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ENVIRONMENTAL ASSESSMENT OF THE SAUCE CHICO RIVER BASIN, ARGENTINA DERIVED FROM SATELLITAL IMAGES AND USE OF GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

The Sauce Chico river basin is located in the southwestern region of the Buenos Aires province in Argentina. The river originates in the Ventania Mountain system and it runs through a huge plain without any permanent tributary. This river constitutes one of the major surface water resources which supplies to the agricultural livestock and human activities in the region. The flooding are some of the main hydrologic processes which limit the practice of human activities. The basin displays a large variability in its climatic conditions. The objectives are to establish the correct methodology to determine the potential evapotranspiration, to analyze the hydric vulnerability, to identify the areas with drainage problems and the processes of hydric erosion, to know the coverage and type of vegetation. A multitemporal evaluation of the environment conditions was developed from the processing and the visual interpretation of the satellite images and the uses of the GIS. A Water Vulnerability Index was applied and the NDVI was gotten. It was proved that the Thornthwaite methodology is the best way of showing the natural hydric conditions. The results showed strong processes of hydric erosion in the higher basin and the left bank of the river. The area with the most hydric vulnerability was the middle and lower basin. The flooding area was located in the east bank of the middle basin during the hydric excess period. The changes in the uses and the coverage of the soil were related with the drought and hydric excess periods. The analysis of these changes showed an increase of the cropped areas and a reduction of the uncovered land. The green indexes showed a very poor distribution of biomass in the whole basin and intense in the mountain area in winter. In spring these indexes showed an increase of the photosynthetic activity of vegetation in the intermountain valleys and in the middle basin. The results play an important role in the decision-making and constitute an essential tool to assess and mitigate the environment impact.

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Key words: Sauce Chico river basin, water vulnerability, water erosion, digital processing images, land use, NDVI.

EVALUACIÓN MEDIOAMBIENTAL DE LA CUENCA DEL RÍO SAUCE CHICO, ARGENTINA, A PARTIR DE IMÁGENES SATELITALES Y USO DE SISTEMAS DE INFORMACIÓN GEOGRÁFICA

RESUMEN

La cuenca del río Sauce Chico se localiza en el Suroeste de la provincia de Buenos Aires, Argentina. El río nace en las sierras del sistema de Ventania y discurre en una extensa llanura sin recibir ningún tributario permanente. Es uno de los principales recursos hídricos superficiales para el abastecimiento agrícola-ganadero y humano de la zona. Los anegamientos son uno de los procesos hidrológicos limitantes para las actividades humanas. El área se caracteriza por la variabilidad climatológica. Los objetivos son determinar la metodología adecuada para el cálculo de la evapotranspiración potencial, analizar la vulnerabilidad hídrica, identificar áreas con problemas de drenaje y procesos de erosión hídrica, conocer el grado de cobertura y tipo de vegetación existente. La evaluación multitemporal de las condiciones ambientales se realizó a partir del procesamiento e interpretación visual de las imágenes satelitales y el uso de SIG. Se aplicó un Índice de Vulnerabilidad Hídrica y se construyó el NDVI. Se comprobó que la metodología de Thornthwaite es la que mejor refleja las condiciones hídricas naturales. Los resultados mostraron intensos procesos de erosión hídrica en la cuenca alta y margen izquierda del río. El área de mayor vulnerabilidad hídrica correspondió a la cuenca media y baja. La zona anegada se localizó al Este en la cuenca media durante el período de exceso hídrico. Los cambios en los usos y cobertura del suelo estuvieron en relación con las épocas de sequía y exceso hídrico. Se observó un incremento de las áreas cultivadas y una reducción del suelo descubierto. Los índices verdes mostraron una distribución muy pobre en biomasa en toda la cuenca e intenso en el área serrana en invierno. En primavera se observó un aumento de la actividad fotosintética de la vegetación en los valles intermontanos y en la cuenca media. Los resultados contribuyen a la toma de decisiones y son una herramienta para mitigar los impactos sobre el ambiente.

Palabras clave: Cuenca del río Sauce Chico, vulnerabilidad hídrica, erosión hídrica, procesamiento digital de imágenes, uso del suelo, NDVI.

1. Introduction

The Sauce Chico river basin is placed in the Pampeana Region (figure 1). It shows plain and depressed areas dominated by vertical movements of water: rainfall and evapotranspiration prevail for on the horizontal ones, superficial and deep runoff. These movements increase while the rainfall increases as was shown during the last thirty years, mainly in the west side of the basin. The water availability thus displays an oscillation which is a direct consequence of climatic condition changes that characterize the region.

The availability of the water is influenced by the geomorphology of the area. The relief is high in the input area of the basin, with heights up to 1200 meters and steep slopes. Those areas of granite rock cropping, heavily joint, with high infiltration water that disables the formation of soil, have not vegetation. In areas with slight slopes, with a potential development of soil, the traditional farming begins which is based on topographic level curves. The cultivated area increases in the area of foothills and plains with deep soils, which represents the highest percentage of the watershed. During wet time, the characteristics of the drainage allow the development of crops throughout the basin and the appearance of water erosion and flooding processes are favored. The problem appears during drought times in the upper basin with the irrigation water supply. In the middle and lower basins, where the major percentage of farmers with irrigation practices is located, the extraction pump and pivot are used. The ongoing flow of the river, fed by groundwater, supports and enables the existence of this activity, but decreases during drought times. Problems of water shortages, mainly in the lower basin, are linked to water use upstream.

Small and medium rural producers of the Sauce Chico river basin must deal with two different problems in terms of deficit or excess water, and both cases restrict the land use. The productive sector is the most vulnerable to hydroclimate changes. During low rainfall times, i.e., rainfall does not exceed 500 mm. annually (Bruniard, 1996), it's possible to carry out an irrigated agriculture with compromising the quality and quantity of water resources. If the rainfall can not achieve the requirements of the consumptive use of crop performance, the fertilization is limited. The situation is usually resolved through the implementation of irrigation systems. The different types of coverage affect differential water content in soil, consumptive use and the processes of erosion and flooding (Quiroga *et al.*, 1996). The situation turns more difficult to be solved if the rain is constant and intense. In the first case, the solutions to reduce the impacts require significant investment but it is often not available for those affected. Thought the characteristics of the area with water erosion, the producers finally find alternative solutions.

The agricultural and livestock sector are absolutely unaware of the characteristics of the basin and how it works, thus the required steps to control the sustainable resource use and the enjoyment of the production facilities can be implemented.

The aim of this study is to assess the physical characteristics of the Sauce Chico river basin through analysis of a dry and a wet period. The specific objectives are to prove the methodology that best reflects the natural hydric conditions, to analyze the Water Vulnerability index, bearing in mind the use of its water by sectors, identifying areas with potential problems of poor drainage and water erosion processes as well as to know the degree of coverage, type of existing vegetation and the relationship between the presence of the river and land use.

This paper comprises four main sections. First of all, the state of the art is included and the specific objectives in order to introduce the scientific framework of this work. The second section presents the materials and methods applied in this paper. The results and discussion are presented in the third section. Finally main conclusions are stated.

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2. State of the art

The problems of water shortages are mainly in the lower basin are linked to water use upstream. Ignorance of the operation and characteristics of the basin contribute to that, faced adverse situations, the agricultural and livestock sector fails to take appropriate steps to decrease or lose the possibility of sustainable resource use and enjoyment of the production facilities.

From the best of our knowledge, there are virtually no researches at date related to this basin as analysis unit. Therefore the present work attempts to make a contribution with the planning and management aspects.

3. Materials and methods

In order to process the data in Geographic Information System derived from topographic charts of the Instituto Geográfico Militar (Military Geographical Institute, IGM, 1968-1969) at 1:50,000; 3763-35-4, Ea. Gran Chaco; 3963-5-1, Ea. Los Cerritos; 3963-5-2 Tornquist; 3963-6-1, Sa. de la Ventana; 3963-5-4, Tres Picos; 3963-5-3, Ea. Fuerte Argentino; 3963-4-4, Pelicurá; 3963-11-1, Ea. La Planicie; 3969-10-2, Chasicó; 3963-11-4, Nueva Roma; 3963-11-3, Ea La Vitícola; 3963-16-2, Médanos y 3963-17-1, Bahía Blanca, a mix of *ArcView 3.2* and *Idrisi Kilimanjaro* programs was carried out. The information obtained was contrasted with direct observation in the field and by flight over basin (figure 2).

The year 2002 is considered for analysis, is within a wet period with record rainfall greater than 1000 mm. (Castañeda and Barros, 1994; Rusticucci and Penalba, 2000; Casado *et al.*, 2006-2007; Torrero and Campo, 2008). Climatological data during 2002, corresponding to Bahía Blanca, Bordenave, Pigüé and Coronel Suárez stations were analyzed. The data were provided by the Instituto de Clima y Agua de Castelar, which belongs to the Instituto Nacional de Tecnología Agropecuaria (INTA). Ombrothermic of Gaussen diagrams were carried out in order to analyze dry times (Castillo and Castellví Sentis, 2001). In order to study the loss of water through evaporation from the soil and transpiration through the plants, as well as the amount of water stored in the soil and drained in surface or in depth, the potential evapotranspiration (EVP) was obtained by means of Penman-Monteith´s method (Monteith and Unsworth, 1990; Smith *et al.*, 1992; Clarke *et al.*, 1996-1999; Allen *et al.*, 1998; Abbate, 2004) and Thornthwaite´s one (Thornthwaite, 1948 and Thornthwaite and Matter, 1957). The EVP permitted know the water lost by evaporation from the soil and transpiration by plants, the amount of water stored in the soil and that which is surface runoff and deep.

Two methods were implemented in order to evaluate which of them better reflects the natural conditions. The advantage of the Thornthwaite method, which makes it often used, is that the temperature dataset used is easily available (Bouwer *et al.*, 2003; da Silva *et al.*, 2007; Stonevičius *et al.*, 2008). In counterpart as this method only consider the mean monthly temperature, the results can be considered as an estimation, and thus they may be only used in preliminary studies. Other limitation of the formula for the calculation of the EVP is the temperature which is not a good indicator of the availability of energy for evapotranspiration.

Besides, the formula does not include the effect of wind which is an important factor in some areas and does not consider the effect of air warm and cool on the temperature of a place (Chang, 1968).

Calculations for potential evapotranspiration:
• According to Thornthwaite (1948):

$$EVP_i = \left(\frac{10 \times T_i}{I}\right)^a \times 0{,}53$$

where:

EVP: Potential evapotranspiration i, cm.
Ti: Temperature of the month $_i$, º C.
I: Heat index.
a: $0.675 \times 10^{-6} \times I^{-3} - 0.771 \times 10^{-4} \times I^2 + 1.792 \times 10^{-2} \times I + 0.49239$

• According to Penman-Monteith (Penman, 1948, adapted by Monteith and Unsworth, 1990):

$$\lambda E = \frac{\triangle R_n \left(1 - e^{-kL}\right) + \left(\frac{\rho \quad C_p}{r_a}\right)\left(e_{as} - e_a\right)}{\triangle + y \left(\frac{1 + r_c}{r_a}\right)}$$

where:

λ: Latent heat of vaporization, Jkg^{-1}.
E: Flow of evaporation, kg m^{-2} s^{-1}.
Δ: Slope of the curve of saturation vapor pressure as a function of temperature, kPa k^{-1}.
R_n: Net radiation, W m^{-2}.
1 - e-^{kL}: Radiation intercepted by the crop.
ρ: Air density kg m^{-3}.
C_p: Specific heat of air J kg^{-1} K^{-1} at constant pressure.
r_a: External or aerodynamic resistance s m^{-1}.
e_{as}: Vapor pressure of saturated air kPa.
e_a: Air vapor pressure kPa.
V : Psychometric constant kPa k^{-1}.
r_c: Internal resistance of the plant canopy to the transmission of water vapor s m^{-1}.

Penman (1956) developed a model of EVP based on a combination of energy budget and aerodynamics methods. The method uses four meteorological variables in order to estimate the EVP: net radiation, air temperature, air humidity and wind characteristics. The advantage of that method consists of his accuracy to calculate the EVP. In counterpart there is a disadvantage: obtaining data is a difficult task. This equation was modified and adjusted, but the underlying principle remains unchanged. The Penman equation is widely used in the hydrological literature and the Penman-Monteith equation provides the best estimates (Dooronbos and Pruitt, 1975; Allen *et al.*, 1994; Dingman, 2002; Burt *et al.*, 2005).

