

Remote Sensing analysis of the meanders migration in the Mamorecillo River between 1985 and 2012, Bolivia

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Abstract — *The morphology of a channel, in a space-time resolution, suffers with sedimentological processes of erosion, transport and deposition. Processes that are more accentuated in meandering channels. In the present work the objective is to analyze, identify and discuss the changes occurred in spatial and temporal sequence in the form of the meanders and river bed of a section of the Mamorecillo River between the provinces of Cochabamba and Santa Cruz - Bolivia. Characterized by being an extensively meandering river - characteristic of the river basin in which it is inserted, the Amazon Basin, the present study, through remote sensing resources, seeks to discuss and correlate the changes occurred in the channel in a period of twenty-seven years (1985-2012). As well as understanding the processes of migration of the meanders that this section of the Mamorecillo River suffered through the sedimentological processes of erosion and deposition and consequently understand the processes in the Amazon basin. For the accomplishment of the work, the studied area was delimited and allied with geoprocessing tools such as software and aerial images, the main geomorphological features were identified and their changes discussed during the studied period. In this work, we intend to correlate and verify the inter-dependence (referring to the sedimentological and / or hydrological contribution) that exists between the Mamorecillo River and the Chimoré and Ichilo rivers.*

Keywords— *Amazon Basin, Fluvial Dynamics, Meanders Migration, Hydromorphology.*

I. INTRODUCTION

To understand and comprehend how rivers operate and, also how changes on their river bed form are fundamental for the use and occupation of their surroundings, especially in the development of activities such as agriculture, livestock, industrialization and urbanization. In this way, the present study achieved an

analysis on the change of meanders in a certain area of the Mamorecillo River.

Christofoletti (1977) emphasizes the river dynamics as the removal, transport and deposition of sediments that are in particular network drainage and that directly reflects on the stability of the river system. Therefore, when disturbances occur in the system, the channel will adjust or readjust until it finds a new balance point. Fluvial dynamics with channel mobility and registration on the flatland, paleochannel and flood basin include temporal and spatial variation. In this case, covering the influence of the hydrological and sedimentary regime (Gilvear et. al. 2000; Zancopé et al. 2009; Micheli & Larsen, 2011; Kiss & Blanca, 2012).

Suguio & Bigarella (1990) characterize in a geological-morphological sense a river as the main "trunk" of a drainage system, represented by a water body confined in a channel (whether this water body is feed by precipitation, groundwater and / or other means)

Currently, several authors classify water courses as intermittent, perennial or ephemeral. The intermittents are those bodies of water that usually flow during the rainy season (i.e. the flood period) and dry up during the dry season. While courses classified as perennial has water throughout all the year, the groundwater usually feeds the channel continuously while the ephemeral channels only run during or slightly after the rains (Suguio & Bigarella, 1990, Carvalho & Silva, 2006)

The usage of classifications such as: rectilinear, meandering, anastomosed and interlaced to distinguish between channels is current. Thus, straight channels are less frequent and are only restricted to a few drainage segments, while anastomosed channels are marked by constant ramifications and subsequent re-encounters with their courses. A channel excessively marked by sinuosity is called a meandering channel. In these channels, the curves become so sharp over time that they meet each other - forming abandoned meanders. The

interlacing is characterized by the presence of small islands between two or more channels with bars (Suguio & Bigarella, 1990, Riccomini et al., 2000).

Goerl et al. (2012), assumes that water acts as the principal modeling agent of the landscape. While Scheidegger (1973) apud Goerl et al. (2012) studies about forms that are caused by the water action according to a hydrogeomorphology definition.

In relation to the morphology of the river channels, it's controlled by several factors, which are classified in a very complex relationship as autocyclic (i.e. drainage network) and allocyclic (those that affect not only the basin but the region where it is inserted as a whole). The autocyclic factors considered are: the discharge (type and quantity), the transported sediment load, channel width and depth and the flow rate consecutively conditioned to allocyclic factors, for example, climatic and geological variables (Temperature, evaporation, precipitation, type of rock/substrate and faults) (Riccomini et al., 2000).

Alterations in meandering fluvial channels will rarely produce immediate responses. Modifications are perceived over time (Brookes, 1996). The meanders evolution and their form variation in a time scale, are characterized by the channel's migration in the plain, increasing the sinuosity index of the meander, which causes the adjacent meanders union provoking the bottleneck of the peduncles. The meanders compose a pattern where suspended and bottom loads are bordering on equivalent quantities of continuous and regular flow. They acquire this feature by crossing plain landform, where the low slope and the small velocity of flowing water creates more accentuated deviations (Christofolletti, 1981, Zancopé et al., 2009).

The changes on the river forms, mainly the migration of meandering channels, occur due to the continuous processes of excavation and deposition in its concave and convex margins, respectively. This process leads to an adjustment of the river in search of a new equilibrium (Hack, 1973, Ouchi, 1985, Gregory & Schumm, 1987).

