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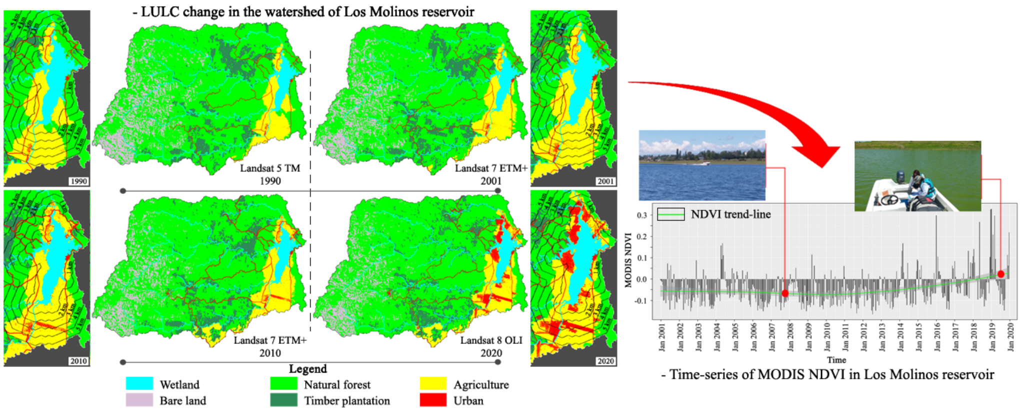
- LULC change in the watershed of Los Molinos reservoir
1990
Landsat 5 TM
1990
Landsat 7 ETM+
2001
2001
2010
Landsat 7 ETM+
2010
Landsat 8 OLI
2020
2020
Legend
Wetland
Bare land
Natural forest
Timber plantation
Agriculture
Urban
NDVI trend-line
MODIS NDVI
0.3
0.2
0.1
0.0
-0.1
Jan 2001
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006
Jan 2007
Jan 2008
Jan 2009
Jan 2010
Jan 2011
Jan 2012
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Jan 2014
Jan 2015
Jan 2016
Jan 2017
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Jan 2019
Jan 2020
Time
- Time-series of MODIS NDVI in Los Molinos reservoir

Assessing land use and land cover change in Los Molinos reservoir watershed and the effect on the reservoir water quality

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ABSTRACT

Understanding and modelling land use and land cover (LULC) change have become one of the major subjects of interest for environmental management due to the negative effects that human activities generate on the normal functioning and dynamics of freshwater resources. Remote sensing and geographic information systems (GIS) are essential tools for assessing the drivers that cause LULC change and its relationship with lake and reservoir water quality.

The objective of this study was to assess the spatial and temporal dynamics of LULC change in the watershed of Los Molinos reservoir (Argentina), and to investigate its relationship with the reservoir´s water quality. Four Landsat imagery was used to analyse the LULC change in the studied watershed and in different buffer zones from 1990 to 2020. Further, the Normalized Difference Vegetation Index (NDVI) derived from a MODIS time-series dataset (2001-2020) was used to explain the effects of LULC change on the status of the reservoir. Results showed that the most significant LULC change started two decades ago and it has intensified during the last ten years. This change is related to the intensification of agriculture activities, and to the increasing conversion into urban areas, mainly on the shores of Los Molinos reservoir. During the period 2010-2020, urbanization located in the 1 km buffer zone defined from the shore of the reservoir increased at an annual rate of 18.02 %. The degradation trend of LULC in Los Molinos watershed significantly contributed to the degradation of water quality of the reservoir. This was corroborated by analysing the MODIS NDVI time-series, which showed that since 2014 the NDVI trend-line presented an increasing behaviour and extreme values of NDVI, related to algal blooms, were more frequently observed.

KEYWORDS: Landsat satellites; LULC change; MODIS NDVI time-series; Reservoir; Watershed.

1. INTRODUCTION

Lakes and reservoirs provide a variety of services to human society, including drinking water, energy, fisheries, navigation, flood storage and recreation. However, these ecosystems are vulnerable to water pollution, such as eutrophication, which is one of the most urgent environmental problems in water resource management all over the world (Smith and Schindler, 2009; Padedda et al., 2017; Bhagowati and Ahamad, 2019). Eutrophication, which is primarily attributed to the continuous increase in the input of essential nutrients into the aquatic systems, such as phosphorus and nitrogen (Guan et al., 2020), results in adverse impacts on ecological functions provided by water resources (Amé et al., 2003; Mendoza et al., 2015; Cai et al., 2020). Although eutrophication is a slow natural process, it can be sharply accelerated by human activities posing potential risks to human health and sustainable development (Ferral et al., 2018; Le Moal et al., 2019; Lin et al., 2020). Different studies suggest that intensive land use practices, such as urbanization, agriculture, mining, afforestation and deforestation, have greatly altered the normal functioning and dynamic of freshwater resources (Ngoye and Machiwa, 2004; Seeboonruang, 2012; Bonansea et al., 2016; Padedda et al., 2017; Le Moal et al., 2019; Rojas et al., 2019; Desta and Fetene, 2020; Guan et al., 2020). Therefore, understanding and modelling of land use and land cover (LULC) change at a watershed scale has become one of the major subjects of interest for environmental management and land use planning since it can be used as an indicator of the impact of human activities over aquatic systems (Yu et al., 2011; Xu et al., 2020).

Remote sensing and geographic information systems (GIS) are essential tools for assessing the drivers that cause LULC change and its relationship with lake and reservoir water quality (Fukushima et al., 2007; Huang et al., 2014; Santos et al., 2017; Wei et al., 2020). These techniques facilitate monitoring and analysis of LULC change and eutrophication more efficiently than ground-based observations due to its time- and cost-effectiveness over large areas as well as remote locations. In this sense, the Landsat Program, which consists of a series of satellites missions, has the ability to monitor and quantitatively characterize LULC change at a scale where natural and human-induced causes can be detected (Loveland and Irons, 2016; Gómez et al., 2016). This can be achieved due to its long history and relatively high spatial resolution (Loveland and Irons, 2016).

On the other hand, different authors suggest that spectral indices (e.g., NDVI, FAI, NDAVI, WAVI, NDTI, MCI, NDPI, CCI, among others) are highly recommended for mapping and monitoring water quality parameters in aquatic environments (Tebbs et al., 2013; Villa et al., 2014; Zhou et al., 2018; Elhag et al., 2019; Kiage and Douglas, 2020). These indices are generally calculated from the combination of visible and infrared bands of remote sensing sensors (Qing et al., 2020). Among several satellites that have been successfully used for evaluating water quality from spectral indices, the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor onboard NASA’s Terra/Aqua satellites has proven useful for deriving assessment of inland and coastal waters due to its shorter revisit time and its ability to provide long-term and dense time-series data (Villar et al. 2013, Chen et al., 2014; Germán et al., 2020; Li et al., 2020).

