Chapter 2
Risk Analysis in Transboundary Water of the Rivers Pilcomayo and Paraguay

Julian Báez, Roger Monte Domecq and Lisa Lugo

Abstract Analysis of Trans-boundary Risks in the Pilcomayo and the Paraguay River Basins could generate relevant technical information about the management of water resources in the proposed basins. The Pilcomayo River Commission (Paraguay, Bolivia and Argentina) has conducted important studies in the water resources field of the Pilcomayo Basin that are currently stored in the Commission's data base. Less information is available for the case of the Paraguay River Basin, especially in the area of study: the confluence area with the Paraná River. The study presents a border management tool for managing the risks associated with extreme events water in rivers shared between Argentina and Paraguay, in order to contribute to an efficient coordination work between local agencies that manage emergencies. This study also aims to identify the main risks that can occur in urban and rural environments of potential areas to be affected by floods, droughts and other natural and anthropogenic phenomena such as erosion, sedimentation and pollution from various sources. A web platform has been developed to collect all available information regarding these Rivers. Alpha 3 CapWEM project (Capacity development in Water Engineering and Environmental Management) in which eight Universities from European and Latin American countries collaborate

J. Báez (✉) · R. Monte Domecq
Unidad de Estudios Hidro-Ambientales, Centro de Tecnología Apropiada, Universidad Católica Nuestra Señora de la Asunción. Campus Santa Librada, Asunción, Paraguay
e-mail: julian_baez@uca.edu.py

R. Monte Domecq
e-mail: roger.montedomecq@gmail.com

L. Lugo
Centro de Tecnología Apropiada, Universidad Católica Nuestra Señora de la Asunción. Campus Santa Librada, Asunción, Paraguay
e-mail: lugo@uca.edu.py

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on improving higher education in the fields of Water and Environmental Management has provided the framework for the present study.

Keywords Water risk • Transboundary analysis • Water resources management • Río Pilcomayo • Río Paraguay

Introduction

The Republic of Paraguay is located entirely in the La Plata River Basin, within are located the Paraguay River, a tributary of the Paraná River, and the Pilcomayo River, a tributary of the River Paraguay. Paraguay and Pilcomayo Rivers have significant cross-border sections with Brazil and Argentina. Particularly the Paraguay River divides the country into two very distinctive natural regions: the eastern region, which accounts for 97 % of the population, with rich soils for agriculture and the western region, representing 60 % of the territory but just with 3 % of the total population and is where major cattle and milk production of the country is concentrated.

The River of Paraguay and Pilcomayo produces cyclic flood affecting population, including those of the capital of the country, Asuncion. The most extreme flooding affected more than 100,000 people in 1983. This works describe the flooding process and develop a Web based information system for the Pilcomayo and Paraguay River, which pretends to become as a tool of flood management.

Paraguay and Pilcomayo River

The La Plata River Basin is the second biggest Basin in South America and the fifth largest in the world; it spreads over a 3.1 million km^2, Fig. 2.1 (Collischonn et al. 2001). The Paraguay River is a major tributary of the La Plata River, and its basin covers 1,095,000 km^2, through the countries of Brazil, Bolivia, Paraguay and Argentina. It has an average flow of 2,700 m^3/s.

In Asuncion, Paraguay, the average flow of Paraguay River is about 3,000 m^3/s, with a maximum of 4,000 m^3/s in June and minimum 2,500 m^3/sec in December, Fig. 2.2. Although during periods of flooding in the port of Asuncion, in coincidence with the warm phase of ENSO, the flow of Paraguay River can be as high as 11,000 m^3/s (Barros et al. 2004).

The Paraguay River overflows cyclically producing population displacement in the cities of Asunción, Alberdi and Pilar. The five major floods in the Paraguay River were in 1905, 1983, 1992, 1988 and 1982 (Barros et al. 2004). In 1983 occurred the highest rise in hydrometric level at the port of Asuncion, Paraguay, reaching 9.02 m.