In view of rivers as responsible for process such as erosion, transport and deposition of sediments, these processes will determine along with other factors, the geomorphologic features of the river itself (Candido, 1971, Zancopé et al., 2009). Factors such as: basin area, basin slope, the river's flow rate and drain volume are few among many factors that accentuate and / or intensify the geomorphological changes and river dynamics. Therefore, rivers behave as natural agents of transformation and modification in the space where they are inserted. In this sense, studies in the Andes-Amazon Basin has been intensified in the last decades (Do Nascimento et al., 2015, Dunne et al., 1998, Salo et al.,

1986, Peixoto et al., 2009, Constantine et al. Atya et al., 2003).

The fraction under study of the Mamorecillo River, is characterized by an extensively meandering channel. Meandering rivers are characterized by presenting themselves with an extremely numerous amount of successive curves in their channel/course. Erosion and deposition processes act in order to accentuate this sinuousness present in the channel, even reaching the point of bottleneck adjacent meanders, forming the so-called abandoned meanders (Christofolletti, 1980, Zancopé et al., 2009).

Channels with meandering patterns are relatively common throughout the entire Amazon basin. They are typically characterized by being in alluvial plain, that is, where the landform is topographically mature. Although, due to geological factors such as faults, this drainage pattern can occur in topographically distinct regions.

Geotechnologies have become great allies for professionals and researchers in the area of Earth Sciences, allowing data acquisition to occur very quickly and safely. Studies of digital cartography, remote sensing, satellite positioning and aerial photogrammetry are the result of technological advent applied on Geosciences. As a consequence, it helped the development of this work by monitoring and evaluating the mobility of the channel with meandering pattern as well in the river dynamics of the Mamorecillo River in a period of twenty-seven years, between 1985 and 2012.

In this context, this study aimed to analyze in a temporal sequence the river dynamics, that is, the change that occurred during approximately two and a half decades in a section of the Mamorecillo River located between the departments of Cochabamba and Santa Cruz, Bolivia. In this study besides the main purpose of understanding and studying the hydrodynamic processes of the channel, the study also highlights the importance of geotechnologies in the aid of Geosciences research.

II. THE MAMORECILLO RIVER

The studied area is located in the Amazon's river watershed and it is held nearby the confluence of Chimoré and Ichilo rivers (Fig. 1). The Mamorecillo River shows a meander pattern, sinuosity of the channel (<1.5), and a predominance of suspension sediments transportation that currently form the alluvial plains (Lombardo et al., 2012, Lombardo, 2014, Hanagarth, 1993). The analyzed area has a total of approximately 39 km of extension (in a straight line), between the geographical coordinates 16°44'27" - 16°26'12" south latitude and 64°50'37" - 64°40'44" west longitude.

Climate changes can affect the river patterns since they have a directly affect in the magnitude and frequency of flows. The Mamorecillo River suffers direct influence of

the El Niño cycle (Aalto et al., 2003) causing small floods and low sedimentation rate. The La Niña cycle, on the contrary, causes great floods and higher sedimentation rates (Aalto et al., 2003, Schöngart & Junk, 2007). Therefore, the river consequently adjusts itself to the process of erosion, transport, and deposition.

The Mamorecillo River meets with Ypacani River and at the end of this course of approximately 260 kilometers, it meets with Chaparé River still on the border between the departments of Cochabamba and Santa Cruz, Bolivia. From this confluence between Chaparé and Mamorecillo rivers, the Mamoré River is born, comprehending the second and most important precipitation of the southern Andes (Espinoza et al., 2015).

The Madeira River has its origins related to the Mamorecillo River, exhibiting an extension of approximately 1100 km running through an expressive part of the Bolivian territory in North direction until its confluence with Beni River in order to form the Madeira River. During the lower and middle Holocene (Plotzki et al., 2013) the Mamoré river advanced and occupied one of the paleochannels of Beni's River. However, since the Middle Holocene, one of its alluvial distributary systems deposited thick sedimentary layers at the south and central part of Llanos de Moxos (Lombardo, 2014, Plotzki et al., 2015).