Advances in remote sensing technology have considerably improved the assessment of a long time-series of LULC change (Huang et al., 2002; Fukushima et al., 2007; Huang et al., 2014; Loveland and Irons, 2016; Gómez et al., 2016; Wei et al., 2020), variations in water quality (Tebbs et al., 2013; Chen et al., 2014; Villa et al., 2014; González-Márquez et al., 2018; Zhou et al., 2018; Bonansea et al., 2019; Elhag et al., 2019; Germán et al., 2020; Kiage and Douglas, 2020; Li et al., 2020, Torregroza-Espinosa, et al. 2020) and eutrophication causes (Smith and Schindler, 2009; Mendoza et al., 2015; Padedda et al., 2017; Bhagowati and Ahamad, 2019; Le Moal et al., 2019; Cai et al., 2020). However, to the best of our knowledge, studies that relate LULC change and reservoir water quality are scarce and dispersed, particularly in the Southern hemisphere. Therefore, the main objective of this study was to characterize and assess the spatial and temporal dynamics of LULC change in the watershed of Los Molinos reservoir (Argentina), and to investigate its relationship with the water quality of the reservoir.

Los Molinos reservoir, located in the central region of Argentina, was built in 1953 for multi-purposes, including water supply for towns located on its shores and for the 30% of Córdoba city (1.4 million inhabitants), power generation, flood control, irrigation, habitat for different species of animals and plants, tourism and recreational activities (Bazán et al., 2005). The watershed of this reservoir is dominated by natural forest, characterized by dry woodland and hard grasses (Cabrera, 1976). In the late 1970s, as a result of a tax deferral plan implemented by the government, afforested areas for sawn timber production were established in the watershed with exotic pines, mainly *Pinus elliottii*, followed by *P. taeda*, *P. radiata* and *P. patula* (Dorado et al., 1997; Cibils-Martina et al., 2017). In the last decades, climate change and high-intensity human activity pressures related to agricultural activities and urban expansion have caused the degradation of the watershed. As a consequence, Los Molinos reservoir has experienced an advance of the trophic state, a degradation of water quality, and multiple algal blooms (Bazán et al., 2005; Bonansea et al., 2018). In the present study, by using Landsat imagery we have focused on assessing the dynamics of spatial and temporal LULC change in Los Molinos watershed from 1990 to 2020. Further, we promoted the Normalized Difference Vegetation Index (NDVI) derived from a MODIS time-series dataset (2001-2020) as an indicator that reflects the status of Los Molinos reservoir and to explain the effects of LULC change on the trophic state of the reservoir. Hence, our study represents a baseline that could provide tools for watershed management to evaluate variation in LULC changes and to assess the interaction of these changes with the reservoir's water quality.

2. METHODOLOGY

2.1 Study area

Los Molinos reservoir (31° 49’ S, 64° 31’ W) is located in Calamuchita Valley, in the central region of Argentina (Fig. 1). This reservoir has a maximum surface area of 2100 ha, a maximum volume of 399 hm^3, and a maximum and mean depth of 53.0 and 14.0 m, respectively (Bonansea et al., 2018). Los Molinos reservoir has four main tributaries and one effluent called Los Molinos river. The watershed of this reservoir occupies an area of 904.89 km^2. The watershed is characterized by a mountainous system called Sierra de Comechingones to the west and Sierra Chica to the east. Elevations of the area range from 2593 to 741 m above sea level (masl), and lithology is dominated by granite with patches of metamorphic rocks (gneiss, schist, migmatite) (Cibils-Martina et al., 2017).

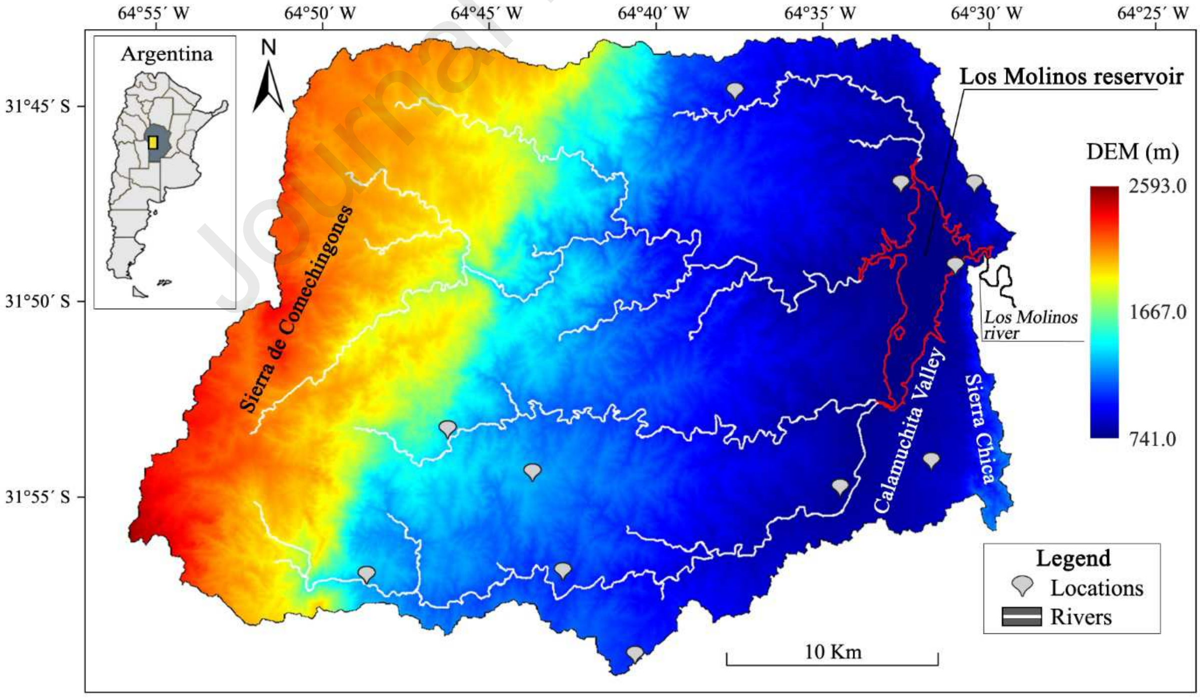

Fig. 1. Location and digital elevation model (DEM) of the study area.