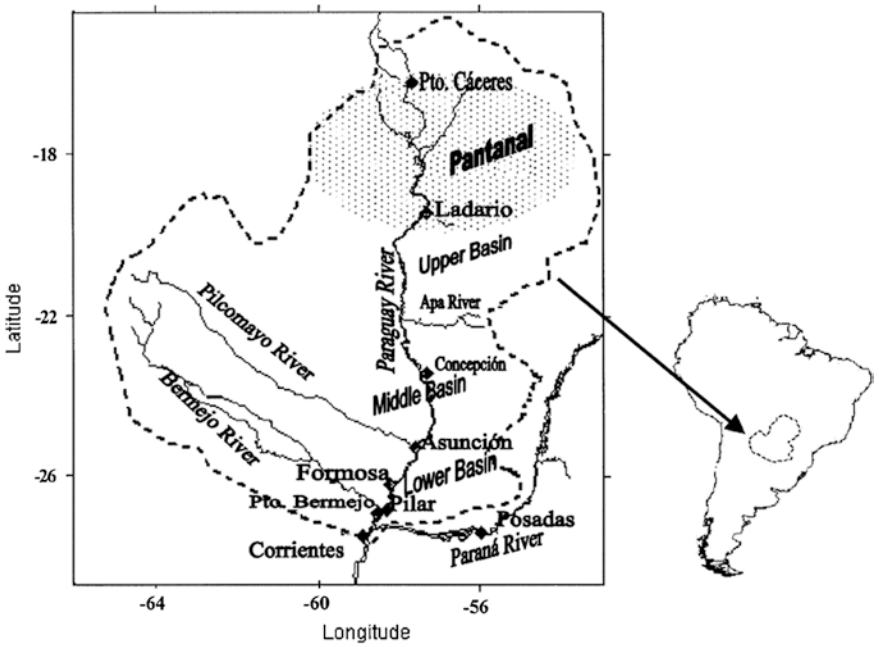

Fig. 2.1 La Plata Basin. Original from Barros et al. (2004)

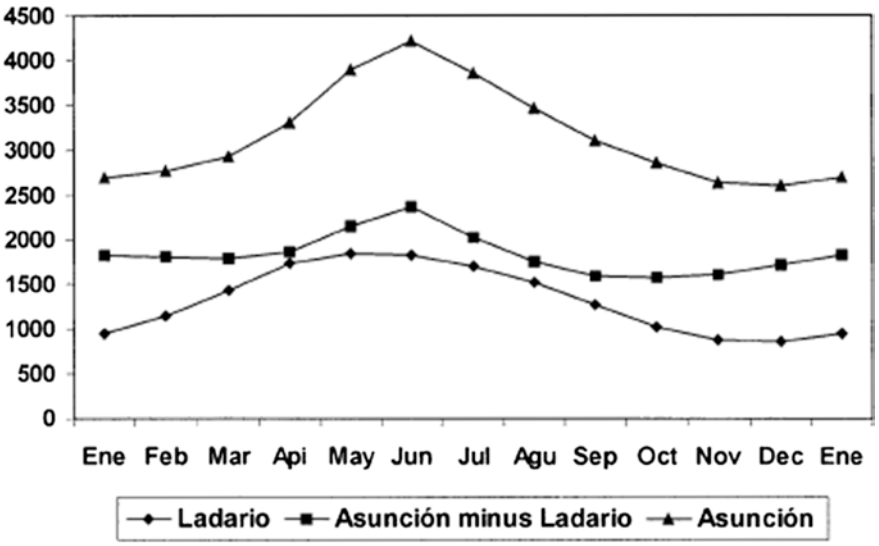

Fig. 2.2 Mean annual stream flow in Asuncion and Ladario. Original from Barros et al. (2004)

After these years there have been no major flooding, and population has grown in flood-prone areas, especially in the city of Asuncion. At present, a river level height of 5 m, referred to hydrometric cero, could cause the displacement of more than 1,500 inhabitants.

River flooding in Asuncion has social and economic consequences, as it causes the displacement of a vulnerable population of about 100,000 inhabitants at northern and southern marshes.

South of Asunción, there are two flood-vulnerable cities to the Paraguay River, Alberdi and Pilar. Both cities were completely under water in the last great flood of 1983. Figure 2.5 shows Pilar city completely flooded.