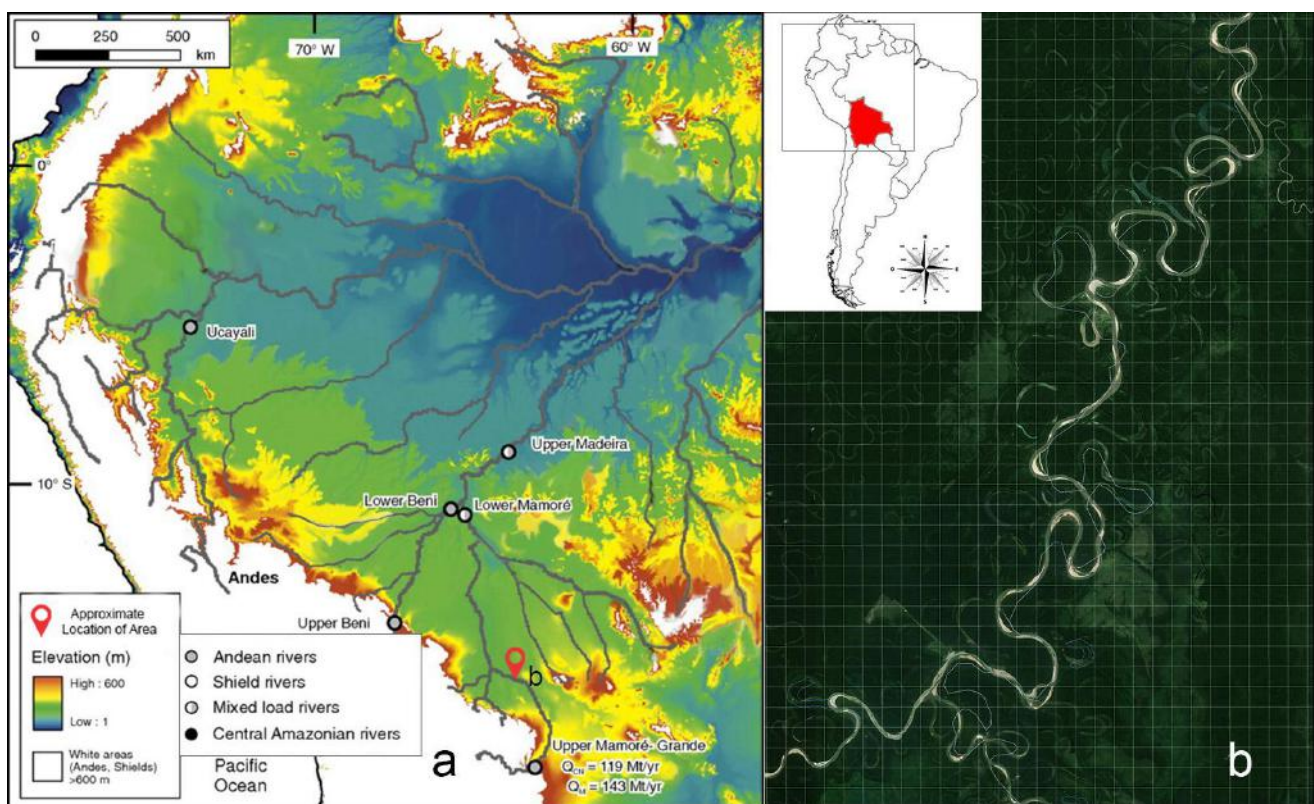


Fig. 2: a) Localization map of the studied area (Adapted from Wittmann et al., 2011) and, b) Studied area detailed.

Because of its own characteristics is important to promote the comprehension of Mamorecillo's river behavior and the alluvial mechanisms that control the accumulation of sediments.

III. METHODOLOGY

The spatial and temporal analysis of the fraction in study of the Mamorecillo River was performed through analysis of images with 30 meters spatial resolution satellite of the Landsat catalog, a platform from the National Institute of Space Research (INPE) between the years of 1985 and 2012, the Earth Engine tool was used as well - which has greatly aided to the understanding about the fluvial dynamics of the channel.

The analysis was performed in an area of approximately 39 km in a straight line, distance that approaches the 90 km when traveled in the channel - accurately because of its meandering form. From the treatment of images in a software developed specifically for this purpose, channel maps were constructed for the years of 1985, 1995, 2005 and 2012. The data obtained was fundamental for the channel hydrodynamics studies, as well to help with the understanding about the changes in the channel geomorphology - and all aspects that are correlated such as, the creation and extinction of meanders, the formation of sedimentary deposits in the bed and river bank, the widening and narrowing of the channel and its river bank.

The meanders were grouped, separated on the upstream in direction to downstream and named as Flames A, B and C (Fig. 2). This procedure was performed in order to facilitate the understanding and visualization of the obtained results, thus simplifying the discussion of the results. In order to better represent the changes occurred in detail, whether in the meanders, the abandoned meanders, or even to verify the performance of sediment accumulation and removal processes in the canal, separate figures were created for each of the Frames (Figures 3, 4 and 5). These figures are discussed the processes suffered in each period of time for each flame.

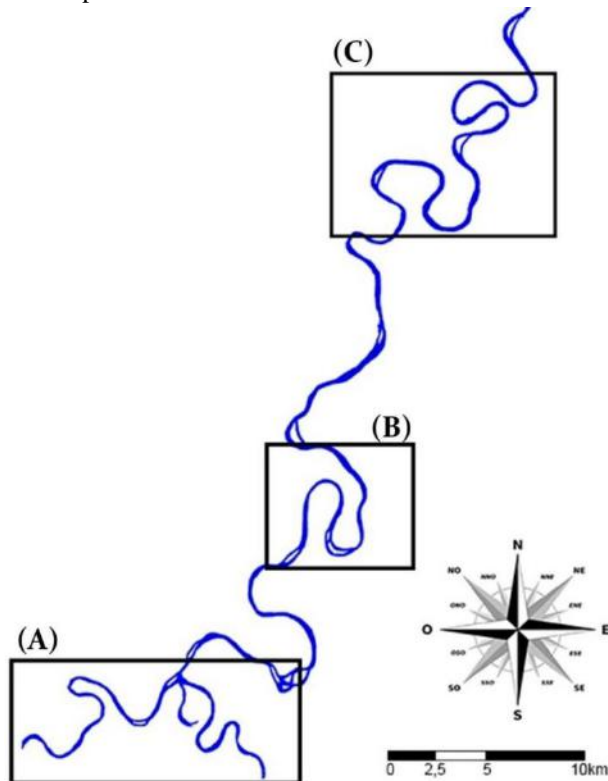


Fig. 2: Patch of Mamorecillo River with Flames A, B and C highlighted.

