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Analysis and Consequences of the Pilcomayo River Complexity as International Boundary between Argentina and Paraguay

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Abstract: The War of the Triple Alliance was an international military conflict in South America, fought from 1864 to 1870 between Paraguay and the Triple Alliance of Argentina, Brazil, and Uruguay. In 1939, according to the provisions of the Arbó-Cantilo Treaty, it was established that the international boundary between Argentina and Paraguay passed through the deepest channel of the Pilcomayo River. The natural complexity of the river, plus the condition of acting as international border, led to perform this analysis. The main goal was to implement geo-processing techniques to map the evolution in the drainage pattern, linked to natural processes or human activities from 1951 to today. Satellite imagery and historical maps were integrated upon a Geographic Information System (GIS); to interpret the changes occurred in the last 60 years along the Pilcomayo River channel which is approximately 20,000 km^2 located in Argentina and Paraguay. The collected information allowed the authors to evaluate and demonstrate the degree of correspondence between the river variation and the topographic position of the international boundary between Argentina and Paraguay, and also to diagnose what could occur in the near future.

Key words: Pilcomayo River meanderings-analysis, international boundary.

1. Introduction

The Pilcomayo River Basin spans through three South American countries: Argentina, Bolivia and Paraguay over an area of approximately 290,000 km^2 with a spatial distribution of 25%, 31% and 44% respectively (Fig. 1). *Pilcomayo o Piscornayu*, it means “river birds” on Quichua language, and it is called *Araguay* in Guarani language that means “water coming down from the land of the wise”. As a tributary of Del Plata River Basin, has their origin in the eastern foothills of the Andes Mountains near Potosi, in Bolivia. In its upper basin, the Pilcomayo River shows a dendritic drainage pattern, becoming a meandering river—typical in flat areas landscape, with the development of wetlands—when it reaches the plains of Chaco. The Chaco region is a vast plain forest and jungle, differing in the Chaco Boreal, Central and South, covering 1,510,000 km², in Argentine territory (40%), Bolivia (35%), Paraguay (20%) and Brazil (5%).

The Pilcomayo River is considered one of the largest rivers with sediment transport in the world, with an average annual rate of 125 million tones, and forms a large river mega fan (> 200,000 km^2) on the eastern slopes of the South America’s Andes [1]. Tapia [2] described the morphological characteristics of the Pilcomayo River, and he mentioned: “The Pilcomayo river channel changes in almost all grown.” and he remarks that “it has not been a good option to consider the Pilcomayo river channel as the international boundary due to the movements of the river channel during floods periods.” In 1940, the Argentine, Bolivian and Paraguayan representatives warned that, within a year, the course had moved 700 m to the south, close to Esmeralda region.

2. Material and Methods

A Geographical Information System (GIS) was

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implemented to integrate satellite imagery and historical maps in order to analyze:

(1) The natural & human changes that occurred on the river channel over the last 60 years;

(2) The relationship between the variation on the river channel and the position of the international boundary between Argentina and Paraguay;

(3) The possible behaviors of the area in the near future.

To achieve the goals above mentioned, hardcopy and digital information were processed and georreferenced to make a multi-temporal analysis possible. Tables 1 and 2 show the selected information processed.

Fig. 2 shows the study area and its relationship to the spatial coverage of each of the sources of information obtained for the analysis, and the scheme on Fig. 3 denotes the time series sequence of information covering more than 60 years.

3. Results and Discussion

The exploration of the study area allowed the authors to reach the following results:

To address morphological variations along the river

Fig. 1 The Pilcomayo River watershed [1].

Table 1 Information processed.

Analogical maps		
Name	**Scale**	**Year of publication**
TARTAGAL	1:500,000	1957
SANTA VICTORIA	1:250,000	1970
CONALI **(*)**	1:100,000	1951

Table 2 Information processed.