Water balances reflect the dynamics of water availability as a function of the temperature, precipitation, evapotranspiration and water storage in soil. The excess and deficit water in the soil are obtained of the water balance. The excesses are considered as the millimeter of sheet of precipitated water that move to the deep underground to feed the groundwater, when the storage capacity of the soil is fulfilled. The excess water also runoff into the natural depressions of the terrain and/or to the drainage network. The event with heavy rains and, depending on the soil infiltration rate, with high intensity of rainfall, vegetation cover, etc.., the runoff can occur without having to fill this capacity. Moreover, groundwater can also feed the rivers (rivers or ponds) and move slowly towards the sea. Water balances were calculated by means of Thornthwaite and Mather´s method (Thornthwaite and Mather, 1955; da Silva *et al.*, 2007; Stonevičius *et al.*, 2008) with data from EVP derived of Penman-Monteith and Thornthwaite methods to Bahía Blanca and Coronel Suárez. Pigüé and Bordenave stations were analyzed only through the latter method due to the lack of data. The comparison of results carried out by means of Thornthwaite and Mather method together with the Penman-Monteith one, determined the most appropriate method to assess water availability in soil depending on natural conditions.

In order to identify the areas with varying degrees of water erosion the Digital Terrain Model was generated. The DTM was obtained from the digitization of topographic level curves on the GIS applied. The model allows obtaining the slopes and the hypsometric map later reclassified. The water erosion map becomes as result of the combination of the previously two. Areas of active and inactive water erosion were identified through the analysis of satellites images, the map of erosion and *in situ* observation of the field.

The Water Vulnerability Index (WVI) of Gaviño Novillo and Sarandón (2000) was applied. This index measures the degree of susceptibility or vulnerability of surface water resources in terms of drainage density and average slope of the basin. Since the differences between values are very subtle in the area of research, it was necessary to modify the index and adjust the final classification in the area considering all values less than 0.4 as low density, those values between 0.4 to 1 as values with medium density and high for values greater than 1. Higher values indicate greater susceptibility of the area to suffer alteration of drainage or contamination as a result of anthropogenic interventions. The values of WVI are obtained from the combination of the class of slope and drainage density raises. For this purpose, the slopes (%) were extracted and reclassified, the sub-basin was delimited and for each of them the drainage Density (Dd) (Horton, 1945) which expresses the relation length of channels per area of the basin, were calculated (km/km^2).

Four satellite images from Landstat 7, TM sensor 227/86 and 87 path/rows, corresponding to August 2, 2002 and November 22, 2002 were used. The images were released by the Comisión Nacional de Actividades Espaciales (CONAE, 2008). The images were digitally processed with the *PCI 6.2* program and visually interpreted. Moreover, they were geometrically corrected based on planar Gauss Krüger coordinates. The mathematical model applied to correct was the so-called *cubic convolution*, with third-degree polynomial. The control points marked were 25 and 37 for images of August and November, with a mean square error of 0.49 and 0.27 pixels, respectively.

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Two mosaics were constructed from data georeferencing. Multitemporal analysis was performed to detect spatial variations in land use, processes of flooding and changes in the Normalized Difference Vegetation Index, NDVI. Composition was obtained in a false color composite (FCC) consisting of the bands (R, G, B): 4, 3, 2; regions of interest were identified and a supervised classification, named *Mahalanobis Distance*, was applied to classify the uses soil. Due to the difficulty in distinguishing the pixels belonging to the composition of water in FCC because of their similarities with the shadow areas of mountains, the analysis was carried out by principal components with bands (R, G, B): 7, 1 and 5. Visually there was a marked contrast between different coverage, however the digital results were not desired so it was decided to make the delineation of flooded areas by hand.

In order to analyze the period NDVI was built for the winter (August) and spring (November). This index, based on the particular radiometric behavior of the vegetation, represents the amount and vigor of the photosynthetic activity and constitutes the basic data for analyzing the impact of water in the basin. The values range from -1 to 1. The higher the outcome, the greater the force the plant to this area analyzed. NDVI time series show the trend of development of natural vegetation and crops. The applied formula for this index can be express as (Tucker, 1979; Chuvieco, 1996):

$$NDVI_{i,j} = \frac{(ND_{i,j,\,IR} - ND_{i,j,R})}{(ND_{i,j,\,IR} + ND_{i,j,R})}$$

where:

$NDVI_{i,j}$: The index of normalized difference vegetation for line i and column j.
$ND_{i,j,IR}$: The level of the digital line i and column j in the infrared band.
$ND_{i,j,R}$: The level of the digital line i and column j in the red band.

4. Results and discussion

4.1. Behavior of water in the Sauce Chico river basin: Relation between infiltration-runoff-coverage

Interactions produced between the surface characteristics of soil and vegetation, and water hasty are the determinant processes in the relation between infiltration-runoff, water storage in soil and erosion (Michelena *et al.,* 2000; Mon and Irurtia, 2004). The storage of water in the soil depends on its physical properties. The texture, as an intrinsic characteristic, is not modified by the practices made to the soil as the porosity and structure are. In the last cases, the features are the most modified, because of the role played mastering all the physical properties of the soil (Dexter, 1997; Andreani, 2000; Amézquita, 2004; Moron, 2005).

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4.1.1. Hydroclimatic dynamics

The characteristics of the Sauce Chico river basin as the shape, orientation and location affect the set of climatological data, introducing important differences between the extreme points of the same. Ombrotermics diagrams (figure 3) for the year 2002, an intense rainfall period, show the spatial and temporal variations of rainfall values for each month and for each of the stations. The 2002 has changed the conditions of wet winters and dry summers used to identify temperate climates along with the trend reflected in the analysis of the data for the period 1991-2000 (Torrero and Campo, 2008).

Potential evapotranspiration calculated by the Penman-Monteith method provides higher values than those obtained by Thornthwaite (table 1). The ensuing difference close to 200 mm., can be appreciated in the water balance of Bahía Blanca and Coronel Suárez with periods with varying recharge, use, excess and deficit and its values, mainly in the increase of drought as well as the disappearance of period of excess. The analysis of the water balances according to Thornthwaite for all the seasons shows insights of gradual drought southward of the basin. The year 2002 was a wet year which makes the emergence of excesses (according to Thornthwaite balances) in the area of Bahía Blanca easier. Excessive focus on autumn, winter and spring and are higher at the ends of the basin while the deficits can be observed in the autumn, spring and summer, increasing southward (figure 4, figure 5).

4.1.2. Water erosion

The factors contributing to water erosion are the lithological composition cropping -orthoquartzites, schists and slates- which favor the presence of numerous crevices, soil characteristics, the absence of vegetation cover and the degree of inclination and orientation of slopes, which impose restrictions on land use and farming practices, through their effects on erosion in farming techniques (Lopez, 1979).

From the analysis of the satellite images and direct observation, active and inactive areas of water erosion in the field were found. The presence of gullies, as a result of soil loss caused by the landslide by water flow, is higher in steeper areas as evidence of the erosive process. In the upper basin these gullies coincide with areas of bare soil where there is not cropping quartz rock with resistant to the erosion. Natural barriers forming dykes were created by farmers with the dual effect of water storage and reduce the erosive effects. In the middle and lower basins, the presence of vegetation evidences the erosive process stability. In many cases, the same areas that in wetter times are inactive by the presence of vegetation are reactivated with increasing erosion during dry periods. However, the process develops when the propely conditions in these areas like the excessive rainfall and clay loam, silt loam to silty clay of the soils are achieved, favoring the appearance of these surface channels (Morgan and Kirkby, 1994; INTA, 1995; Munguía, 2003; Pedraza, 1996).

A substantial difference in the gradients can be observed from the map of slopes obtained through the Digital Terrain Model (figure 6, figure 7). The strong slopes are conducive to the runoff and thereby to the torrential runoff (Carrica, 1998) and deepening of the valley. These characteristic give to the watercourse high capacity and competence to increase the process of river erosion. The great breadth and positive relief power of Ventania, with inclination values exceeding 8 % in northwest, north and northeast, do contrast with the low amplitude and energy of the plain that extends from 350 m altitude, with gradients less than 2 %. Western slopes display higher degree of slopes than those in the east as consequence of the structural characteristics. Evidence of parallel courses of 1st and 2nd order related to the tectonic faults is conducive to water erosion process. The degradation becomes greater in the latter due to their relative orientation with respect to the sun (Torrero and Campo, 2008). Moreover, flat areas are located in the interfluvium of the highland. They are in tandem 64 % of the watershed. The high storage coefficient (6.4) indicates a high degree of water erosion.

The entire river along and up the entrance to the lower basin, the presence of gullies, higher than 5 %, distinguish it from the rest of the river plains. These areas represent 13 % of the entire surface. The disposition sinuosity (figure 8) with encased meanders is indicative of erosive reactivation, which is attributed to an increase in the gradient, resulting from the decline in sea level during the last glaciation and the consequent rise of continental by isostatic compensation. This leads to a rejuvenation of the basin while the hypsometric analysis indicates an intermediate stage between the stage of maturity and youth, moving towards the stage of maturity (Kostadinoff *et al.*, 1981; Torrero and Campo, 2008).

The map of water erosion emerge a result of the maps hypsometric and slope combinated (table 2, figure 9). The major areas capable of water erosion are concentrated in high area and to a lesser extent, along the river to about 60 meters. The areas showing more resistant conditions to this type of erosion are located south of the basin and cover an important area of the lower basin. The larger areas, which correspond to those with low and moderate erosion, are found in greater proportion in the middle basin.

4.1.3. Water Vulnerability Index - WVI

Four areas of varying degrees of vulnerability, depending on the water combined data of average slopes and drainage density (Dd) of sub-basin delimited (table 3, table 4, table 5, figure 10, figure 11, figure 12), are identified in the Sauce Chico river basin. Drainage density is a fundamental property in the watershed analysis because it indicates the state erosion and control drainage efficiency (Jones, 1997; Senciales, 1999). All values obtained indicate a low density according to Strahler (1964); however, the remarkable difference between them can in this case, be classified into high, medium and low. The area with higher Dd, where the surface runoff travels quickly, coincides with the highest average slope and hence reduces the time of concentration and the flood peak increases due to the lower infiltration. The middle and lower basins with slope and Dd low, to which the agriculture use can be added, increase the time of concentration and attenuate the peak discharge.

The area with the highest WVI has a 61 % of the basin and extends from 350 m to the mouth, with the exception of two sub-basins that developed between these heights. The

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southernmost part of the basin is the more fragile within this area by its hydrographic characteristics and it present the greatest anthropogenic impact (Torrero and Campo, 2008).

4.2. Multitemporal analysis

4.2.1. Flooding and inundations

Flooding can be defined as the accumulation of surface water as consequence of the rainfall intensity when the infiltration capacity is exceeded. This process is related to the low topographic slope of the plain that leads to the slow movement of water by the local slope to natural depressions. As consequence two concentrations relatively scattered in the middle basin are generated (Lat: 38º 15'- Long: 62° 24'). The lagoons show a small sheet thickness characterized by a slow horizontal movement and a great stay. The process ends when the water evaporates or infiltrates by vertical movements (Fuschini, 1994). From the visual analysis and the combination of satellite images, the areas that are flooded on a permanent and stationary were detected and calculated (figure 13).

During the period of low or absence of precipitation, accumulation of water can be only found in an area of 1.5 km^2 distributed in distant areas within the medium and low watersheds. When the rain exceeds the infiltration capacity, the flooded area increases to 4.3 km^2 and is located mainly on the left bank of the river, in the middle basin, between 190 m and 280 m of altitude in typical Haplustolls Argiudolls soils. In this case, the low slope modifies the characteristics of the Haplustolls soils which are relevant for being relatively free of the saturated with water and hydromorphic. The flooded area includes almost all areas that have water in times of drought which increase their surface in wet periods. A few isolated areas affected are beyond these limits. Towards the North the decreasing of the flood is related with increased topographic gradient and the presence of rocky outcrops. In the South, in the lower basin, the flooded areas are not observed despite the low slope and aquic Ustifluvent and aquolic Salorthids soils (INTA, 1995), except a small area of 0.033 km^2 which only has water in the period drought. The same description can be done in the center of the basin with an area less than 0.028 km^2. Permanent surface water is 1.4 km^2.

It is important to highlight that the land classified as having moderate erosion in periods of intense precipitation, suffers floods. Despite the high storage coefficient, the river, even during periods of drought in the area that extends 350 m below the flow remains, evidences of an important groundwater supply. This situation increases the appearance of areas flooded during periods of intense rainfall.