2.2 Analysis of LULC change

A Landsat image from the beginning of each decade was selected to retrospectively characterize and assess the spatiotemporal variations in LULC change of Los Molinos watershed between 1990 and 2020. Thus, four 30-m spatial resolution Landsat Level-2 images of the studied area (Path: 229, Row: 82) were downloaded from the USGS website (https://earthexplorer.usgs.gov/), including one Landsat 5 Thematic mapper (TM) (February 28, 1990), two Landsat 7 Enhance Thematic mapper Plus (ETM+) (February 02, 2001; February 11, 2010), and one Landsat 8 Operational Land Imager (OLI) (March 02, 2020). The selected cloud-free images corresponded to the summer season, preferably between February and March, when vegetation presents its highest productivity. Using images of the same season, we have minimized discrepancies in reflectance of the evaluated land classes. The ETM+ February 02, 2001 image was used instead of an image of the year 2000 because no cloud-free images were available during the summer of that year.

The Landsat Level-2 scenes are on-demand products which are generated from the corresponded Level-1 precision and terrain corrected product (L1TP). Level-2 data consists of pixel values that estimate spectral reflectance as measured at the Earth’s surface eliminating the presence of atmospheric scattering or absorption effects (Teixeira Pinto et al., 2020). Therefore, by accounting for atmospheric effects, Level-2 data products contain surface reflectance values as measured *in-situ*, improving comparison between multiple images and sensors and helping in the detection and characterization of LULC change.

Since May 31, 2003, ETM+ images have presented a failure called scan-line corrector off (SLC-off) resulting in strips of data lost in the ETM+ images acquired afterwards (USGS, 2004). Fortunately, as the SLC-off has not affected the radiometric and geometric quality of the ETM+ sensor, 80% of the pixels of each image are scanned in a perfect way (Chen et al., 2011). To fill the un-scanned pixels of the February 11, 2010 ETM+ image, the SLC-off Gap-Filled Products, Phase Two Methodology article was applied (USGS, 2004).

According to the characteristics of the watershed of Los Molinos reservoir, a support vector machine classification algorithm provided by the ENVI software Feature Extraction Module was used to classify and evaluate the LULC of the studied area. Different studies suggest that a support vector machine algorithm could result in a higher classification accuracy than the maximum likelihood classifier (Huang et al., 2002; Xu et al., 2013). A total of six LULC classes were identified for the different periods, including wetland, bare land, natural forest, timber plantation, agriculture and urban area. Wetland consisted of areas of open water, including rivers, streams, and reservoirs. Bare land referred to sparse plant cover, rocks, gravels, sandy land and bare soil. Natural forest consisted of areas dominated by natural shrubs, thickets and herbs. Timber plantation corresponded to the exotic pines for timber production. Agriculture consisted of agricultural and livestock development, and urban included residential and industrial areas and roads. Between 60 and 120 training data (samples of known identity) that were well distributed across the watershed were chosen for each land use class of each image. *In-situ* investigations, previous author's knowledge of the studied area, and high-resolution Google Earth Pro images were used to help in the identification and validation of LULC classes. All processed images presented a kappa coefficient higher than 0.88, showing a good accuracy in the classification procedure (Chuvieco Salinero, 2008). Thus, four LULC maps of Los Molinos reservoir watershed were obtained for the selected years (1990, 2001, 2010 and 2020).

To describe the dynamic of LULC change in the studied watershed and in different buffer zones defined from the shore of the reservoir, we generated a “from-to” change matrix which was used to evaluate the transition from one LULC class to another between successive land cover maps. Further, the quantification of LULC change was assessed by using the LULC change rate described in the following Equation (Li et al., 2009):

$$k = (S_2 - S_1)/S_1 * 1/T * 100\% \qquad \text{Eq. (1)}$$

where k is the land-use change rate for each land-use type, S_1 and S_2 are the areas of the land-use type at the beginning and at the end of a period, respectively, and T is the time interval (years).

2.3 NDVI time-series evaluation

In the present study, the NDVI was used to estimate algal presence or algal blooms in Los Molinos reservoir, due to its optical characteristics and because it is sensitive to pigment absorption (Zhu et al., 2015). NDVI time-series of Los Molinos reservoir was derived from MODIS sensor using the 250-m spatial resolution MOD13Q1 composition product. Each value of MOD13Q1 is atmospherically corrected (Vermote and Vermeulen, 1999) and indicates the best quality pixel value within the observed 16-days period (Zhang et al., 2019). Dates that present pixels with clouds over the reservoir were removed using the quality flag information in MOD09GQ. In order to avoid land effects, for each evaluated date an NDVI average value was calculated among pixels located further than 250 m from the shore of the reservoir (Germán et al., 2020).

NDVI ranges from -1 to +1. Negative values usually indicate pure water pixels and positive values are strongly correlated with the greenness of the water due to the presence of photosynthetic organisms such as algae (Germán et al., 2020). Values equal or greater than 0.1 can be interpreted as algal scums or blooms (Kiage and Douglas, 2020).

MODIS sensor is operational since 2000, so the NDVI time-series was created from January 2001 to January 2020. The derived MODIS NDVI time-series was analysed using the

Local Regression model (LOESS), which is a non-parametric approach that uses local weighted regression to fit a smooth curve (Cleveland et al., 1992). This method can reveal trends and/or cycles presented in the data set that might be difficult to model with a parametric curve (Cleveland et al., 1992). Using a seasonal-trend decomposition model based on LOESS method (Cleveland et al., 1990), the time-series (Y_t) was decomposed into trend (T_t), seasonal (S_t), and remainder or random (e_t) components at each period of time. Thus, the NDVI time-series was simply described as the sum of the three components using the following equation:

$$Y_t = T_t + S_t + e_t \qquad \text{Eq. (2)}$$

Finally, to compare the variable in different time periods, normalized annual anomalies at each 5 years period boxplots were used.

3. RESULTS AND DISCUSSION

3.1 Land use changes at watershed scale

The spatio-temporal distribution of LULC in Los Molinos watershed was obtained using Landsat imagery from 1990 to 2020 (Fig. 2). During the studied period, the watershed was mainly dominated by natural forest, which slightly decreased at an annual rate of -0.04%, from 67.02% in 1990, to 66.23% of the total watershed in 2020 (Fig. 3). The most important transition of natural forest was to timber plantation, followed by bare land and agriculture (Table 1).