Satellite imagery		
Mission	**Sensor**	**Year**
LANDSAT	MSS	1976
LANDSAT	TM	1987
LANDSAT	TM	1992
LANDSAT	TM	2010
COSMO -SKYMED	---	2013

*Triangulation made by the National International Boundary Commission (CONALI).

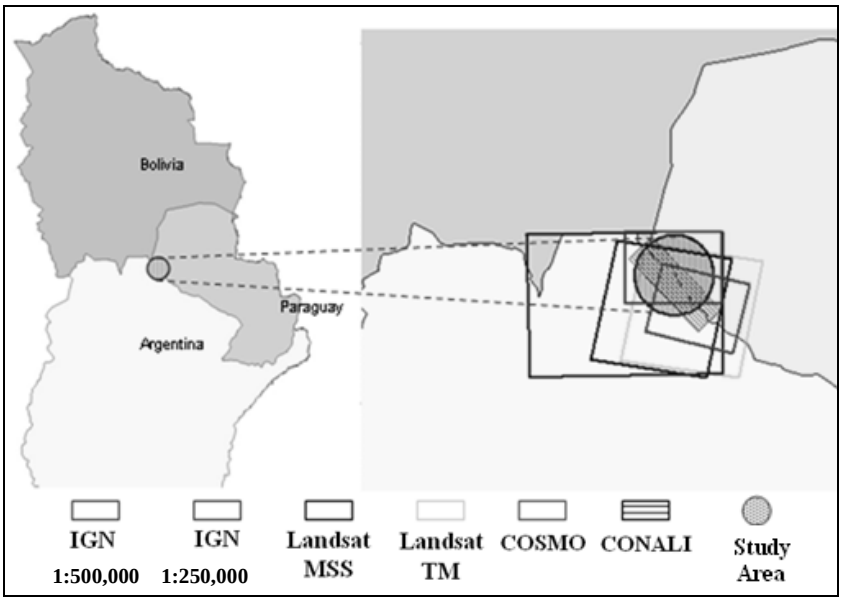

Fig. 2 Study Area—Spatial coverage of the processed information.

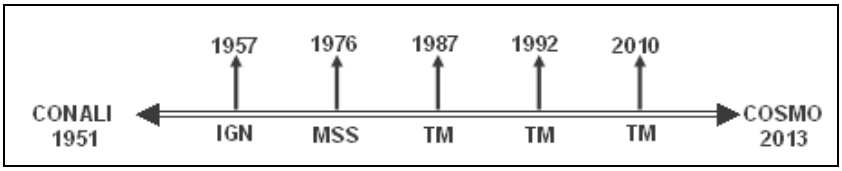

Fig. 3 Sequence of information processed.

Channel, the Fig. 4 has been prepared, where two points of analysis (a-b) were identified with different degrees of variation, observed on the four satellite selected scenes. Note that point (a) is situated close to a river meander with few variations during the period 1976-1994, but from 2010 the course leaves the meander. The point (b), however, is an area that has showed a high degree of variation, attending that seven kilometers of the river channel had been abandoned during 1987;

The area under analysis has also suffered anthropogenic disturbances related with the construction of water channels by Argentina and Paraguay, with possible implications for the location of the international boundary. The Fig. 5 shows different situations of the works carried out on the course of the Pilcomayo River;

What could happen with the location of the international boundary in this area in the near future? To illustrate the possible variations that could occur in the near future, the authors has prepared the scheme shown in Fig. 6.

In (a), it is presented the Pilcomayo River on a natural state, without any disturbances during 1987. In