Large floods coincide with the occurrence of the El Niño-Southern Oscillation (ENSO), particularly with its quality phase or El Niño (Barros et al. 2004). This behavior confirms the high dependence of flooding in the lower reaches of the Paraguay River, south of Concepción, with extraordinary rainfall recorded during the summer in the middle basin, specifically between Apa and Pilcomayo rivers (Fig. 2.1). Therefore, monitoring of rainfall in this region allows forecasting the future behavior of the river in Asuncion and Pilar.

Another variable that affects the behavior of the Paraguay River hydrometric levels is its tributary, the River Pilcomayo. Experience with significant flooding rains due to high volume in 2012 in the Central Chaco of Paraguay, had significant impact on the Paraguay River in Asuncion during the month of May of that year.

Pilcomayo River has very particular geomorphological and hydrological characteristics that have result in the continued waters retreat of this river to its source, in Bolivia. The most significant feature is that the Pilcomayo begins in the Bolivian highlands at altitudes above 1,000 m, reaching a vast plain in the territories of Argentina and Paraguay. This situation generates an annual sediment transport of extraordinary magnitude, about 140 million tons (Martin-Vide et al. 2012). These sediments have to be removed each year in order to avoid the rapid decline of the river.

The Pilcomayo River flows south-eastwards from the Bolivian Andes, across the Chaco Plains, down, in principle, to the Paraguay River at Asunción (Fig. 2.3). The drainage basin covers the southern Andean ranges of Bolivia along 500 km of Main River with an average slope of 1 %, whereas most of the rest of the channel sets the border between Argentina and Paraguay along 835 km in a very flat landscape with an average slope of 0.04 %, (Martin-Vide et al. 2012). It spills over the plains during the rainy season from January to March. The sediment load of the Pilcomayo is one of the largest in the world: 140 million tons per year, which is mostly wash load from the upland Andes. The mean concentration of suspended sediment is 15 g/l. The maximum-recorded concentration is as high as 60 g/l. The river has built a large fan covering a surface of 210,000 km^2, with many abandoned channels. Today, it is a river prone to avulsion, raising border disputes between the two lowland countries, Argentina and Paraguay. Moreover, the very special feature of Pilcomayo River is that it does not actually flow into the Paraguay River. Very far upstream of the mouth in the Paraguay the channel blocks itself with sediment and wood debris forcing water and sediment to spread

Fig. 2.3 Location map of Pilcomayo River and its hydrographic network

across the plains. Moreover, the point of blockage has moved hundreds of kilometers upstream throughout the 20th century. Many environmental issues arise because of this collapse (channel discontinuity), not the least of them is the migration of fish. The future of the river concerns Bolivia and the two lowland countries.

The hydrological regime of the Pilcomayo described by (Martin-Vide et al. 2012) is quite predictable in its general trends. Every year a rainy season produces high discharges in the period of January, February and March. On the contrary, the dry season brings the discharge down from June to October. For the gauging station 1 (Fig. 2.3) located at the end of the mountainous upper part of the river, 1,000 km upstream of Asunción, where the catchment area is 82,000 km^2, the mean discharge is some 720 m^3/s in February but only 35 m^3/s in September (twenty times lower).

The Pilcomayo is a tributary featuring an annual 3-month "pulse" of water and sediment that cannot reach its main river (the Paraguay). Whereas water spills over the plains, feeds the marshes and contributes to the groundwater so that it is finally drained far downstream as clear water, sediment has no other choice except to raise the land of the plains and fill the river channel itself, contributing altogether to the river channel instability in the alluvial fan. The river essentially reaches a local base level as it crosses the Chaco Plains, so that it spreads across the floodplain and fan complex.

The last major flood of the river took place in April of 2012, affecting mainly the Paraguayan Chaco, and it was associated with the lack of sediment removal in Argentine territory in addition to extraordinary rainfall in the central Chaco in Paraguay. The volumes of precipitation exceeded 500 mm in 3 days, which represents 70 % of the annual rainfall in this region. The consequences were catastrophic, causing even the loss of human lives.

Both rivers have social and economic implications for Argentina and Paraguay. Paraguay River is a vital communication channel for trade in Paraguay and a threat

in flood situations for coastal populations. In drought seasons Paraguay River level arises not only navigation problems but also scarcity for drinking water from both countries. Pilcomayo River, in contrast, is a source of drinking water in the province of Formosa as well as for use in irrigation systems in Argentina and Paraguay.