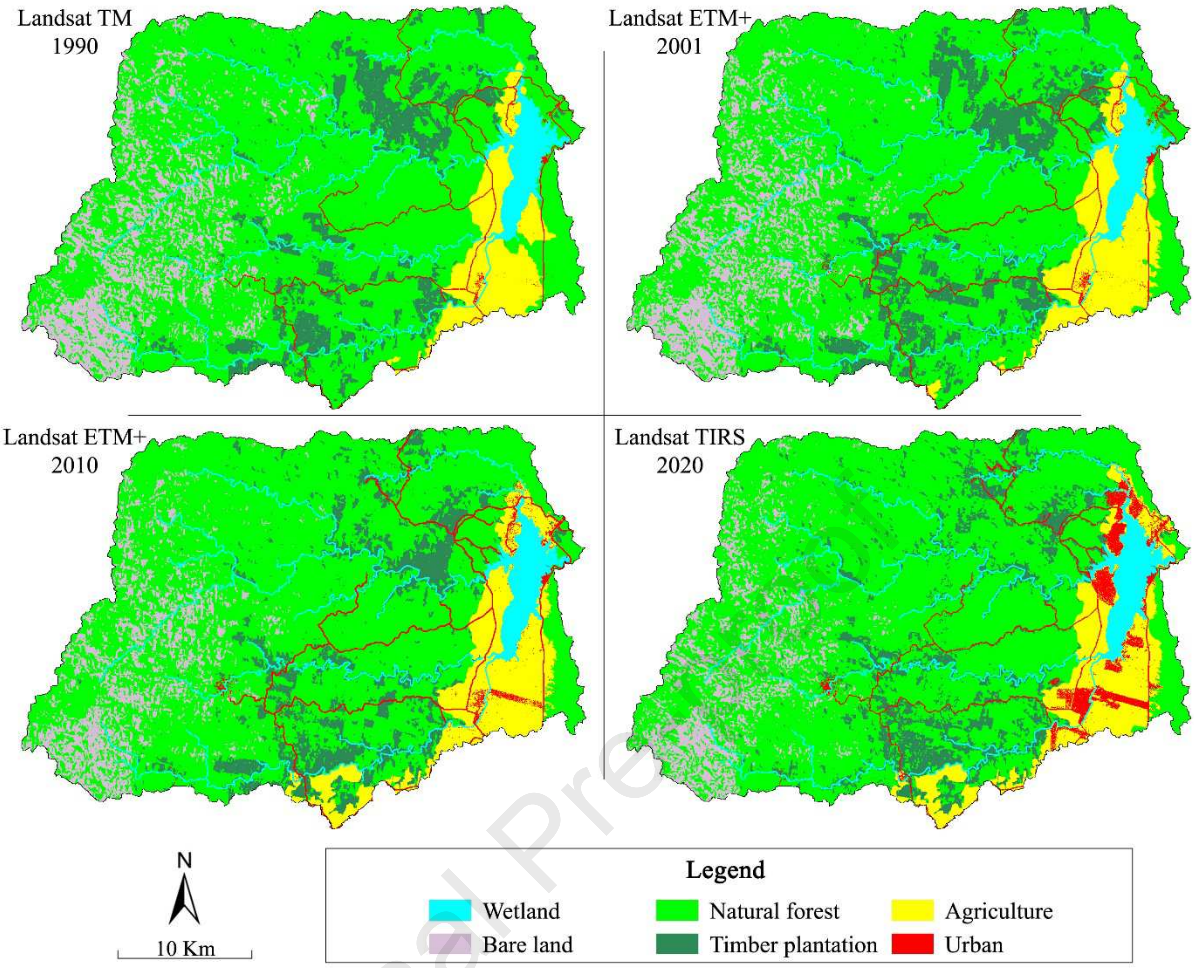

Fig. 2. LULC classification maps in the watershed of Los Molinos reservoir for the studied period (1990-2020).

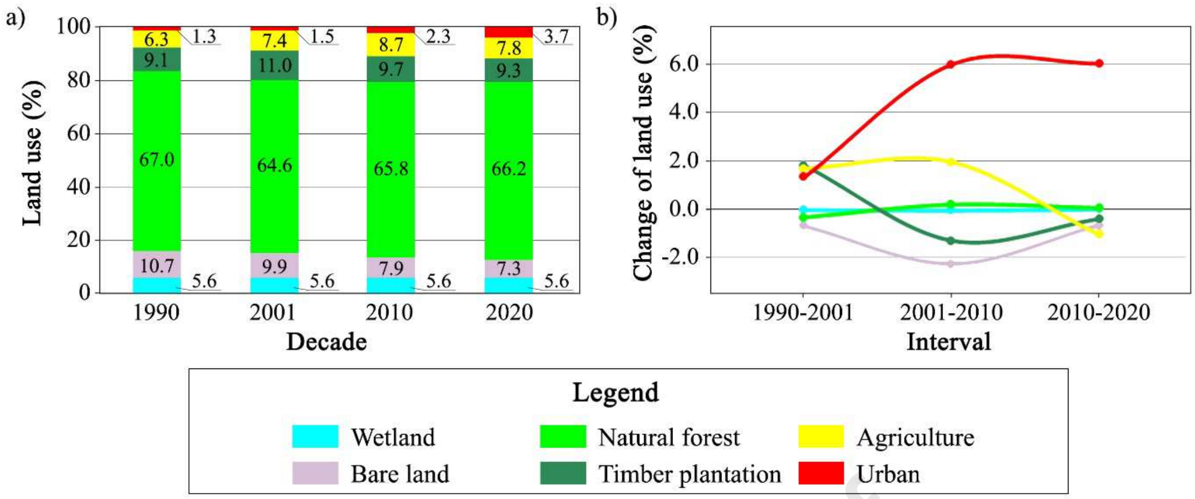

Fig. 3. a) LULC proportions for each decade; b) Comparison of the annual rate of change for each class during the studied period.

Table 1. Transition matrix of land use change in Los Molinos watershed during the studied period (km^2).

Period	LULC	Wetland	Bare land	Natural forest	Timber plantation	Agriculture	Urban	*Total*
1990-2001	**Wetland**	50.85	0.00	0.00	0.00	0.00	0.01	*50.86*
	Bare land	0.00	70.60	25.90	0.01	0.00	0.04	*96.55*
	Natural forest	0.00	18.64	541.04	34.68	11.17	0.95	*606.47*
	Timber plantation	0.00	0.03	17.99	64.40	0.02	0.22	*82.65*
	Agriculture	0.00	0.00	0.06	0.00	55.95	0.58	*56.59*
	Urban	0.00	0.00	0.02	0.02	0.01	11.73	*11.77*
	Total	*50.85*	*89.26*	*585.00*	*99.11*	*67.15*	*13.52*	-
2001-2010	**Wetland**	50.77	0.00	0.00	0.00	0.00	0.08	*50.85*
	Bare land	0.00	54.87	34.32	0.01	0.00	0.06	*89.26*
	Natural forest	0.00	16.20	516.96	34.28	14.71	2.85	*585.00*
	Timber plantation	0.00	0.02	43.63	53.18	0.57	1.71	*99.11*
	Agriculture	0.00	0.00	0.67	0.00	63.68	2.80	*67.15*
	Urban	0.00	0.01	0.11	0.01	0.07	13.31	*13.52*
	Total	*50.77*	*71.11*	*595.69*	*87.49*	*79.03*	*20.81*	-
2010-2020	**Wetland**	50.77	0.00	0.00	0.00	0.00	0.00	*50.77*
	Bare land	0.00	47.23	23.83	0.03	0.00	0.01	*71.11*
	Natural forest	0.00	19.25	537.14	32.41	5.10	1.79	*595.69*
	Timber plantation	0.00	0.00	36.45	50.18	0.66	0.20	*87.49*