With regard to inundations due to the overflowing of rivers and streams, there were no significant problems, despite environmental conditions. Nonetheless, three small areas involved were identified. One of them, located at the boundary between the foothills and plains, 340 m far; other to 240 m in the headwaters of one of the temporary streams. The third is the largest and is located in the vicinity of the mouth in the intertidal functional plain (Torrero and Campo, 2008). Conditions that favor the processes of continental water erosion are combined in this area, such as the low slope and the soil characteristics, consisting of fine sand and silty clays consolidated, partly saline. Together, these three sites cover an area of 0.1 km^2.

4.2.2. The role of vegetation cover, land use and NDVI

The vegetation index is closely related to vegetation type and climatic conditions, as well as the predominant pattern of land use. In the analysis of vegetation cover, the height, density, and continuity of ground cover, response of vegetation according to environmental conditions and anthropogenic changes should be considered. The vegetations covers have a different effect depending on how dense they are, as well as, how they are distributed or grouped. Such characteristics reduce the erosion processes because of dissipate the energy of moving water to provide flow roughness (Quiroga *et al.*, 1996; Munguía, 2003).

The natural vegetation in the basin is manifested by a scarce tapestry of steppe xerophilous vegetation where shrubs of low freightage and hard pastures alternate. The shrubby vegetation is typical of the semiarid conditions when the soils are dry (Galizzi *et al.*, 1998). Grasslands are of steppe grasses. In the immediate vicinity of stream Saladillo de Lázaga vegetation reflects the relation between salinity-landscape. Here a shrubland develops with isolated grasses, pasture grasses with a predominance of intermediate and low grasses and halophilic meadows. In the gentle hills, vegetation consists of perennial xerophilous grasses where species of the genus *Stipa*, as *S.brachychaeta*, *S.dusenii*, *S.trichotoma*, as well as others, are dominant. Between these shrubs, invasive plants as *Salpichroa origanifolia*, *Medicago hispida*, *Trifolium repens* develop. The shrub vegetation is represented by *Berberis ruscifolia*. On watercourses the vegetation is more hygrophilous being represented by *Cortadera dioica*, *Senecio bonaeriensis*, *Melica macra*, etc, particularly in the area of the streams and springs. The vegetation is impoverished on the hillside, and it is limited to isolated patches as a result of the presence of rocky outcrops. The grasses such as *Stipa* and *Melica Brasiliana Pampas* predominate on the high hillside and in the lower parts where it is possible to detect some association with *Piptochaetium sp*. At the summit the vegetation is very poor and of low standard, an example is the *Plantago bismarchkii* (Bruno *et al.,* 1999).

Different uses affect the water content of the soil in different ways, consumptive use and losses soil from erosion. In agricultural soils, the water holding capacity varies seasonally, depending on the time and place of cultivation. The main limiting factor in crop production is water, and the temperature also plays an important role. The prolonged period of low rainfall is one of the dangers that farmers must deal with. In the central, Northern of the medium basin and the upper basin, under dry farming systems, it is necessary to optimize the use and rational management of this resource through the efficient use of rainwater; the rest of the area under study - irrigated agriculture- through the reordering water (Senigagliesi and Zelijkovich, 1989; Gil, 1997; Morgan, 1997; Luque and Paoloni, 2005).

Agricultural crops characteristics in the basin are oats, wheat and maize. They are planted applying techniques of ground handling in bands, based on topographic level curves towards the conservation and reduce water erosion. It is also common the implementation of tillage for the slope, a practice that promotes water erosion with the formation of gullies or furrows. The fields adjacent to water courses generally do not protect the banks and, in consequence, lateral erosion when floods are raged by heavy rains is generated. In the high basin, the use within the highland area is exclusively livestock and agricultural and livestock in the valleys. Farm types and crops are developed in the lower basin while in South of the medium basin are horticulture, fruits, grains thick and thin, as well as sowed pastures and mixed.

The fallow period takes place between crops in summer (March to October). Winter grasses such as rye (which produces abundant volumes of waste that decomposes more slowly than other grasses in winter and very commonly used by their great resistance to cold and drought tolerance) or oats are planted after the maize harvest. The usual rotation in this space is wheat-maize. October is a critical period for wheat (summer grass) due to its close relation with the performance of the consumptive use and water useful (Quiroga and Paccapelo, 1990). This moment coincides with the development of floral organs; therefore, low water availability in the soil can affect the formation of pollen, reducing the number of grain. Wheat crops and raising cattle are mainly on Haplustolls soils. Consequently, part of the land is allocated to pasture of alfalfa, green summer (sorghum) and weeping grass.

Digital classification of land uses was obtained with a confidence range of about 96 %. Within the urban area the salt field, near the town of General Daniel Cerri is included. The same reflectivity of the pixels of both areas prevented the separation of them (figure 14, figure 15). The image corresponding to November shows an increase of areas with crops and forestall because of precipitation just occurred at the same time that the grain requires it for their development. There is also a notable decrease in bare soil plots and a replacement tillers of the soil (in August) for pastures and vegetation growth.

The graphs showing the responses of time averaged pastures and crops and forestall supports the mapping results of classification of land uses. It also shows the similarity in the progress of each element in spite of the different values depending on the time (figure 16, figure 17).

The green indexes obtained show a very poor distribution of biomass across the basin and intense in the highland area during August with a close relation with the drought period of low winter temperatures. For November, during the spring, a significant increase in photosynthetic activity of vegetation was detected as a result of the heavy rainfall and higher temperatures. These two factors contribute to the transpiration and the transfer of radiation processes, mostly in the upper basin to over the valleys between the mountains. In the middle basin, the more vegetated areas coincide with the wheat crops and the lower basin with horticultural areas. The surface with less vigorous vegetation is grazed fields or plots newly planted with maize or sunflower. The natural pastures begin to decrease your energy level. During the winter the middle basin has little or no vegetation cover and there is an intensification of the state in some plots, mainly in the area without external inflow water in which the flooded areas are still highlighted. The differential response of vegetation for each case is shown in frequency histograms (figure 18).

The sequence of images shows the development of vegetated areas from bare ground or low vegetation in winter to an intermediate to high stage in the spring. The red color represents the dense vegetation; yellow and green, the less dense/vigorous and, finally, blue corresponds to negative rates identifying sites without vegetation (roads, urban areas, bare soil, saline) (figure 19, figure 20).

Vegetation plays an important role in the hydrology of the bed and sediment dynamics, reduces the water velocity and enhances the material's gully increasing the resistance to erosion and therefore the stability of the lateral canal.

5. Conclusion

The comparison of the data of potential evapotranspiration calculated by Penman-Monteith and Thornthwaite methods and, subsequently, the development of water balances, allowed us to identify that the methodology that best reflects the natural conditions is suggested by the Thornthwaite. Evapotranspiration is overestimated when Penman-Monteith method is applied; consequently, the water balance does not reflect the excess that are conducive to the emergence of flooding signs and bodies lagoons increased, as can be seen in satellite images analysis. Therefore, in this paper the results obtained by Thornthwaite are considered. The charts ombrothermic do not reflect major drought periods during the year 2002. The most critical months for the stations under analysis are February for Bahia Blanca, January for Bordenave, September for Coronel Suárez and July, and September for Pigüé. Water balances show the gradual manifestation of the need for water to the South and periods of excess water in all seasons, with the particularity of the highest values recorded at the ends of the basin.

So much exposed in the previous paragraph together with the topographic conditions, they are factors that contribute to the process occurrence of water erosion. Vegetation plays an important role because it reduces the magnitude of effect. Moreover it presence can be considered as an indicator of stabilization while it absence implies the lack of active processes. The factors that favor the generation of gullies in the upper basin are the topographic gradient associated with mountain chain and the scanty vegetation. In the North of the middle basin, the heights diminish but the intensity of the process remains high or even very high on the left bank of the river; the appearance of gullies is presented throughout the remainder of the riverbed associated to the gradients edges and edaphic characteristics. Erosion by gullies covers a large area and its importance owes to the changes that produce in soil structure. The low slope of the soils in the middle and lower basins, predominantly silt loam, clay loam and salty texture makes difficult the drainage during periods of excess water. Considering that the area is agricultural and livestock, the characteristics of the drainage and the slope transform this area in an area with great water vulnerability, and therefore, more susceptible to any contamination or alteration of the surface drainage as a result of natural processes or anthropogenic activities. In the basin there were no flooding problems of great magnitude.

Land uses change depending on environmental conditions in the basin and thus the use and water resource management. This is the case of an area located in the North and Central basin, with large and medium farms that are developed under farming systems dry and a middle and lower basin of irrigated agriculture with a predominance of horticultural activity. The responses of these areas against the passage of a drought situation to opposite with excess water, at a critical time as the period of crop development is remarkable and is evidenced by the increase in cultivated areas

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and the reduction of bare soil. Therefore, the erosion processes are greater in times of low rainfall when vegetative cover is poor and does not fulfill its function of water interception.

Bearing in mind that all the climates characteristics, edaphic and geomorphologic do influence in the behaviour of water and produce changes in the space, and considering degradation effects that affect the development of the agriculture, is necessary that small and medium farmers be aware of the situation in order to take this characteristics present when they work the land and use sustainable of the fluvial resource.

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TABLES

Table 1. Real and potential annual evapotranspiration in mm according to Thornthwaite and Penman-Monteith.

	According to Thornthwaite				According to Penman-Monteith			
	EVP Real	**EVP Potential**	**Excess**	**Deficit**	**EVP Real**	**EVP Potential**	**Excess**	**Deficit**
Corone Suárez	747,63	747,63	225,87	0	973,5	1339,8	0	366,3
Pigüé	746,43	746,43	145,67	0	s/d	s/d	s/d	s/d
Bordenave	577,02	693,32	111,28	116,3	s/d	s/d	s/d	s/d
Bahía Blanca	654,78	822,17	214,42	167,39	869,2	1659,1	0	789,9

Table 2. Water erosion in the Sauce Chico river basin.

Hypsometry (m) Slope (%)		0 - 100	100 - 250	250 - 450	450 - 700	700 - 1200
		Very low	Low	Moderate	High	Very high
< 1	Very low	🟩	🟢	🟢	🟨	🟨
1 - 2	Low	🟢	🟢	🟨	🟨	🟧
2 - 5	Moderate	🟢	🟨	🟨	🟧	🟧
5 - 8	High	🟨	🟨	🟧	🟧	🟥
> 8	Very high	🟨	🟧	🟧	🟥	🟥

Table 3. Medium slope of the sub-basins of Sauce Chico river.

Sub-basins	Medium slope (%)	Meaning
1	9	Medium
2	18	High
3	8	Medium
4	10	Medium
5	2	Low

Table 4. Density of drainage of the sub-basins of Sauce Chico river.

Sub-basins	Length of flow (km)	Area (km^2)	Dd (km/km^2)	Meaning Dd
1	134	155	0,86	Medium
2	233	194	1,20	High
3	19	147	0,13	Low
4	15	127	0,12	Low
5	150	965	0,16	Low

Table 5. Water Vulnerability Index for the Sauce Chico river basin.