Uncertainties and the consequent related risks in water resources engineering design and operation are unavoidable. Water resources projects are always subject to a probability of failure in achieving their intended purposes. As an example, a flood control project may not protect an area from extreme floods. A water supply project may not deliver demanded water. This failure may be due to failure of the delivery system or may be due to lack of supply. A water distribution system may not deliver water meeting quality standards even though the source quality does. The rational in the selection of the design and operation parameters and the design and operation standards are continually questioned.

The EU ALFA III project "Capacity Development in Water Engineering and Environmental Management—CapWEM" has considered a pilot project named "Risk Analysis in Transboundary Rivers". One of the deliverables of the pilot project is a Web platform called "Information System for Transboundary Risk Management in Paraguay and Pilcomayo rivers". This system aims to organize the information of hydrological extremes, droughts and floods, border sections of the rivers Pilcomayo and Paraguay to serve as a support for decision-making.

Risk Analysis of Transboundary Rivers in the Context of Climate Variability and Change

Extreme flood events and the economic, social and environmental impacts and losses in human life they cause have significantly increased in recent years. Against this already serious background, enhanced climate variability and climate change are expected to increase the frequency and intensity of floods (UNECE 2009).

Floods are part of the water cycle and supply floodplains with sediment and nutrients, the main reason for early settlement in and development of floodplains. Both natural characteristics and human interventions and activities in river basins influence the amplitude, frequency, duration and impact of floods. Increasing climate variability and climate change have the potential to exacerbate flood problems in many regions around the world due to their effects on precipitation volume and timing. Population and economic growth are the dominant drivers behind observed increases in flood damage. Human behavior often reduces the resilience of the land and water resources in the system.

Flood risk is defined as "a combination of probability of a flood event and of the potential adverse consequences for human health, environment, cultural heritage and economic activity associated with a flood event" (UNECE 2009).

Another risk factor for the study area is drought, especially in the region of the Pilcomayo River, where the recurrence of drought threatens not only agricultural

and livestock production, but also drinking water availability for the poorest inhabitants of the region.

The SINERGIA project (International System of Water Resources Studies and Management of Impacts due to Global Warming in the Paraguay River Basin 2011), developed a vulnerability map for the Paraguay River Basin, shown in Fig. 2.4. The survey area corresponds to the areas 16, 19, 20, 21 and 22, which are described below:

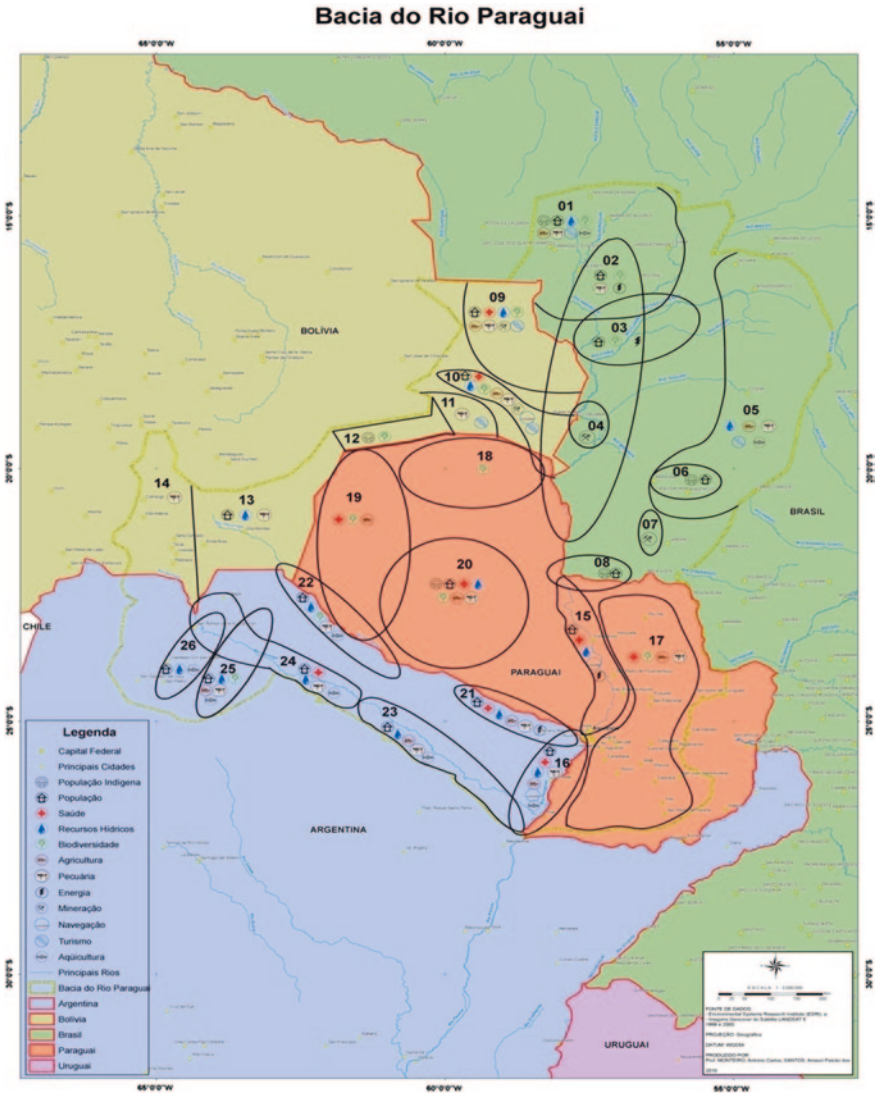

Fig. 2.4 Identified vulnerabilities by SINERGIA project as consequence of climatic factors

AREA 16 (Paraguay/Argentina)

- Any change in hydrological regime has impacts on the area of confluence of the Paraguay and Pilcomayo River, causing flooding in low urban areas and consequently economic losses, as well as coastal erosion of the Paraguay River and retreat of the mouth of the Pilcomayo River. In drought seasons there are water uptake problems and subsequent treatment for drinking water.
- Increased rain causes vector-borne diseases as dengue, yellow fever, and leptospirosis and because of the drought, occurs vector-borne diseases as Hantavirus and respiratory diseases.
- Worsening drought and severe storms affect water transport at critical points for navigation.

ÁREA 19 (Paraguay)

- Drought causes vector-borne diseases (Hantavirus) and contributes to increase the risk of desertification of National Parks, as well as threatens biodiversity.
- The variability in precipitation threats harvest rainwater.

ÁREA 20 (Paraguay)

- Intense rainfall causes urban flooding because there are not enough gutters and waterproofing asphalt streets.
- In Filadelfia, Chaco there is an increasing amount of acute diarrheal diseases (EDAS), serious cases of dehydration, mainly affecting the indigenous population. Drought causes vector-borne diseases (Hantavirus, respiratory diseases).
- Droughts increase the risk of desertification of National Parks, and threaten biodiversity.
- The variability in rainfall threatens rain water harvesting. In the other hand, drought in Central Chaco affects agricultural and forest productivity.

ÁREA 21 (Argentina/Paraguay)

- Changes on hydrological regime impact on the area of confluence of the Paraguay and Pilcomayo River, causing flooding in low urban areas and consequently economic and labor lost, coastal erosion of the Paraguay River and retreat of the Pilcomayo River mouth.
- Appearance of hydric related diseases and permanence of water related vectors.
- Changes in hydrological regime impacts in the area of confluence of the Paraguay and Pilcomayo River, flooding of agricultural and livestock areas, and consequently economic loss of crops affecting small farmers.
- Water consumption increases due to high temperatures (November to March) which generates a deficit to the timber industry and the cities located along Route 86 (Argentina).

Fig. 2.5 City of Pilar complete flooded, located south of Asuncion. May 1983

ÁREA 22 (Argentina/Paraguay)

- Intense rainfall causes flooding due to Pilcomayo River overflows and land loss due to coastal erosion.
- Long droughts cause forest fires, resulting in loss of biodiversity and ecosystems.
- Long droughts and floods result in loss of grazing (for goats, pigs, horses, sheep, and cattle). Droughts that occurs during winter season causes animal mortality for lack of food.
- The change in the hydrological regime resulting in high pressure on the isinglass sector of Pilcomayo River.