	Agriculture	0.00	0.00	0.46	0.01	64.18	14.38	*79.03*
	Urban	0.06	0.00	1.46	1.37	0.93	16.99	*20.81*
	Total	*50.83*	*66.48*	*599.34*	*83.99*	*70.87*	*33.38*	-

Intensive land use classes, which include timber plantation, agriculture and urban area, increased during the studied period (1990-2020). However, the change of these land uses did not occur at equal rates. Between 1990 and 2001, timber plantation presented a strong increase at an annual rate of 1.81 %, mainly from natural forest (34.68 km^2) (Fig. 3.b, and Table 1). Since 2001, due to timber production (Cibils-Martina et al., 2017) and wildland fires (Bonansea and Fernandez, 2013; Fernandez et al., 2014), the area occupied by sawn plantations has decreased at an annual rate of -1.30 % from 2001 to 2010, and -0.40 % from 2010 to 2020. During these time periods, 43.63 km^2 and 36.45 km^2 of timber plantation changed to natural forest, respectively. According to different authors, scarce information about forest management and wood processing in the region discourages the application of environmental and economical sound forest practices that increase the productivity of forest land (Dorado et al., 1997; Cibils-Martina et al., 2017).

Agriculture, mainly located in Calamuchita Valley and around Los Molinos reservoir, showed an annual growth rate of 0.84% during the 30-year studied period. During the periods 1990-2001 and 2001-2010, agriculture land increased at an annual rate of 1.70 and 1.97 %, respectively. The most important transition to agriculture was from natural forest (11.17 km^2, for the period 1990-2001, and 14.71 km^2 for the period 2001-2010). From 2010 to 2020, agriculture has decreased at an annual rate of -1.03 % due to conversion to urban area.

The most consistent upward trend of class change was the progressive gain of urban area. During the last 30 years, urban area has had an increasing annual rate of 6.12 %. In the beginnings of 1990s, urbanization occupied an area of 1.30 % (11.77 km^2) of the total watershed. During this decade, this category has increased at an annual rate of 1.34 %.

However, since 2001 urban area has abruptly increased its annual rate to 6.00 and 6.03 %, for the periods 2001-2010 and 2010-2020, respectively. Most of the urban area was obtained from a conversion of agriculture, mainly between 2010 and 2020, where 14.38 km^2 of agriculture land was converted to urbanization.

Results show that urbanization increased mainly on the shore of Los Molinos reservoir (Fig. 2). Therefore, an exhaustive LULC change analysis was done in different buffer zones defined from the shore of the reservoir (Fig. 4). By analysing the different buffer zones, we observed that from 1990 to 2001 the rate of change was similar for each land use class with the exception of timber plantation, which presented the highest land-use change rate in the 1 km buffer zone (14.59 %) due to the expansion of a timber plantation located in the northwest area of this buffer zone (Fig. 5.a). Figure 5 also shows that the increase in urban area until 2001 was unremarkable in the different buffer zones. However, since 2001 different urban investment projects, primarily located close to the shores of Los Molinos reservoir, have generated a drastic change in LULC of the watershed. This was more evident in the 1 km buffer zone of the period 2010-2020, where urban area presented a drastic increasing annual rate of 18.02 %, and the proportion of land occupied by urbanization presented an exponential increase (6.06 % in 1990, 6.97 % in 2001, 10.96 % in 2010, and 30.71% in 2020). In addition, Figure 5.b shows that during the last decades the most consistent trend of inter-class changes in the buffers zone has been a progressive loss of natural forest, which was replaced by the increase of intensive land use classes. For example, at present, more than the 80 % of the 1 km buffer zone corresponds to intensive land use classes, mainly agriculture (46.40 %) and urban area (30.71 %).