Sub-basins	Density of drainage	Medium Slope	IVH
1	Medium	Medium	Medium
2	High	High	Low
3	Low	Medium	High
4	Low	Medium	High
5	Low	Low	Very high

FIGURES

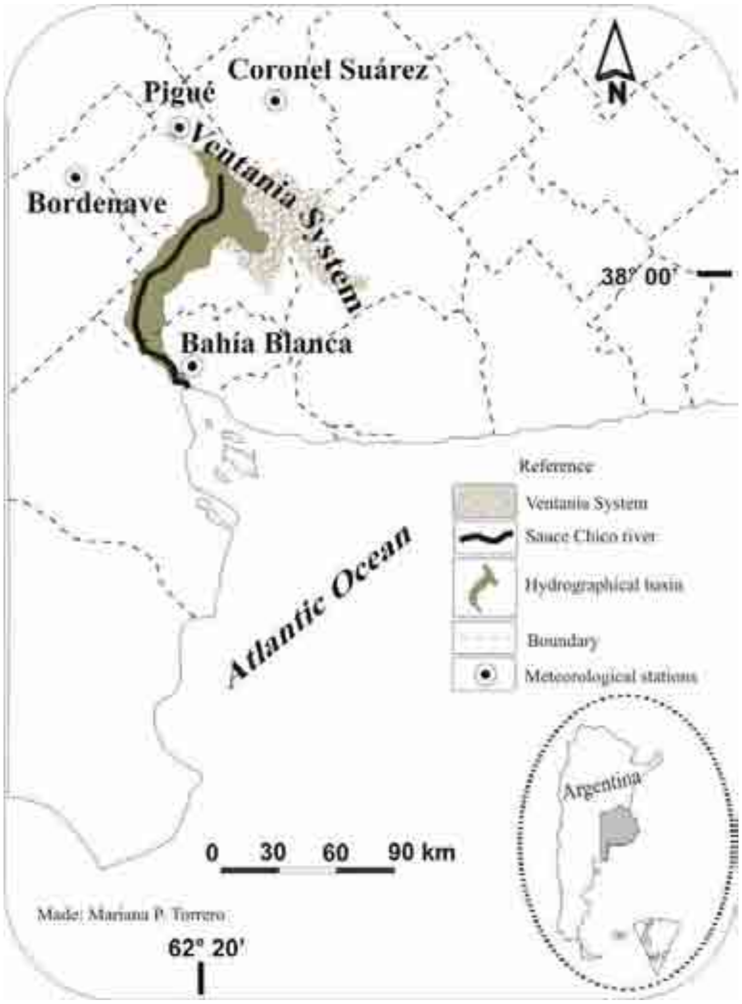

Figure 1. Area of study.

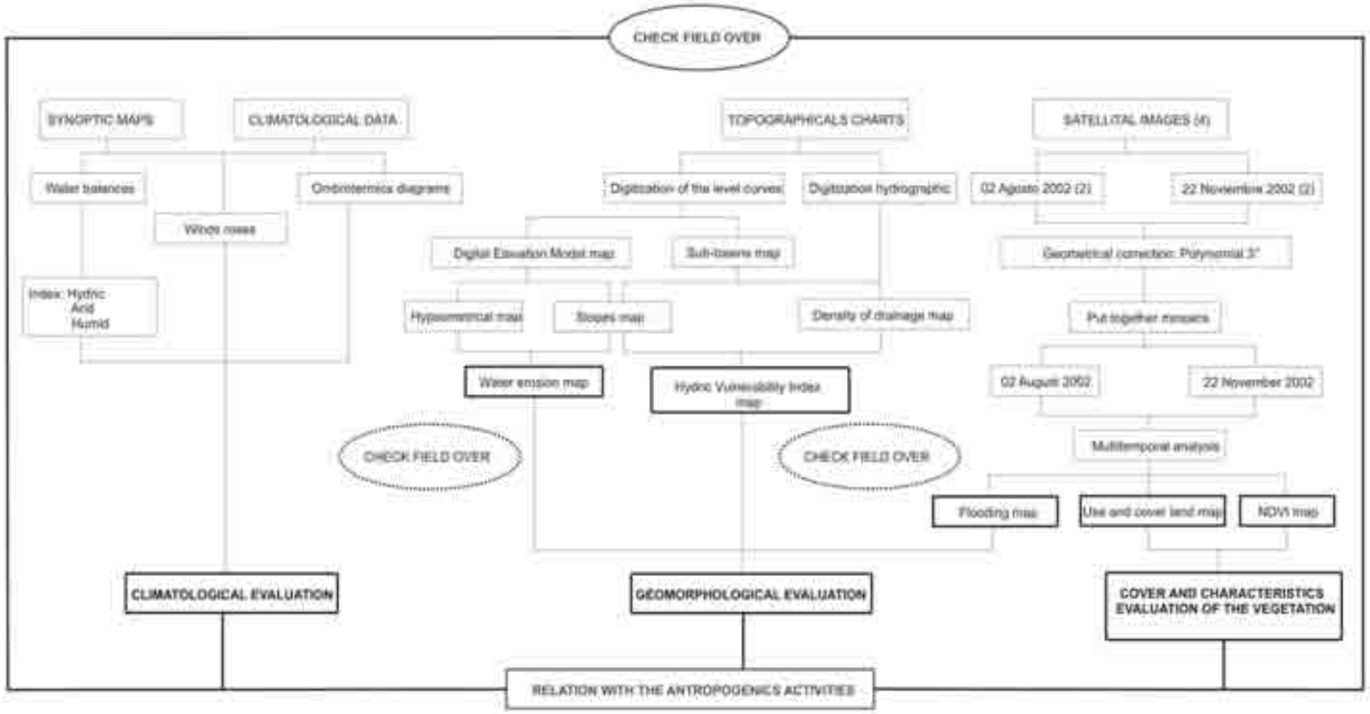

Figure 2. Methodological scheme followed in the environmental assessment in the Sauce Chico river basin.

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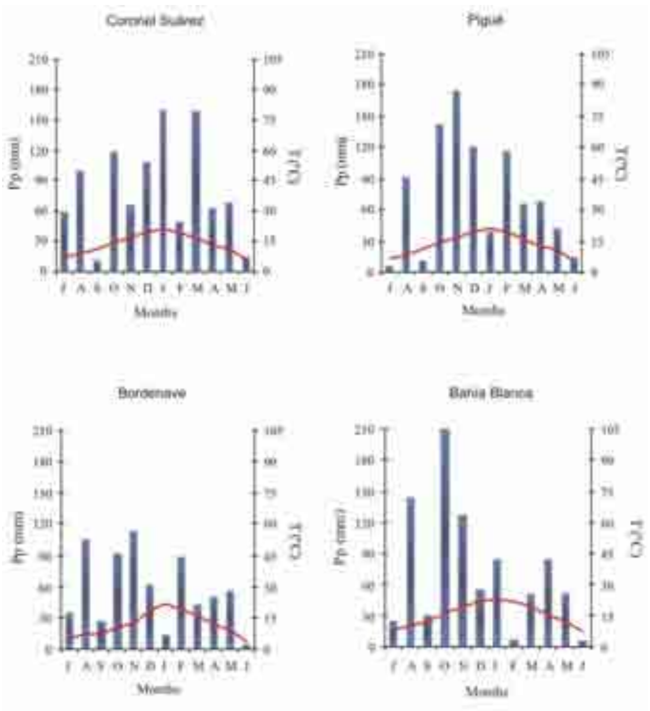


Figure 3. Ombrotermics diagrams. Year 2002.

Source: It was made by author on data were supplied by Instituto de Clima y Agua de Castelar (INTA, 2006).

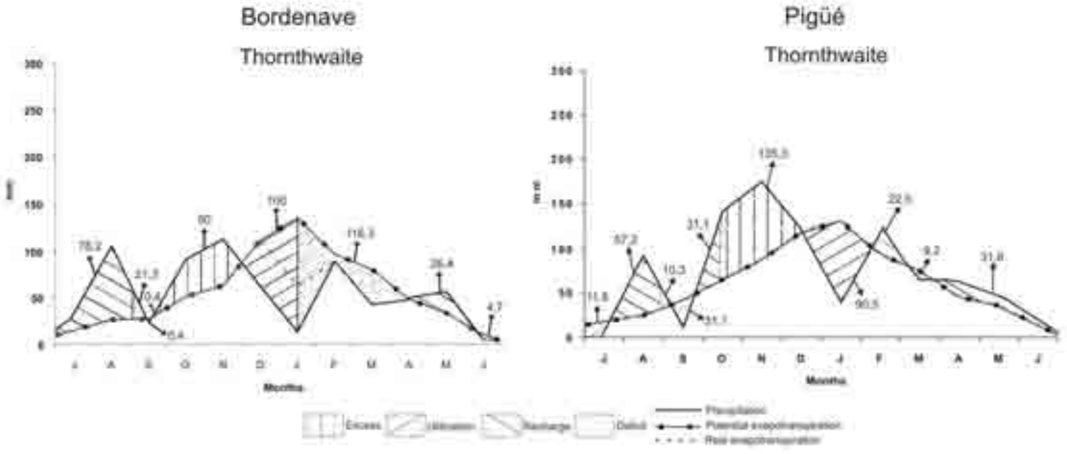


Figure 4. Water balance for Bordenave and Pigüé - 2002.
EVP data: According to Thornthwaite.

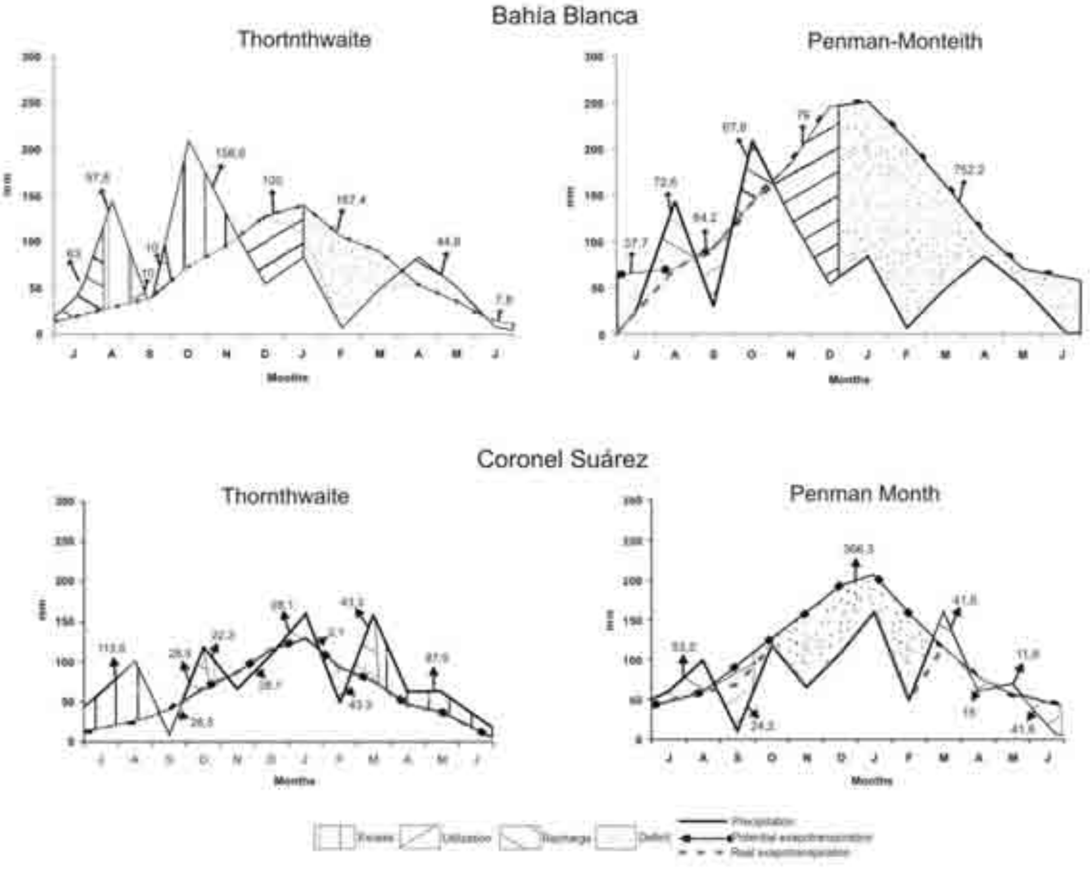


**Figure 5. Water balance for Bahía Blanca and Coronel Suárez - 2002.
EVP data: According to Thornthwaite and Penman-Monteith.**