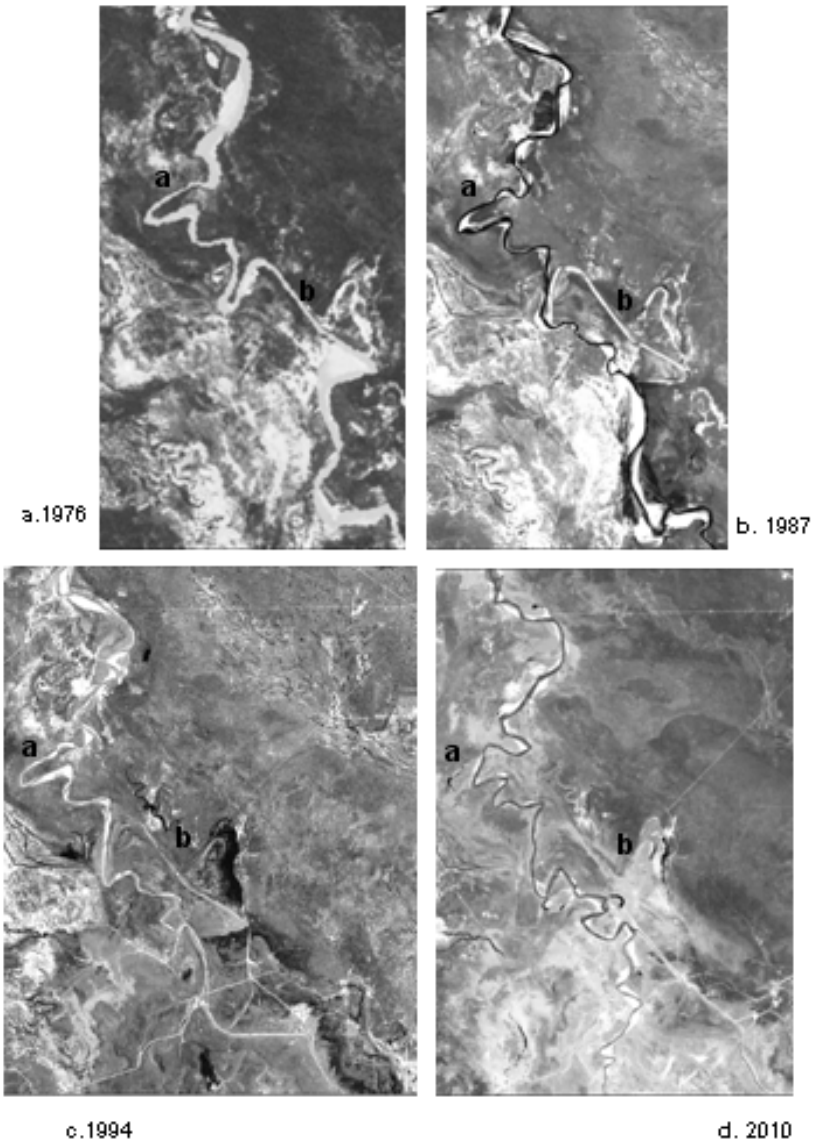

Fig. 4 Evolution of meanderings along the river.

(b), it has been digitized the outline of the international boundary along the river Pilcomayo, as mentioned in the Treaty of the year 1939. In (c), the red X sign indicates an old water channel built by Paraguay. Furthermore, it can be seen how the main channel of the river is drying, indicated by the trace of the international border. In (d), there were mapped current water channels that derive the waters of the Pilcomayo River to Paraguay and Argentina, while the international border remains in the original trace (thalweg) of the Pilcomayo River.

In (a), it has been identified the international boundary in accordance with the main river channel and what it is said on the Treaty of year 1939;

In (b), due to natural displacement of the channel, it is schematically shown the phenomenon of “winning and losing territory” a long time. This happens naturally in many sectors of the Pilcomayo River, leading to identify it as a “moving boundary river”;

The anthropogenic disturbances, related to water channel works, modified the natural evolution of the river course. It is possible to identify different river behaviors upstream and downstream of the worksite, as it is shown in (c).