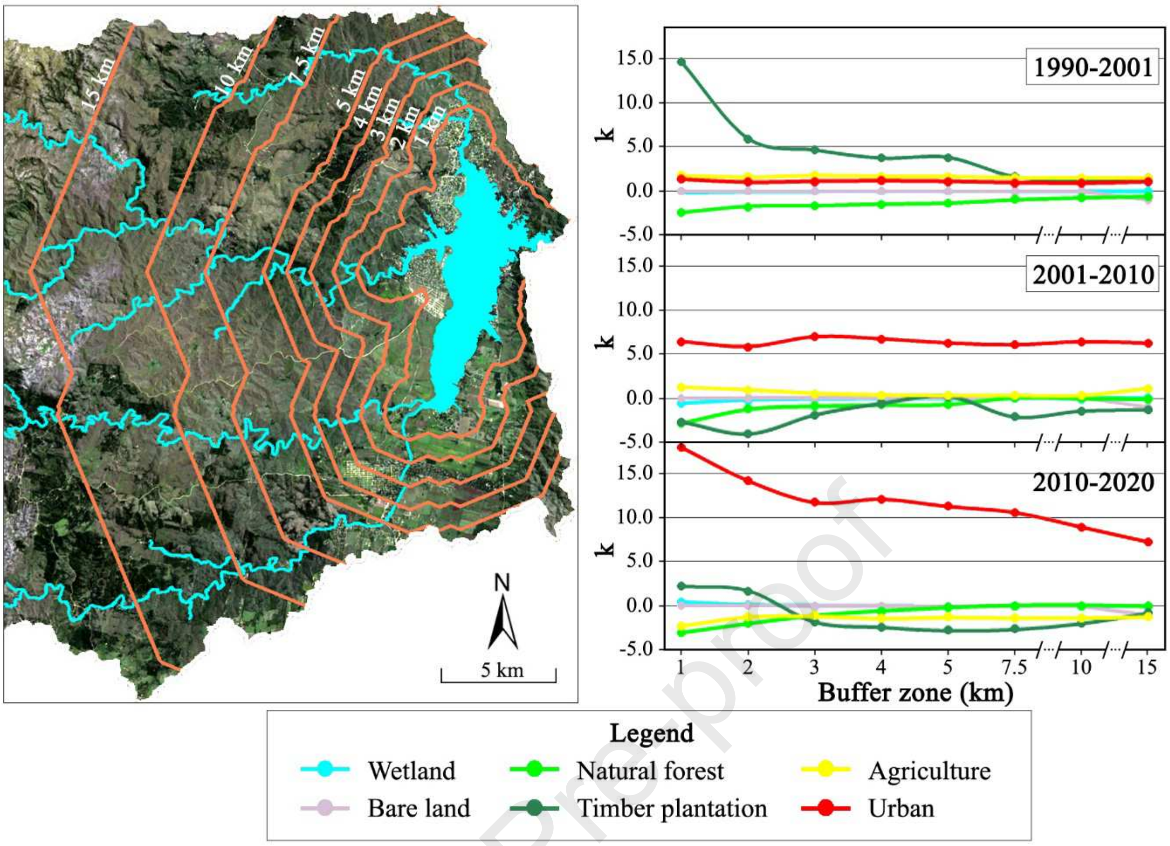

Fig. 4. Comparison of the rate of change for each class in different buffer zones.

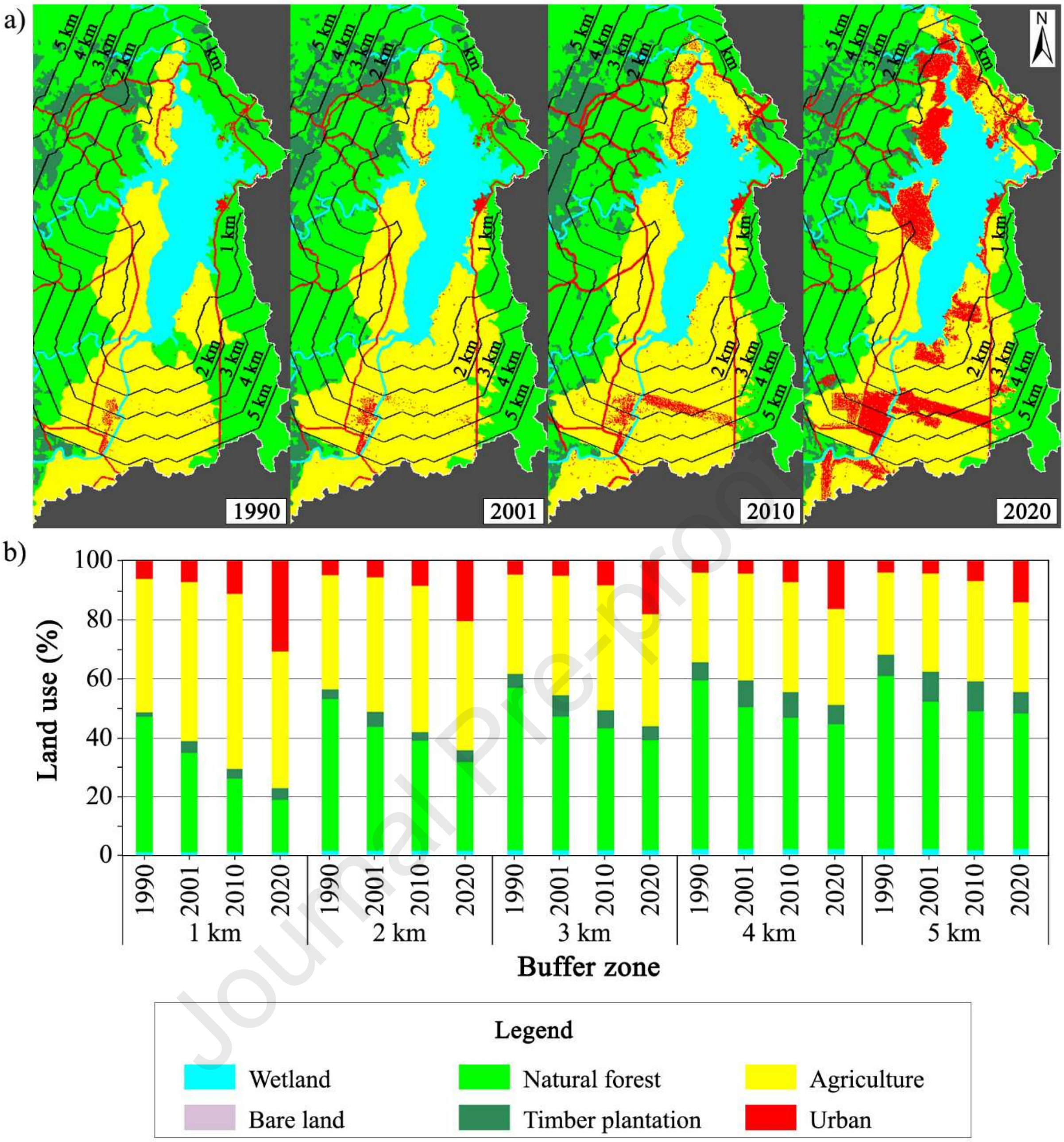

Fig. 5. a) LULC classification maps of the buffer zones defined from the shore of the reservoir (1990-2020); b) LULC proportions for each buffer zone during the studied period.

3.2 NDVI time-series analysis

Figure 6 shows the 16-days averaged NDVI time-series generated from MODIS sensor for Los Molinos reservoir. The calculated NDVI values range from -0.17 (on July 11, 2012) to 0.33 (on January 01, 2019). It is possible to observe that from 2001 to 2013 the

NDVI trend-line remained practically constant and retrieved NDVI values were similar to -0.05. However, since 2014 the trend-line has had an increasing behaviour, passing from negative NDVI values, typical of pure water, to positive values which could be related to the presence of algae. Further, since 2014 there has been an increase in the amount of positive retrieved NDVI values compared with previous years. This is in accordance with Figure 7.a which shows that positive annual anomalies of NDVI had been found since 2014. Additionally, Figure 7.b shows that since 2014 there has been an increase in the number of records that exceed the NDVI threshold of 0.1, which according to Germán et al. (2020), and Kiage and Douglas (2020), it could be related with the presence of algal blooms in the reservoir. These events have been more evident during the last two years (2018 and 2019), followed by 2004.