IV. DISCUSSION AND RESULTS

During the twenty seven year period on which the images were evaluated, significant changes occurred in the bed form of the studied area. It is possible to observe the accentuation of the erosive processes acting on the margins, in conjunction with sediment deposition processes on the banks of the Mamorecillo River (Fig. 3,

4 and 5). In some analyzed portions a gradual increase in the meandering amplitude is observed to the point of causing the bottleneck of the channel, creating in a natural way a redefinition of the channel and consequently of the flow of the river. In figure 3, we observe the performance of these processes that caused a total spatial change in the confluence of the channel. In the same way, depositional processes foment the formation, thickness, and also the geomorphological modification of the channel margins. From 1985 to 2012, the SW portion of the river (Fig. 3) presented an exceptional temporal evolution. In 1985 was perceived the confluence forming the main trunk of the river and also, near by the confluence, a meander already in process of strangulation. It is also possible to identify places where erosion processes work in an evident way - to cause a future bottleneck of the canal, consequently forming abandoned peduncles. Therefore, when the canal is strangled, a new meander will form - due to erosion processes, sediment transport and deposition, and the sedimentological contribution of the canal (Zancopé et al., 2009).

When compared the 1985 year with 1995 it is possible to observe that there is a change on the geomorphologic aspects of the channel. The meander - active, which existed nearby the river's confluence, suffered a shutdown of the channel, being abandoned. It is also observed the abandonment of a secondary peduncle which previously formed the main channel of the river. The erosion suffered by the meanders caused floods and progression of the river towards its bank. Between the years of 2005 and 2012, it is noticed a complete modification of the river's confluence, this change was already in progress in the year of 1995. The bottleneck of the meander located at NW of the confluence in 1995 happened as a result of erosive processes in the river bank. In the images from 2005 and 2012 years, it is noticed the channel reviewed and running at the exact point where the channel bottleneck happened. In this way, it is noticed a geomorphologic change in the bed of the river at the confluence of Chimoré and Ichilo rivers, noticing the old channel - in progress in the year 1995 as an abandoned peduncle located between the confluence of these rivers.

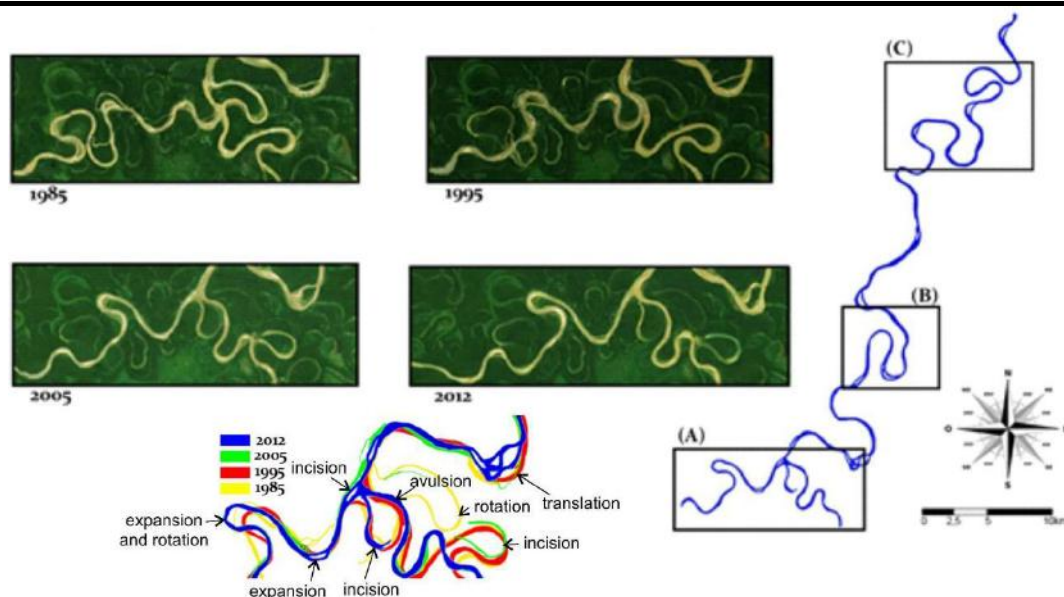


Fig. 3: Space-time evolution of the patch relative to Flame A and the processes that happened in the analyzed period.

The river's central region analyzed (Fig. 4) shows significant geomorphological changes over the period of study. According with the geological photo interpretation from images taken of the channel in the year of 1985 it is noticed a meander feature extremely sinuous which it is highlighted the erosional movements on the concave margin - by symmetry the action of deposition processes on the convex margin. In function of these processes the narrowing of its margin is accentuated.

The meander abandonment process turns more visible in the year of 1995 when the bottleneck of channel happened, that is, this channel patch got a new course.

However, the meander in the study is still active and it receives a lower flux of water becoming a secondary meander on the channel. In the year of 2005, it is observed that the meander was practically aborted from the channel, in this way the processes of sediments deposition strongly influenced the bottleneck of the channel while biological processes of vegetation growth in the aborted meander became evident. In the year of 2012, the channel is highlighted being geomorphically distinct from the year of 1985 when the growth of vegetation covered almost all the peduncle abandoned.

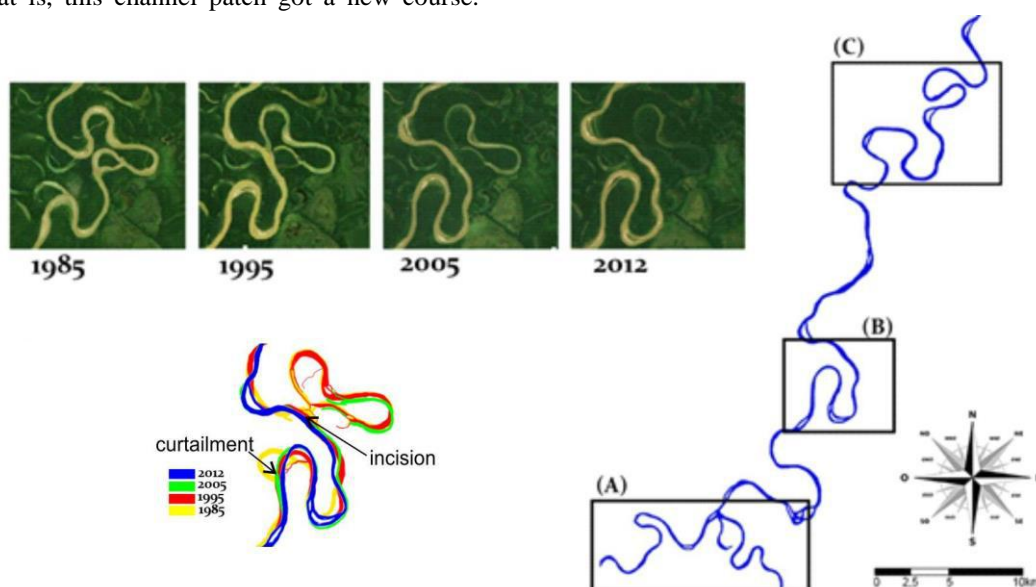


Fig. 4: Time-Space evolution of the patch relative to Flame B and, the processes that happened during the analyzed period.

In Figure 5 from the sequence of highlighted images (1985, 1995, 2005 and 2012) it is possible to observe the dynamic evolution in this patch at N-NE of the channel.

In the analyzed images from 1985, it is noticeable an accentuation in the number of abandoned meanders. These meanders were formed in function of processes that

acted in the channel before 1985. Probably the remotion of sediments inputted in the meander's margin. Therefore, in this period was only one very narrow and thick margin, indicating a spot of rupture of the meander in a near future.

The peduncle cut in an advanced process is visible on the images from 2005. Also, already in process, it is the redefinition of the channel. Notwithstanding was still the feeding of meanders by the river flux it is noticeable that the processes of sediments deposition in the local became strongly active in a way that the place stopped suffering

from the sediments accumulation. As well, it is evident the action of erosion processes in the meander located in the upper right part of the image in the year in question, which by similitude will suffer similar process. In the year of 2012, it can be identified the meander's rupture (S-SO portion of the square), being verified vegetation growth processes in smaller proportion than the central part analyzed while the smaller meander, located in the upper right part (Fig.5), starts the process of rupture by the bottleneck of the meander in function of erosion and transport of sediments happening in the margin part of it.

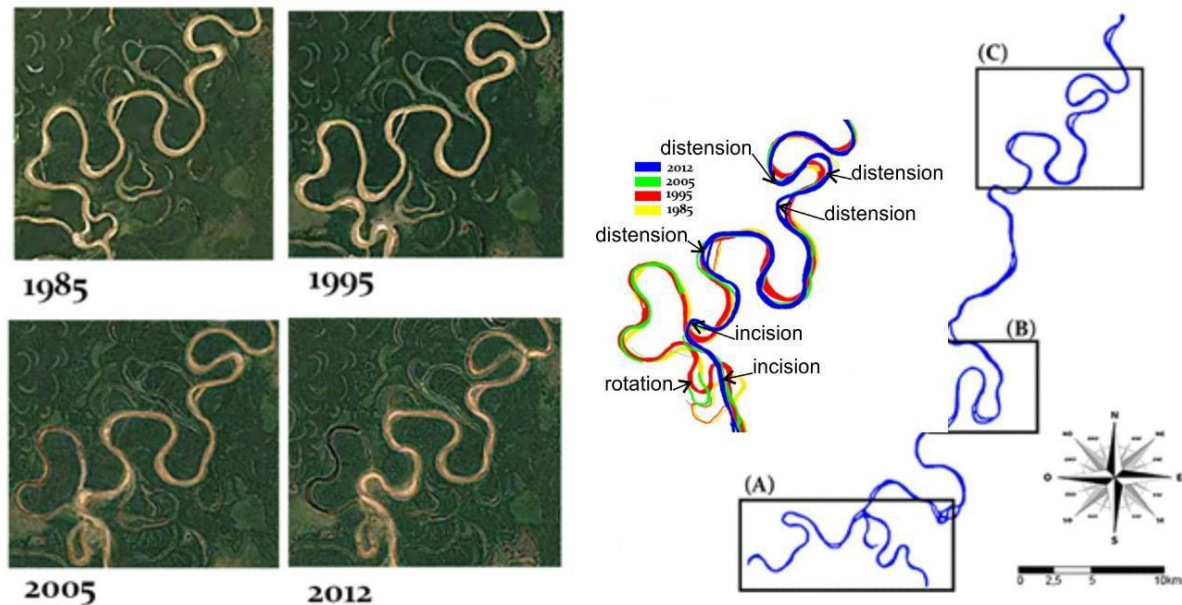


Fig.5: Time-Space evolution of the patch relative to Flame C and, the processes in the analyzed period.

The comparative analyses through the decades lead us to realize that between the years of 1985 and 2005 the Mamorecillo River has an increased sinuosity index higher than the subsequent period (2005 to nowadays). For Hickin & Nanson (1975) it is caused by the increase in the radius of curvature of a curve is indirectly proportional to the radius of curvature of the adjacent curve. In this way, the adjacent meanders unite through the peduncle bottleneck due to the high expansion of the meanders. Thereby, in the first 20 years of study occurred a fast lateral migration of the channel on the Mamorecillo River plain, being observed that in the convex marginal cords, paleochannels, abandoned channels and avulsion by a resumption of the flow in these last forms of relief of the river.

Another fact related to this is the change in the meanders' axis direction. The increase in the rate of curvature and meander length allies in expansion and rotation are consequences of the adjustment of detrital load constituent flow (Hickin & Nanson, 1975). In order to find its balance between the processes and forms, the

Mamorecillo River also developed forms to shortening curves. This being the inverse process of meander's expansion and directly related to the expansion rate.

On the Mamorecillo River, the processes of curve expansion and abandonment of channel by peduncle cut are more frequent. The meander expands and then it is abandoned, causing a sideways migration throughout the channel's course. Therefore, the relation between the sideways migration, sedimentation, and erosion happens within the meanders band.

In Figure 6, formed by the schematic superposition of channel maps from the years 1985 (yellow), 1995 (red), 2005 (green) and the most recent channel, 2012 (blue), exemplifies the processes that happened on the analyzed meanders from Mamorecillo River. The differences observed in the river's channel show the different behavior during the study period. Highlighting that all these processes are common to the meandering dynamics and discuss the sedimentation process by lateral addition. These consist basically in the successive lateral accumulation of sediments - especially within the curve

of the meandering canal. This accumulation is justified by the continuous removal of sediments from the concave margin (erosion) and the deposition of these sediments in the convex margin, causing constant lateral migration of the channel (Christofoletti, 1981; Bigarella, 2003).

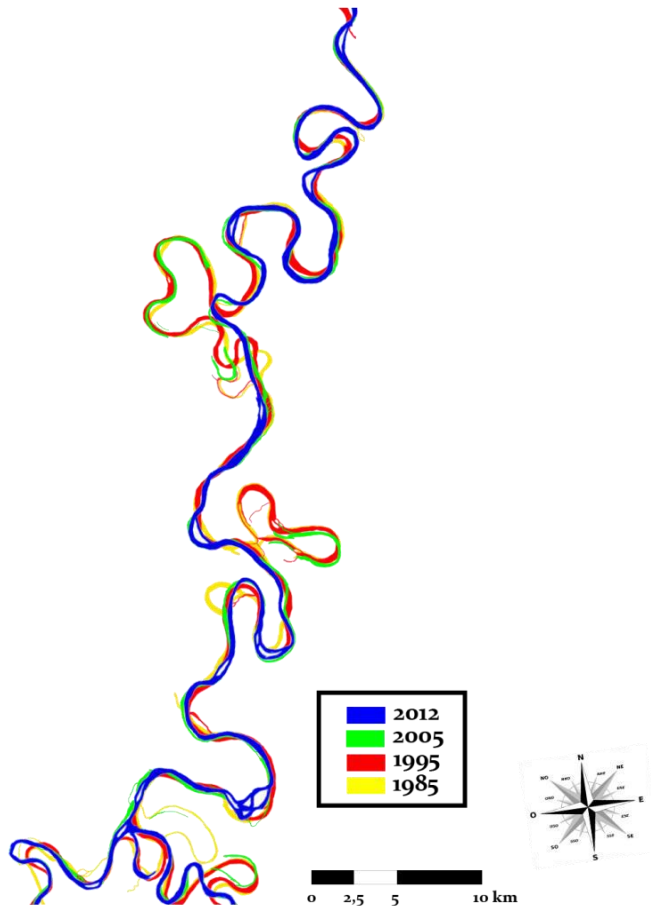


Fig.6: Schematic overlap of Mamorecillo river patch studied in the years of 1985, 1995, 2005 and 2012.

V. CONCLUSION

For this study, the use of tools applied to geoprocessing, Geographic Information System (GIS), proved to be extremely efficient in analyzing, understanding and describing the meander migration processes in the fraction of the studied Mamorecillo River.

The shape of the form from which the meanders appear, is directly related to the sedimentological processes that act on them, like the sediments contribution provided by the Chimoré and Ichilo rivers in the channel.

The endogenous processes or even exogenous factors that act on the section under study of the Mamorecillo River acted in order to make this part of the channel evolve to assume a more rectilinear form. These factors developed in such a way that the meandering form of the river was slightly minimized when compared to its initial state in 1985.

As part of a larger dynamic system, the Mamorecillo

River is influenced not only by autocyclical factors, but also by the Ichilo, Sacta and Chimoré rivers that comprise it. Characterized as a meandering stretch of the river, the hydrodynamics and hydrogeomorphology of its flow results in morphological processes characterized by a permanent erosion of its concave margin and greater deposition in margins where the point bars (the convex margins) are located.

The variation in the form and migration of the meanders in the studied section of the Mamorecillo River is related to natural processes of erosion, transport and deposition of sediments. Emphasis is given to some of these natural processes: the [inter] dependence of the sedimentological contribution and also, the energy flow of its forming rivers, namely: Chimoré and Ichilo. Climatic factors such as the rainy season, where the consequence is the period of the floods which is related to erosive processes causing new meanders to appear.

REFERENCES

- [1] Aalto, R., Maurice-Bourgoin, L., Dunne, T., Montgomery, D. R., Nitttrouer, C. A., And Guyot, J.-L.: Episodic sediment accumulation on Amazonian flood plains influenced by El Niño/Southern Oscillation, *Nature*, 425, 493–497, 2003.
- [2] Araújo, E. P. De; Teles, M. G. L.; Lago, W. J. S. (2009) Delimitação das bacias hidrográficas da Ilha do Maranhão a partir de dados SRTM. *Anais XIV Simpósio Brasileiro de Sensoriamento Remoto*, Natal, Brasil, 25 – 30 abril 2009, INPE, v. 1, pp. 4631 – 4638.
- [3] Bigarella, J.J. 2003. *Estrutura e origem das paisagens tropicais e subtropicais*. Florianópolis: Editora UFSC, 2003.
- [4] Brookes, A. River channel change. In: Petts, G; Calow, P. (Ed.). *River flows and channel forms*. Oxford: Blackwell Science, 1996. p. 221- 240.
- [5] Cândido, A. J. Contribuição ao estudo dos meandramentos fluviais. *Notícia Geomorfológica*, Campinas, v. 11, n. 22, p. 21-38, 1971.
- [6] Christofoletti, A. *Geomorfologia*. São Paulo: Hucitec, 1977.
- [7] Christofoletti, A. *Geomorfologia*. 2º Ed. São Paulo: Edgard Blüchler, 1980. 188p.
- [8] Constantine, J. A., Dunne, T., Ahmed, J., Legleiter, C., And Lazarus, E. D.: Sediment supply as a driver of river meandering and floodplain evolution in the Amazon Basin, *Nat. Geosci.*, 2014.
- [9] Do Nascimento Jr., D. R., Sawakuchi, A. O., Guedes, C. C. F., Giannini, P. C. F., Grohmann, C. H., Ferreira, M. P.: Provenance of sands from the confluence of the Amazon and Madeira rivers based

- on detrital heavy minerals and luminescence of quartz and feldspar, *Sediment. Geol.*, 316, 1–12.
- [10] Dunne, T., Mertes, L. A. K., Meade, R. H., Richey, J. E., And Forsberg, B. R.: Exchanges of sediment between the flood plain and channel of the Amazon River in Brazil, *Geol. Soc. Am. Bull.*, 110, 450–467, 1998.
- [11] Espinoza, J. C., Chavez, S., Ronchail, J., Junquas, C., Takahashi, K., Lavado, W.: Rainfall hotspots over the southern tropical Andes: Spatial distribution, rainfall intensity, and relations with large-scale atmospheric circulation, *Water Resour. Res.*, 51, 3459–3475, 2015.
- [12] Gilvear, D.; Winterbottom, S.; Sickingabula, H. Character of channel planform change and meander development: luangwa river, Zambia. *Earth Surface Processes and Landforms*, v. 25, p. 421-436, 2000
- [13] Goerl R. F. Kobiyama M. Dos Santos, I, Hidrogeomorfologia: princípios, conceitos, processos e aplicações *Revista Brasileira de Geomorfologia*, v.13, n.2, p.103-111, 2012.
- [14] Gregory, D. I.; Schumm, S. A. The effect of active tectonics on alluvial river morphology. In: RICHARDS, K. (ed.) *River channel: environment and process*. Oxford: B. Blackwell, Cap. 3, p. 41- 68, 1987.
- [15] Hack, J. T. Stream-profile analysis and stream-gradient index. *Journal of Research of the United States Geological Survey*, v. 1, n. 4, p. 421-429, 1973.
- [16] Hanagarth, W.: *Acerca de la geoeología de las sabanas del Beni en el noreste de Bolivia*, Instituto de ecología, La Paz, 1993.
- [17] Hickin, E. J.; Nanson, G. C. The character of channel migration on the Beatton River, northeast British Columbia, Canada. *The Geological Society of America Bulletin*, v. 86, n. 4, p. 487-494, 1975.
- [18] Kiss, T.; Blanka, V. River channel response to climate-and human-induced hydrological changes: case study on the meandering Hernád River, Hungary. *Geomorphology*, v. 175-176, p. 115-125, 2012.
- [19] Latrubesse, E. M., Amsler, M. L., De Moraes, R. P., And Aquino, S.: The geomorphologic response of a large pristine alluvial river to tremendous deforestation in the South American tropics: The case of the Araguaia River, *Geomorphology*, 113, 239–252, 2009
- [20] Lombardo, U., May, J.-H., And Veit, H.: Mid- to late-Holocene fluvial activity behind pre-Columbian social complexity in the southwestern Amazon basin, *The Holocene*, 22, 1035–1045, 2012.
- [21] Lombardo, U.: Neotectonics, flooding patterns and landscape evolution in southern Amazonia, *Earth Surf. Dynam.*, 2, 493–511, 2014.
- [22] Micheli, E. R.; Larsen, E. W. River channel cutoff dynamics, Sacramento River, California, USA. *River Res. and Applic.*, v. 27, p. 328-344, 2011.
- [23] Ouchi, S. Response of alluvial rivers to slow active tectonic movement. *The Geological Society America Bulletin*, v. 96, p. 504-515, 1985.
- [24] Peixoto, J. M. A., Nelson, B. W., And Wittmann, F.: Spatial and temporal dynamics of river channel migration and vegetation in central Amazonian white-water floodplains by remotesensing techniques, *Remote Sens. Environ.*, 113, 2258–2266, 2009.
- [25] Plotzki, A., May, J. H., And Veit, H.: Past and recent fluvial dynamics in the Beni lowlands, NE Bolivia, *Geographica Helvetica*, 66, 164–172, 2011.
- [26] Plotzki, A., May, J. H., Preusser, F., Roesti, B., Denier, S., Lombardo, U., And Veit, H.: Geomorphology and evolution of the late Pleistocene to Holocene fluvial system in the south-eastern Llanos de Moxos, Bolivian Amazon, *Catena*, 127, 102–115, 2015.
- [27] Riccomini, C.; Giannini, P. C.; Mancini, F. 2000. Rios e processos aluviais. In: *Decifrando a Terra*. São Paulo. p. 191-210.
- [28] Salo, J., Kalliola, R., Hakkinen, I., Mäkinen, Y., Niemela, P., Puhakka, M., And Coley, P. D.: River dynamics and the diversity of Amazon lowland forest, *Nature*, 322, 254–258, 1986.
- [29] Schöngart, J. And Junk, W. J.: Forecasting the flood-pulse in Central Amazonia by ENSO-indices, *J. Hydrol.*, 335, 124–132, 2007.
- [30] Zaconpé, M. H. C.; Peres Filho, A.; Capri Jr, S. Anomalias do perfil longitudinal e migração dos meandros do rio Mogi Guaçu. *Revista Brasileira de Geomorfologia*, v. 10, p. 31-42, 2009.
- [31] Wittmann, H., Von Blanckenburg, F., Guyot, J. L., Maurice, L., And Kubik, P. W.: From source to sink: Preserving the cosmogenic ¹⁰Be-derived denudation rate signal of the Bolivian Andes in sediment of the Beni and Mamoré foreland basins, *Earth Planet. Sc. Lett.*, 288, 463–474, 2009.
- [32] Wittmann, H., Von Blanckenburg, F., Maurice, L., Guyot, J. L., Filizola, N., And Kubik, P. W., Sediment production and delivery in the Amazon River basin quantified by in situ-produced cosmogenic nuclides and recent river loads. *Geological Society of America - GSA Bulletin*; May/June 2011; v. 123; no. 5/6; p. 934–950; doi: 10.1130/B30317.1001-005.