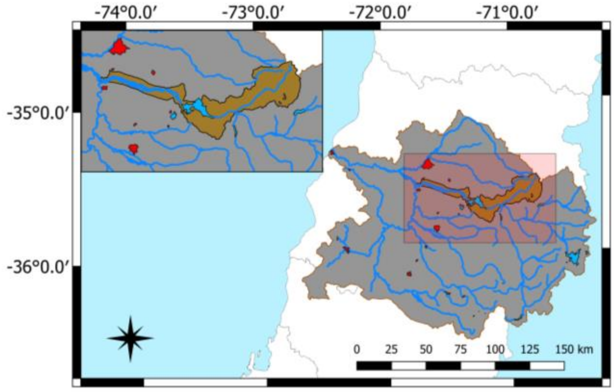


Figure 1: Localization of the Maule River Basin within the Middle Maule sub-basin. Red areas are cities.

The Maule River Basin is composed of 9 sub-basins. This study focuses on the Middle Maule sub-basin (top left map in Figure 1), which has a surface area of 943 km^2 (MOP-DGA, 2003). According to the land and vegetation use cadaster carried out by the Chilean Geospatial Data Infrastructure (IDE, 2017), it can be found for the year 2016, that the land use was mainly classified in 3 groups: vegetation, agricultural land, and forests. The rest corresponds to bodies of water, and meadows and thickets. This sub-basin has a high hydroelectric activity with at least four power stations in Maitenes, Carretones, Bajo Lircay, which correspond to passing plants, and in Colbún, it can be found a reservoir plant (MOP-DGA, 2008).

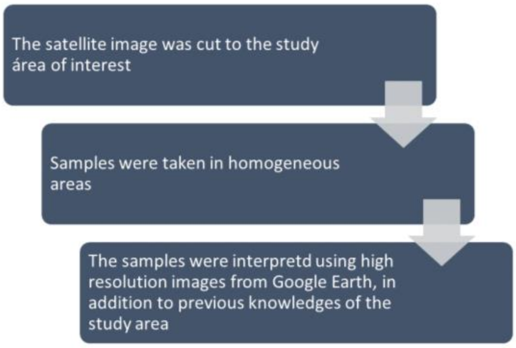
Inside the sub-basin area does not contain any city or town, but in its vicinity, it can be found Talca, San Clemente, Maule, Colbún, and San Javier. The water bodies that stand out in this sub-basin are Maule, Claro, and Blanquillo rivers, in addition to having two lagoons: La Turbia and Laguna del Caracol. Also, it contains a large amount of Colbún Lake, an artificial reservoir. Many estuaries and streams are also found, in which stand out Loss Tricahues, Los Teatinos and Armerillo estuaries, and the Los Boldos, La Laguna, and El Burro streams.

2.2 Satellite Imagery

Considering the long period range for this study, the Landsat scenes were used. The images are freely available on the website of the United States Geological Survey (USGS). The database corresponds to an image of Landsat 4-5, for the year 1999, and an image of Landsat 8 for the year 2019. Both scenes were selected considered cloudiness conditions, which were the months of October to December for 1999 and 2019, respectively. Both scenes have a spatial resolution of 30 m, and the data are available in 185 km x 180 km, defined in a Worldwide Reference System (WRS-2; Loveland and Irons, 2016). For the classification, the Bands Blue, Green, and Red were used, corresponding to the bands 1, 2, and 3 for Landsat 4-5 TM (1999 image), and the bands 2, 3, and 4 for the Landsat 8 OLI (2019 image).

2.3 Classification

In the preprocessing stage, both images used the Dark-Object-Subtraction-1 (DOS1) atmospheric correction algorithm to improve the estimation of land surface reflectance (Gomez-Dans, 2020). The supervised classification method was used to classify the land cover. For the training set, the classification carried out by the IDE (2017) was used, that is, the categories of land use are Bare soil, Agricultural land, Forests, Meadows and Thickets (MaT), Water and Snow. Image processing was performed on the free QGIS 3.8.2 software developed by the OSGeo foundation, using the Semi-Automatic Classification Plugin (SCP; Leroux et al., 2018). For each class, 50 samples were collected using high-resolution imaging (Google Earth), following Rudke et al. (2019). Figure 2 presents the flowchart of the classification process:



The satellite image was cut to the study área of interest

Samples were taken in homogeneous areas

The samples were interpretd using high resolution images from Google Earth, in addition to previous knowledges of the study area