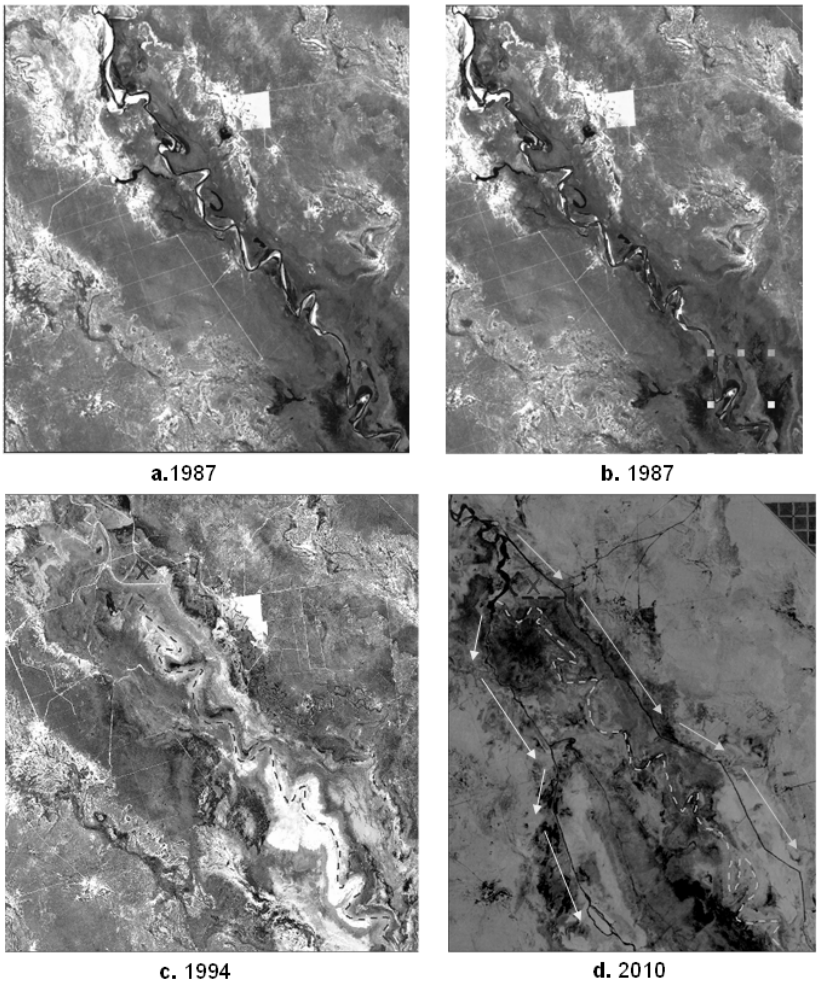

Fig. 5 Time series and waterworks along the river.

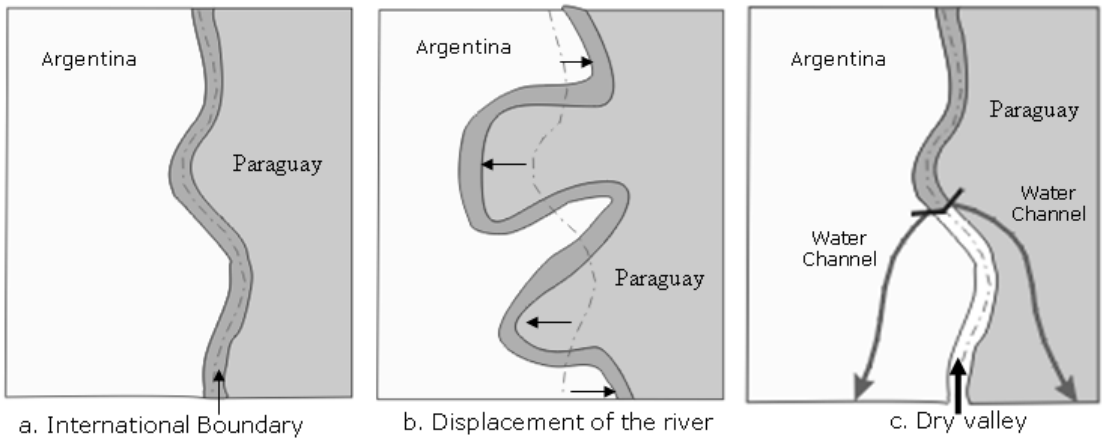

Fig. 6 Pilcomayo River channel movements.