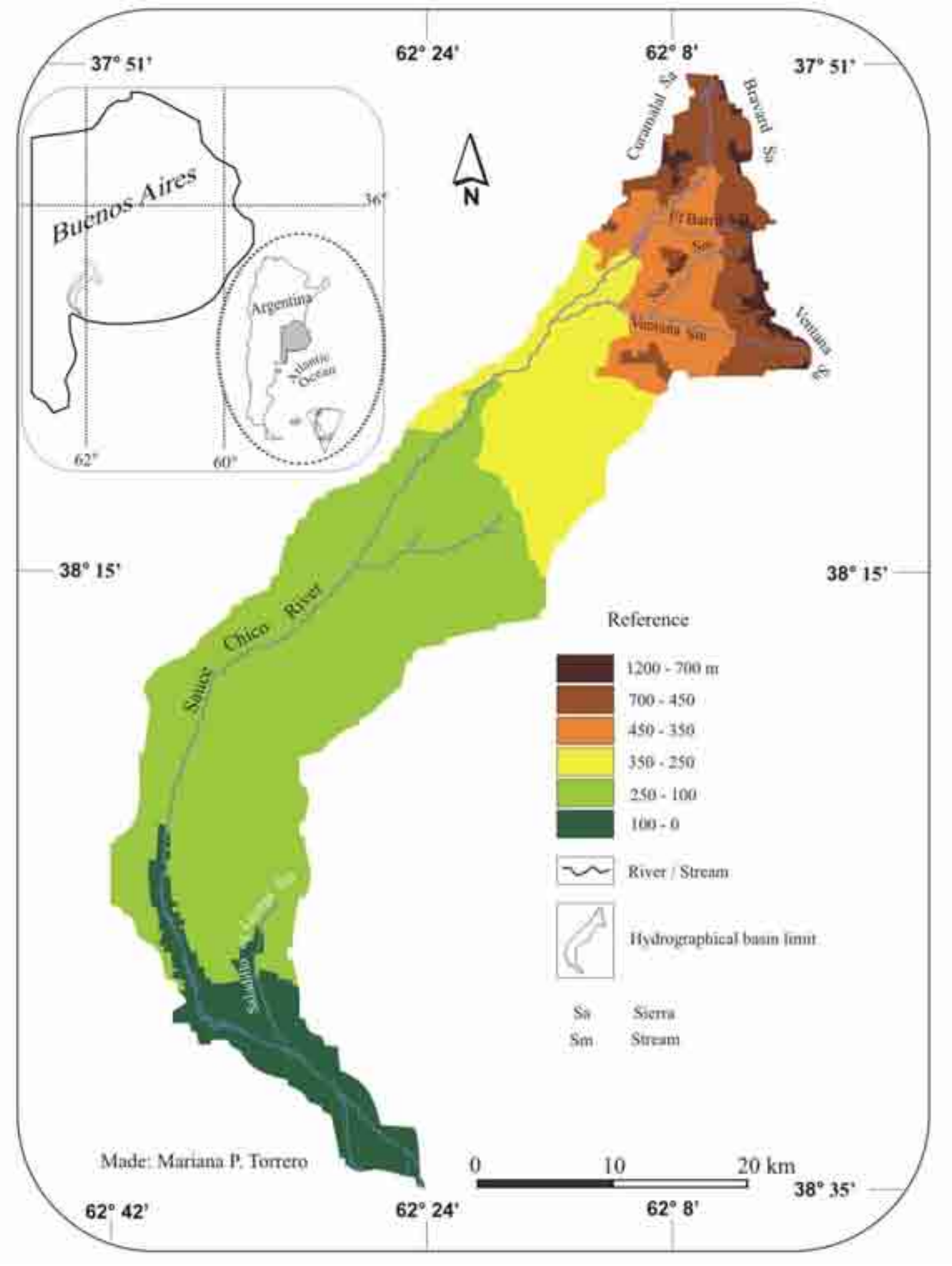


Figure 6. Hypsometrical map. Sauce Chico river basin.

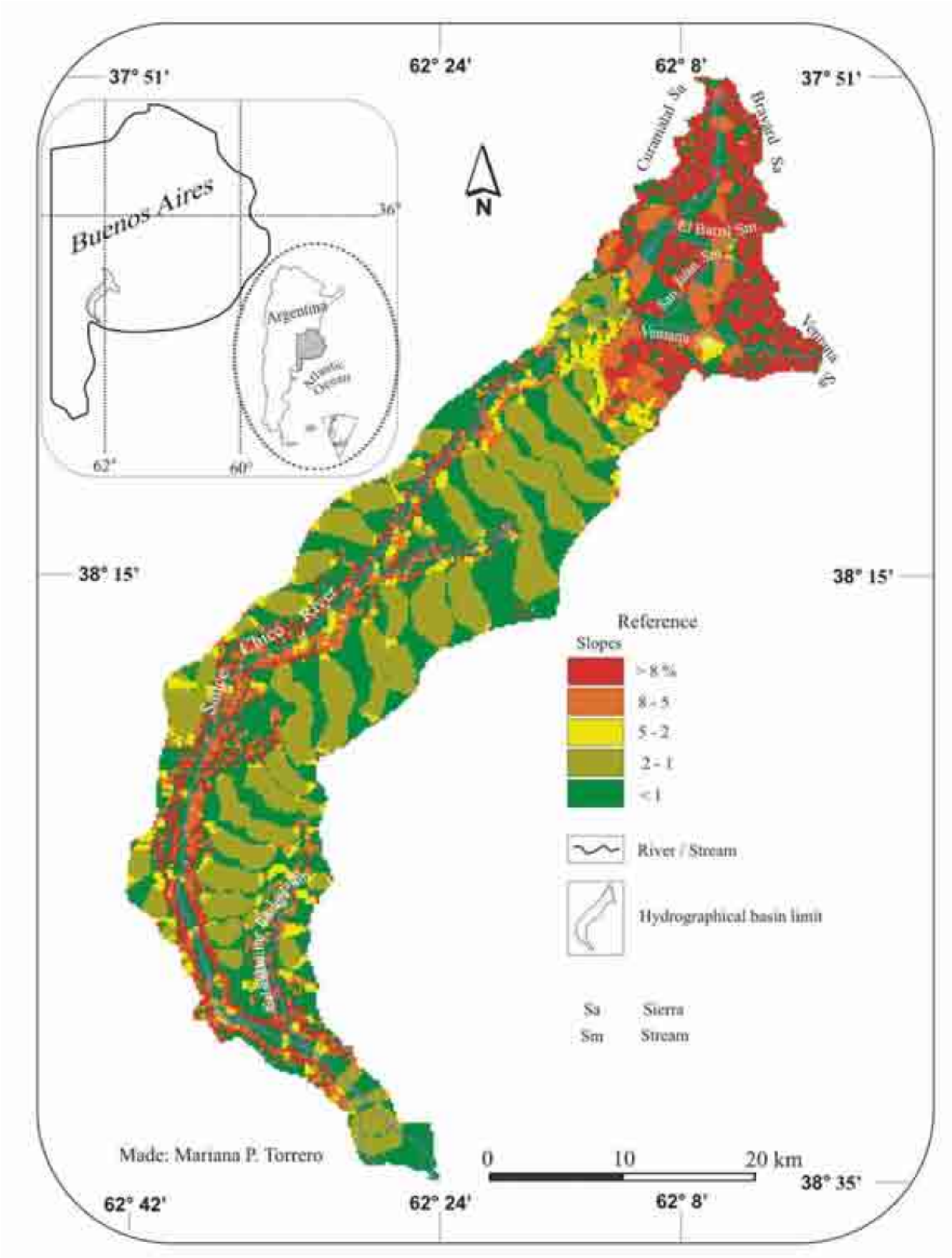
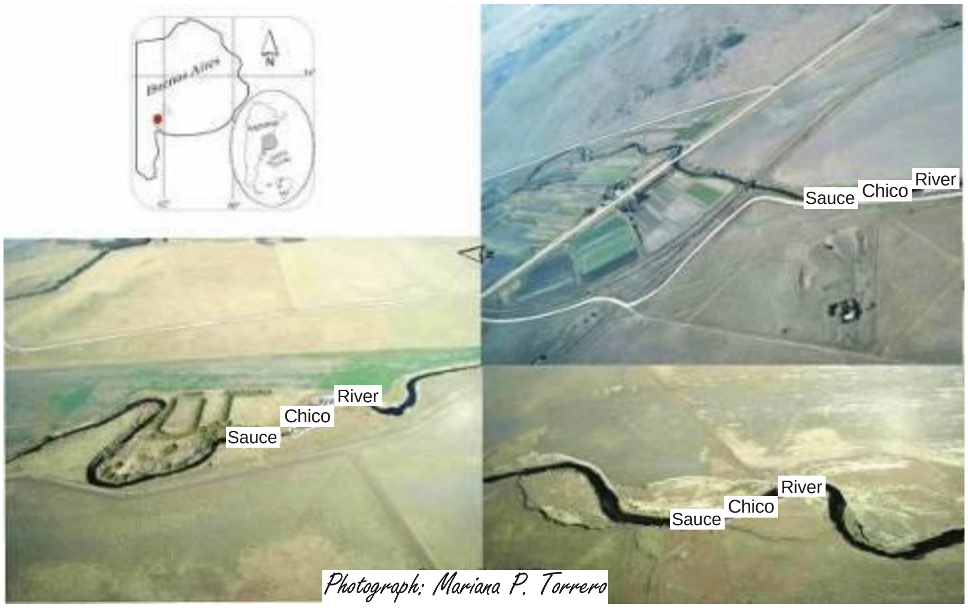


Figure 7. Slopes map. Sauce Chico river basin.



Photograph: Mariana P. Torrero

Figure 8. Meanders. Sauce Chico river.

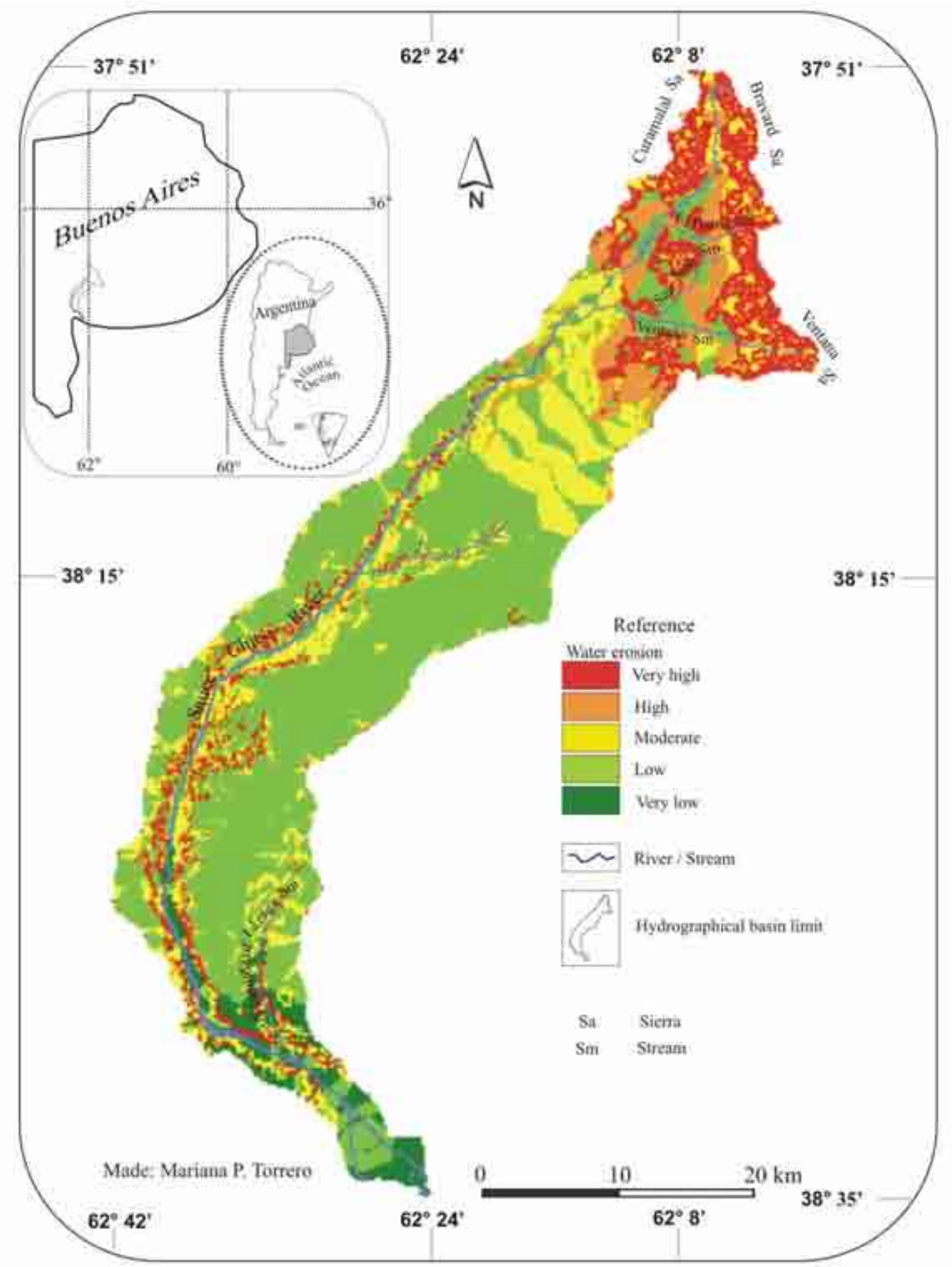


Figure 9. Water erosion map. Sauce Chico river basin.