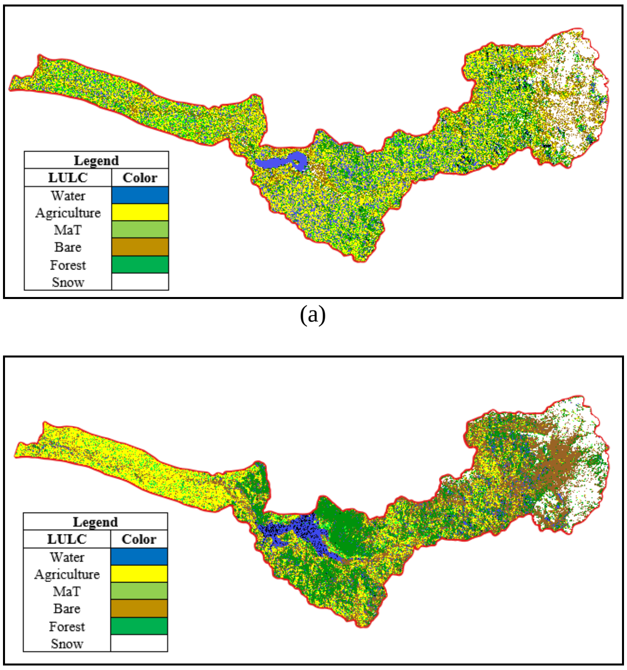
Figure 2: Flowchart of the Landsat satellite image classification process for both the years 1999 and 2019.

For each image (1999 and 2019), at least 300 scattered samples were taken. The classification algorithm used was Spectral Angle Mapping (SAM; Kruse et al., 1993). This method considers that the image data was converted to surface reflectance, determining the spectral similarity by the angle formed between two spectra (Markoski and Rolim, 2012). After classification, an ASCII point-by-point file was generated and subsequently converted to a comma-delimited values (csv) file. The csv file with the soil classification was compared and worked on the free Octave programming software, that uses the M language. In this software, it was calculated both the number of specific changes per class and the amount of soil that remained in its category. The results were analyzed comparing the percentage difference and maintenance between both years for each pixel.

3. RESULTS AND DISCUSSION

Figure 3 shows the results obtained by the supervised classification. Figure 4 presents the LULC percentage for each year and the changes between 1999 and 2019. Regarding the classification and comparison of land cover it is evident that the main land occupation for 1999 corresponds to agriculture (33.8%) followed by forests with (20.7%), while for 2019 the highest use of soil corresponds to areas without vegetation (30.4%) followed by agriculture and forests (23.6% and 23.1% respectively).

Besides, it can be seen that the bodies of water decreased by 7%. On the other hand, agricultural activities have also decreased by 10.2%. Regarding meadows and thickets, the amount of soil has remained almost constant with a decrease of 0.3%. The amount of snow present has decreased by 2.1%. The land classified as forest has presented an increase of 2.4%. Finally, it was found a high growth of areas without vegetation, with an increase of 16.3%. This increase in bare soil contributes to the high levels of temperature in the region (Alvenäs and Jansson, 1997). This result relates to the land degradation process found in other studies for Chile (Aronson et al., 1998; Nahuelhual et al., 2012; Pereira, 2019; Schulz et al., 2010).



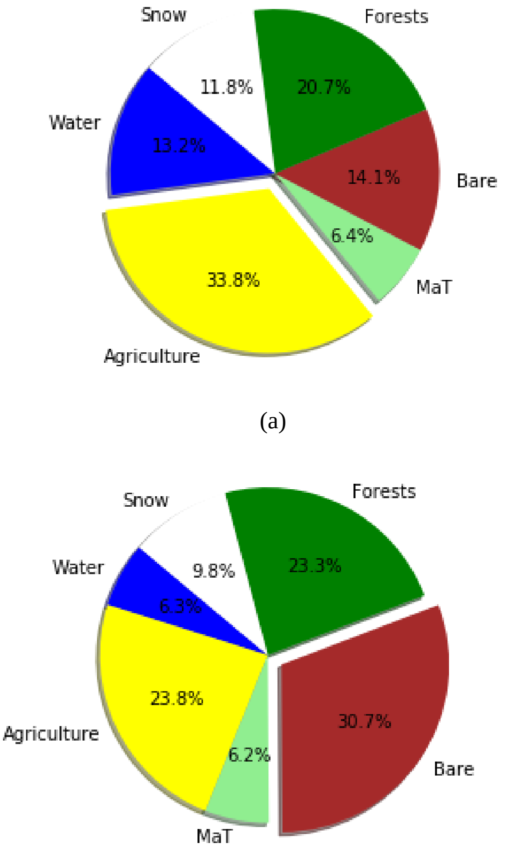
(a)

(b)

Figure 3. Results of supervised classification SAM for (a) 1999 and (b) 2019.