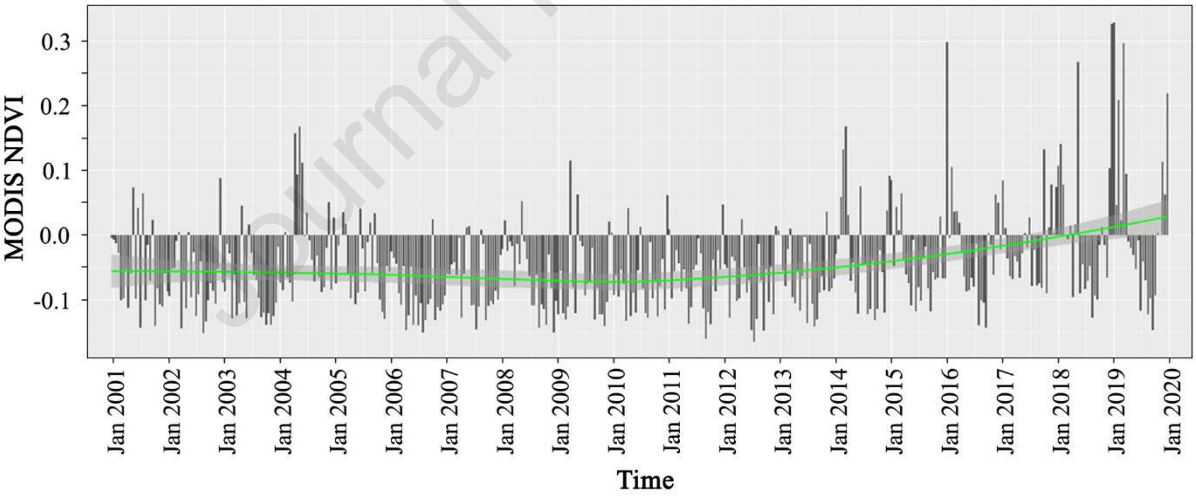

Fig. 6. Time-series of MODIS NDVI. Green line represents the NDVI trend-line generated with the LOESS smoothing model.

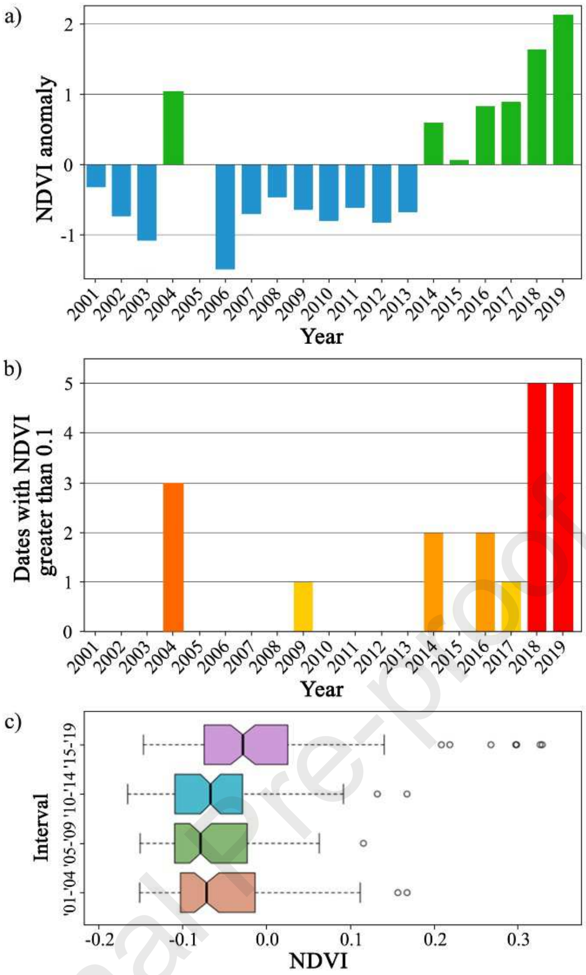

Fig. 7. a) Inter-annual variations in NDVI anomaly; b) Number of dates whose NDVI were higher than 0.1; c) Box-plots of NDVI classified by time interval.

Figure 8 shows the components of the decomposing time-series dataset. This Figure, which is in agreement with our results, highlights that the NDVI trend component presented a peak in 2004. Afterward, the NDVI trend-line went down, and then it kept fluctuating until 2014. Since 2014 the trend-line has presented an increasing trend curve, and higher values have been registered during the last five years. This is also proven in Figure 7.c which shows that the box-plot created for the interval 2014-2019 presented the highest median value. In addition, the outliers or extreme values observed in the 2014-2019 interval, which can be related with algal scums or blooms, were higher than the rest. Finally, the seasonal component of the decomposing time-series dataset (Fig. 8) shows two main periodic peaks that were related to warmer water registered in summer (January to March) and spring (September to December) seasons which could lead to algal growth (Bonansea et al., 2019).