Torrero, M. P., Campo, A. M. and Uboldi, J. (2010): "Environmental assessment of the Sauce Chico river basin, Argentina derived from satellital images and use of geographic information systems" GeoFocus (Artículos), nº 10, p.18-53. ISSN: 1578-5157

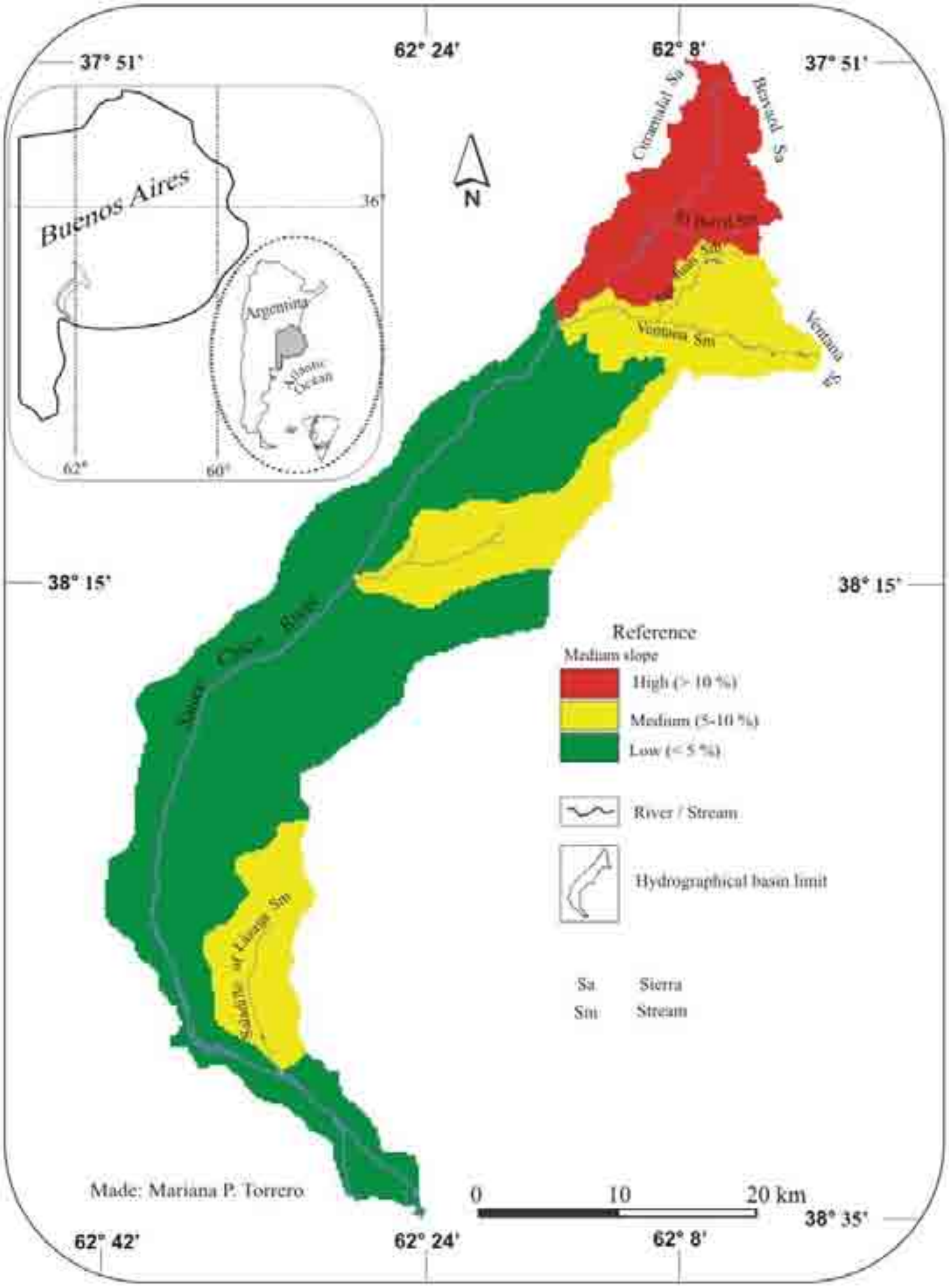


Figure 10. Medium slope of the sub-basins of Sauce Chico river.

Torrero, M. P., Campo, A. M. and Uboldi, J. (2010): "Environmental assessment of the Sauce Chico river basin, Argentina derived from satellital images and use of geographic information systems" GeoFocus (Artículos), nº 10, p.18-53. ISSN: 1578-5157

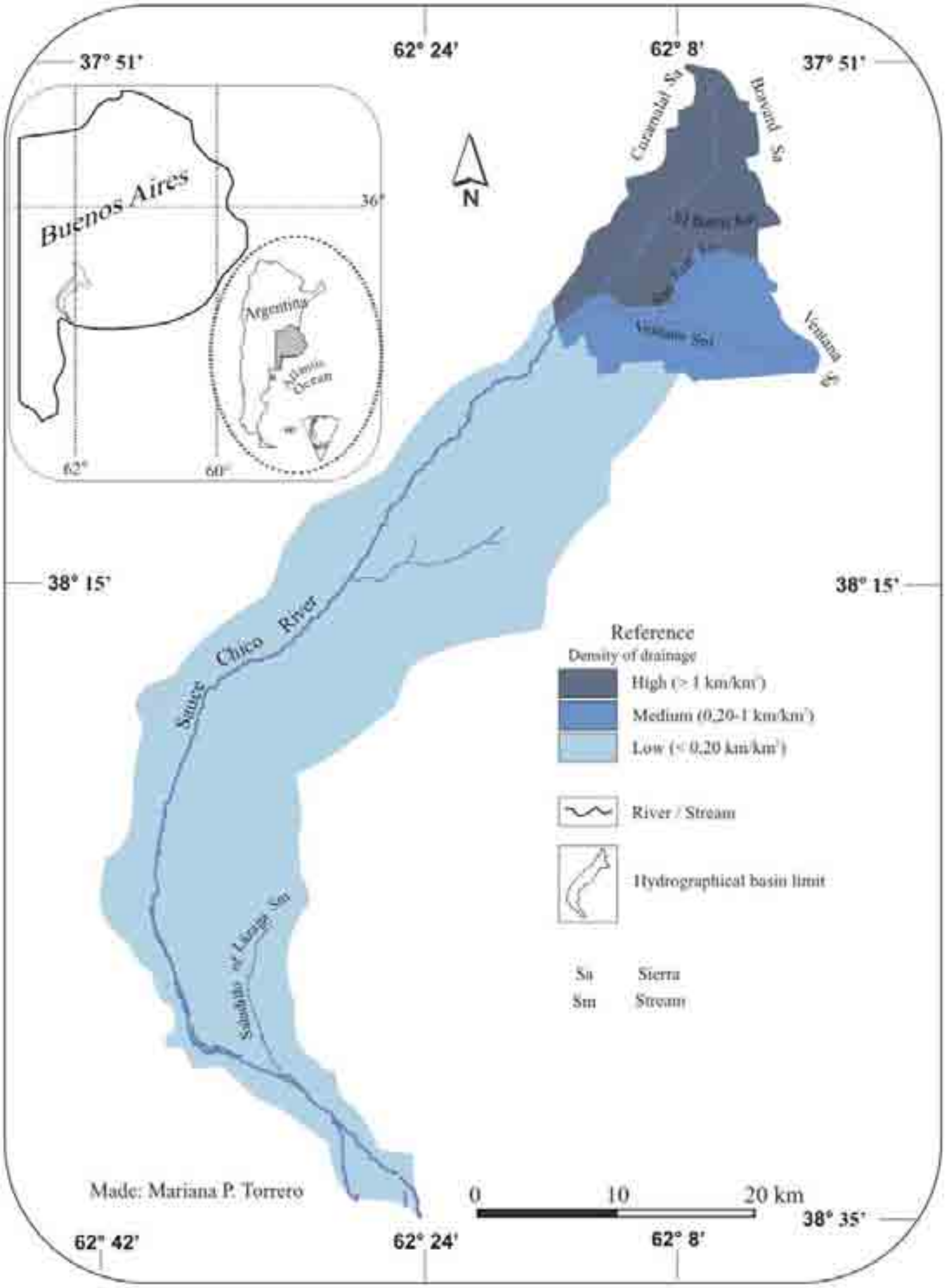


Figure 11. Density of drainage of the sub-basins of Sauce Chico river.

Torrero, M. P., Campo, A. M. and Uboldi, J. (2010): "Environmental assessment of the Sauce Chico river basin, Argentina derived from satellital images and use of geographic information systems" GeoFocus (Artículos), nº 10, p.18-53. ISSN: 1578-5157

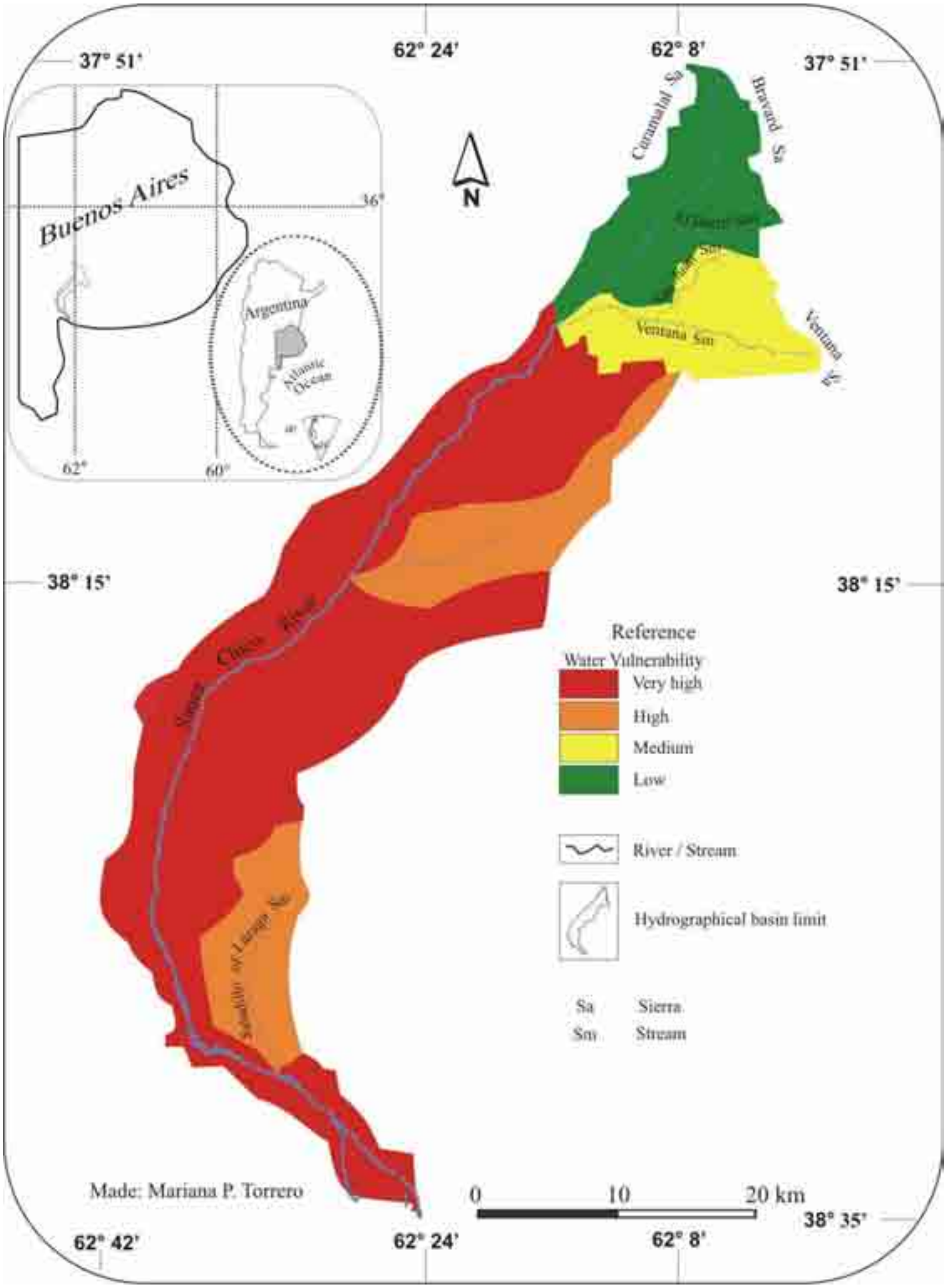


Figure 12. Water Vulnerability Index for the Sauce Chico river basin.