For the specific change of soil (Table 1), several significant changes in LULC can be observed. The same result can also be seen in the Sankey diagram, shown in Figure 5. This shows the changes in land cover, where the width of the arrow indicates the magnitude of the specific change. In the left column are the corresponding classification data for 1999, while in the right column are the classification data for 2019.

The bodies of water had a considerable change, with 32% of the change in 1999 to forest in 2019; 21.6% have dried up in areas without vegetation, and 24.7 % have classified as agricultural use. When analyzing the change of agricultural land, most of it has mainly gone to areas without vegetation and forests, with 31.1% and 24.6%, respectively. 41.2% of meadows and thickets have changed to agricultural land, while 24% have given rise to soils without vegetation. Forest areas have mostly changed to soils without vegetation and agricultural land, with 28.5% and 21.7%, respectively. Otherwise, the categories with the highest percentages of soil cover maintenance, that is, that did not change over time were snow, soils without vegetation, forests, and agriculture with 46.7%, 40.3%, 33.3%, and 30.1% respectively.



(a)

(b)

Figure 4. LULC percentage of the class change between (a) 1999 and (b) 2019. The highest percentage is highlighted.

LULC	Water	Agriculture	MaT	Bare	Forest	Snow
Water	11.6	24.7	6.1	21.6	32.0	1.0
Agriculture	4.1	30.1	7.2	31.1	24.6	2.7
MaT	4.9	41.2	11.8	24.0	15.8	1.9
Bare	6.0	19.6	6.3	40.3	10.5	16.0
Forest	7.8	21.7	4.6	28.5	33.3	3.6
Snow	4.1	2.4	2.4	33.6	10.1	46.7

Table 1. Changes in LULC in percentage (%), specifying each type of change.

According to the total changes in land cover (Table 2), an alarming figure of 24.7% change from land to cover without vegetation can be seen, is the most considerable change recorded, followed by forests and agriculture. This is consistent with the growth of 16.3% of areas without vegetation presented in Figure 5. Forests and agricultural soils take second and third place with 16.2% and 13.4% respectively.

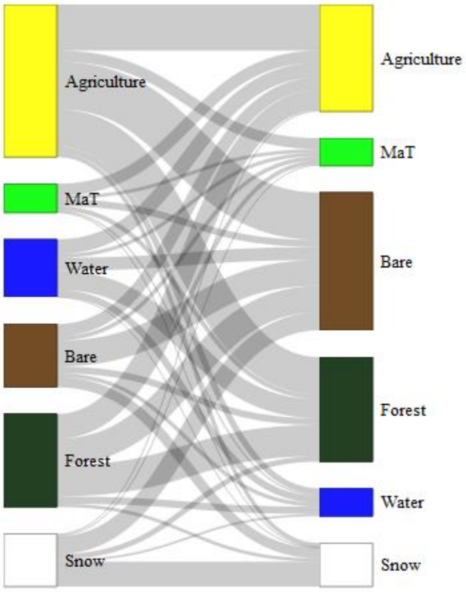


Figure 5. Sankey diagram for the specific LULC change. The left column is for the year 1999, while the right column corresponds to 2019.

LULC	Total class change	Class maintenance
Water	4.6%	1.5%
Agriculture	13.4%	10.2%
MaT	5.3%	0.8%
Bare	24.7%	5.7%
Forest	16.2%	6.9%
Snow	4.2%	5.5%

Table 2. Change and maintenance of LULC compared to the total quantity of pixels. Example: 4.6% of other classes of LULC became water bodies, while 1.5% have maintained in the original class.

4. CONCLUSIONS

When comparing both images, a large amount of agriculture is concentrated in the western sector of the basin in the year 2019. If analyzed for 1999, a more heterogeneous soil is observed, where the composition is diverse throughout the sub-basin. On the other hand, in 2019, the types of land cover are segregated and grouped with the same class.

At first glance, it can be deduced that the results indicate a decrease in bodies of water, vegetation, whether agricultural or natural. These results could be directly associated with the drought facing Chile and especially the Maule Region. Among the possible causes of this event, we can mention the increase of hydroelectric plants in the Maule River between the years of study, as well as the urban growth of nearby towns, in addition to the agricultural activity in the Region that corresponds mainly to agricultural and forestry monocultures (Salas et al., 2016). This could initiate new studies oriented to the impact of each activity mentioned above on the phenomena detected.

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