

LARGE-SCALE CARTOGRAPHIC REPRESENTATION OF RELIEF FEATURES FROM SANDYZATION PROCESS

Representação Cartográfica em Grandes Escalas de Feições do Relevo do Processo de Arenização

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Received in 15th April 2020

Accepted in 14th October 2020

Abstract:

In topographic maps, contour lines and elevation points usually represent the variation of height and slope. Contour lines interval defines the level of detail for relief representation. Geomorphological features we can identify on maps are related to contour lines generalization. In this study, we aim to define the necessary level of detail for the cartographic representation of relief features from the sandyzation process. The methodology comprises: defining the relief features associated with sandyzation at the study area by literature review; describing the aspects of data survey using Remotely Piloted Aircraft (RPA) to generate the orthophoto mosaic and the Digital Surface Model (DSM); and using the DSM to extract contour lines at different scales. We defined eight relief features (denudational landform, rill, ravine, micro-residual hill, dune, depositional fan, concentrated flow, and gully) for contour cartographic representation at 1:5,000, 1:1,000, 1:500, 1:200, and 1:100 scales. The results show the scales in which the relief features have their geomorphological characteristics better represented by contours lines. Since there is no reference for suitable scales for the cartographic representation of landforms related to the sandyzation process, this study can contribute to geomorphological researches in areas where this process occurs.

Keywords: erosion; geomorphology; topographic map; digital surface model; contour lines.

How to cite this article: COSTA, B. S. C.; SLUTER, C. R.; IESCHECK, A. L.; RODRIGUES, E. L. S. Large-scale cartographic representation of relief features from sandyzation process. *Bulletin of Geodetic Sciences*. 26(4): e2020019, 2020.



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Resumo:

Em mapas topográficos as curvas de nível e os pontos cotados representam a altitude e a declividade do terreno. A equidistância entre curvas de nível define o grau de detalhamento da representação do relevo. As feições geomorfológicas que se pode identificar nos mapas estão relacionadas com a generalização das curvas de nível. Neste trabalho, objetiva-se definir o nível de detalhamento necessário para a representação cartográfica das feições de relevo resultantes do processo de arenização. A metodologia compreende: definição das feições de relevo associadas à arenização na área de estudo por revisão bibliográfica; descrição do levantamento de dados por Aeronave Remotamente Pilotada (RPA) para a geração do ortofotomosaico e do Modelo Digital de Superfície (MDS); uso do MDS para a extração de curvas de nível em diferentes escalas. Foram definidas oito feições de relevo (forma denudacional de relevo, sulco, ravina, micro-relevo testemunho, duna, leque deposicional, canal de escoamento e voçoroca) para a representação cartográfica das curvas de nível nas escalas 1:5.000, 1:1.000, 1:500, 1:200 e 1:100. Os resultados mostraram as escalas nas quais as características geomorfológicas das feições do relevo são melhor representadas por curvas de nível. Como não há referências sobre escalas básicas para a representação cartográfica das formas de relevo relacionadas ao processo de arenização, esse estudo pode contribuir para as pesquisas geomorfológicas em áreas onde esse processo ocorre.

Palavras-chave: erosão; geomorfologia; mapa topográfico; modelo digital de superfície; curvas de nível.

1. Introduction

Cartographic representation of the relief is essential to geomorphological mapping and the description of the landscape. Depicting the relief features is highly dependable on the map scale, and the level of contour lines generalization influences the geomorphological features we can identify on maps. The relief features can appear or disappear on the map according to the scale of representation. Besides that, the contour lines should represent the relief with a high detail level for geomorphological studies. In the Brazilian geomorphological mapping, some landforms are represented only by point and line symbols (IBGE 2009). We can know the features' geographic position with these kinds of symbols, but it is not possible to visualize their geomorphological characteristics.

In the present study, we analyzed the landforms derived from erosive dynamics related to the sandyzation process. Sandyzation (*"arenização"* in Portuguese) is a natural process that occurs in a fragile landscape, and it can be intensified by human activities (Suertegaray 1987, Verdum 2012, IBGE 2009). The landscape fragility is related to poorly consolidated or unconsolidated sandy soils, recently formed under humid conditions; these soils are susceptible to erosion as they are exposed, transported, and removed by hydric and eolian dynamics (Suertegaray 1987, Suertegaray and Verdum 2008). In this study, we adopted the regional term sandyzation, instead of desertification, to describe the process of relief erosion that occurs in some areas with a fragile landscape in the southwest region of *Rio Grande do Sul* state, in the sub-region denominated as *Campanha Gaucha*, south of Brazil (Suertegaray 1987, Suertegaray and Verdum 2008). The sandyzation process explains patches of exposed sand in the landscape, regionally called *"areais"* (Suertegaray 1987). According to Suertegaray and Verdum (2008), sandyzation is a single phenomenon associated with hydrological and eolian processes that occur in some landscape relief patterns. The main difference between sandyzation and desertification is that the first one occurs in a region of humid climate with an average precipitation of 1400 mm per year, without dry season, but with climate variability characterized by periods of dry spells and rainy episodes (Suertegaray and Verdum 2008).

Field survey data and satellite imagery are important to understand the sandyzation and define relief patterns associated with this process. Sandyzation occurs in low slopes and low heights areas and medium slopes of hills or slopes of residual hills (Suertegaray, Guasselli and Verdum 2001, Suertegaray 2012). The process starts with

hydric dynamics, where there is the formation of ravines and gullies (Suertegaray 1987). The transport of sediment by surface runoff due to torrential rain episodes generates depositional fans (Suertegaray and Verdum 2008). The grouping of these fans forms deposits of exposed sand (Suertegaray 2012). Wind deflation is responsible for expanding the exposed sand area, suffocating the grassland vegetation characteristic of this region of *Rio Grande do Sul* state (Suertegaray 2012).

According to Kohler (2001), the definition of both spatial and temporal scales is essential to establish the approach level in geomorphological mapping. Because of the dynamics characteristics of erosion, transportation, and deposition of sediments from sandization, the study of the landforms associated with this process should be developed based on large scale analyses. The changes in the landscape, due to the eolian and hydric dynamics, and to human activities, are responsible for reworking sandy sedimentary soils that form rills, ravines, and gullies (Suertegaray 1987, Verdum 2012, Verdum and Soares 2010), and the spatial dimensions of these landforms (IBGE 2009), justify the analysis at large scales.

In topographic maps, contour lines and elevation points represent the variation of height and slope (BRASIL 1984). The contour lines intervals define the level of detail of the cartographic representation. There are gaps in the territory's coverage at different scales in the Brazilian topographic mapping, mainly for large scales. Moreover, some relief features may not be represented in topographic maps. An alternative is to use Digital Terrain Models (DTM) for extracting contour lines (DSG 2016a). Defining the level of detail of the relief representation depends on the spatial resolution and accuracy of the DTM.

The efficiency of research works based on spatial analysis is highly dependable on the scale of the cartographic representation of the phenomenon, once the results must reach the expected quality. A spatial data field survey for relief representation can be expensive and time-consuming. Therefore, efficient fieldwork planning should consider a prior definition of the level of detail and the cartographic product scale. There are many studies concerning the use of satellite data to map areas with sandization process (e.g., Suertegaray 1987, Suertegaray, Guasselli and Verdum 2001, Guasselli and Evers 2012, Caneppele 2017), and others that analyze the landforms related to sandization using in situ measurements (e.g., Verdum and Soares 2010, Fujimoto, Gonçalves and Zancanaro 2010). However, no work defines the suitable scales for the cartographic representation of relief features associated with the sandization process. Defining a suitable scale is essential to support geomorphological mapping and studies in the sandization areas and understand this process.

The determination of which relief features represent the sandization process demands defining the level of detail required for the cartographic representation. In this context, this study aims to define the level of detail required for the cartographic representation of the relief features associated with the sandization process. The results described in this article are part of a doctoral research project that intends to study the *Pampa* biome's landscape characteristics to propose a better solution for cartographic representation in Brazilian topographic maps.

The study area is regionally called *Cerro da Esquina* and is located in *São Francisco de Assis* municipality in the State of *Rio Grande do Sul*, in Brazil (Figure 1). We chose this area because relevant research results describe the relief features associated with the sandization process. Also, we have high spatial resolution topographic data derived from a Remotely Piloted Aircraft (RPA) survey.

The study area is in the *Guara* Formation and is characterized by fine to coarse sandstones (Wildner et al. 2007). The *Cerro da Esquina* is in the north portion of the *Ibicui* river, in a region with erosional hill landforms with low hill slope, ravines, and gullies (Guasselli and Evers 2012), and slopes with residual hills (Verdum and Soares 2010). It covers an area of 11.7 ha, with 7.6 ha of exposed sand.