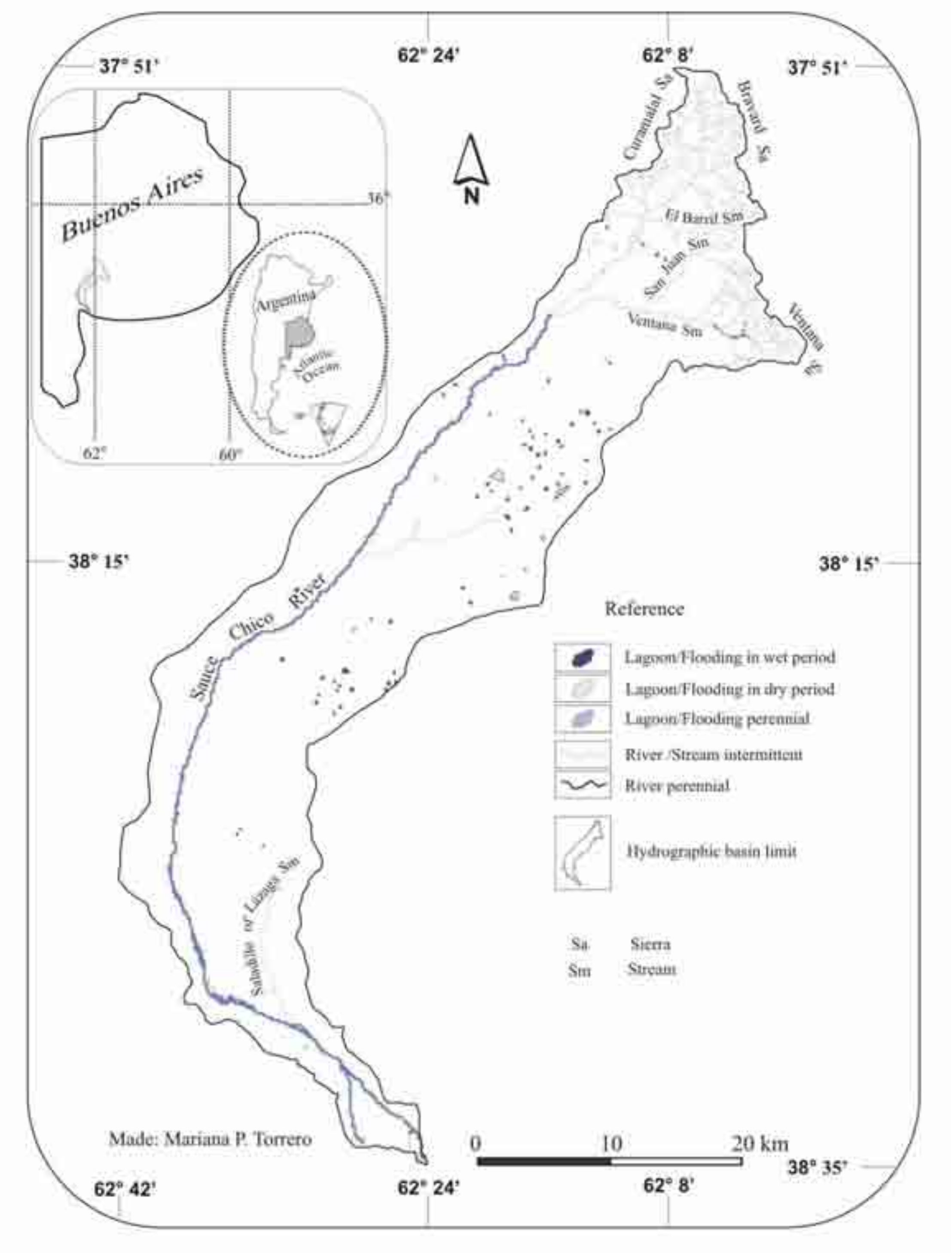


Figure 13. Lagoons and flooding in the Sauce Chico river basin.

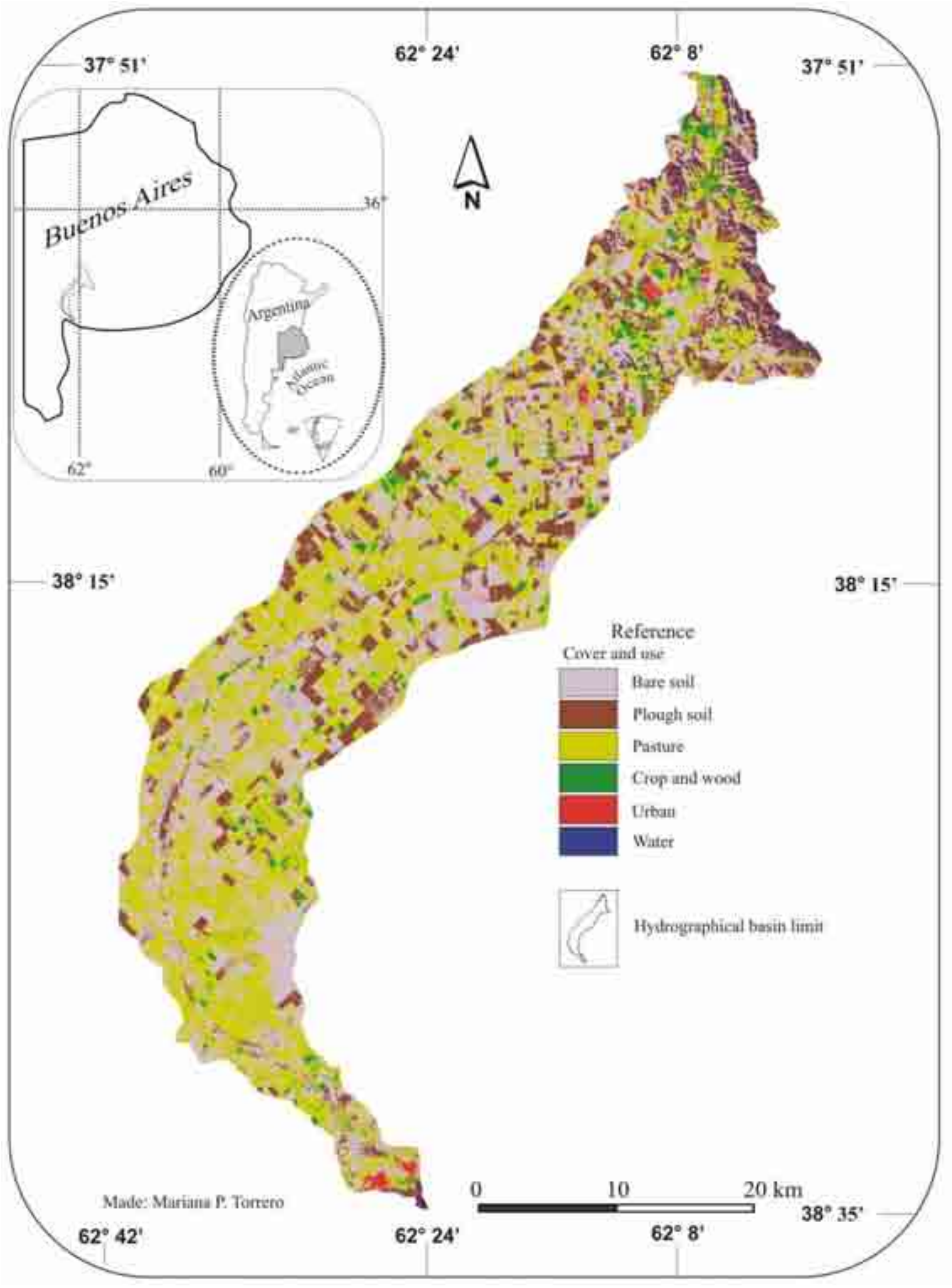


Figure 14. Land use in the Sauce Chico river basin. August 2002.

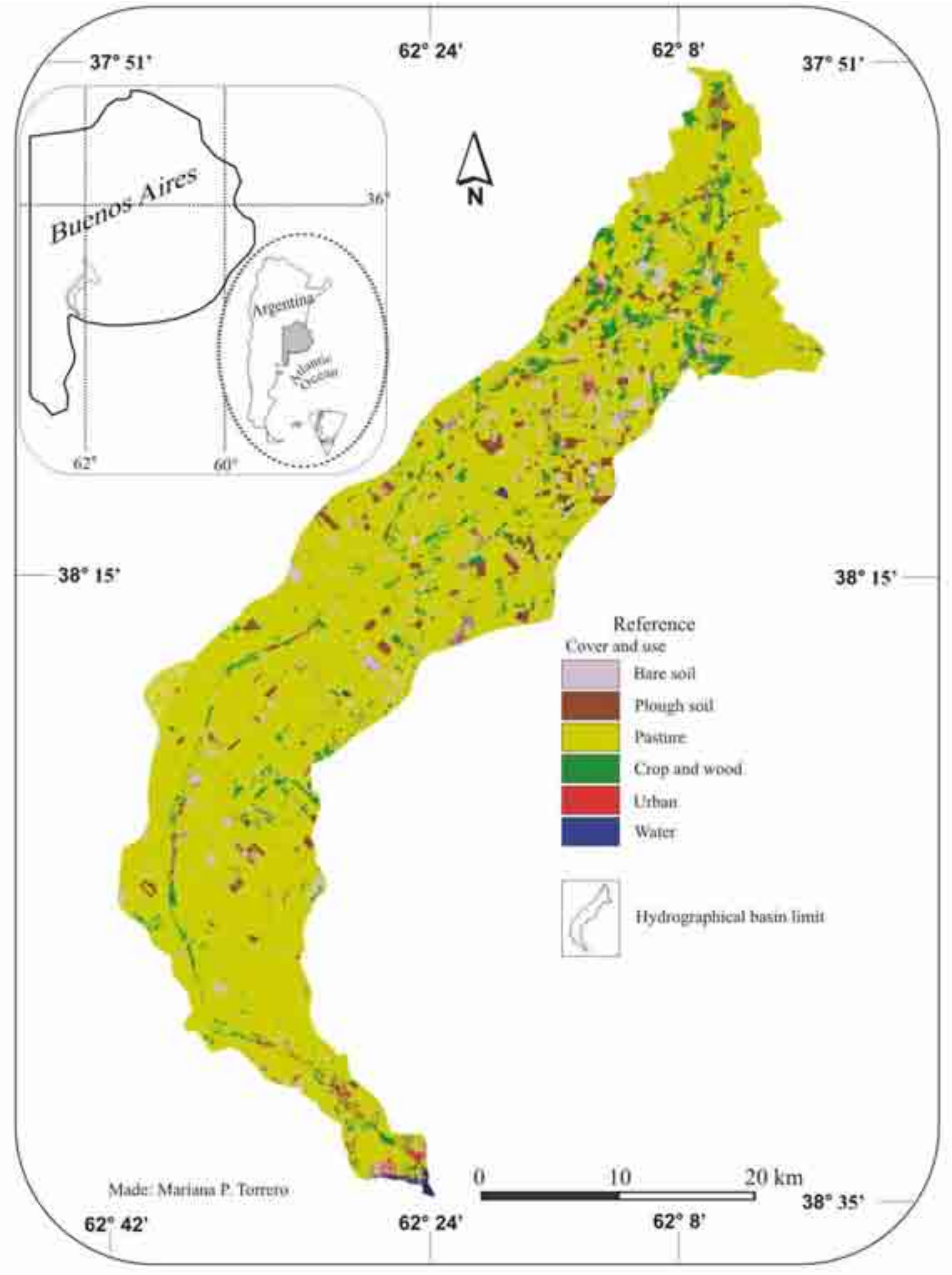


Figure 15. Land use in the Sauce Chico river basin. November 2002.