SINERGIA project identified major vulnerabilities in rivers Pilcomayo and Paraguay at their cross-border section. Water risk analysis in these rivers is completed with the knowledge of the behavior of droughts and floods in the region, considering that Risk is the product of the threat of occurrence of an extreme natural event by the vulnerability and exposure of the region where extreme event occurs (Fig. 2.5).

Information System for Risk Management at Paraguay and Pilcomayo Transboundary Rivers

The information system for risk management at Paraguay and Pilcomayo transboundary Rivers, was the result of three seminars developed between 2012 and 2013 in Asuncion, Paraguay and Resistencia, Chaco, Argentina. During these seminars, developed with the support of CapWEM project, it was defined the scope of the study and the facilities of the system itself.

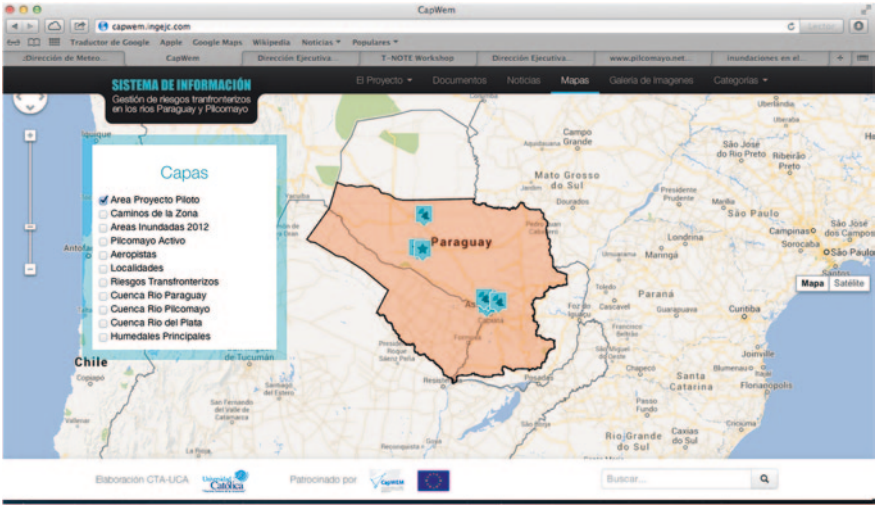

Fig. 2.6 Main screen of the system developed. Figure shows the project area

The general objective of the system is to implement a transboundary management tool for managing the risks associated with extreme hydrological events in rivers shared between Argentina and Paraguay, to establish coordination between local emergency Agencies. The specific objectives are:

- To identify and classify the main natural hydrologic threats in the study area, flood, drought, river coastal erosion, sedimentation and water quality, as well as, anthropogenic threats like urbanization.
- To identify the vulnerable areas in the study region.
- To evaluate the socioeconomic impact of extreme Hydro meteorological events which affect human life, urban and rural infrastructure, and impacts on the agricultural and cattle sector.

This study do not pretend to develop new specific knowledge in flood, drought, water quality or another things in the basin of Pilcomayo and Paraguay River, it pretends to gather published information, organize and store it in a data base, which can be visualized in the Web based plataform.

The system provides information related to hydrographic basins, scientific studies related to flooding and drought, meteorological and hydrological data from public institutions, as well as distribution of communities with their populations, many of them vulnerable.

Major main structure of the platform can be viwed Fig. 2.6 and the first results in—Fig. 2.7. If you want to test the system, go to http://capwem.ingejc.com.

The platform is still under development. However, there are important meteorological and hydrological information derived from several automatic weather stations from DINAC (Civil Aviation National Direction, Paraguay) and other institutions.

Fig. 2.7 Main screen of the system developed. Road (*brown line*) and flood impacts area of 2012

Conclusions

The Pilcomayo and Paraguay rivers are very important for the country. The Pilcomayo is under continuous threat, flood, drought, sediments and water quality. On the other hand, the Paraguay Rivers get importance because is the main communication way of the country and during low flow and high level of rivers will be a threat for both, companies and populations.

The platform under developing and continuous work will have a great chance to become as a tool where the users will have the ability to get information in order to take decisions in case of floods and drought. Our focus is in the rivers Pilcomayo and Paraguay, but the platform has capacity to incorporate information for all the country.

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