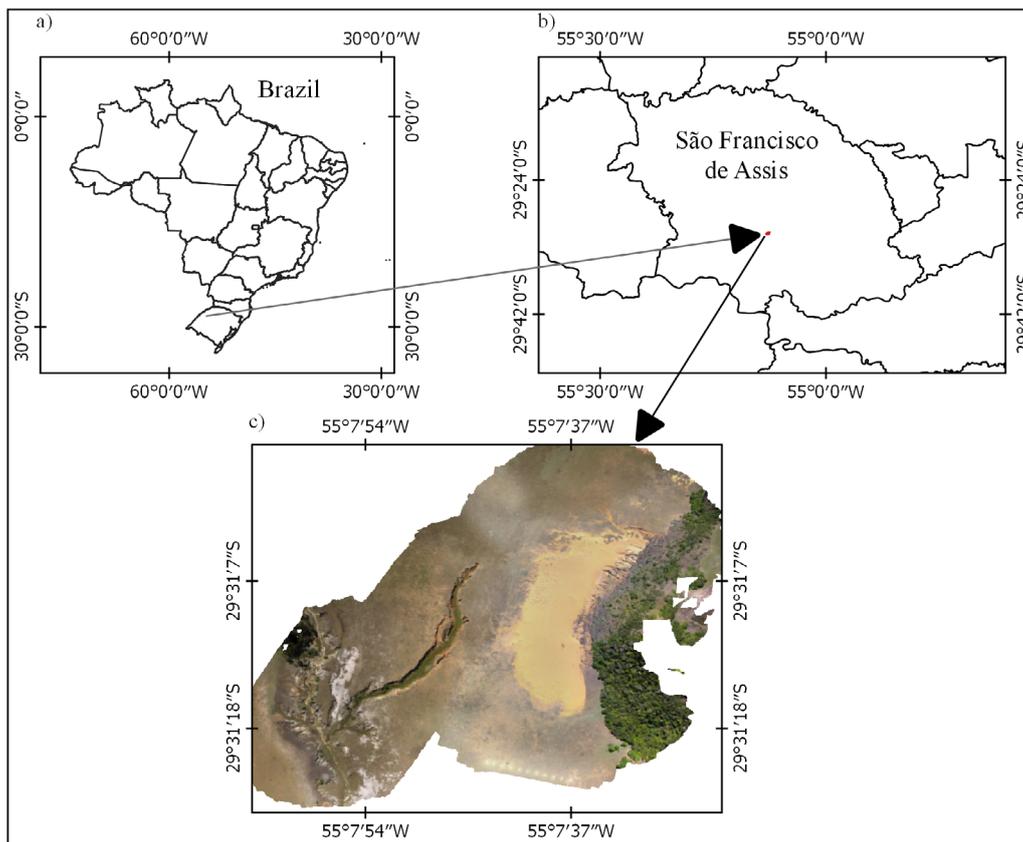


Figure 1: Location of the study area at a) the *Rio Grande do Sul* State of Brazil; b) *São Francisco de Assis* Municipality; c) Orthophoto mosaic.

2. Methodology

We divided the methodology into three steps. Firstly, we defined the study area's representative landforms based on the literature review that describes the landforms' geomorphological characteristics. The geomorphological characteristics of each landform are essential to analyze the results. In the second step, we described the aspects of data survey using Remotely Piloted Aircraft (RPA) to generate the orthophoto mosaic and the Digital Surface Model (DSM). After that, we used the DSM to extract contour lines at different scales and analyzed the landforms' resulting cartographic representation at these scales. In this study, we considered the DTM as a surface representing the height variation of a terrain surface and the DSM, a surface representation that includes all non-terrain objects (Wang, Hu and Tao 2004). We used DSM to generate the contour lines instead of the DTM because, in the study area, there are no features other than the relief itself.

2.1 Geomorphological Features of the study area

The study area's landforms are originated by erosive and depositional processes (Verdum and Soares 2010), resulting from landscape dynamics. We defined the representative landforms analyzed in this research based on the literature review and visual analysis of the orthophoto mosaic and the DSM. These landforms (Figure 2) are denudational landform (Fujimoto, Gonçalves and Zancanaro 2010), rill, ravine, micro-residual hill, dune, depositional fan, concentrated flow (Verdum and Soares 2010), and gully (Guasselli and Evers 2012).

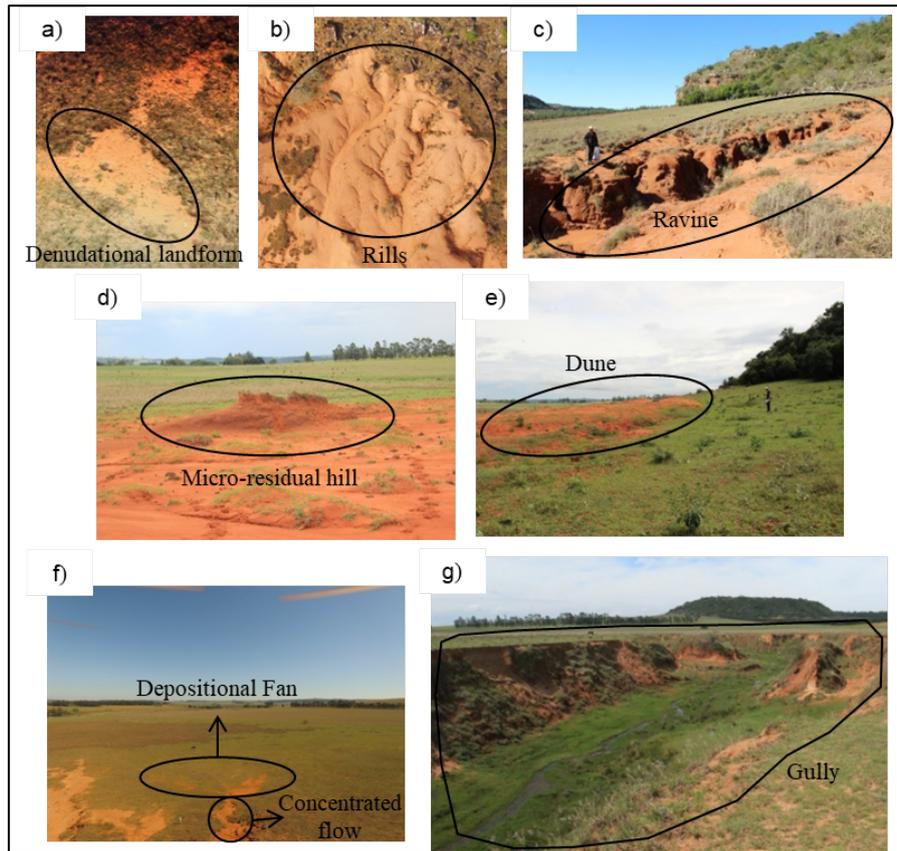


Figure 2: Landforms at the study area: a) Denudational landform; b) Rill; c) Ravine; d) Micro-residual hill; e) Dune; f) Depositional Fan and Concentrated flow; g) Gully.

2.2 Orthophoto mosaic and DSM

We used a DSM and an orthophoto mosaic with very high spatial resolutions for cartographic representation and spatial identification of the study area's relief features. The orthophoto mosaic and the DSM were generated with RPA data, surveyed on September 2nd, 2016, and using Structure from Motion (SfM) and Multi-View Stereo (MVS) approaches.

The RPA survey was carried out using 16 Ground Control Points (GCPs) distributed in the study area and seven additional GCPs in the ravine landform. There was also one reference point as a stationary Global Navigation Satellite System (GNSS) receiver (base receiver). These GCPs were marked on the ground with vinyl targets, and their center points coordinates were surveyed using Topcon Hiper Lite Plus dual-frequency receivers, with the fast static relative positioning technique. After post-processing, the horizontal accuracy for the GCPs coordinates was 1.44 cm, and the vertical accuracy was 0.08 cm. The point's coordinates were used to validate and georeference the aerial images. The height of the RPA flight was 110m with 5cm of Ground Sample Distance (GSD). The forward and lateral overlaps of aerial photos were 80% and 60%, respectively. The 3D point cloud construction was done using SfM, and MVS approaches, and it was used for the DSM generation, with approximately 9cm of spatial resolution. The aerial images were orthorectified, and the resulting orthophoto mosaic had approximately 5cm of spatial resolution.

2.3 Cartographic landform representation

To determine the level of detail required for the landforms’ cartographic representation, we first defined five different scales. Then we extracted the contour lines from the DSM and analyzed the landforms considering these scales. We established the scales based on the premise that some quantities are cognitively easier to visualize and mentally calculate than others. These quantities are 2, 5, and 10, and that is why cartographic scales usually are 1:1,000; 1:2,000; 1:5,000; 1:10,000; and so on. As this study is related to very large scales, we analyzed the 1:100, 1:200, 1:500, 1:1,000, and 1:5,000 scales. The intervals between contour lines are coherent with the Brazilian topographic mapping (BRASIL 1984, DSG 2016b). Table 1 presents the scales for cartographic landforms representation and their respective contour intervals.

Table 1: Scales and contour intervals for the cartographic representation of landforms.

Scale	Contour interval (meters)
1:5,000	2
1:1,000	1
1:500	0.5
1:200	0.2
1:100	0.1

We used the orthophoto mosaic as reference data for the spatial identification of the landforms, and we analyzed the contour lines according to the scales shown in Table 1. This analysis defined the level of detail for the cartographic representation of each sandyzation process’s landform. We based our analysis on the geomorphological characteristics of each landform. That allowed us to verify and discuss if the contour lines depicted at each scale represent the landforms’ geomorphological characteristics.

Figure 3 illustrates the scheme we used for representing the landforms at 1:1,000, 1:500, 1:200, and 1:100 scales. The largest rectangle indicates the scale of analysis (1:100). In the subsequent scales, the rectangle that depicts the region related to the 1:100 scale allows us to understand the spatial relationship among those scales.

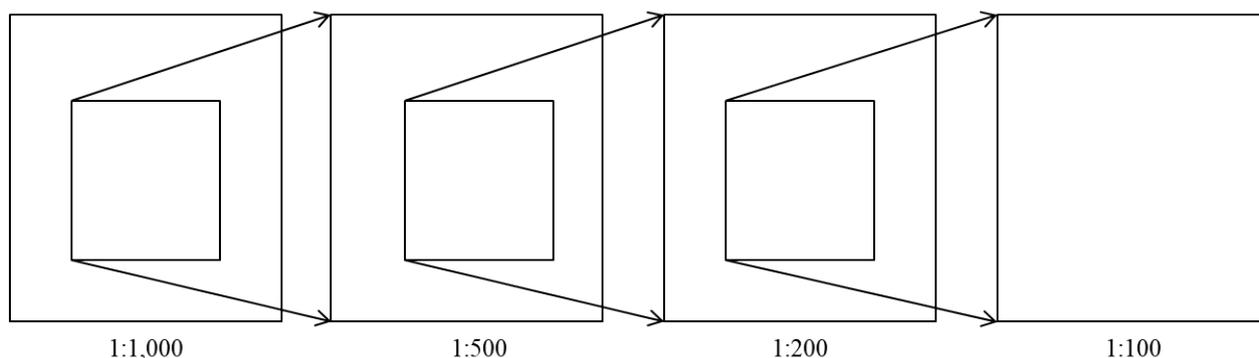


Figure 3: Illustrative scheme of the contour lines representation at different scales.

3. Results and Discussion

The very high spatial resolution of the DSM and the orthophoto mosaic made it possible to identify some landforms of the sandization process areas. Figures 4 and 5 show the landforms' spatial location in the DSM and orthophoto mosaic, respectively. Figure 6 shows the landforms' spatial location in a contour lines representation at a 1:5,000 scale. The rectangles in Figures 4, 5, and 6 correspond to the areas where there are different landforms (1. denudational landform, 2. rill, 3. ravine, 4. micro-residual hill, 5. dune, 6. depositional fan, 7. concentrated flow, and 8. gully) that we analyzed at 1:100 to 1:1,000 scales.

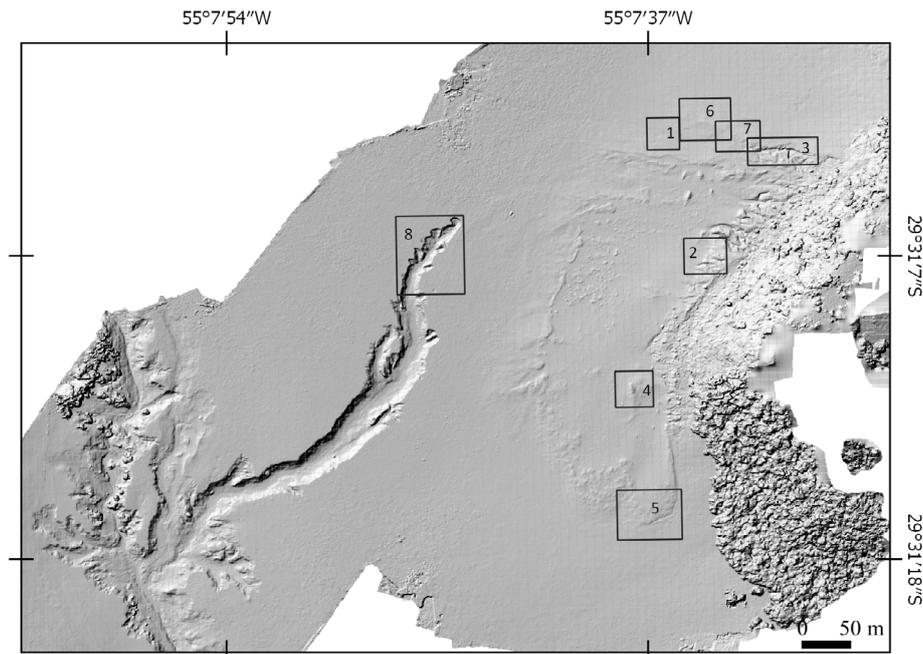


Figure 4: DSM of the study area at 1:5,000 scale with the landforms' spatial location.

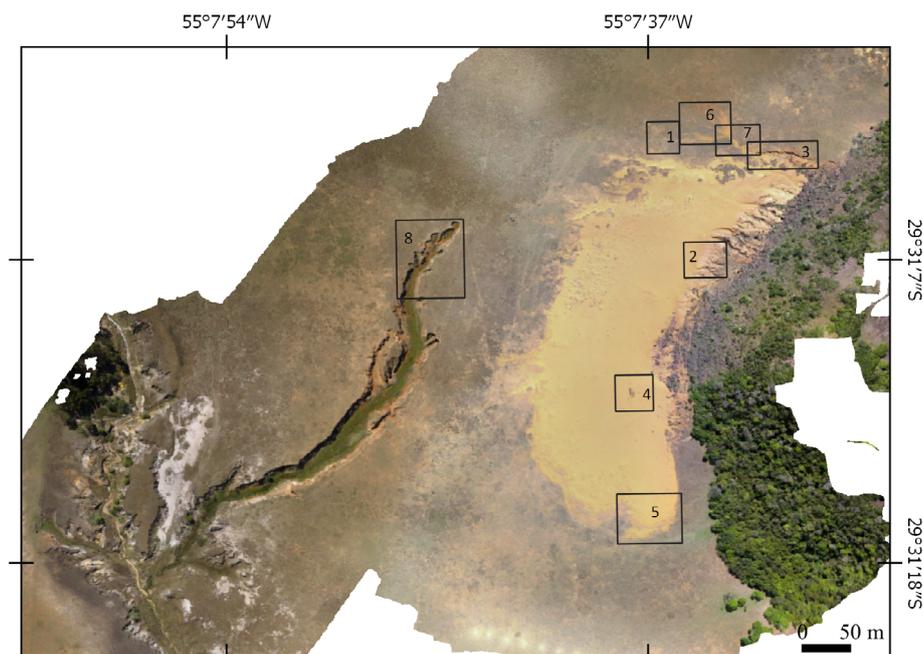


Figure 5: Orthophoto mosaic of the study area at a 1:5,000 scale with the landforms' spatial location.

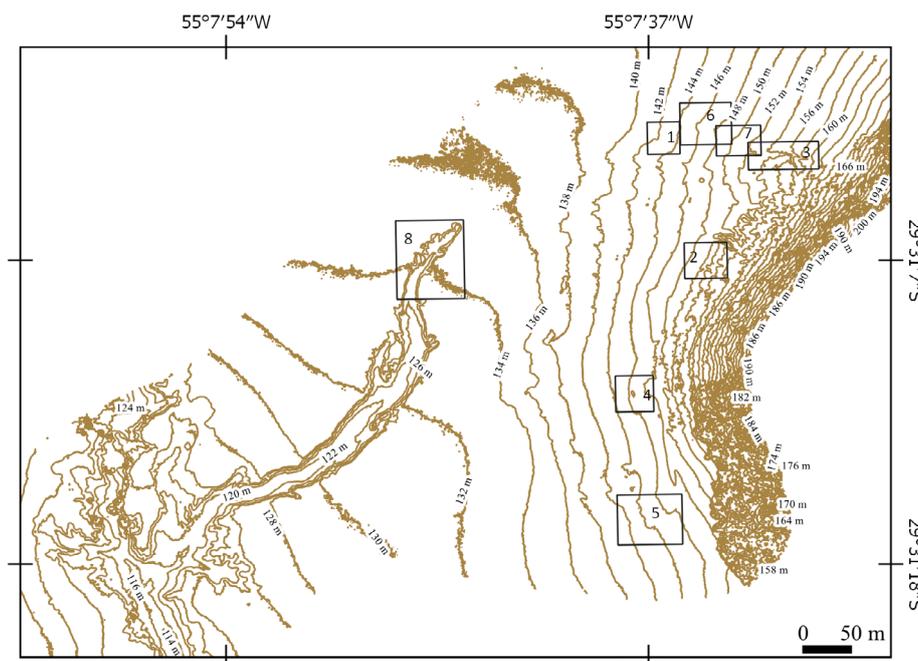


Figure 6: Contour lines with 2m intervals of the study area at a 1:5,000 scale with the landforms’ spatial location.

Figure 7 shows the cartographic representation of the denudational landform at different scales. The denudational landform is a micro-relief feature characterized by small depressions or steps caused by the loss of iron oxides on the surface (Fujimoto, Gonçalves and Zancanaro 2010). This micro landform is regionally called *degrau de abatimento* (Uagoda et al. 2004). The denudational landform has a rounded or semicircular elongated shape and occurs in the headwater drainage (Uagoda et al. 2004, Fujimoto, Gonçalves and Zancanaro 2010) and in areas where the superficial erosion is not relevant (Fujimoto, Gonçalves and Zancanaro 2010).

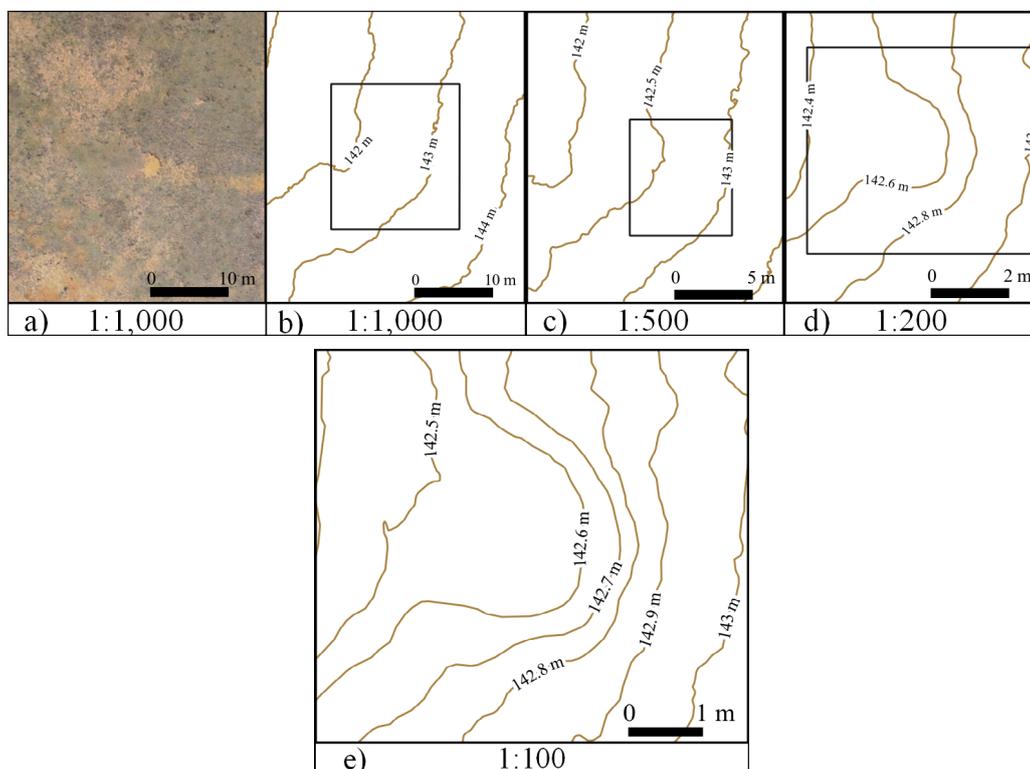


Figure 7: Denudational landform: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

Figures 7(a, b) show a denudational landform area, number 1 on the orthophoto mosaic (Figure 5), represented at a 1:1,000 scale. The analysis at different scales indicates that one can depict this micro landform at a 1:200 scale (Figure 7d) and, consequently, at a 1:100 scale (Figure 7e). The rounded or elongated semicircular shape is visible at both scales. At these scales (Figures 7d, e), it is possible to identify the region where the terrain collapsed. The scales smaller than 1:200 represented in Figures 7c (1:500), 7b (1:1,000), and Figure 6 (1:5,000) are not suitable for identifying the denudational landform. At a 1:500 scale (Figure 7c), the contour lines can only show where there is this kind of landform, but even that, with a low level of detail. At a 1:1,000 scale (Figure 7b) and at a 1:5,000 scale (Figure 6), the contour lines can neither represent the geomorphological characteristics of the denudational landform nor its spatial location.

Figures 8.1 and 8.2 represent the rills at different scales. The study area's rills are small shallow channels formed due to the surface runoff (Verdum and Soares 2010). According to Suertegaray (2011), the rills favor the concentrated runoff and evolve into ravines and gullies.

Figure 8.1a shows a rill, number 2 on the orthophoto mosaic (Figure 5), represented at a 1:1,000 scale. The shallow channels' geomorphological characteristics are better represented at 1:200 (Figure 8.1d) and 1:100 (Figure 8.2e) scales. At a 1:100 scale (Figure 8.2e), it is possible to identify the rills' shallow channels and the flow direction of the surface runoff. At a 1:200 scale (Figure 8.1d), these characteristics are still represented by the contour lines at a less level of detail. At a 1:500 scale (Figure 8.1c), one can barely perceive the shallow channels' cartographic representation. At this scale, the contour lines represent the deeper and larger channels that characterize surface runoff in ravines. At a 1:1,000 scale (Figure 8.1b), the contour lines are not able to represent the shallow channels, just the deeper ones with an advanced process of erosion in ravines. At a 1:5,000 scale (Figure 6), the contour lines indicate only the spatial location of the deeper channels in ravines, but it is not possible to see their geomorphological characteristics.