Torrero, M. P., Campo, A. M. and Uboldi, J. (2010): "Environmental assessment of the Sauce Chico river basin, Argentina derived from satellital images and use of geographic information systems" GeoFocus (Artículos), nº 10, p.18-53. ISSN: 1578-5157

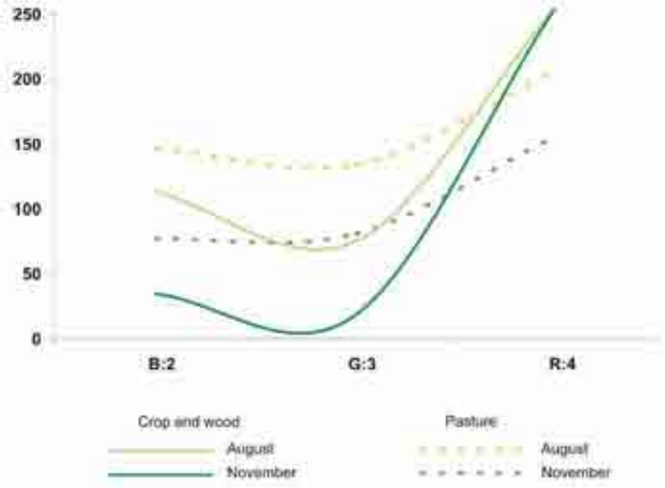


Figure 16. Spectral response of vegetation.

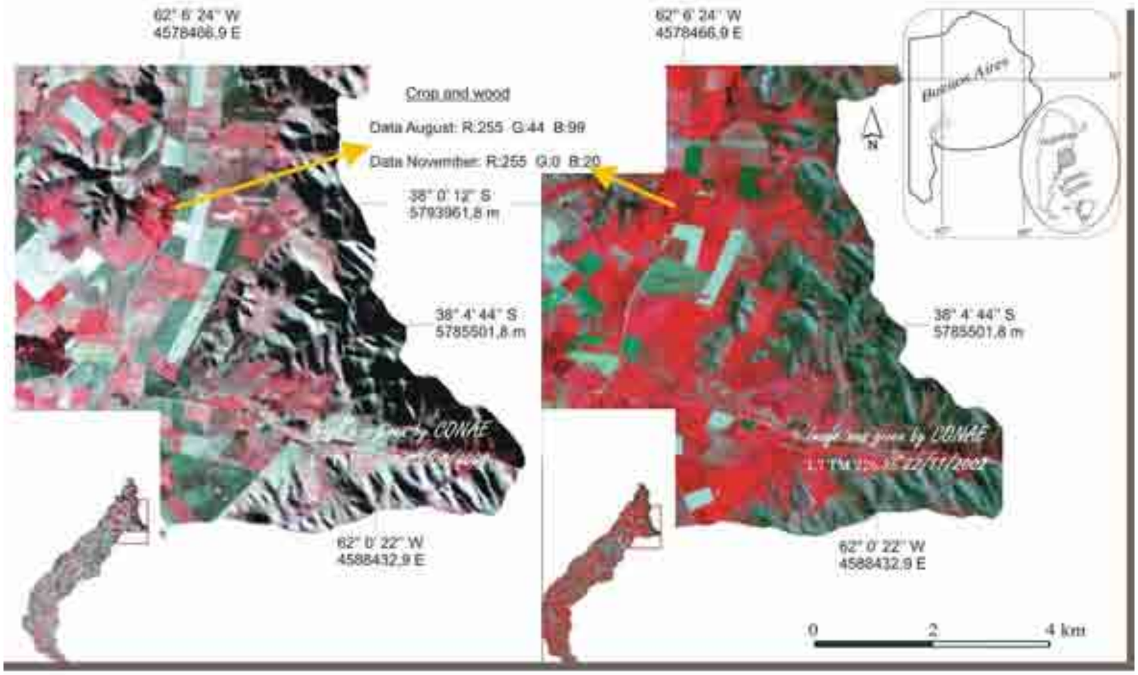


Figure 17. Spectral response of crops and wood in different periods.

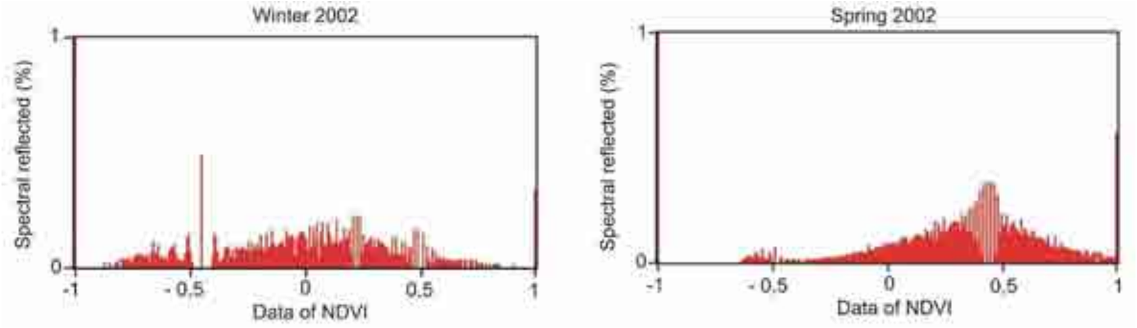


Figure 18. NDVI histograms.

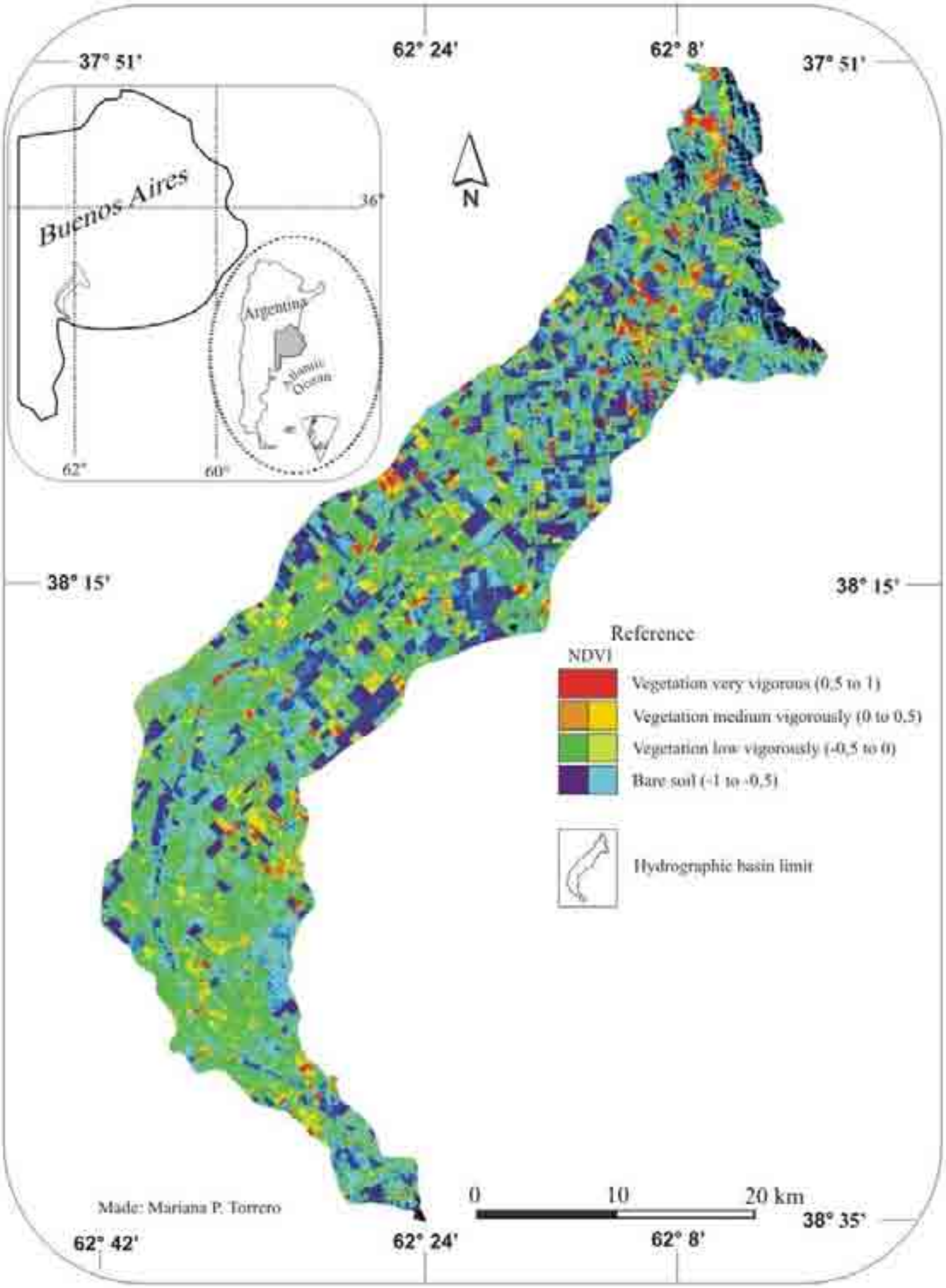


Figure 19. Vegetation index - August 2002.

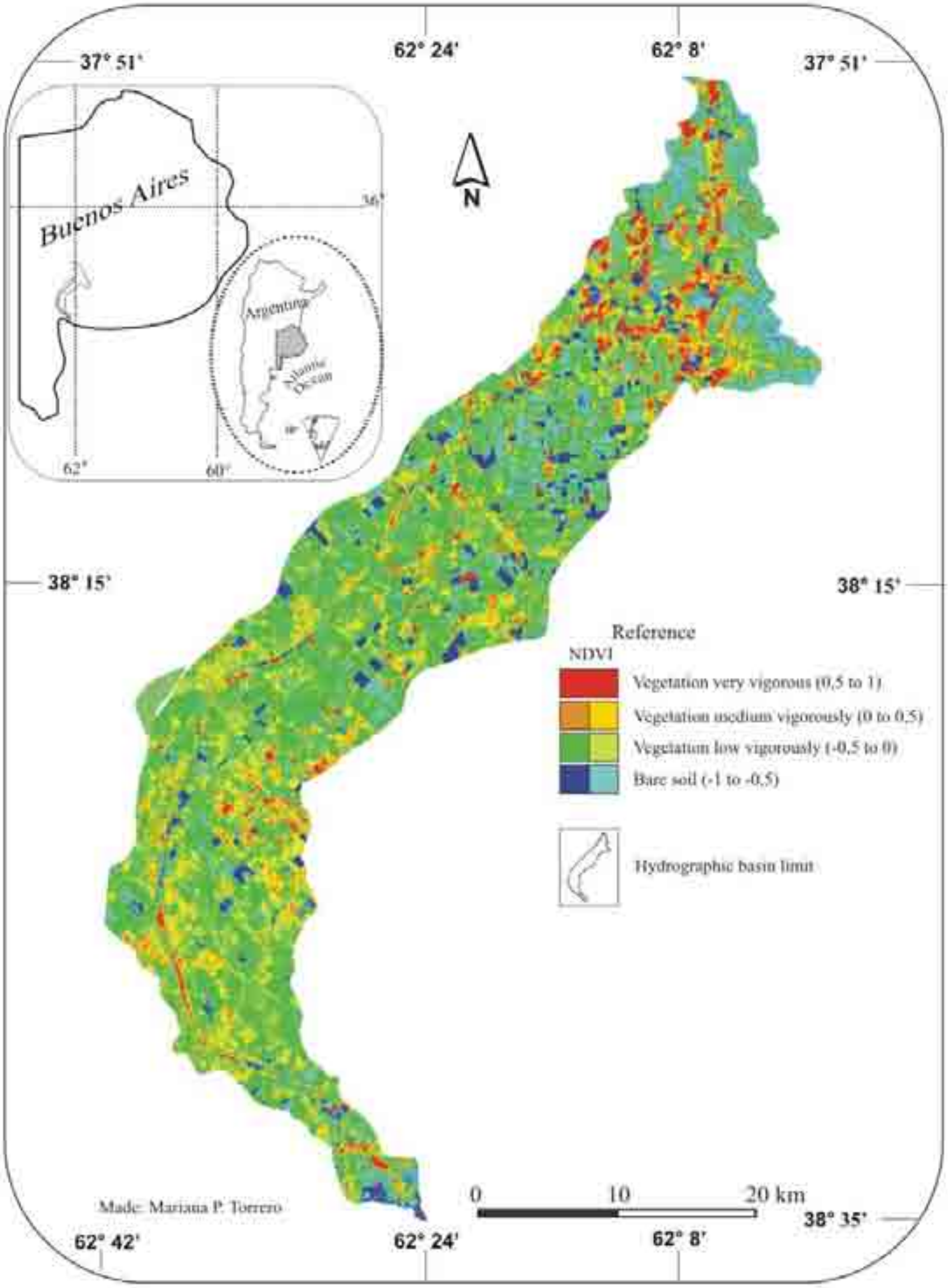


Figure 20. Vegetation index - November 2002.