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Papers

Correlation between land use and geomorphological features: a proposal of analysis using retrospective mapping

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Abstract
Different studies of geomorphological science are dedicated to understanding the effect of human action on the natural dynamics of environments. Following it, this article aims to identify the effect of agriculture and conservation techniques on the dynamics of slope and bottoms of valley processes in a degraded rural area. We selected, for it, the sub-basins of Areia Dourada stream, located in the city of Marabá Paulista (SP), as objects of study, in which we used the principles of retrospective mapping, with the mapping of land use and superficial surface cover and the geomorphological features of 1963, 1979, 1997, 2011 and 2016. For the analysis, along with the mappings and field records, we used the Pearson's Correlation Coefficient (p), together with quantified data, to evaluate the changes of the forms of relief from land use in the five mapped years. As a result, we verified: **joint** development of the erosive processes in different topographic compartments; feedback system between slope and bottoms of valley processes; the low efficiency of the agricultural terraces, both in the cultivated areas, but especially in the pasture areas, in order to contribute to the erosive dynamics by feeding erosive subsurface processes, while not containing the surface ones.

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INTRODUCTION

Several studies on geomorphology aim to identify the effects of human activities on natural systems, focusing on a field dedicated to interpreting anthropic interferences as geomorphological agents, denominated anthropogeomorphology (NIR, 1983).

For our analysis, we deemed the retrospective geomorphological mapping as a resource that allows monitoring and identifying changes in landforms over historical time. Based on this technique, authors of several studies pinpointed the effects of human activities on different environments, such as: changes in the fluvial dynamics of rivers crossing the city of São Paulo, State of São Paulo – Brazil (LUZ; RODRIGUES, 2015); mining effects (PASCHOAL, 2014); the influence of impoundments of water on morphohydrography (SIMON, 2010); the influence of impoundment of water of the Paraná River and consequent changes on the regional baselevel and on the reactivation of the drainage network (QUARESMA, 2012); the influence of overgrazing, which contributes to the formation of linear erosion phenomena on lands rarely subjected to such processes (ZANATTA; LUPINACCI; BOIN, 2017a), among others.

Among processes to which soils are subjected, significant changes happen only with the replacement of native flora and fauna. In agricultural and urban areas, new soil covers are part of an environment that operates according to the dynamics predetermined by natural physical constraints – which start operating in an artificial plan whose logic, far from the natural dynamics, is determined by economic, political, and social relations.

To illustrate changes in processes to which soils are subjected, in the state of São Paulo, Brazil, Bertoni and Lombardi Neto (1990), found that soil loss accounted for 0.004 t/ha/year in native forests. In pasture lands, the volume was 100 times higher, accounting for 0.4 t/ha/year, whereas for sugarcane cultivation it was 3,100 times higher, accounting for 12.4 t/ha/year. Considering soil characteristics, the authors identified that sandy soils correspond to the most severe soil loss in t/ha.

Among effects exerted on soils, which contribute to erosion, Wendling et al. (2005), found a significant reduction in the organic carbon concentration and in soil aggregate stability on soils under agricultural cultivation, when compared with values before deforestation. According to Kiehel (1979, *apud* WENDLING et al., 2005), the formation of aggregates is related to the mechanical action of roots and to the excretion of substances with cementing action; moreover, the more exposed the soil surface is, the greater the reduction in the stability of the aggregates, thus favoring surface sealing processes and inducing surface runoff and erosion.

Charlton (2008) warns that vegetation removal consequently increases the proportion of superficial runoff of pluvial water, thus accelerating erosion-related processes. Under these conditions, higher volumes of sediments and water affect fluvial channels and change the valley forms. Abdon (2004) verified that overgrazing, inadequate soil management, and misuse of certain areas have favored the development of ravines and badlands, thus increasing the amount of water and sediments that reach the main basin channel. This effect resulted in deep alluvial deposits of the Taquari river and changes in its course, in such a way to overflow and flood wide field areas, previously used for extensive livestock.

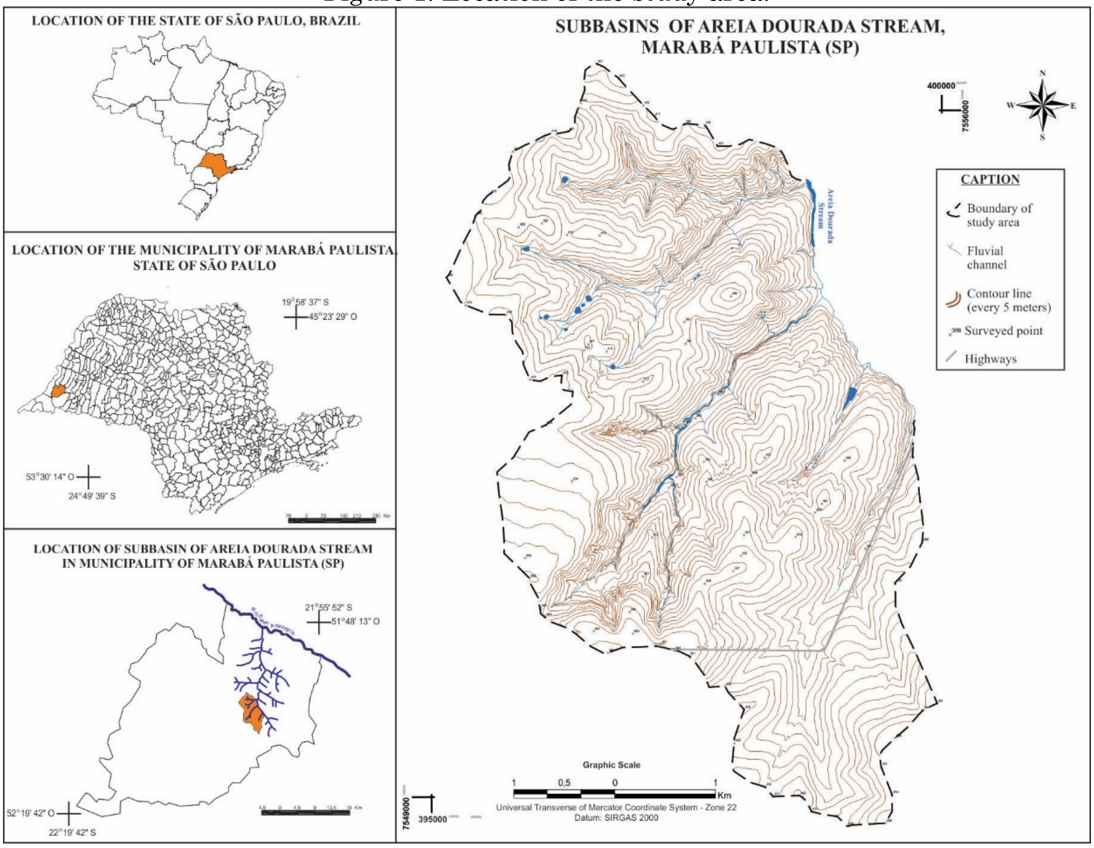
Within this context, we aimed at identifying the effect of anthropic actions on erosion processes and valley forms throughout 53 years in a degraded rural area, in a set of subbasins of the Areia Dourada stream (Figure 1), located in the municipality of Marabá Paulista, Western region of the state of São Paulo – Brazil.

To do so, we used principles of retrospective mapping for surveying data on geomorphology and land use, as well as statistical techniques for analyzing the surveyed information, seeking to identify changes and hypothesizing the influence of human activity on the intensity and dynamics of geomorphological processes.

CARTOGRAPHIC MATERIALS AND TECHNIQUES

We performed the geomorphological mapping and the mappings of land use and land cover based on topographical data of maps from Instituto Geográfico e Cartográfico do Estado de São Paulo (IGC), an institution that promotes knowledge of characteristics of the São Paulo territory, dated from 2000, in a 1:10,000 scale, 057/019, 057/20, and 058/20 sheets. Based on these maps, we vectorized contour lines with a 5-m equidistance, surveyed points, in addition to the respective altimeter values, also considering this scale as the standard value for the cartographic production.

Figure 1. Location of the study area.



Source: by the Authors, 2019.

For the geomorphological mapping and the mappings of land use and land cover of the five mapped years, we used different sources and photo interpretation techniques according to the characteristics of remote-sensing products (Table 1).

Table 1. Photographs used for mapping geomorphological features and those related to land use and land cover

Source	**Year**	**Scale/Resolution**	**Photographs in the catalog**	**Type of mapping**
State of São Paulo	1963	1: 25,000	FX91A-2857 and 2858; FX92-2871 and 2873; and FX93-2921 and 2922.	Photo interpretation in digital stereoscopy.
Terrafoto S.A.	1979	1: 25,000	FX91A-2857 and 2858; FX92-2871 and 2873; and FX93-2921 and 2922	Photo interpretation in digital stereoscopy.
Aerial surveys conducted in Presidente Venceslau (municipality of São Paulo, state of São Paulo – Brazil) and surrounding areas	1997	1:35,000	07/5884; 07/5885 and 07/8856.	Photo interpretation in digital stereoscopy.
Empresa de Planejamento Metropolitano S.A.	2010	Resolution of 0.45 m	SF_22_YB_I_2_ NE and SE; and SF_22_YB_II_1_NO and SO.	Photo interpretation and correction of data in the field.
Google Earth – Quickbird satellite	2013	Resolution of 0.6 m	No information.	Photo interpretation and correction of data in the field.

Source: by the Authors, 2019.

With materials of the years 1963, 1979, and 1997, concerning aerial surveys conducted in flight lines**,** we were able to work with digital stereoscopy, thus acquiring the three-dimensionality of the features. To this end, we followed the guidelines proposed by Souza and Oliveira (2012) for obtaining the anaglyphs from the *StereoPhoto Maker* software. Conversely, for materials dated from 2010 and 2013, which consisted in orthophotographs and satellite imagery, we corrected the data in the field due to the impossibility of obtaining three-dimensionality of the features through the aforementioned method.

Noteworthy, although there are differences between scales of the aerial surveys and the scale we used in this study, we performed photo interpretation with as much zoom and detail as possible, considering that the surveyed features can be mapped and studied according to the scale and materials we used for performing the geomorphological mapping.

We mapped geomorphological features according to their spatial nature and adopted the geometry (points, line, polygons) that best adapted to their characteristics. Hence, we quantified data as regards area (hectare), quantity (number), or extent (km) according to the adopted mapping procedure (Table 2). Features calculated in hectare were transformed into percentages of the area concerning the total area of the subbasins.

Table 2. Characteristics of geomorphological features and types of data processing

Spatial nature	Feature	Geometry	Size estimation
Area	Features that indicate laminar erosion	Polygon	Hectare (ha)
	Terrace and alluvial plain		
	Agricultural terrace		
	Reservoir		
Quantity	Furrows	Line	Total number of mapped features
	Ravine		
	Erosion control features		
	Contention Basins		
Extent	Fluvial channel with flat valley form	Line	Total kilometers (Km) of extent
	Fluvial channel with V-shaped valley form		
	Fluvial channel with undermining of margins		
	Abrupt break slope		
	Abrupt break slope with upwelling of water table		

Source: by the Authors, 2019.

When choosing features to be mapped and the symbology to be used in geomorphological maps**,** we followed the principles of the French mapping system (TRICART, 1965) and the system of the International Institute for Aerial Survey and Earth Science (ITC) – which is currently called the University of Twente's Faculty of Geo-Information Science and Earth Observation, whose aim is to develop capacity and to utilize geospatial solutions to deal with national and global problems – proposed by Verstappen and Zuidam (1975), since we sought for procedures that enabled us to recognize dominant morphogenetic processes. We adapted the methodologies to meet the studied universe, and created new symbols for typical features of the area, which did not exist in the original proposals; in addition, we assigned different colors to highlight erosion features, mapped in red, and the anthropic forms, mapped in gray (Figure 2).

To differentiate linear erosion features, according to Zanatta, Lupinacci and Boin (2017b), we considered furrows as small vertical incisions that can be repaired by simple soil preparation procedures (LAL, 1990; SALOMÃO, 2012; SOIL CONSERVATION SERVICE, 2006); ravines as deeper incisions, with the formation of floor surface with sidewalls (FOOKES, 2007; KARMAN, 2008); and badlands, whenever linear erosion reaches and exposes the groundwater (DAEE**;** IPT, 1989; FOOKES, 2007; SALOMÃO, 2012).

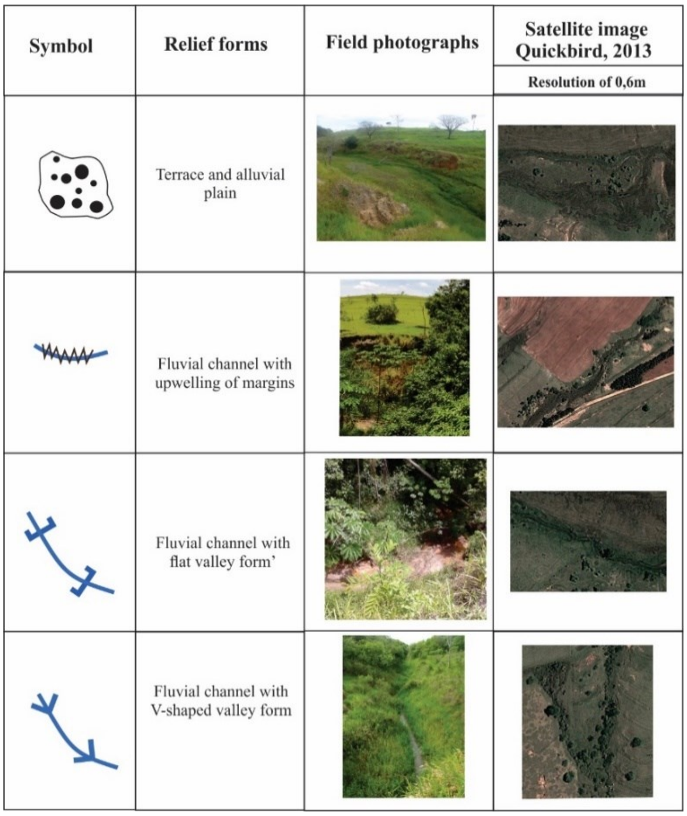
Figure 2. Symbols used in geomorphological maps.

Elements	Denomination			Symbol	Reference
Interflow	Slope forms	Convex			Verstappen and Zuidam (1975)
		Concave			Verstappen and Zuidam (1975)
		Straight			Verstappen and Zuidam (1975)
	Divide line				Tricart (1965)
	Pass				Tricart (1965)
	Forms of denudational origin	Water flow	Features that indicate laminar erosion		Adapted from Verstappen and Zuidam (1975)
			Furrows		Tricart (1965)
			Ravine		Tricart (1965)
			Badlands		Tricart (1965)
		Gravitational	Terracette		Verstappen and Zuidam (1975)
	Topography	Countour lines with 5m equidistance			Cartographic convention
		Surveyed point		×426	Cartographic convention
		Topographical rupture	Smooth		Tricart (1965)
			Smooth with upwelling of water table		Adaped from Tricart (1965)
			Abrupt		Tricart (1965)
			Abrupt with upwelling of water table		Adapted from Tricart (1965)
Running water action	Forms of flow	Fluvial channel			Tricart (1965)
		Pluvial channel			Tricart (1965)
		Undermining of margis			Dibieso (2013)
	Forms of accumulation	Flat areas and fluvial terraces			Tricart (1965)
	Valley forms	Plan			Tricart (1965)
		In ‘‘V”			Tricart (1965)
Anthropic forms	Agricultural terraces				Adapted from Verstappen and Zuidam (1975)
	Contetion basins				Zanatta, Cunha and Boin (2014)
	Erosion control				Zanatta, Cunha and Boin (2014)
	Channel of anthropogenic origin				Simon (2010)
	Reservoir				Cartographic convention
	Highway				Cartographic convention
	Rural road				Cartographic convention

Source: by the Authors, 2019.

It is worth mentioning that we could map valley forms based on photo interpretation and the analysis of orthophotographs and orbital imagery due to specificities of the erosion and depositional dynamics of the study area. Hence, in some sectors, we identified flat valley forms due to excess sediments. Nevertheless, we could not delimit alluvial plains due to the scale limits, and we mapped such areas considering the symbology suggested by Tricart (1965). Moreover, in some sectors, the intense erosion dynamics present in fluvial channels allowed us to observe the significant dissecation of valley forms due to steep margins. This exceptional dynamics of the fluvial system has allowed, after mapping the valley forms according to the proposed symbols (Figure 3), to linearly quantify these valleys (in km).

Figure 3. Identification of fluvial features in the field and photographs.



Source: by the Authors, 2018.

For land use and land cover, we followed the procedures and nomenclatures established by the Brazilian Institute of Geography and Statistics (IBGE, 2006), which is the main provider of data and information about Brazil, identifying the areas of: Seasonal Semideciduous Forest; reforestation; wetland vegetation; forestry; temporary crop; pasture; and dirty pasture. Since, according to our methodology, the surface soil cover has spatial dimension per occupied area, we quantified these data based on their percentage about the total study area.

With information on the mappings of land use and land cover and on geomorphology, which was quantified according to the spatial dimension, we applied the Pearson's Correlation Coefficient (*p*) in the Excel program® to evaluate the intensity of correlation concerning changes in the area occupied by thematic classes of land use and land cover and geomorphological features over the 53 years, from the period between the first mapping (in 1963) to the last one (in 2016). As a result, values were distinguished with tones that vary according to the intensity of the correlation: null, when the correlation is equal to 0; weak, when it is equal to 0.1 ⊦ 0.2; moderate, when it is equal to 0.3 ⊦ 0.5; strong, when it is equal to 0.6 ⊦ 0.8; very strong, when it is equal to 0.9; and perfect, when it is equal to 1.00; green tones were used for positive correlations, concerning the proportional increase of the features; red tones, for negative ones, concerning the inversely proportional increase of features; and white tones, concerning the null correlations. The classification of intervals was based on and adapted from Figueiredo Filho and Silva Junior

(2009).

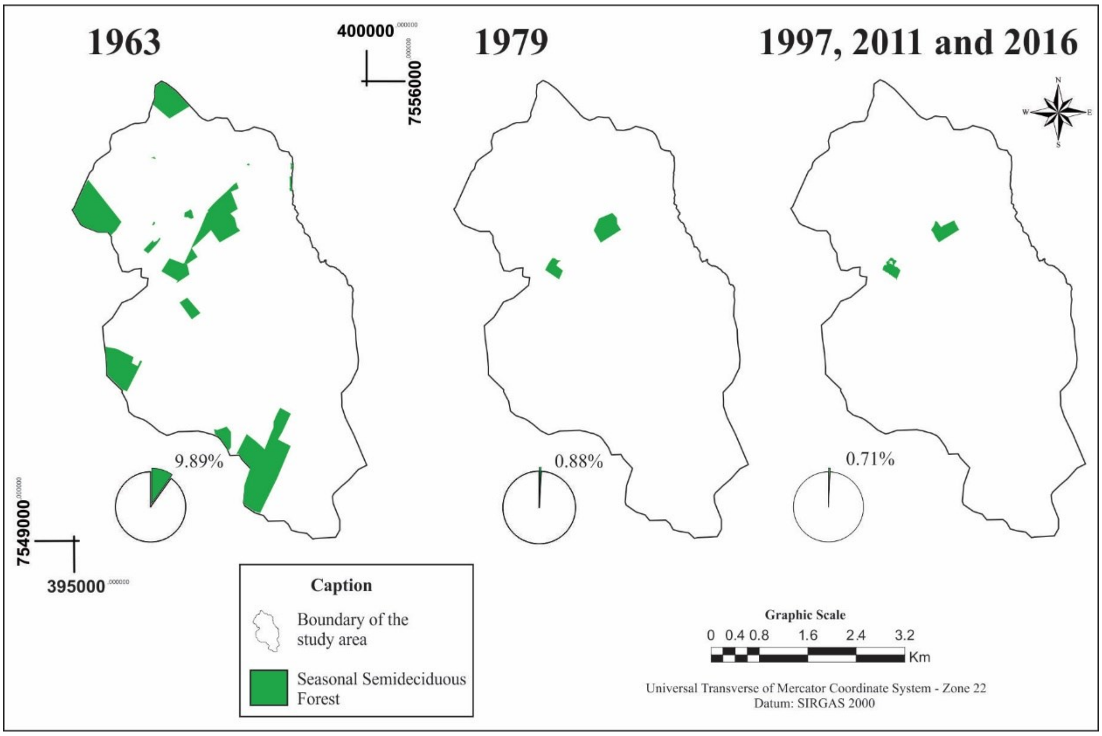
We analyzed the result of the aforementioned correlation together with mappings, field photographs, and other studies developed in Santo Anastácio river basin, in such a way to compare and provide information on correlation and to formulate hypotheses about the dynamics of the current processes from a historical perspective.

RESULTS AND DISCUSSION

The occupation of Marabá Paulista began at the basin of Areia Dourada stream, with the formation of the village of Areira Dourada in the mid-1930s, by northeastern tenant farmers who cultivated cotton (PREFEITURA DE MARABÁ PAULISTA, 2019).

From the formation of the village to the first mapped year, 1963, a period of approximately three decades, we found a reduction of about 90% of the native forest cover in the study area, i.e., 9.89% of the 4,623 ha that compose the subbasins (Figure 4).

Figure 4. Seasonal Semideciduous Forest in the subbasins of Areia Dourada stream, Marabá Paulista (SP), in 1963, 1979, 1997, 2010, and 2016.



Source: by the Authors, 2019.

In 1963, surface soil covers that replaced the Seasonal Semideciduous Forest were divided between temporary crops (46.62%), pasture (23.41%), and dirty pasture (18.47%). In the following period, 1979, the temporary crop area decreased to 3.63%, and pasture (69.09%) and dirty pasture (24.84%) prevailed. In 1997, pasture occupied 94.78% of the entire study area (Table 3).

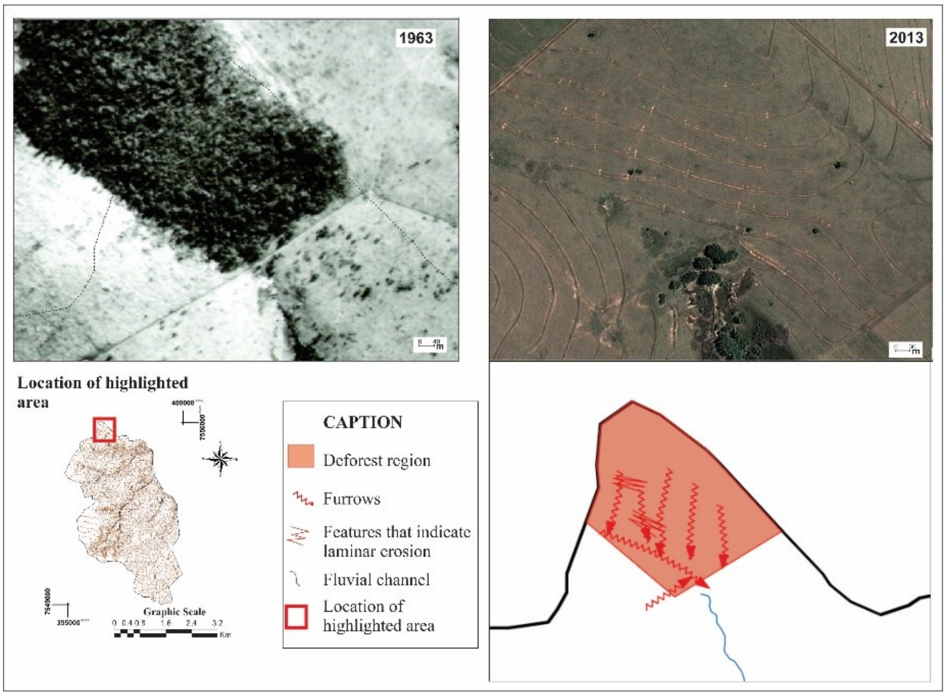
Table 3 Land use and land cover (% of occupied area) in 1963, 1979, 1997, 2010, and 2016.

Land use and land cover	1963	1979	1997	2010	2016
Seasonal Semideciduous Forest	9.89	0.88	0.71	0.72	0.70
Reforestation	0.00	0.00	0.70	1.23	1.20
Wetland vegetation	0.70	0.60	0.94	1.61	1.57
Temporary crop	46.62	3.63	0.80	18.32	13.45
Forestry	0.91	0.96	0.08	0.11	4.24
Pasture	23.41	69.09	94.78	72.92	74.30
Dirty pasture	18.47	24.84	1.99	5.09	4.54

Source: by the Authors, 2019.

These new surface soil covers resulted in effects on the landscape functioning that differ from those produced by the native forest cover. In pasture-covered areas, processes, such as linear erosion, were more frequently developed (Figure 5).

Figure 5. Deforestation and development of erosion features in the pasture area. Sector N of subbasins of Areia Dourada stream, Marabá Paulista (SP).



Source: by the Authors, 2019.

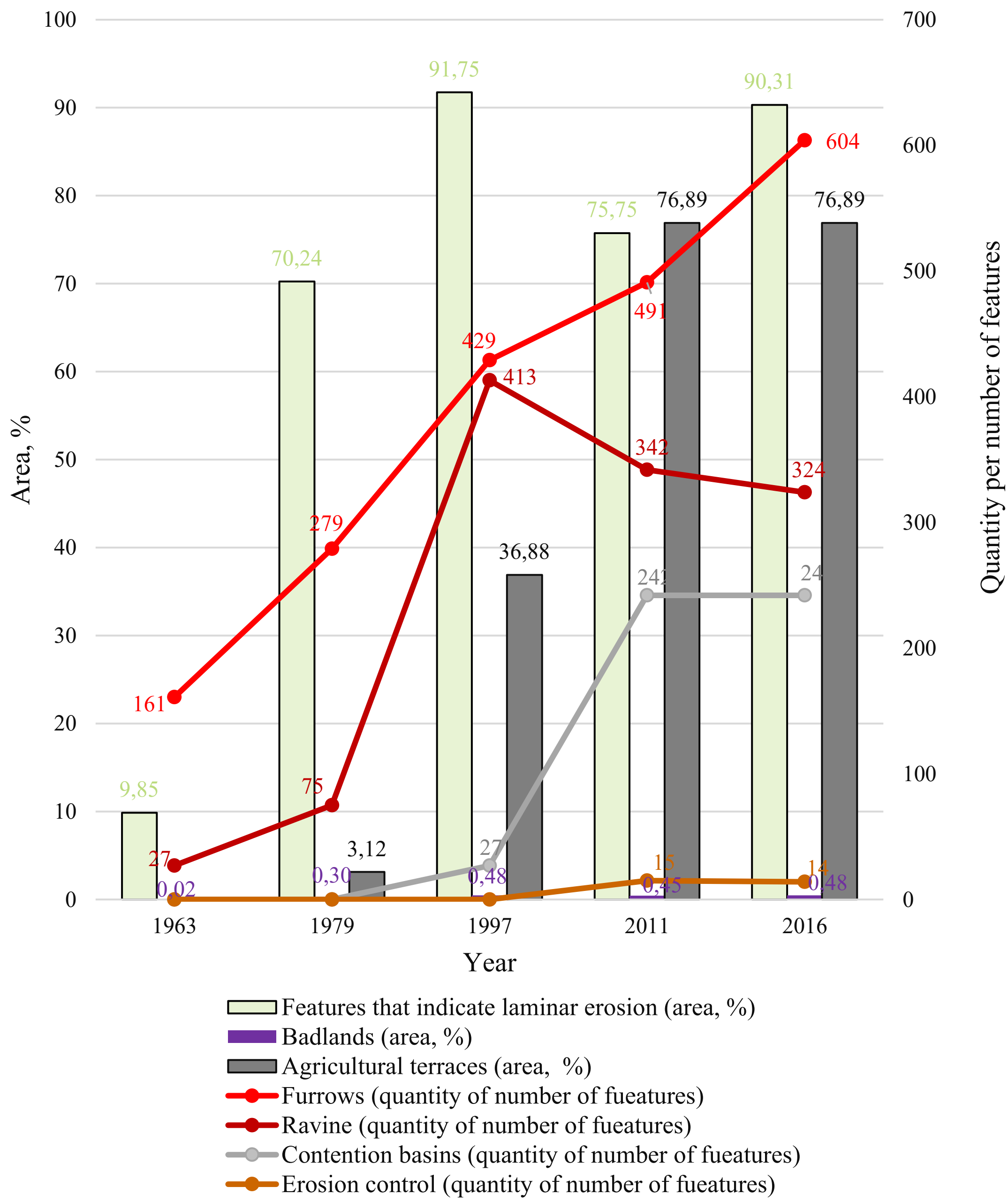
In the pasture area that replaces the native vegetation (Figure 6), we observe the emergence of seven linear erosions, and consequently of the better paths by which pluvial water is concentrated towards the fluvial channel, eroding the surface layer of the soil. This phenomenon strongly influences the excessive trampling cattle, thus creating favorable conditions for the channeling of pluvial water.

Rodrigues et al. (2006) clarify that this advance in pastures between the 1970s and 1990s also occurred in most of the Pontal do Paranapanema region, located in the state of São Paulo – Brazil, resulting from soil impoverishment due to its intense use and erosion, which increased the cost of cultivation and made agriculture unfeasible for small farmers. Under these conditions and devoid of alternatives, these farmers sold their land to major cattle breeders, who, according to Francisco (2011), in an environment where erosion prevails, introduced conservation practices in the region, with the construction of agricultural terraces.

Later, in 2011, the pasture area diminished, increasing the sugarcane cultivation with the advance of sugar companies in the region by land rent. This temporary crop started occupying 18.23% of the land in 2011, decreasing to 13.43% in 2016 due to the end of lease contracts, according to reports obtained in the field, thus resuming pasture and forestry-related activities.

Soil covers that replaced the Seasonal Semideciduous Forest throughout these five years provided an expressive and growing increase in erosion forms in number (furrows and ravines) and affected area (features that indicate laminar erosion and badlands) in the 53 analyzed years, even when employing conservation techniques from 1979 onwards, which did not mitigate erosion effects in the area in the following years (Figure 6).

Figure 6. Erosion features and techniques for conservation and containment of erosion processes in 1963, 1979, 1997, 2011 and 2016.

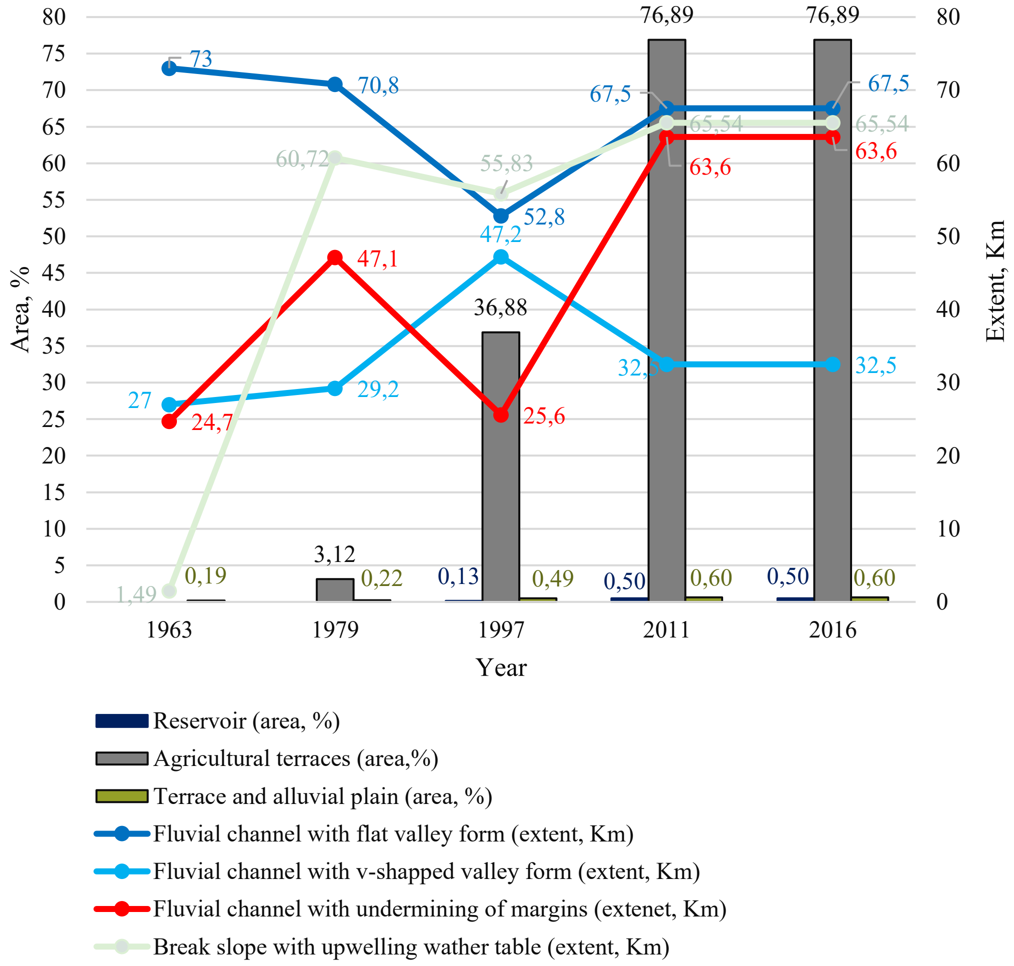


Source: by the Authors, 2019.

Stein, Ponçano and Saad (2003) also found this relationship between conservation techniques and erosion processes in the Santo Anastácio river basin. According to the authors, larger water infiltrations provoked by agricultural terraces led to an increase in recharges of groundwater, which previously existed within native forests. Such recharges, within the area of the Adamantina Formation, a geological formation in the Bauru basin, located in the western region of the state of São Paulo – Brazil, result in upwelling of water table in slopes, with the flow of water directed to territories already fragile and poorly protected by the continuous and intense land use, which drives the development of erosion phenomena.

According to the obtained information, we observed the proportional increase in erosion features, in addition to the greater use of agricultural terraces in the study area, as well as the extent of upwellings of water table due to abrupt break slopes, reflecting the significant changes in valley forms that occurred especially from 1997 onwards, and where the use of agricultural terraces became the standard of cultivated areas (Figure 7).

Figure 7. Agricultural terraces, upwellings of water table, and fluvial channel features.



Source: by the Authors, 2019.

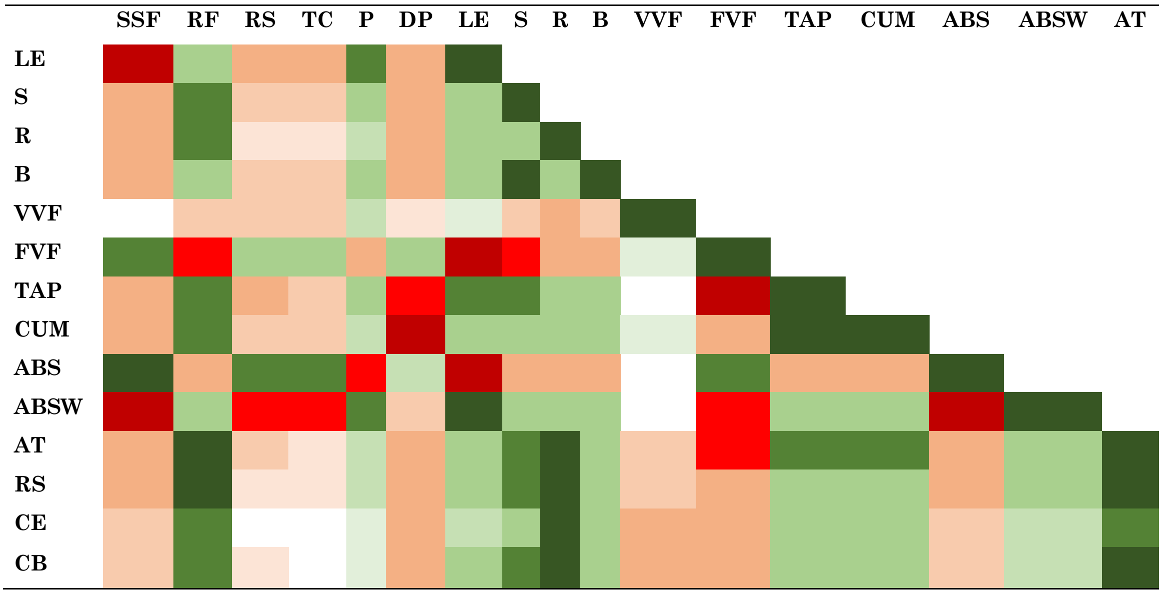
In 1997, when compared with previous years (1963 and 1979), channels with flat valley forms decreased as terraces and alluvial plain increased due to alluvial deposits of the channels. In other sectors, we perceived an increase in V-shaped valley forms, indicating the river incision dynamism, which is probably caused by the increase in break slopes with an upwelling of water table. These upwellings of water started favoring the emergence and development of new fluvial channels in slope concaves.

In 2011, there was a reduction in V-shaped valley forms and an increase in river channels with flat valley form and terraces and alluvial plain (Figure 7), indicating the constant alluvial deposits of river courses due to intense erosion activity in the slopes (Figure 6). Moreover, in the same year, we found 63.6% of fluvial channels with undermining of margins due to the increase in the amount of water and sediments deriving from the slopes.

In the five-year interval, from 2011 to 2016, we perceived no changes in fluvial features. This finding is probably related to the short time between the evaluated years, in such a way we cannot verify significant changes in the valley forms considering the increase of processes in the slopes.

After evaluating the correlation between data on geomorphology and land use, we verified the inefficiency of conservation techniques in containing erosion processes, the influence of pastures on stimulating such processes, and the proportional increase between erosion features (Table 4).

Table 4. Pearson's Correlation Coefficient (PCC) concerning the variables of land use and geomorphological features throughout the years 1963, 1979 and 1997, and 2011 and 2016.



Caption:		
Correlation intensity	Positive	Negative
Perfect		
Very strong		
Strong		
Moderate		
Weak		
Null		

Caption: Seasonal Semideciduous Forest (SSF); Reforestation (RF); Wetland vegetation (WV); Temporary crop (TC); Forestry (FR); Pasture (P); Dirty pasture (DP); Terrace and alluvial plain (TAP); Flat valley form (FVF); V-shaped valley form (VVF); Channel with undermining of margins (CUM); Features indicating laminar erosion (LE); Furrows (F); Ravines (R); Badlands (B); Abrupt break slope (ABS); Abrupt break slope with upwelling of water table (ABS-UW); Channel of anthropogenic origin (CA); Reservoir (RV); Contention basins (CB); Agricultural terraces (AT); Erosion control features (ECF)

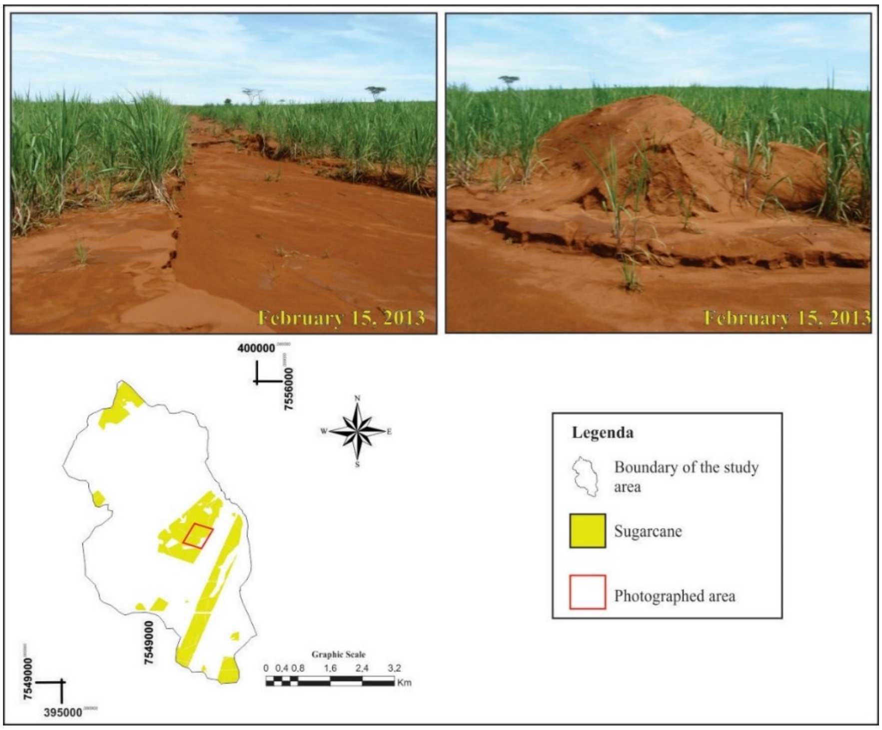
Source: by the Authors, 2019.

Seasonal Semideciduous Forest, which reduced throughout the analyzed period, presented a negative correlation with erosion forms, having perfect correlation with features that indicate laminar erosion; a very strong correlation with the formation of badlands; and strong correlation with furrows and ravines. This correlation is partly justified by the increase in erosion features in areas that were previously occupied by original vegetation (Figure 6). Nevertheless, it is also because of the ongoing decrease in this vegetation and the increase in erosion features, which cannot be understood as the emergence of erosion only in places where deforestation has occurred. Increase in erosion features virtually occurs in the entire study area, under several conditions of land use.

Pasture, the predominant soil cover in the study area, presented a perfect positive correlation with features that indicate laminar erosion; a positive strong correlation with furrows; a moderate positive correlation with ravines; and a positive very strong correlation with badlands.

Regarding temporary crops, the correlation was negative, being strong with badlands and very strong with features that indicate laminar erosion. In the field, we noted features that indicated laminar erosion and the formation of furrows in areas for sugarcane cultivation. We could not map these features due to the constant corrections of agricultural terraces (Figure 8).

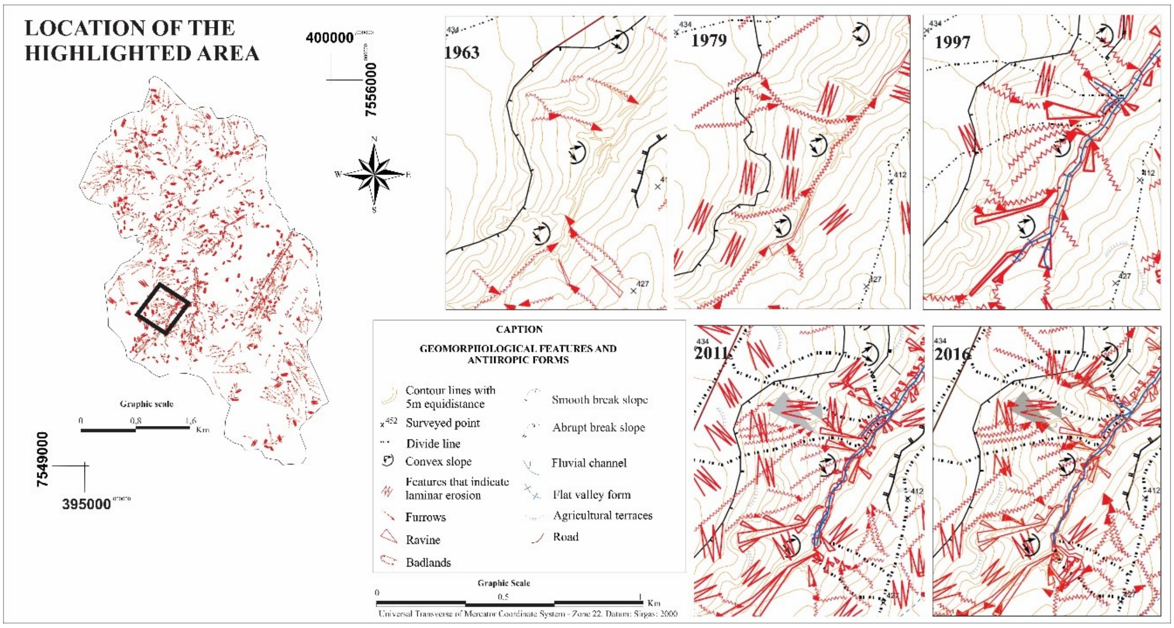
Figure 8. Features of laminar erosion and furrows in soils of sugarcane cultivation (2013). Photographs were taken after rainy events.



Source: by the Authors, 2019.

According to our analysis, the development of erosion processes jointly occurs, in such a way that erosion features showed a positive correlation with each other: features that indicate laminar erosion had a strong correlation with furrows and ravines, and a perfect correlation with badlands. Furrows had a very strong correlation with ravines and badlands, and the correlation between ravines and badlands was strong. These correlations indicate that evolution in erosion forms is interconnected with other processes occurring in the same subbasin (Figure 9).

Figure 9. Evolution of erosion forms at the W subbasin, affected by the formation of badlands from 1997 onwards.



Source: by the Authors, 2019.

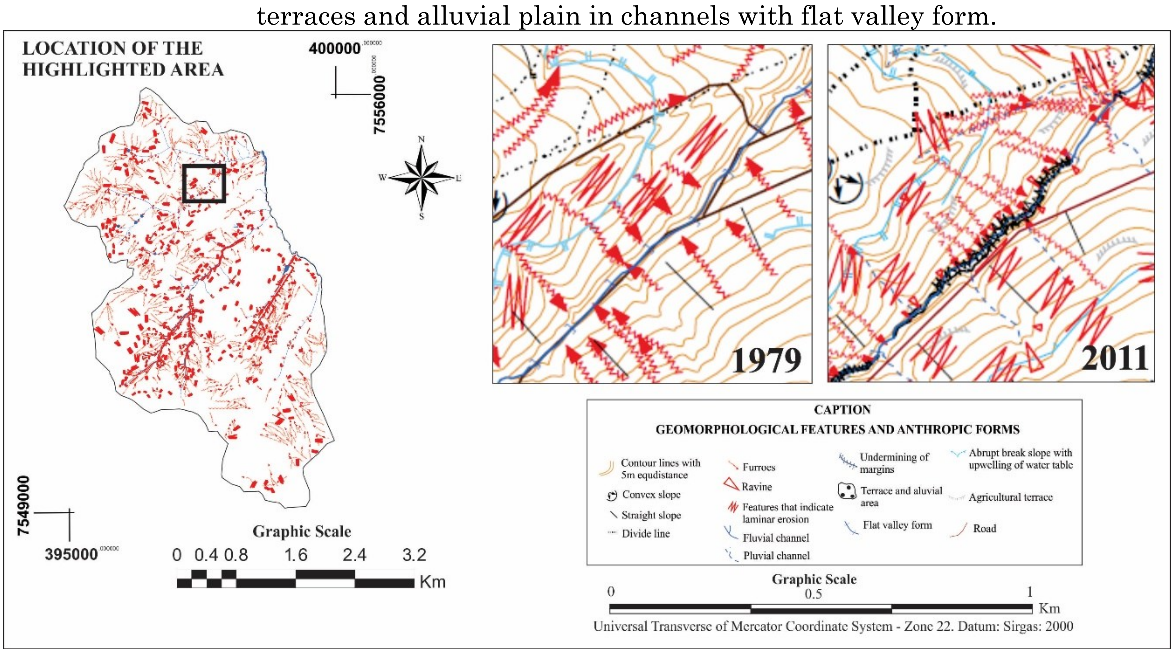
There is a connection between erosion forms (Figure 9). In 1963, several furrows were directed to the slope concave. In 1979, the formation of a ravine was registered in this slope concave, thus increasing the number of furrows and features that indicate laminar erosion in other slopes. In 1997, the aforementioned ravine developed into a badland, and other ravines emerged on its margins, to which furrows from higher sectors converge. In 2011 and 2016, this dynamics was intensified, with ravines migrating upstream and dozens of ravines emerging in lower slopes, with a greater number of furrows and features that indicate laminar erosion.

As for conservation techniques, the correlation indicated the low efficiency of terraces and contention basins in soil conservation, since they present a positive correlation with all erosion forms: very strong with furrows; perfect with ravines; and strong with badlands.

Furthermore, we observed that changes in valley forms are also related to processes occurring in slopes and to conservation techniques (Figure 4). Erosion forms presented a negative correlation with V-shaped and flat valley forms, and a positive correlation from very strong to perfect with terraces and alluvial plain. Erosion processes in slopes increase the flow of water and sediments towards valley forms, in such a way to expand sedimentation areas, resulting in the positive correlation with terraces and alluvial plain, and also in the reduction of channels with V-shaped and flat valley forms, where there was a negative correlation with all erosion forms (Figure 10).

As we highlighted in Figure 10, the increase in erosion features between 1979 and 2011 enabled greater sedimentation of valley forms, thus expanding the deposition area. Moreover, in this period, we observed that this excessive sedimentation provoked changes in the course of the main channel with undermining of margins. This process, upon reaching the base of the slope, has favored its collapse, in such a way dozens of small ravines emerged, which are developed by regressive erosion. Stein, Ponçano and Saad (2003) also pinpointed this relationship in a study on Santo Anastácio river basin and on Areia Dourada stream.

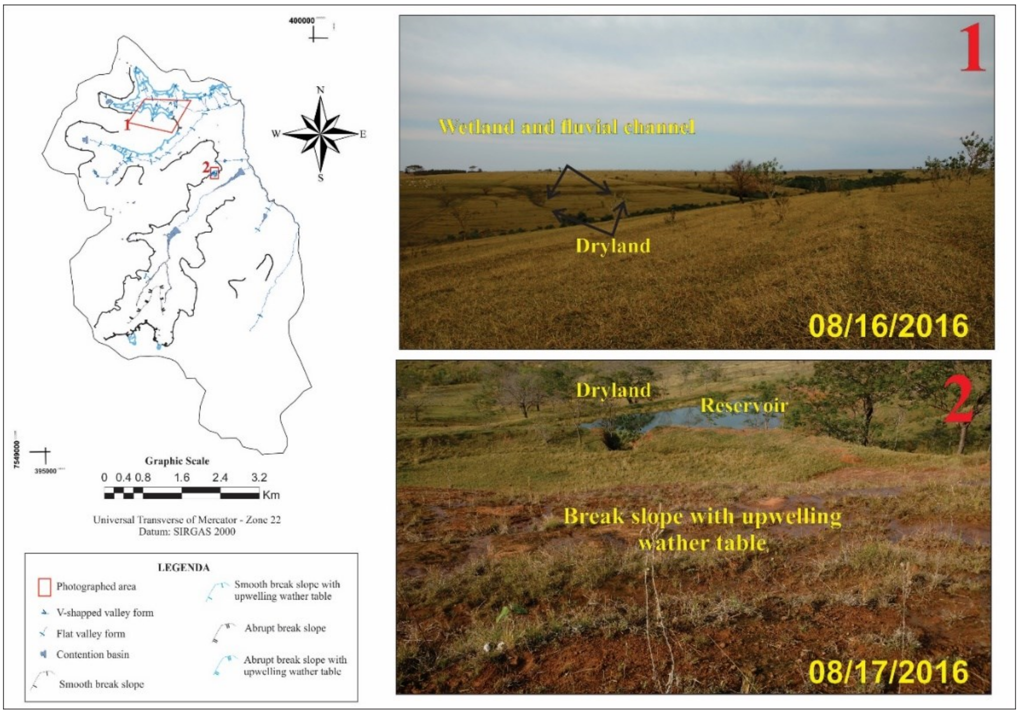
Figure 10. Erosion processes in slopes with the consequent undermining of margins and formation of terraces and alluvial plain in channels with flat valley form.



Source: by the Authors, 2019.

Upwellings of water table in break slopes, when jointly verified with geomorphological mappings especially from 1979 and 1997, gave rise to small fluvial channels downstream with V-shaped valley forms. In 2011, the length of these channels decreased due to the construction of reservoirs, which limited the flow until the upstream impoundment of water. We did not verify downstream runoff (Figure 11).

Figure 11. Tributaries of the main channel before (1997) and after (2011 and 2016) the impoundment of water and formation of reservoirs. (1) Absence of runoff downstream upwelling of water table in sector NW; (2) Absence of runoff downstream upwelling of water table in sector W.



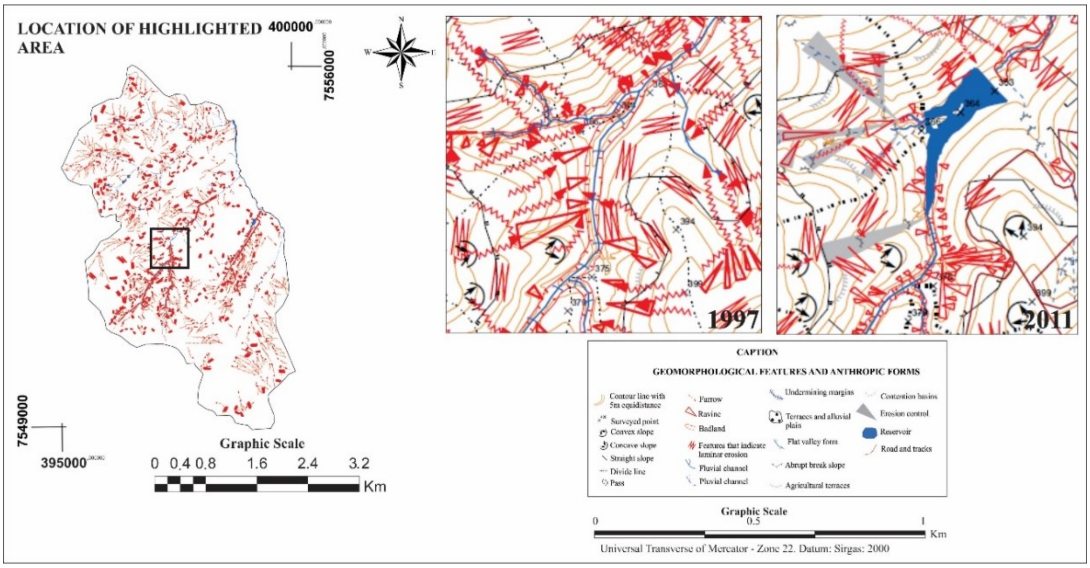
Source: by the Authors, 2019.

Thus, the negative correlation between abrupt break slopes with an upwelling of water table and V-shaped valley forms is disregarded when evaluated together with mappings and records of the field, since conservation techniques and reservoirs were variables that mostly interfered in valley forms. The increase in water infiltration due to conservation techniques and the impoundment of water transformed channels with V-shaped valley forms into pluvial channels (Figure 8).

Regarding the basin with the major process of formation of badlands (Figure 12), we found changes in erosion dynamics after the impoundment of water with reservoir formation, erosion control, and contention basins, hence altering the location and development of ravines when compared with previous years. Thus, we recorded the emergence of dozens of ravines in lower slopes from 2011 onwards.

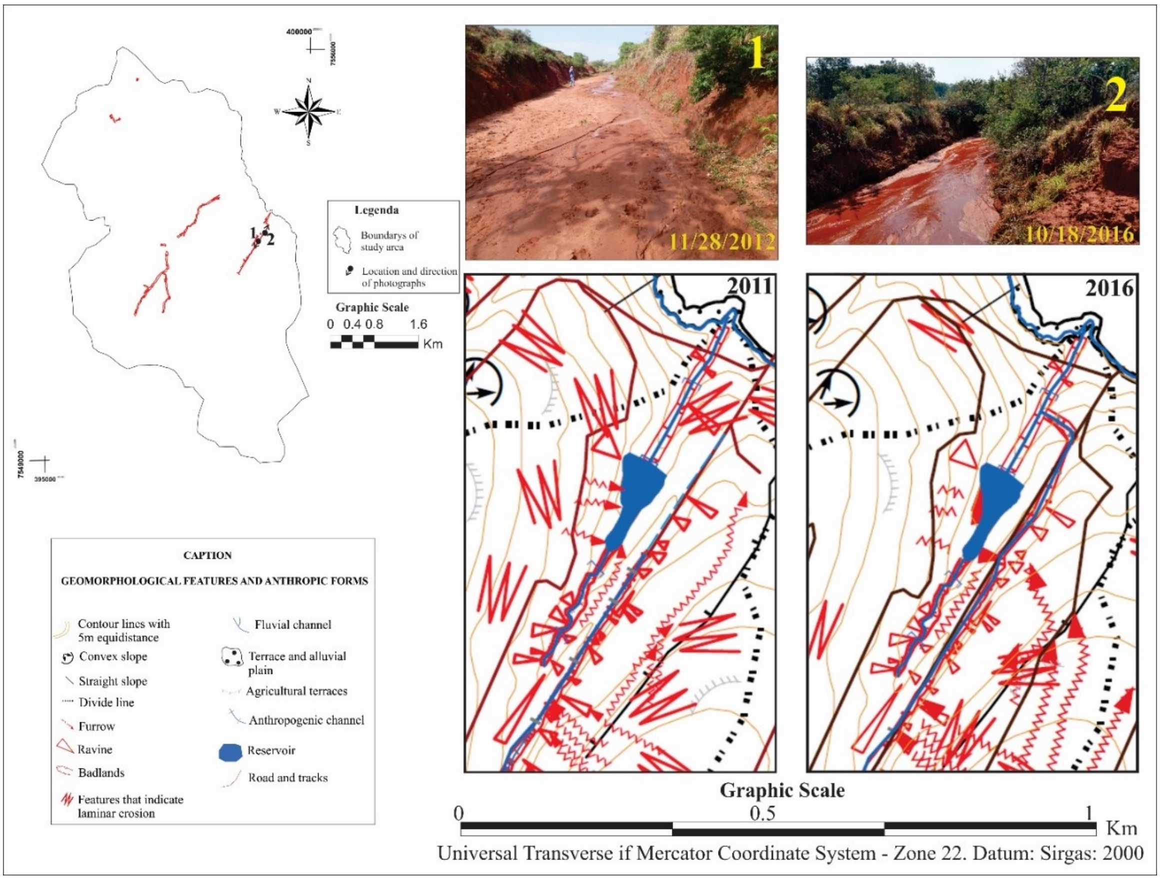
We mapped another badland in the southeast sector of the study area, whose runoff is directed to a former rural road (Figure 13). In this area, until 2011, the flow of water at the base of erosion was absorbed by the soil, whereas in 2016 the surface runoff started affecting the river channel, which is also affected by the process of formation of badlands, downstream the impoundment of water. This increase in the flow of water at the base of erosion occurs due to greater infiltration of water provided by contention basins and agricultural terraces in the slopes.

Figure 12. Changes in the pattern of formation and development of ravines after impoundment of water of badlands.



Source: by the Authors, 2019.

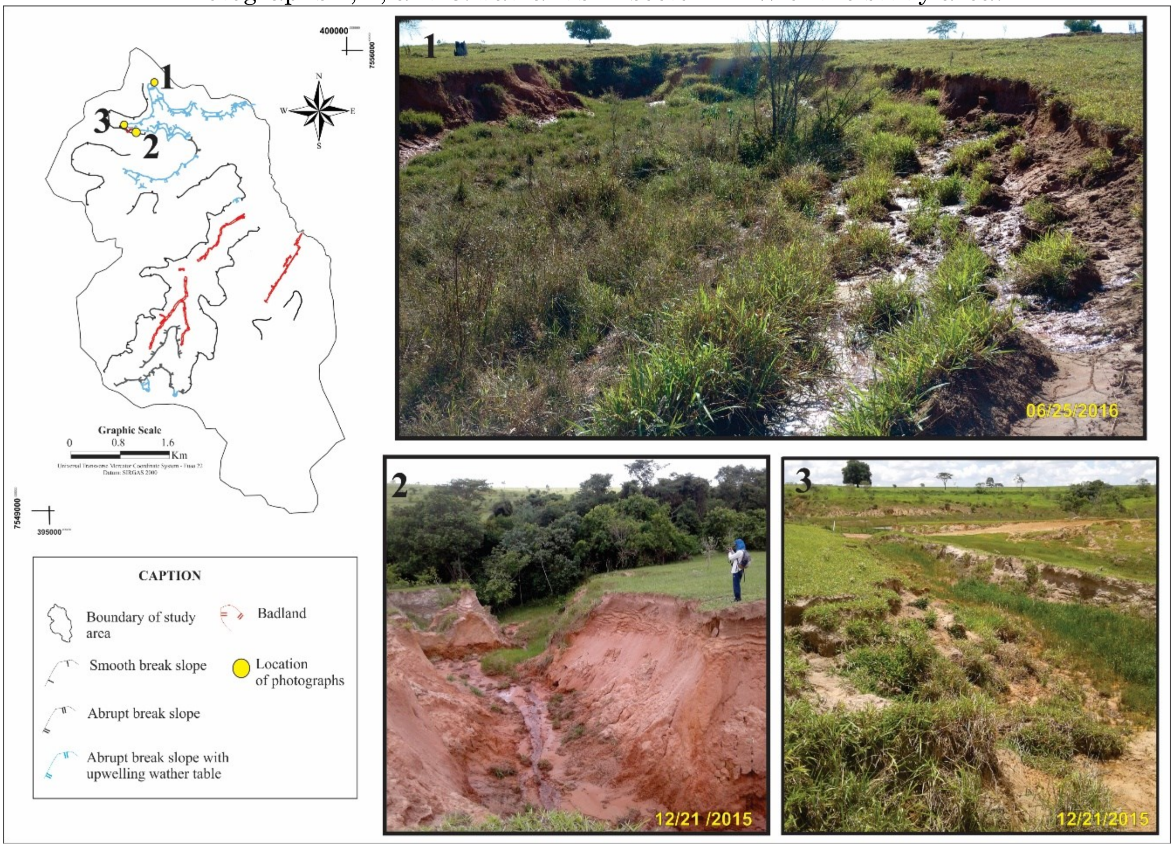
Figure 13. Influence of agricultural terraces on the flow of water in the channel of anthropogenic origin, resulting from the process of formation of badlands affecting the rural road. (1) Surface runoff at the base of badland in 2012; (2) Surface runoff at the base of badland in 2016.



Source: by the Authors, 2019.

In the northernmost sector of the study area (Figure 14), agricultural terraces provided a higher volume of abrupt break slopes with upwelling of water table within sectors of land overgrazing. Under these circumstances, of excessive use and greater flow of water deriving from break slopes with upwelling of water table, we noted the formation of badlands in 2011 and in 2016.

Figure 14. Formation of badlands downstream break slopes with upwelling of water table. Photographs 1, 2, and 3: badlands in sector NNW of the study area.



Source: by the Authors, 2019.

Overall, we can state that our data demonstrate the existence of intense use in virtually all slopes, at the expense of reforestation and crops that provide improvements in the structure of sandy soil and greater protection against the erosion effect of the rains, thus favoring the formation and development of erosion processes. Therefore, we can predict that, if the current conditions remain, erosion phenomena and continuous soil loss tend to increase, even when employing different conservation techniques.

FINAL CONSIDERATIONS

Through the applied techniques, we identified the erosion and depositional dynamics of the study area, in addition to verifying the connection between erosion forms in the several topographic elements of the area. These erosion forms provoked changes in valley forms, with the undermining of river margins, promoting the collapse of lower slopes and the emergence of many ravines. Such ravines increase the flow of water and sediments in valley forms, establishing an erosion-alluvial deposits cycle that provides feedback.

Pastures consisted in catalysts for many of the identified linear processes. Excessive trampling cattle generated the compaction of the surface layer, where furrows are developed. These furrows are inserted in the erosion dynamics previously mentioned

Conservation techniques have contributed to the development of erosion processes through recharges of groundwater, which, associated with intense land use, favored the subsurface processes characteristic of badlands; at the same time, they did not reduce surface processes. As for impoundments of water in channels with the formation of badlands, such impoundments changed the erosion development by the emergence of dozens of small ravines in every lower slope, which were no longer restricted to slope concaves, as recorded in periods before the impoundment of water.

In general, by retrospective mapping and Pearson's Correlation Coefficient, we can hypothesize the influence of land use and land cover on changes in geomorphological features identified in the study area throughout 53 years. Such findings may contribute to the understanding of erosion dynamics, a relevant issue for a possible recovery of subbasins of the Areia Dourada stream.

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