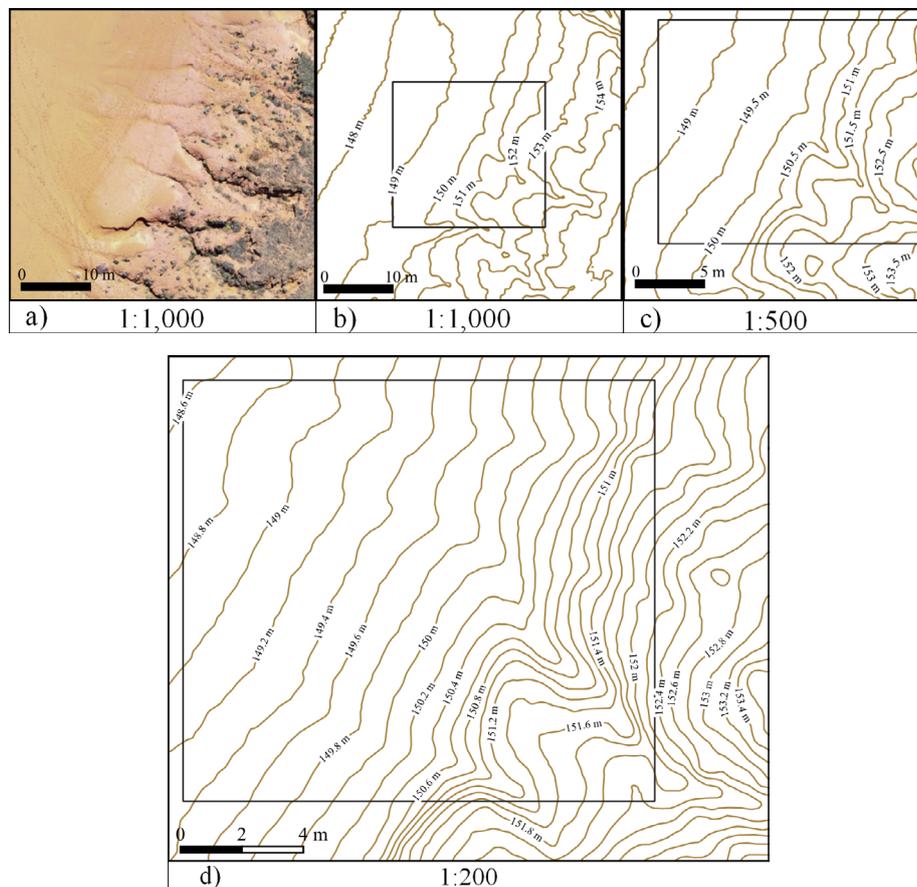


Figure 8.1: Rill: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale.

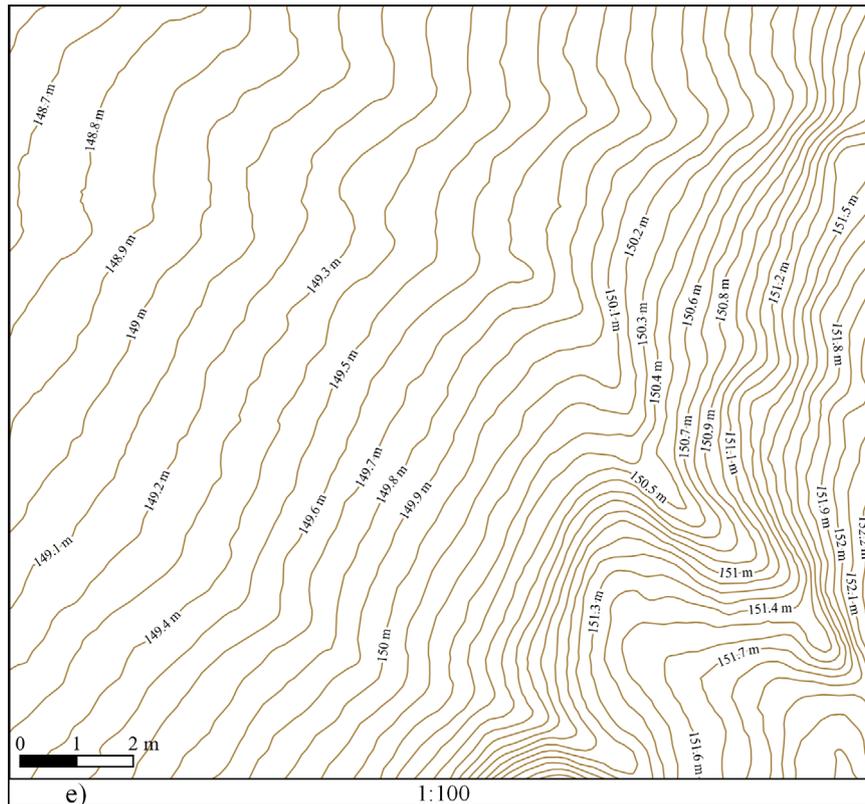


Figure 8.2: Rill: e) contour lines at 1:100 scale.