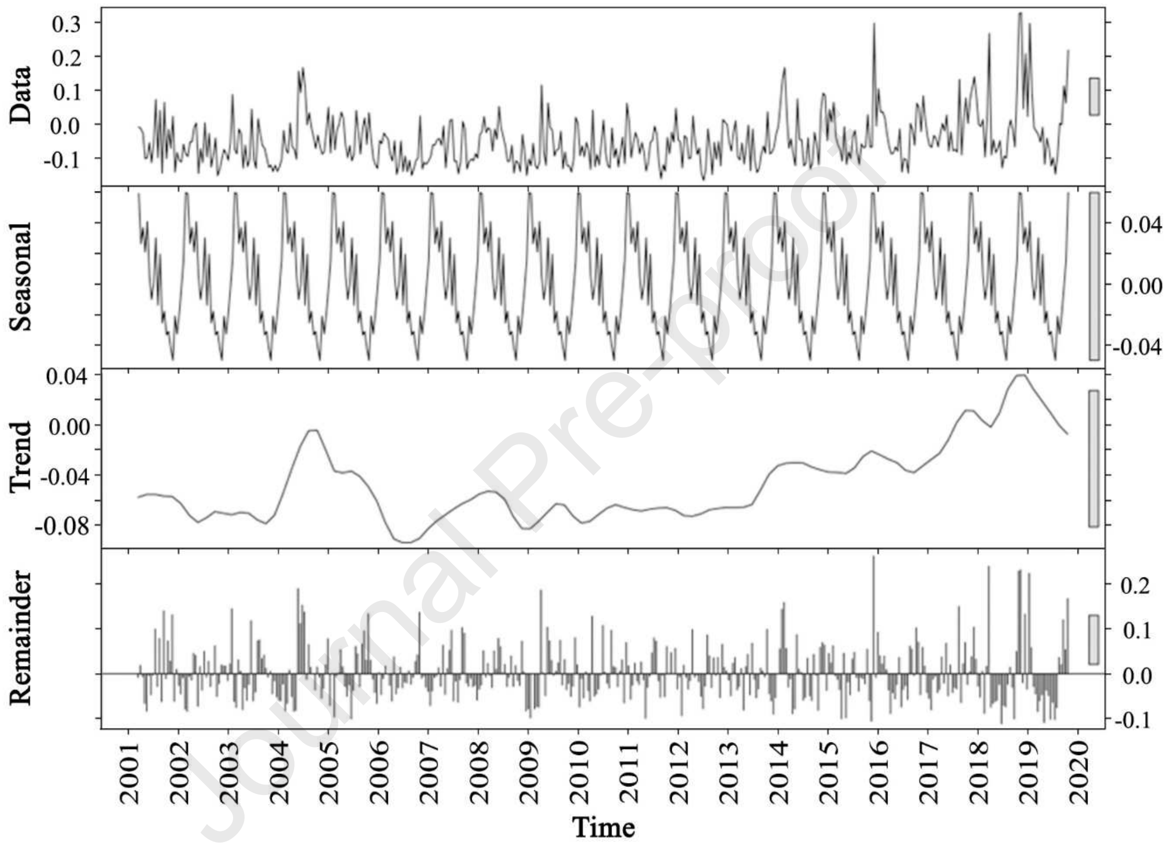

Fig. 8. Decomposed seasonal, trend and remainder components for MODIS NDVI time-series.

3.3 Relationship between LULC change and reservoir water quality

During the last decades, the watershed of Los Molinos reservoir has experienced an intensive LULC change due to the impact of human activities. Although the watershed is dominated by natural forest, intensive land use classes have principally increased in the region of Calamuchita Valley and around Los Molinos reservoir. The most significant LULC change started two decades ago and it has intensified during the last ten years. This change was related with the intensification of agriculture activities, and with the increasing conversion of agricultural land to urban area, primarily related with urban investment projects located close to Los Molinos reservoir.

Results of this study also indicate that the degradation trend of LULC in the watershed significantly contributed to the degradation of water quality of Los Molinos reservoir. This was corroborated by analysing the MODIS NDVI time-series. As results showed, from 2001 to 2013, the NDVI trend-line remained practically constant and low values related with pure water were retrieved. However, since 2014 and as a consequence of urban expansion, the NDVI trend-line has presented an increasing behaviour, and extreme values, which could be related to algal blooms, have been more frequently observed, mainly during the last two years.

Although urbanization and agriculture activities have generated an economic development for the region, different studies suggest that watersheds are extremely sensitive to an increase in intensive land use classes with significant impacts on eutrophication and water quality of aquatic environments, including rivers, lakes and reservoirs (Welde and Gebremariam, 2017; Desta and Fetene, 2020; Kiage and Douglas, 2020; Torregroza-Espinosa et al., 2020; Wei et al., 2020). During the process of urbanization, a permeable vegetated land surface is replaced by concrete and other impervious materials which can drastically transform surface hydrological processes altering the balance between infiltration and runoff. This is because the rain retention capacity is reduced, and runoff and erosion are sharply increased (Shi et al., 2007; Rojas et al., 2019; Kiage and Doulglas, 2020). According to Huang et al. (2014), the increase in urban area also generates an increase of domestic sewage discharge, which may significantly increase the amount of nutrients in waters causing negatively impacts on water quality of water bodies. Furthermore, the adverse impacts of agriculture expansion on water quality related with point and non-point pollution sources have been assessed by different authors. According to Welde and Gebremariam (2017), large amounts of chemical fertilizers used in agriculture activities flow to rivers and into the reservoir after rains, being an important factor increasing eutrophication process and algal blooms. Further, livestock manure, heavy metals and other organic and inorganic materials produced by agricultural activities can easily enter into water bodies through surface runoff, leakage, drainage, evaporation, and other processes (Wei et al., 2020).

Therefore, due to the increasing behaviour of the NDVI trend-line registered in the reservoir which can be related with LULC change at a watershed scale and with rapid urbanization along the lakeshore, we could expect that if water environmental policies do not focus on controlling the discharge of urban sewage and agricultural pollution sources, Los Molinos reservoir will be entering into an accelerated eutrophication process with negative consequences on water quality and human health .

Finally, the extreme values of NDVI registered during 2004 could be related with a wildland fire that occurred in the watershed of Los Molinos reservoir during September, 2003, which was considered the most serious of the decade (Fernandez et al., 2014). Wildland fires lead to changes in vegetation structure and soil properties increasing the risk of runoff, biomass loss and severe erosion (Miller and Yool, 2002). Wildland fires can also have a significant impact on water quality (Germán et al., 2018). During the fire event registered in Los Molinos watershed, a total of 62.6 km^2 was burned (Bonansea and Fernandez, 2013). This fire was followed by a severe drought and by December, 2003 a rainstorm caused great floods on the reservoir's tributaries with high concentration of ashes. As a consequence, the input of flows with high concentration of suspended sediments and nutrients into the water body were registered, causing the occurrence of an algal bloom event which could have led to an increase in retrieved NDVI values registered in 2004 (Bazán et al., 2005; Bonansea and Fernandez, 2013; Fernandez et al., 2014).

4. CONCLUSIONS

The present study was carried out to assess the spatial and temporal variations in LULC in Los Molinos watershed. Further, the relationship between LULC change and water quality of the reservoir was analysed.

Satellites images, acquired by Landsat sensors provided evidences that Los Molinos watershed has undergone significant LULC alterations and transformations, mainly in the region of the Valley and close to the shore of the reservoir. Although natural forest is the dominated land use class, intensive land use classes, such as agriculture and urbanization, show an increasing trend, confirming that LULC change has been principally influenced by human activity.

The most consistent upward trend of class change at a watershed scale was the progressive gain of urban area, which has shown an annual increasing rate of 6.12 % during the last 30 years. The maximum LULC change has occurred during the last decades due to investment projects located close to the shores of Los Molinos reservoir that have replaced agriculture land by urbanization. During the period 2010-2020, urban area located in the 1 km buffer zone of the reservoir increased at an annual rate of 18.02 %. It is important to note that at present, more than the 80 % of the 1 km buffer zone corresponds to intensive land use classes, mainly agriculture (46.40 %) and urban area (30.71 %). Although urbanization and agriculture activities have generated an economic development for the region, an increase in eutrophication and a decrease in water quality of Los Molinos reservoir have been observed. This was evidenced by analysing the MODIS NDVI time-series which showed that since

2014 as a consequence of LULC change, the NDVI trend-line has presented an increasing behaviour and extreme values of NDVI related to algal blooms have been more frequently observed, primarily during the last two years.

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- LULC of the watershed was obtained using Landsat imagery from 1990 to 2020.
- MODIS NDVI time-series was used to reflect the status of Los Molinos reservoir.
- The relationship between LULC change and water quality was assessed.
- Intensive land use classes lead to water quality deterioration and eutrophication.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: