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ROLE OF VEGETATION INDUCING SEDIMENTATION IN AN ARTIFICIAL EARTH CHANNEL

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Abstract

The biogeomorphic role of vegetation has been explored in different contexts with advances in the understanding of sedimentation and hydrodynamic changes in channels and riparian zones. However, it is yet to be better established regarding their role in small earth-derived canals water gullies, the development of these issues, and canal users. These cases present some ambiguity based on the presence of vegetation with both a positive filtering role and a negative role due to competition for water resources. This study verified whether vegetation development has more prominent role as reducer of the transport of suspended sediments along the artificial channel than the natural river system, focusing on the role of vegetation as a filter of the sedimentary load. We monitored the scenario in terms of vegetation growth by gathering statistically related data on discharge, flow velocity, and turbidity. Our results indicate the main influence of the natural channel flow since the vegetation was the main element of the artificial system. The vegetation, functioning as a sediment filter in the rainy season, is removed in the dry season due to lower flows and evapotranspiration. We understand that vegetation should be addressed as part of the channel management process, providing users with favorable turbidity indices and lower risks of structures breaking, as well as the formation of extenders of fluvial and riparian habitats in the rainy season.

Keywords: Biogeomorphic Succession; Anthropogeomorphology; Artificial Open Channels; Sedimentation; Hydrogeomorphology.

Resumo / Resumen

PAPEL DA VEGETAÇÃO COMO INDUTOR A SEDIMENTAÇÃO EM CANAL ARTIFICIAL DE TERRA

O papel biogeomórfico da vegetação tem sido explorado em diferentes contextos com avanços na compreensão da sedimentação e das alterações hidrodinâmicas nos canais e zonas ripárias. Contudo, não estão bem estabelecidas em pequenos canais derivados de terra, os regos d'água, como se desenvolvem estas questões e os usuários dos canais. Nesses casos se percebe uma ambiguidade frente a presença da vegetação com um papel tanto positivo de filtragem, quanto problemático pela competição pelo recurso hídrico. Este estudo verificou se o desenvolvimento da vegetação é o principal redutor do transporte de sedimentos em suspensão ao longo do canal artificial em comparação ao sistema fluvial natural, se atentando ao papel da vegetação como filtro da carga sedimentar. Foram realizados monitoramentos de cenários, conforme crescimento da vegetação, com dados da vazão, velocidade dos fluxos e turbidez sendo relacionados estatisticamente. Nos resultados o canal natural apresentou a vazão como principal influência, já a vegetação foi o principal elemento sobre o sistema artificial. A vegetação, funcionando como filtro de sedimentos na estação chuvosa, é retirada na estação seca devido à redução das vazões e a evapotranspiração. Entende-se que a vegetação precisa ser abordada como parte do processo de gestão dos canais, permitindo aos usuários índices favoráveis de turbidez e menores riscos de rompimento das estruturas, bem como a formação de extensores dos habitats fluviais e ripários na estação chuvosa.

Palavras-chave: Sucessão Biogeomórfica; Antropogeomorfologia; Canais Abertos Artificiais; Sedimentação; Hidrogemorfologia.

PAPEL DE LA VEGETACIÓN COMO INDUCTOR DE LA SEDIMENTACIÓN EN UN CAUCE ARTIFICIAL DE TIERRA

El papel biogeomórfico de la vegetación ha sido explorado en diferentes contextos con avances en la comprensión de la sedimentación y los cambios hidrodinámicos en canales y zonas ribereñas. Sin embargo, no están bien establecidos en pequeños canales derivados de la tierra, cárcavas de agua, cómo se desarrollan estos problemas y los usuarios del canal. En estos casos, se aprecia una ambigüedad en la presencia de vegetación tanto con un papel filtrante positivo como con un papel negativo debido a la competencia por los recursos hídricos. Este estudio verificó si el desarrollo de la vegetación es el principal reductor del transporte de sedimentos en suspensión a lo largo del cauce artificial en comparación con el sistema fluvial natural, prestando atención al papel de la vegetación como filtro de la carga sedimentaria. Se realizó un monitoreo de escenarios, de acuerdo al crecimiento de la vegetación, relacionando estadísticamente los datos de caudal, velocidad de caudal y turbidez. En los resultados, el cauce natural presentó el caudal como principal influencia, ya que la vegetación fue el elemento principal sobre el sistema artificial. La vegetación, que funciona como filtro de sedimentos en la época de lluvias, es removida en la época seca debido a la reducción de los caudales y la evapotranspiración. Se entiende que la vegetación debe ser atendida como parte del proceso de manejo del cauce, permitiendo a los usuarios índices de turbidez favorables y menores riesgos de rotura de estructuras, así como la formación de extensores de hábitats fluviales y ribereños en época de lluvias.

Palabras-clave: Palabras clave: Sucesión Biogeomórfica; Antropogeomorfología; Canales Abiertos Artificiales; Sedimentación; Hidrogeomorfología.

INTRODUCTION

Biogeomorphic succession is a process driven by the interrelation among flows, sedimentary load, and vegetation and is an important variable in the terrestrial model evolution, with repercussions in the fluvial channel and riparian zone (CORENBLIT, 2007; RODRIGUEZ-GONZALEZ et al, 2022), altering even the surface connectivity from the slope to the valley floor (HUPP, 1986; STEIGER; GURNELL, 2002; LEE; SHIH, 2004; GURNELL et al. 2012; CHENG ZHANG et al. 2022). Dawson et al (2022) consider that vegetation plays a role in river channels in the river engineering, even though these are regarded as feedback relationships, that is, matters emerging from changes in the shapes of channels and their dynamics, as proposed by Lelpi et al (2022). Tánago et al (2021) corroborate it by pointing out that vegetation exerts control over the fluvial dynamics, also repercussing on the shapes of the channels and their surroundings, based on their resistance to flow, formation of deposits, and alteration of flows.

Inside the gutters and marginal strips, vegetation is also influenced by the runoff. According to the predictive modeling by Merritt et al (2009), , human action in changing the flow rates also reflects on the behavior of the associated vegetation. Given their significance, still regarding the processes in the gutters, the theme has also been investigated in the context of natural channels with natural succession (GURNEL ET AL, 2006; NEPF; GHISALBERTI, 2008; STOFFEL; WILFORD, 2011; CURRAN; HESSION, 2013; HUAI, 2021). Therefore, studies have addressed environments with anthropic control (ADITYA et al, 2010; CHESTER; ROBSON, 2013), artificial channels (SABBATINIA et al, 1998; SILVA, 2018; ERRICO et al, 2020), and laboratory research for simulating vegetation in test channels (ROMDHANE, et al 2018; LI et al, 2022).

Several studies have focused precisely on the role of vegetation as a sediment trap, such as Noe and Hupp (2009), D'Ippolito et al (2021), and Henriques et al (2021), who address such a retention of both nutrients and particles. As computational techniques advanced, some other studies have involved simulations based on data obtained from real channels (PARHI et al, 2012; LI et al 2022) or modeling in digitally designed channels (ISLAM et al, 2008; VARGAS-LUNA et al, 2015; TANG et al, 2014). Nonetheless, Ferreira et al (2021) suggest that it is challenging to reconcile methods aimed at channel modeling, given the information necessary for calibration.

In terms of processes developed by the vegetation, input data are complex and encompass the growth of stems, stalks, and leaves, thus implying obstacles associated with a greater efficiency retaining particulate matter in suspension (SHARP; JAMES, 2006; YANG et al, 2021). These issues need to be faced in the most diverse geomorphological, climatic, and anthropic contexts. For example, Huang and Nanson (1997), Pu et al (2021), and Zhu et al (2022) indicated that dense and rigid marginal formations contribute to narrow channels and concentrated flows, whereas flexible vegetation inside channels promotes the widening of the gutters.

In general, vegetation promotes lower flow velocity and its turbulence, enhancing the accommodation of particles (AFZALIMEHR et al, 2011; SOLER et al, 2021; GIACOMAZZO et al, 2022), as well as changes in shear (GHISALBERTI; NEPF, 2004; HUAI, et al, 2012; LI et al, 2014; ZHANG et al 2021). This same biomass protects banks and beds, leading to a lesser potential for the remobilization of particles, even reflecting on the development of erosion forms in sequent areas and on the evolution of channels (YEN, 2002; LELPI et al 2022).

However, in anthropic environments, vegetation will act in two manners. In a given scenario, the propagation of the plant mass interrupting the flow, especially in irrigation channels, thus needing to be removed to reestablish the service (CHAYKA et al, 2020). However, in some transposition systems, sedimentary deposition is advantageous providing the vegetation with the burden of reducing these particles (BIGGS et al, 2021; LAMA et al, 2021; ONWUKA et al, 2021), affecting parameters such as turbidity (SOLER et al, 2021), in addition to the ecological issue (CHESTER; ROBSON, 2013; MAGELLAN et al, 2021).

Considering the diversity of processes and the approaches presented, the control of sedimentation by vegetative growth should be better understood. Once associated with natural courses and slopes, these channels create an artificial and controlled biogeomorphic succession by their users, who define the time to remove the biomass as they balance the demand for the water resource (flow) and its apparent quality (turbidity). Tsujimoto (1999) and Ciotti et al (2021) point out that it is fundamental to manage vegetation when it affects river dynamics, with influences that can be either positive or negative, especially concerning human actions.

Thus, it is worth mentioning that studies on vegetation and sedimentation have commonly addressed natural channels, laboratories, and virtual simulations (as seen in D'Iappolito et al 2022). This is an opportunity to observe an artificial channel on a half-slope with controlled inflow but subordinated to seasonal variations in sediment load and vegetative development. Once clarified, these aspects will contribute to improve the management of these channels, especially to understand how their users can optimize maintenance, availability, and quality of water resources. In this sense, this work verified whether the growth of invasive and aquatic vegetation is the main driver in the reduction of particle transport along the artificial gutter in small earth channels. These small artificial channels are present throughout the world and are common in drainage headwaters. Thereby, despite being constantly neglected in academic and water management approaches, they should be more widely investigated (SILVA, 2018; RODRIGUES; SILVA, 2020).

Our study corresponds to an eight-month timeframe, when the vegetation prevailed in the wet section until the cutting, when the dry season was established and the sediment load transport was reduced. The processes monitored offer some important answers about the relationship among vegetation, artificial channels, and their users in the context of climatic seasonality. Such a knowledge might help rural extension by guiding the management processes of these channels and improving their concerning legislation.

The centuries-old relationship among channel users, responsible for maintaining or removing vegetation, has built a controlled environment represented by the artificial channel and the flow system; however, with natural elements such as the transport of sediments from the natural channel and vegetation growth. This scenario offers a unique opportunity to expand the knowledge of real systems and make them available for further comparisons with fully controlled laboratory or virtual environments, like simulations and modeling.

METHODS

STUDY AREA AND FLOW SYSTEM

The Taquara stream (area of 18 km²) is the basin in study. It is a third-order channel in the municipality of Patrocínio/MG, Southeastern Brazil, and has been investigated regarding its climatological, geological, pedological, geomorphological, water aspects, in addition to occupation (CASSETI, 1971; MACHADO, 2001; GRASSO, 2010; SILVA; ALLAN SILVA, 2012; SILVA, 2018). On that basis, the verticalization of discussions on anthropic and hydro geomorphological processes are favored.

The smooth relief formed by river terraces allows human intervention by opening artificial channels along the half slope. The semi-humid tropical climate, with two well-defined seasons, contributes to a marked change in the landscape linked to the variation in water availability, both in the soil and in the channels. the soil of the slopes are rich in sandy materials, with modern and traditional agriculture sharing space with pastures and forestry, thus enhancing the remobilization of sediments.

The flow system chosen represents the types of projects formed by transposition dams, marginal dikes, and continuous flows, in addition to the water use profiles. In this context, the marginal occupation and maintenance of the channels by the vegetation users advance. All monitoring sites were defined from three sections in the natural channel and three in the artificial channel (Figure 1).

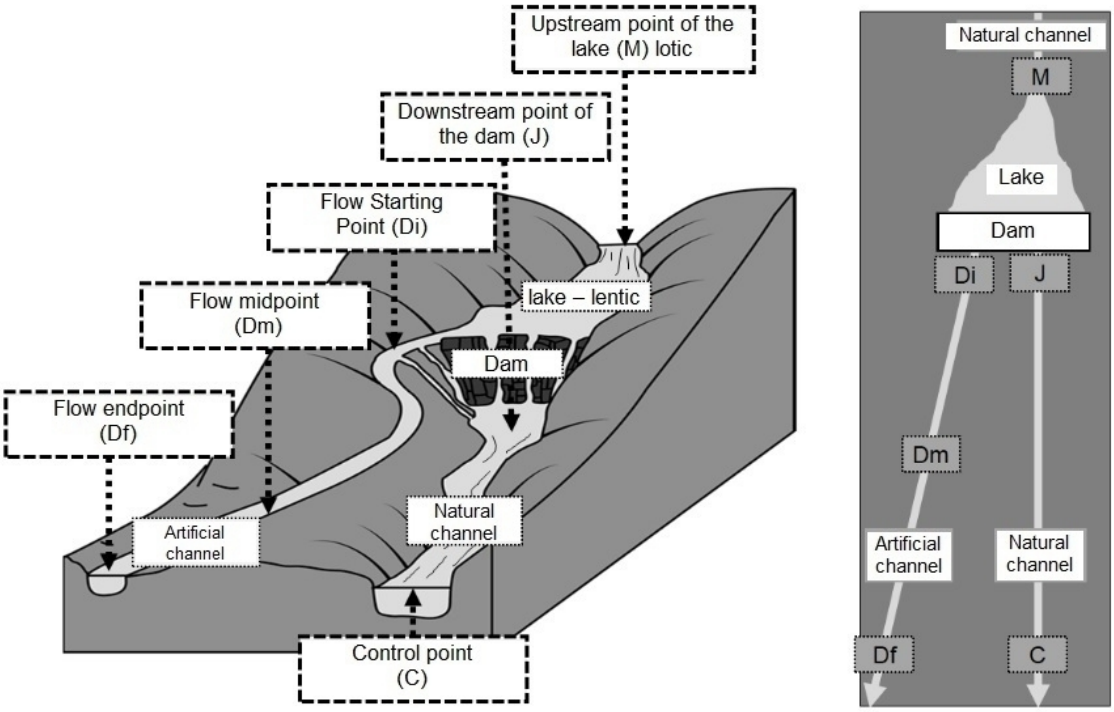


Figure 1 - Monitoring sites of flow systems with cross-sectionals in both natural and artificial channels. Where: M – is point 1 in the natural channel, upstream side dam; J – point 2 in the natural channel, downstream side dam; C – point 3 in the natural channel following point 2; Di – point 1 in the artificial channel at the beginning of the streaming; Dm – point 2 in the artificial channel; Df – point 3 at the end of the artificial channel. Source: Silva, 2018.

PLUVIOMETRY

We carried out the rainfall monitoring by installing three rain gauges as proposed by the National Water Agency (ANA – *Agência Nacional das Águas*, 2011), with daily collection of precipitated heights. Considering the low variation of the data obtained, the values refer to the closest rain gauge upstream the beginning of the flow system. We obtained the historical series (from 1985 to 2015) for comparing with the hydrological year from the ANA, at the *Charqueada do Patrocínio* pluviometry station, 3,000 meters away from the study area. The consistent information is available through the HIDROWEB, a management system for monitoring data on Brazilian water resources.

DEFINITION OF SCENARIOS AND PROVISIONAL INSTRUMENTATION

We performed eight monthly monitoring sessions between October 2015 – the beginning of the rainy season – and May 2016, when the dry season was established, and the first vegetation was removed from the artificial channel. Based on Lord et al (2009), we chose the provisional instrumentation for a rapid data collection under different approaches, which allows characterizing the hydro geomorphological scenarios, further described in the subsequent items.

CROSS-SECTIONAL SHAPE

The shapes of the cross-sectionals were designed to understand the changes driven by natural processes (erosion, sedimentation, vegetation development) in the channels over time, as well as anthropic processes (removal of materials and management of flow volume). We collected the channel data on width, length, and depth by taking measurements every 10 cm, based on the rectangular shape of the artificial channels, with 1 meter wide and 50 cm deep on average. We also considered the marginal strips of the channels and recorded the shapes and measurements of the anthropic dikes.

MONITORING OF VEGETATION PROPAGATION

We obtained the percentage of vegetation occupation in the channels (fluvial vegetation mosaic) based on Gurnell et al (2012). Using a graduated bar, we defined the areas with and without vegetation according to the same sections used to measure the velocities(Figure y). Subsequently, the vegetated area was subtracted from the total area of the channel (equation 2):

(2) $At - Av = Af$

Where: At – total cross-sectional area; Av – area of the section occupied by stems, roots, and leaves, and Af – the area of free flow of vegetation.

The values are given in square meters, where $Af = 0$ is the water circulating in the middle of the dense vegetation mass. At this stage, we used an underwater recording camera to find the main plant species inside the channels to identify potentially unseen species on the surface and sedimentary deposition in plant structures (Figure 2).

FLOW VELOCITY

Flow velocity allowed us to obtain the flow rate and study the hydraulic behavior of the vegetation growth inside the channel. Velocity data in m/s were measured with a pluviometry micro-mill (Global Water BC 1200 – graduated rod).Velocity was collected every 10 cm in up to three depths to obtain the flow rate. The flow was calculated based on the mean values (Equation 1). As for the velocity in the context of vegetation propagation, according to Figure 2 and based on Sand-Jensen (2008), we performed meter insertions in areas both vegetated and obstacle-free. In this latter case, the channel was sectioned with sampling sections 20 centimeters apart and the velocity of each section probed every 10 centimeters horizontally and up to three levels vertically.

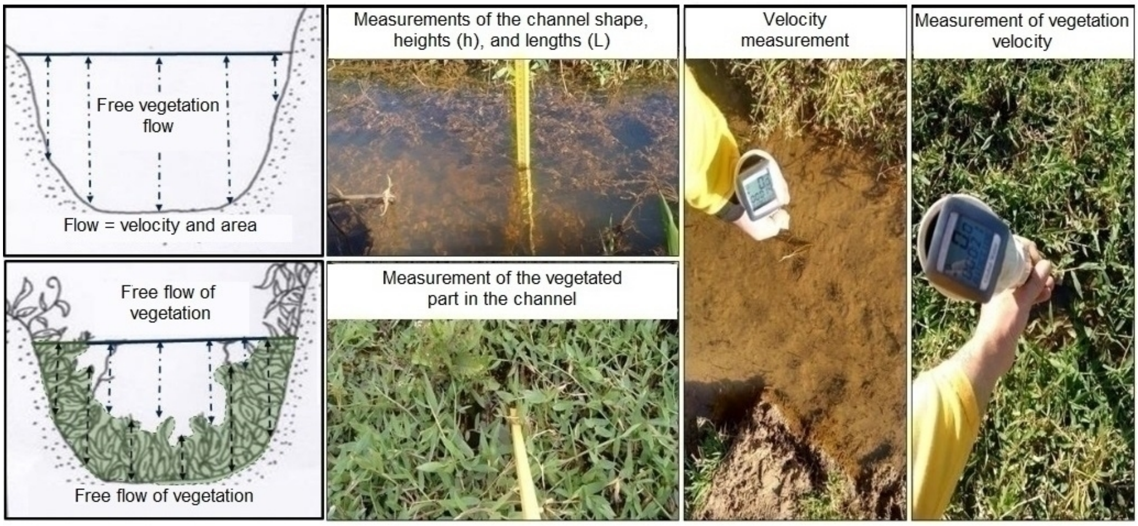


Figure 2 - Monitoring of the vegetation progress in the channel and the flow velocity in the middle of the free and vegetated channels. The presence of vegetation does not mean that the water has stopped circulating, but that the flow dynamics now operate influenced by obstacles such as stems and leaves.
Source: Silva, 2018

FLOW RATE

We obtained the flow rate based on the flow velocities at the ford obtained from the records via operator with provisional instrumentation (CETESB, 2011). The values were associated with the cross-sectional area, providing the amount of water in displacement at each unit of time (Equation 1).

(1) $Q = V \times A$

Where: Q is the flow rate (m^3/s), V is the velocity (m/s), and A is the wetted section area (m^2). Smaller channels like those in this study had their flow rates converted to liters per second (l/s).

TURBIDITY

Turbidity is the lesser transparency of an aqueous sample, expressed by the presence of suspended particles in the water column. It is measured through nephelometry (N.T.U), an indirect method that determines the intensity of light incident at a 90º angle (CETESB, 2011). The collections were always carried out in triplicates, according to Carvalho (2008). We performed the sampling vertically in the water column to be analyzed by the Alfakit 2000 turbidimeter, which allows defining the number of particles that interfere with the passage of light in the sample.

RESULTS

We introduce the monitoring in both the natural and artificial channels, for flow, flow velocity, presence of vegetation, and turbidity, within a timeframe without removing the vegetation from the artificial segment. The hydrological year analyzed followed the trend of the historical average (Figure 3a), an important issue distinguishing the behavior of users in the face of vegetation growth and hydro-sedimentary dynamics.

The greatest seasonal variation in the flow rate occurred in the stretches of the natural channel (Figure 3b), from over 800 l/s to the highest and lowest records. This channel showed an average gain of 33% in the water volume, throughout a stretch of 1700 meters, from the downstream of the dam (p2) to the control site (p3). In turn, the flow variation in the artificial channel did not exceed 185 l/s; there was a reduction, not an increase, in the flow rate of 89%, from its initial site to the selected landmark, 1655 meters away. The records of propagation speed for the flows inside the analyzed gutters varied more frequently and more widely in the natural cross-sectionals, with an average of 2.35 m/s and a peak of 3.1 m/s, while the artificial channel had an average of 0.59 m/s, with only one record above 1 m/s (Figure 3c).

As for materials suspended in the water column, considering the turbidity in both the natural channel and the beginning of the artificial channel, the distance between the mean and the maximum, and minimum values is short (Figure 3d). The middle segment of the artificial channel varied very little, with very low turbidity values close to the average. The turbidity values at the end of the artificial channel showed a great variation, a peak that differed from the other values found.

The natural sections were not completely covered by the vegetation (Figure 4a), with maximum values of 50% of vegetation occupation and an average of 24%. The scenarios observed in the dry season showed little interaction between flow and plant stems. The artificial channel, Figure 4b, shows a different condition, with the generation of 100% vegetated stretches, with stems, roots, and leaves permeating the flows. The final segment was characterized by rapid and intense vegetation occupations, followed by sudden reductions in these percentages due to the users cleaning the channel.

Among the plant species found in areas exposed to the sun (Figure 5), grasses predominate (highlighting the invasive species *Urochloa*), with some resistance from native species, such as water pine (*Myriophyllum aquatcum*) and leather hat (*Hydrocotile*). Native pteridophytes were observed in the shaded and mixed areas, such as ferns and maidenhair ferns, in addition to invasive species like São José lilies (*Hedychium coronarium*), taioba (genus *Xanthosoma*), and yam (*genus Dioscorea*). It is worth emphasizing that this vegetation was a refuge in the rainy season for both aquatic and terrestrial species, encompassing fish, amphibians, reptiles, mammals, and birds.

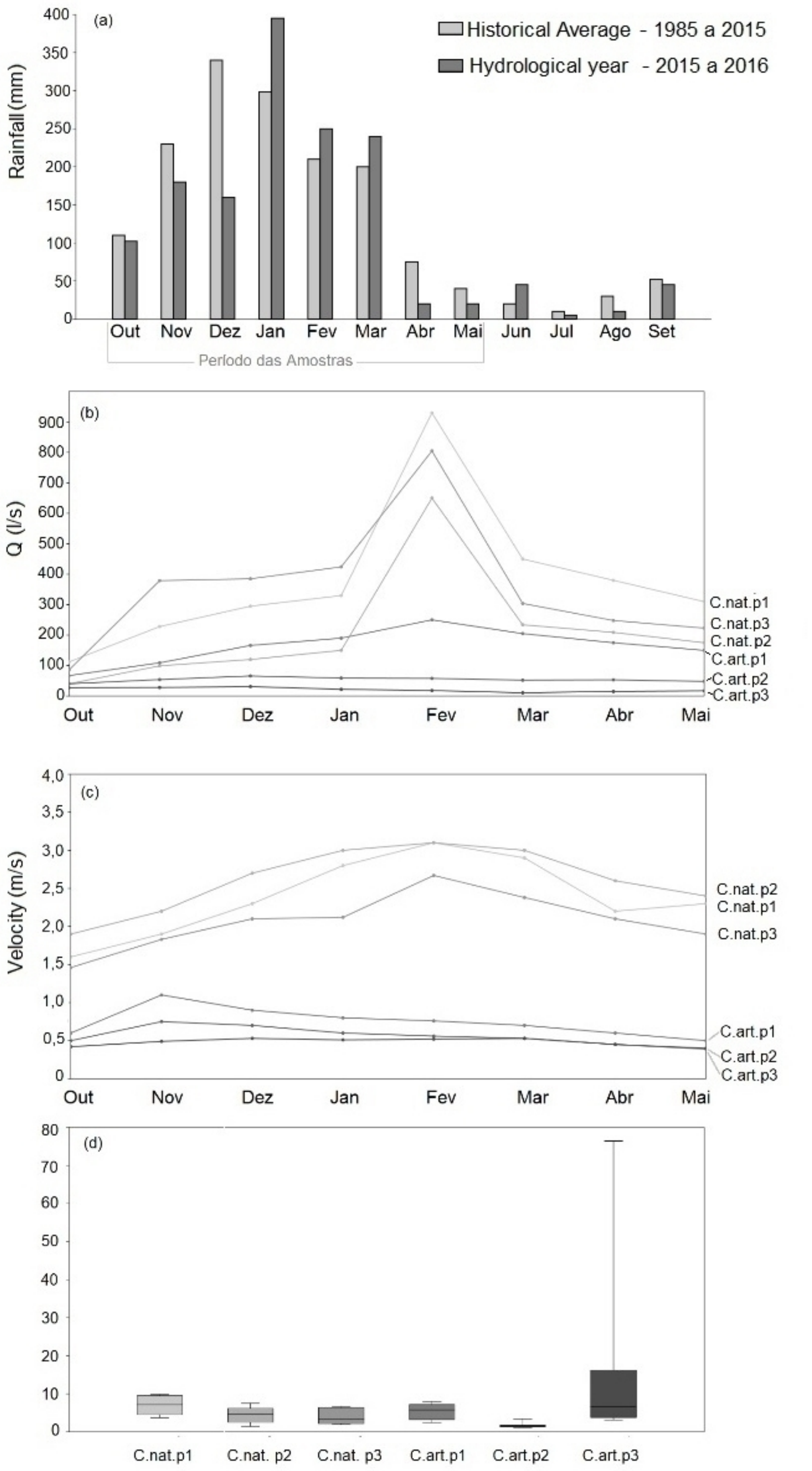


Figure 3 – (a) average rainfall between 1985-2015 and the hydrological year 2015/2016; (b) flow rates in the scenarios surveyed between October 2015 and May 2016 for three sites in the natural channel (p1 – before the transposition, p2 after the transposition, and p3 is a control site 1700 meters away from the transposition) and three sites in the artificial channel (p1 at the beginning of the flow, p2 870 meters from the beginning, and p3 at 1655 meters from the beginning of the flow); (c) average speed in the sections considered both in the artificial and natural channel; (d) box plot for turbidity at the same sampling points for flow rates.

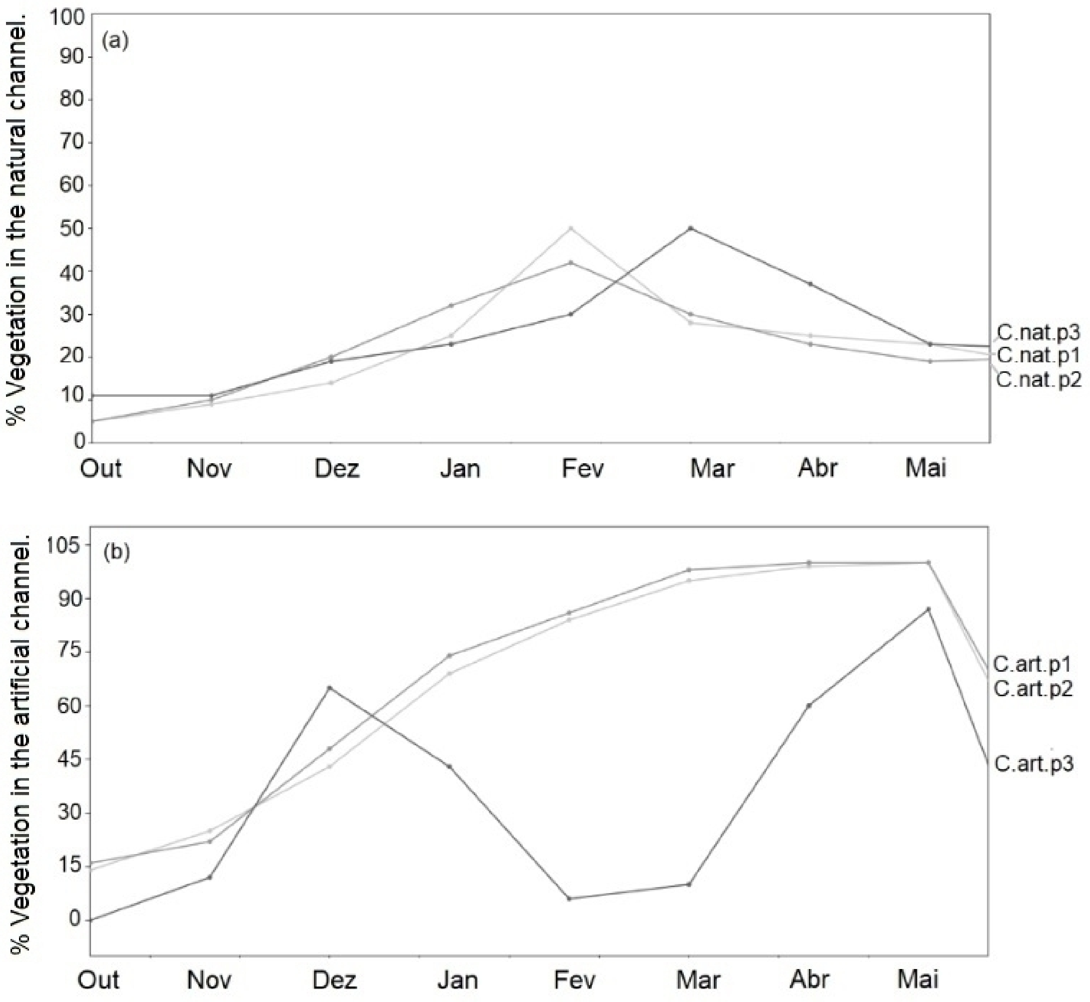


Figure 4 – Evolution of vegetation growth with a percentage taken from the natural channel (a) in sections p1, p2, and p3, and the (b) artificial channel for p1, p2, and p3 by the stems, leaves, and roots of the vegetation

We selected a segment of 870 meters from the total length of the artificial channel, average widths and depths of 90 and 50 cm, respectively, to show the progression of the vegetation inside it (Figure 6). There was an intense vegetation development in the studied scenarios, reaching 100% of the area in five months. Meanwhile, the percentage of turbidity reduction from the beginning to the end of the segment increased over the months, even in periods of higher turbidity values in the bottom of the valley (natural channel). The spatialization of the free flow velocity data amid vegetation shows a lower velocity from the vegetation progression (Figure 7), with a decrease in the areas with free and laminar flow, favoring sectors with turbulent characteristics provided by the vegetable mass.

Still in this segment, although the inflow and flow velocities varied very little, the vegetation growth data varied considerably, which also occurred in the lower turbidity percentage between the two control sections of the artificial channel (Table 1). However, the most significant value of the standard deviation, which indicates a greater data dispersion and weakens the representativeness of the average, occurred in the varying percentage of turbidity reduction.

Figure 5 – (a) artificial channel covered by grass, leather hat, and water pine; (b) morphology of the leather cap with long, flexible stems and emerged leaves; (c) grass morphology with rigid stems and flexible leaves; (d) stretch occupied by yam creating a shading area, with only the rigid and punctual stems interacting with the flows; (e) example of the channel almost completely covered by vegetation, mainly grasses; (f) top view of the artificial channel with stems and leaves retaining sedimentary particles; (g) underwater recording of leaves and stems with particle accommodation on their surfaces.

We performed an analysis of the magnitude of the coefficients (Table 2) to identify potential equivalent or similar behaviors between the surveyed variables. The results showed that the flow velocity inside the artificial channel was negatively correlated with vegetation (-0.609). The analysis between velocity and flow rate revealed a modern positive correlation (0.593). The lower turbidity shows its positive correlation with flow rate (weak correlation) and a strong effect of vegetation (0.895). The flow rate was little correlated with vegetation, with the lowest value, (0.161); in addition, the correlation between flow velocity and turbidity reduction also proved insignificant (-0.251)

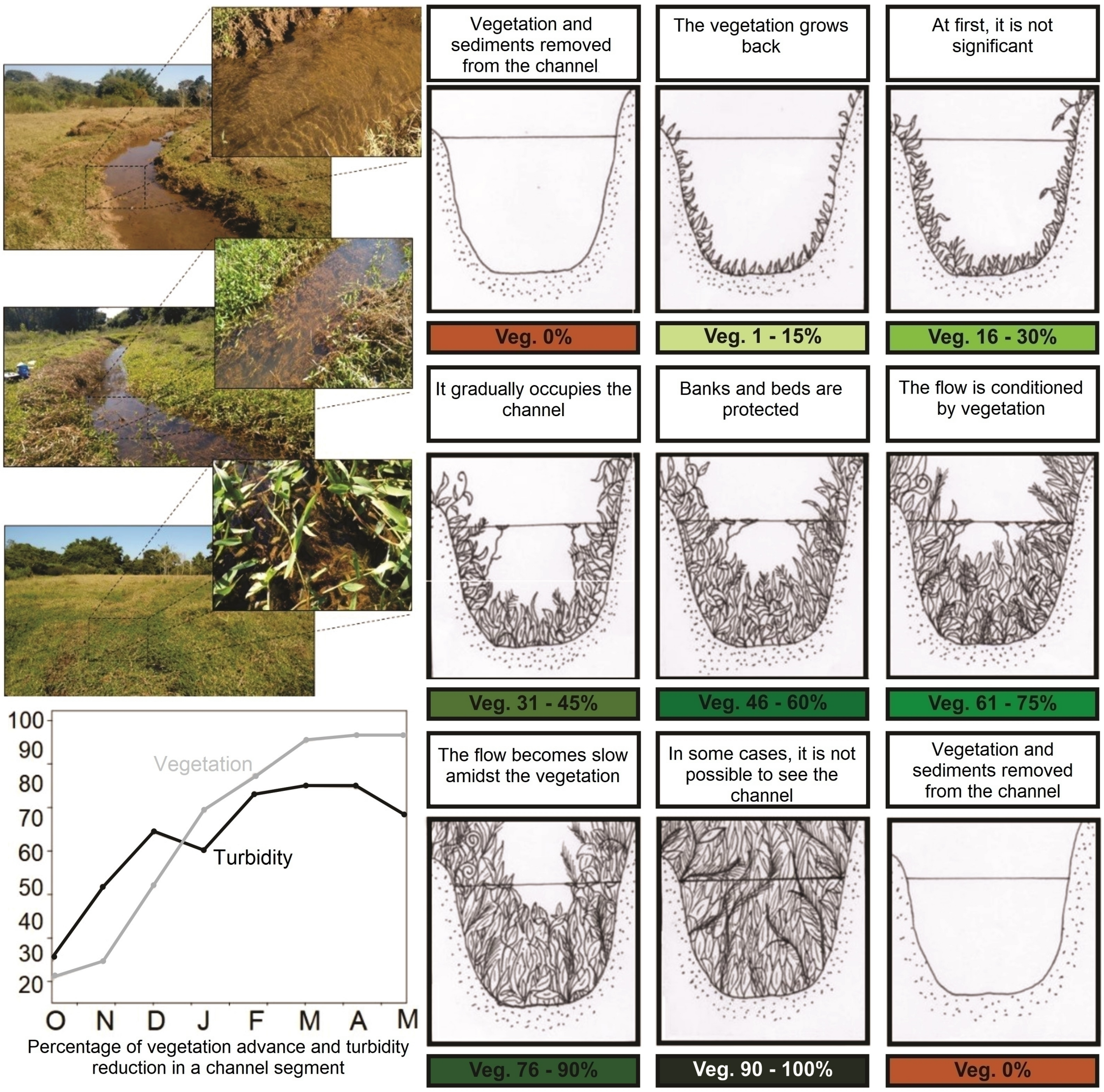


Figure 6 – Behavior of vegetation, mainly grasses, in the channel intake in 8 scenarios observed between October 2015 and May 2016, including the graph of percentages of vegetation progression within the channel and turbidity reduction between the two ends of the considered segment.

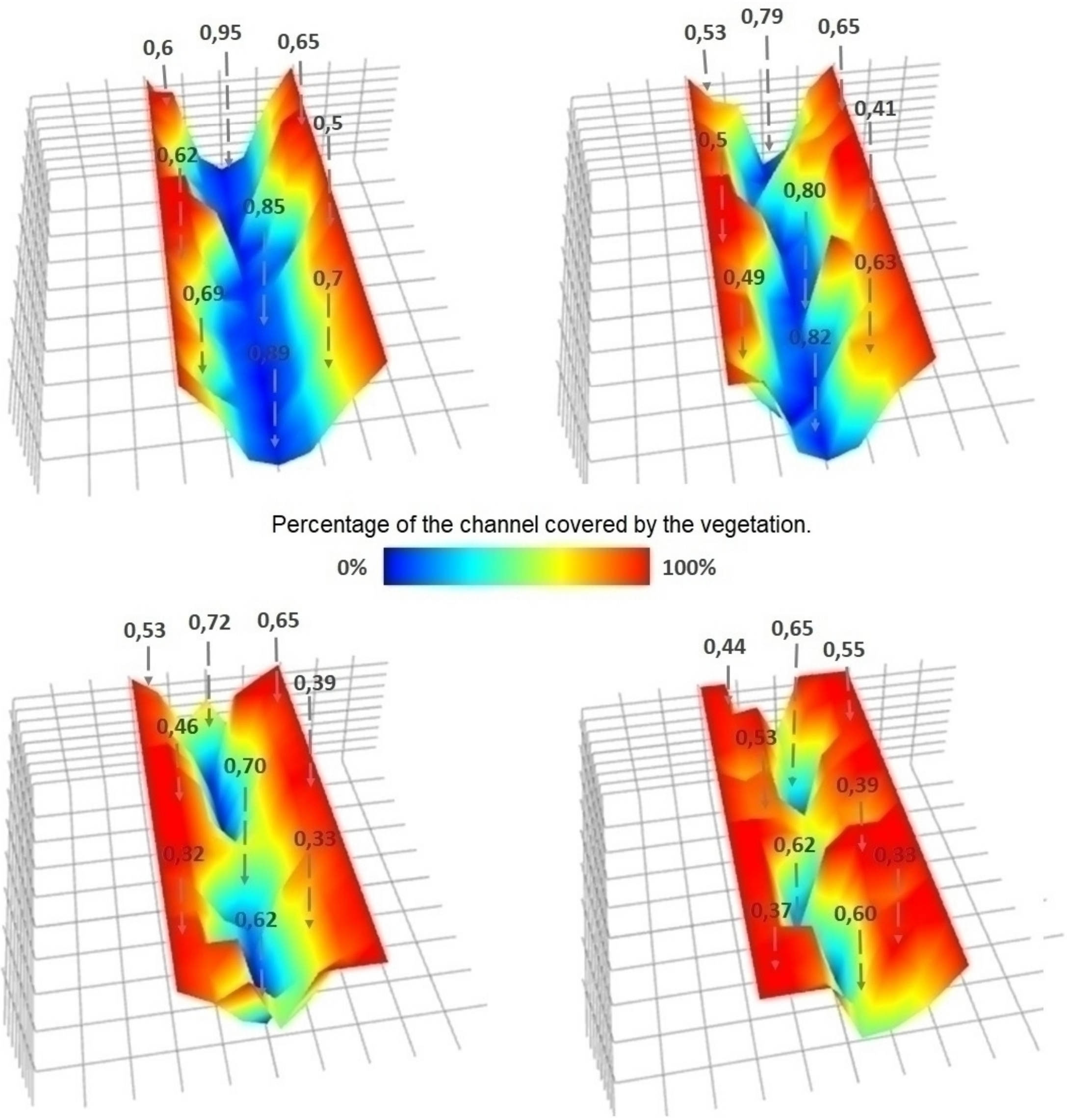
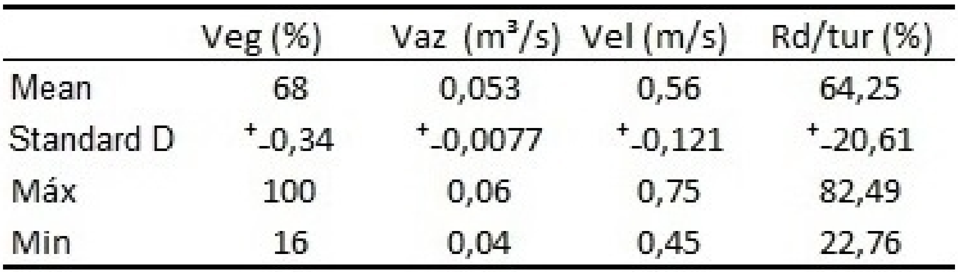


Figure 7 – Distribution of average flow velocities in the artificial channel, indicated by the values associated with the arrows, based on the percentage of vegetation occupation within the artificial channel, expressed by color variations, in four scenarios carried out every 60 days. As the vegetation advances over the channel, the flow velocity is reduced by the change from laminar to turbulent.



	Veg (%)	Vaz (m³/s)	Vel (m/s)	Rd/tur (%)
Mean	68	0,053	0,56	64,25
Standard D	±0,34	±0,0077	±0,121	±20,61
Máx	100	0,06	0,75	82,49
Min	16	0,04	0,45	22,76

Table 1 – Mean, standard deviation, maximum and minimum values of vegetation (Veg), flow rate (Vaz), flow velocity (Vel), percentage, and percentage of turbidity reduction (Rd/tur) from the beginning to end of the segment.

	Veg	Vaz	Vel	Rd/ tur
Veg	1			
Vaz	0,1613983	1		
Vel	-0,6092792	0,5939931	1	
Rd/Tur	0,8952989	0,488254	-0,2517274	1

Table 2 – Correlation matrix between the parameters of vegetation (Veg), flow rate (Vaz), velocity (Vel), and percentage (Rd/tur) of turbidity reduction in the segment

We performed a multiple linear regression (Figure 8) considering that the turbidity variable would be most influenced by the other components, , which generated a high coefficient of determination (R^2=0.9407). Such a result indicates that the variation in y (turbidity reduction) might be strongly attributed to the varying x-axis (vegetation, velocity, and flow rate).

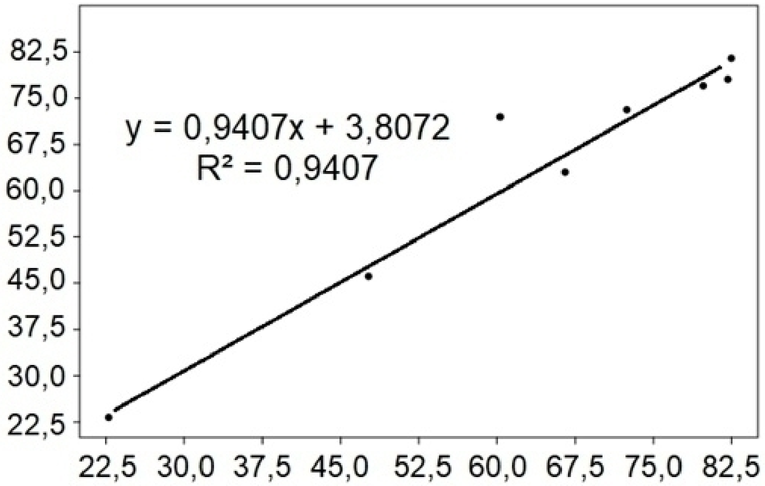


Figure 8 – Multivariate regression where the dependent variable Y is the turbidity reduction along the artificial channel and the independent variables x are vegetation, discharge, and flow velocity.

Knowing the behavior of the vegetated segment in the artificial gutter allowed us to plot the stretches in both the natural and artificial channels, generating an exploratory graph showing both attributes and samples (Figure 9). The bi-plot shows that vegetation is fundamental to analyze the behavior found in the artificial channel, mainly in the initial and middle sites, with the third site more associated with turbidity. In contrast, both the flow rate and flow velocity are more associated with the stretches of the natural channel and its dynamics between rapids and wells.

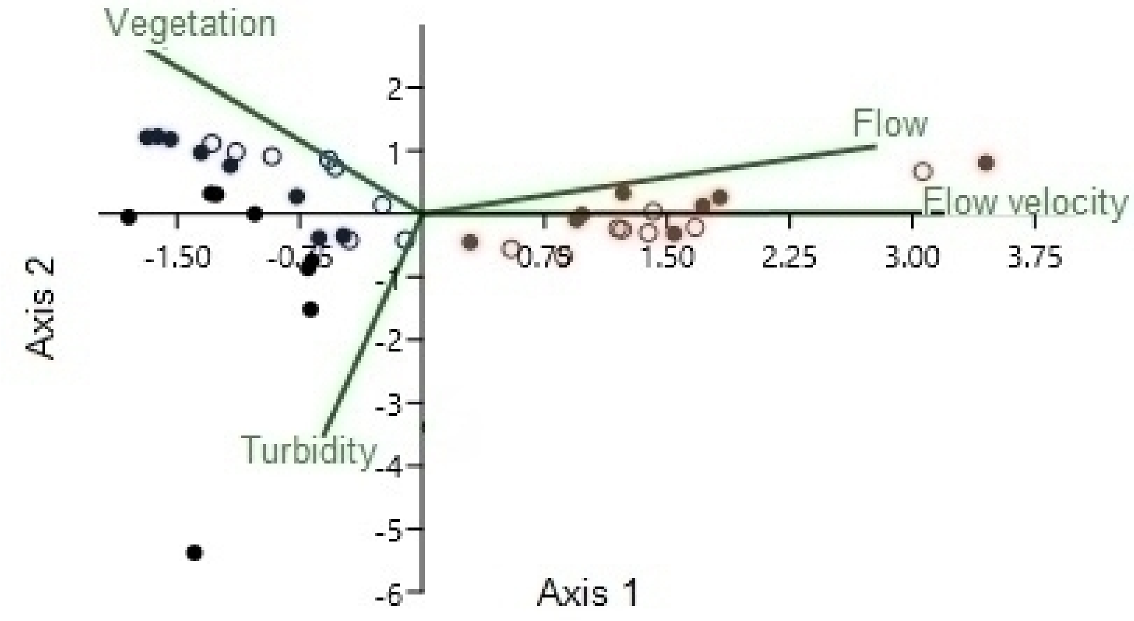


Figure 9 – PCA bi-plots illustrating the distribution of cross-sectionals in natural canals (section before the shunt with red circle, control section with red dot) and artificial (initial section with blue circle, middle section with blue dot and final section with blue dot). black) against four measured variables (turbidity, vegetation, flow velocity, and discharge) for each of the eight sampling periods.

DISCUSSION

The analysis of the hydro geomorphological scenarios corroborates the hypothesis that vegetation growth is central to the retention of suspended particles in artificial earth channels. Therefore, it should be investigated for their correct maintenance; however, we should also consider the rainfall scenario (figure 2a) since climatic seasonality influences drainage (figure 2b). For example, at the late dry season, the soil is more exposed to erosion processes. According to Zhu et al (2018), soils with less vegetation cover generate greater runoff and provide a greater volume of materials. Castro et al (2012) also pointed out such an issue when studying areas under semi-humid climate, like in our studied basin. The authors point out that vegetation recovery is fundamental to attenuate surface flows and accommodate materials.

According to Silva (2018), in this basin, the resumption of vegetation, crops and pastures at the early rainy season gradually retains sediments, impacting, for example, turbidity (3d). Thus, the transition between dry and wet periods is marked by the remobilization of materials that start to interact with local topographic signatures (TAROLLI; SOFIA, 2016), like in roads, retention wells, and artificial channels. According to Croke and Moclker (2001) and Roy (2022), elements dispersed in the environments might facilitate or hinder surface hydrological connectivity. In this sense, the vegetation and structures explored herein are valid examples of such (dis)connectivity. In contrast, in some stretches of the natural channel, tree vegetation was replaced by pasture, thus intensifying connectivity and promoting higher flows, as indicated for February in Figure 3b. Gurnell et al (2012), Corenblit et al (2014), and Politti et al (2018) also pointed out that rivers are strongly conditioned by the presence of vegetation mediating and ruling processes related to flow rates and sediment transport, which are related to the evolution of the shapes of the channels and the fluvial relief. In this case, the natural channel was disadvantaged by a secondary plant arrangement that imposed less resistance than its original riparian dynamics. Returning to the issue of the artificial canal, it is worth considering it as a dependent operating structure. Its inlet flow, for example, is controlled by the cross-sectional area, which, in turn, is defined by its users. The flow rates gradually reduce along the gutter (figure 3b) due to the processes of evaporation, evapotranspiration, and infiltration that occur from these earth structures promoting underground replenishment (BOUWER 1999; HAMED et al 2021). Despite the well-known complexity of estimating these transfers, based on Barkhordari and Shahdany (2022), in the channel studied herein, the lower flows generate a decrease of 92% in the cross-sectional area from the beginning to the end of the flow. Gutters with smaller dimensions are more easily taken over by vegetation (figure 4b), which causes the flow to interrupt and generates maintenance demands at shorter intervals (SILVA, 2018).

As for the flow velocities (figure 3c), the greater flow and slope in the natural channel make the laminar flow more efficient in erosion and transport processes. Figure 4a shows that the banks of this channel are less occupied by vegetation than the artificial channel (figure 4b). The slow flows conditioned by the low slope and the vegetative obstacles (Figure 5) reduce the transport capacity, thus promoting sedimentation. Errico et al (2018) point out that vegetation generates hydraulic resistance and two zones of velocity profiles: a shear zone and another with free and fast flow. As seen in figures 6 and 7, the artificial channel investigated herein showed an expansion of the shear zone with the suppression of free flow. Thus, it is widely accepted that velocities below 0.45 m/s compromise the transport of fine sand, while those below 0.3 m/s, smaller materials (CARVALHO, 2009).

The intense deposition in the artificial channel, with an average of 0.59 m/s, should also be attributed to the profile of sediment capture promoted by the vegetation (Figures 5 and 6), which impacts the drop in turbidity in the artificial channel in relation to the natural channel (figure 3d). According to Table 1, the vegetation, mainly represented by Myriophyllium, Hydrocotile, and Urochloa, completely occupies the channel, helping to reduce the turbidity by 82%, with a high coefficient of determination (Figure 8). This means that vegetation is more important in reducing turbidity than the flow velocity, as well as the volume of water propagating through the artificial gutter.

Fischer-Antze et al (2001) and Ramesh et al (2021) corroborate this condition when studying the process of plant influence on the interruption of particles along the channel. Establishing a comparison with Gharabaghi et al (2001), where vegetable filters reduced suspended particles by 50% in a stretch of 2.44 meters, reaching 98% in 19.52 meters, we found a drop in turbidity that reached 79%, albeit over a greater distance, 870 meters. Gathagu, Mourad, and Cantou (2018) pointed out that filter strips retained 46% of the sediment load in channels with agricultural basins.

The role of vegetation as a particle filter does not go unnoticed by users, who allow its growth in the rainy season precisely for it to favor the reduction of these corpuscles. Giacomazzo et al (2022) considers water transparency an important factor for various human activities and can be altered using vegetation as a sedimentary barrier.

Therefore, as the bi-plot of figure 9 shows, the stretches of the natural channel are more subordinated to the flow rates and the flow velocity that promote changes in the channel, from the removal, transport, or accommodation of particles (impacting on the turbidity), depending on the flood or flow rate. In the stretches of the artificial conduit, in turn, vegetation prevails in the explored dynamics, reducing the flow velocity and the dimension of the gutter, which may lead to overflows and service interruptions.

A specific case refers to the final stretch of the artificial channel where turbidity becomes the main parameter observed, given the maintenance, always carried out when, in the users' understanding, the vegetation ceases to be an advantageous system for reducing turbidity and starts to prevent the channels from working.

At the late rainy season and as dry days advance, vegetation is also seen as a competitor for water resources and is then removed since the transport of sediments is greatly reduced and its filtering role becomes insignificant. Other investigations have also found the influence of plant growth observed herein, such as Yagci and Strom (2022) when considering the ecomorphological role of vegetation in river restoration.

Yamasaki et al (2021) performed simulations with artificial vegetation and found a trend of vegetation growth along the channel from the retention of sedimentary materials, which has repercussions on the hydrodynamic dynamics of these sections. According to Hoch et al (2022), these vegetative aspects along the channels also suggest the role of vegetation in the development of habitats, strongly contributing to the ecology of river systems.

CONCLUSION

This study demonstrated the preponderant role of vegetation plays in the behavior of small artificial earth channels, especially in the retention of particles available for transport. Thus, it is clear that in earth channels, vegetation offers multivariate services, including irrigation, fish farming, and animal and human watering; therefore, it must be managed and not simply removed at any time, even more so when considering the ecological role of these systems can take. As to the drainage system, even with the flow rate in the natural channel presenting responses adjusted to the rainfall, the transposition system undeniably changes the hydrological connectivity. Regarding this matter, we highlight the following points:

(1) During the rainy season, when the water coming from the natural channel is highly turbid, residents see the action of vegetation in the artificial channel as beneficial since it helps to reduce particles, thus generating lower levels of turbidity.

(2) As vegetation grows in the artificial channel, it reduces the transfer of sediments, promoting their accommodation both in the bed and in their structures. This condition is important for allowing users to have water resources with lower turbidity levels throughout the rainy season.

(3) This same vegetation is responsible for the progressive reduction of the channel, given its development and sedimentation; therefore, the obstruction of the water passage becomes inevitable, as well as the end of the transposition structure itself. In places where channels are not maintained, they cease to exist.

(4) In the process of cleaning the channels, the turbidity of the flow rates increase again, and the material removed is deposited on its banks, forming anthropic dikes. These human topographic signatures generate a disconnection between the artificial channel and the slope since part of the surface flows does not reach the artificial channel or the bottom of the valley, being retained near the dikes.

(5) In the dry season, when the turbidity is very low due to the poor connection between the suspended materials on the slope and the valley floor, the vegetation must be removed to facilitate the passage of the flow, which is reduced by the climatic conditions.

Thus, in regions with well-defined seasons, the management of these channels is better organized based on seasonal logic and the sedimentary load available for transport. For this purpose, it is important to guide users to understand the advantages of this management and realize that the channel also provides ecosystem services that need to be addressed and maintained. The insertion of artificial habitats, extensions of the natural ones, requires the stretches to be kept vegetated, functioning as refuges in the rainy season, the period of reproduction of a series of species linked to these environments. Further studies should deepen the understanding on the occurrence of changes in natural flow rates from transposition systems, as well as their repercussions on fluvial and riparian dynamics. Finally, we expect that the methods gathered here will allow new investigations to develop and enlarge the amount of data and analysis on this subject. Such studies would contribute to establishing comparisons with laboratory and modeling research, which are fundamental to a more efficient management of water resources. Fragile environmental contexts that are threatened by constant changes and pressure on water consumption should be especially analyzed for requiring a careful management of the vegetation inside the channels. In turn, the vegetation in the channels might play an important role in both the quality and quantity of water available to users, in addition to the formation of fluvial habitats conditioned by artificial biogeomorphic succession.

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Silva, R. E. - The author proposed the research, collected data and analyzed the data.
Rodrigues, S. C. - The author reviewed the analyzes and assisted in writing and revising the results.
Vieira, A. A. B. - The author reviewed the analyzes and assisted in writing and reviewing the results.

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