Upstream, the river will continue with the displacements of its channel and, in this regard, leading to variations in the location of the international boundary, as shown schematically on the diagram (b).

Downstream, the location of the international limit will remain unchanged, having been established from the position of the thalweg (The line that connects the lowest points in a valley or river channel). The

construction of both water channels led to the abandonment of the river's natural course, so it will remain unchanged over time, as it is evidenced on the processed images. The paleo-channel is easily detectable in satellite imagery, by variations manifested in the vegetation.

4. Conclusions

The use of geo-processing tools, such is the case of GIS and satellite data processing, have allowed the authors to integrate and analyze information from various sources and formats quickly and efficiently, being able to highlight some achievements:

The selected software, from ESRI (Environmental System Research Institute), allowed successfully accomplishing the proposed goals of the research;

The possibility of having carried out a multitemporal analysis, precisely and objectively, has only been possible due to the existence of satellite scenes that have recorded situations that no longer exist;

Historical, analogical maps were scanned and georreferenced to overlay with satellite imagery information;

The existence of satellite images without cloud coverage, allowed the authors to observe the Pilcomayo River natural evolution, and enable to interpret anthropogenic disturbances;

Radar imagery let the authors view the current state of the Pilcomayo River.

Finally, two major conclusions of the study are remarked:

This analysis has determined that over the analysis area chosen for this study, the current limit is a "dry-border" between the two countries and, at least for this sector of the Pilcomayo River, it will remain naturally unchanged;

Fig. 7 would help to understand the design of water channels build by Argentina and Paraguay: The image on the left (Landsat TM-1992) shows the Pilcomayo River during a flood event, and the image on the right (COSMO-2013) presents the trace of pipes. Note the similarity between the surface runoff coverage in the flooded season and the layout of the pipes. Obviously, they were designed to improve surface runoff in an area of very low regional slope. Whether the construction of these channels was a good idea or not, is beyond the scope of this investigation.

These ideas have been presented at the 3rd International Conference on the Use of Space Technology for Water Management and Prince Sultan bin Abdulaziz International Prize for Water, organized by the United Nations (in cooperation with European Space Agency—ESA, Inter-Islamic Network on Space Sciences and Technology —ISNET, and Secretariat of the Group on Earth Observations—GEO) in Rabat, Morocco, from 1st to 4th of April, 2014. [3]

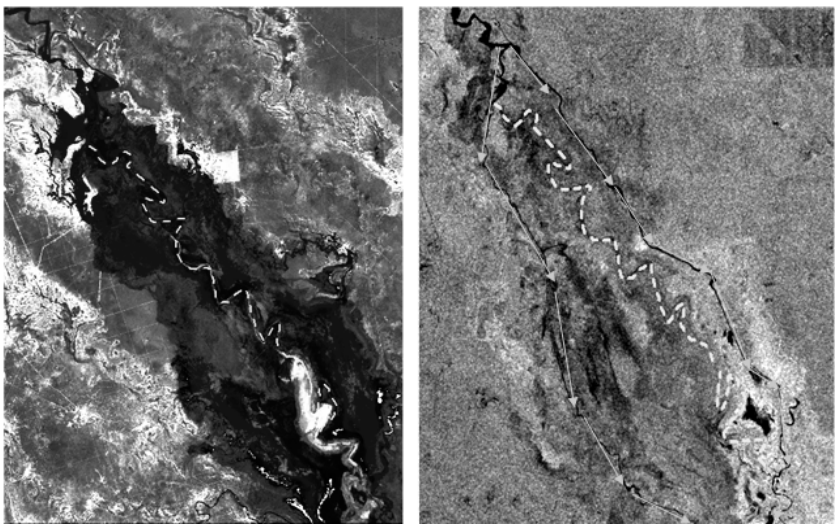

Fig. 7 Scenes of Landsat TM (1992) and COSMO (2013).

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