Figures 9.1 and 9.2 show the cartographic representation of the ravine at different scales. The ravines were described by Suertegaray (2011) as the second phase of the sandization process. The ravines are formed by hydric dynamics responsible for enlarging the rills due to the surface runoff's erosion. The exposed sediments are transported and deposited during rain episodes (Suertegaray 2011).

Figure 9.1a shows a ravine, number 3 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. The ravine's geomorphological characteristics are better represented by the contour lines at a 1:500 scale (Figure 9.1c) and larger ones. At a 1:100 scale (Figure 9.2e), the contour lines represent the ravine slope and the channel formed due to the concentrated flow at a high level of detail. Also, the level of detail of this scale makes it possible to represent the sediment flow direction. At a 1:200 scale (Figure 9.1d), the contour lines still represent the geomorphological characteristics, but with a less level of detail. At a 1:500 scale (Figure 9.1c), the contour lines delineate the same geomorphological characteristics represented at a 1:100 or a 1:200 scale. Consequently, one can use the 1:500 and larger scales for a more detailed analysis of the erosion process. At a 1:1,000 scale (Figure 9.1b), the contour lines allow us to spatially identify the ravine because it can represent the deeper channels and the concentrated flow direction. However, the ravine slopes' representation has a lower level of detail than the one at larger scales, as expected. At a 1:5,000 scale (Figure 6), the contour lines represent the spatial location of the ravine, but the geomorphological characteristics, such as slopes, are not depicted. At this scale, the contour lines represent only the direction of the sediment flow.

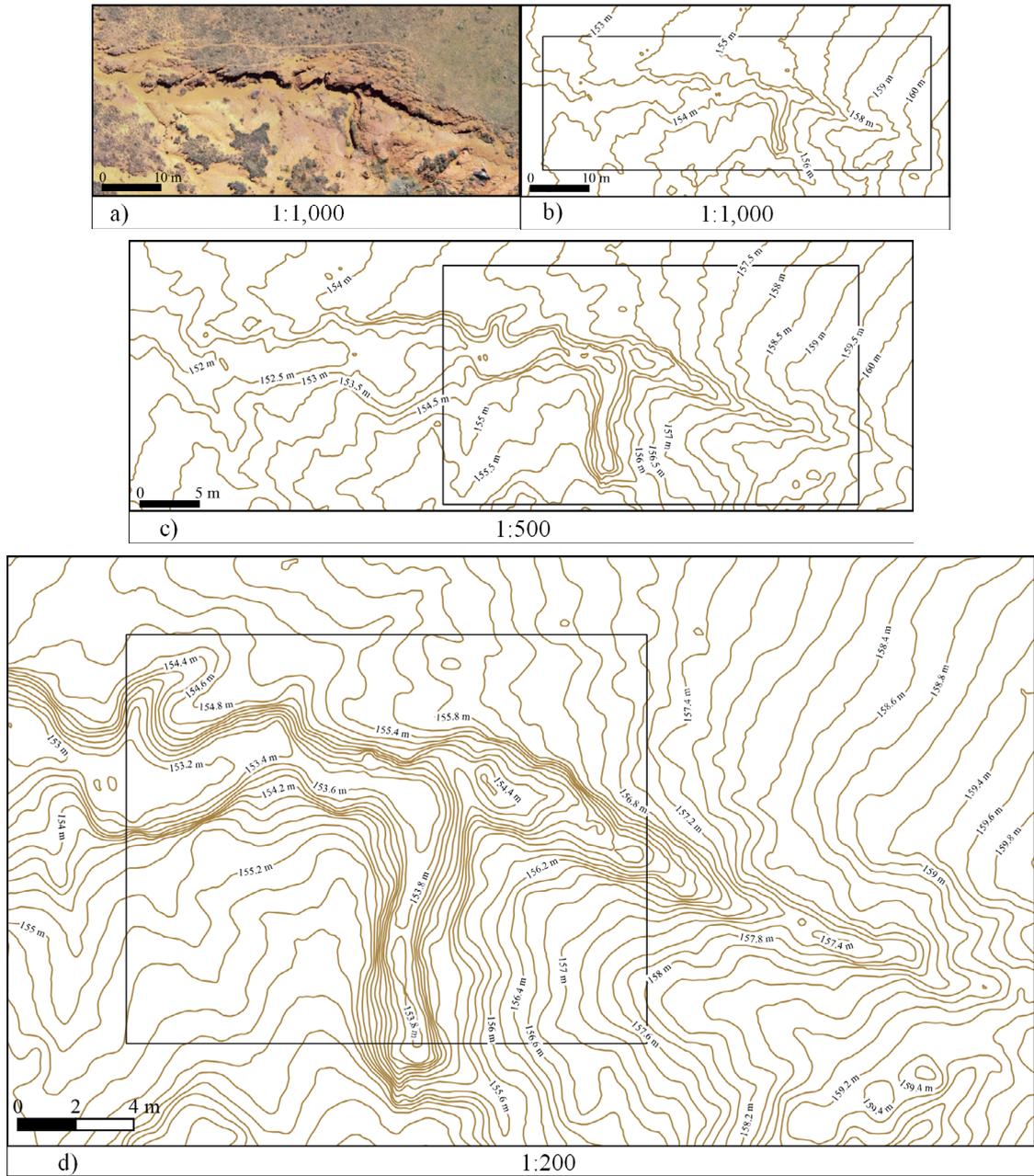


Figure 9.1: Ravine: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale.

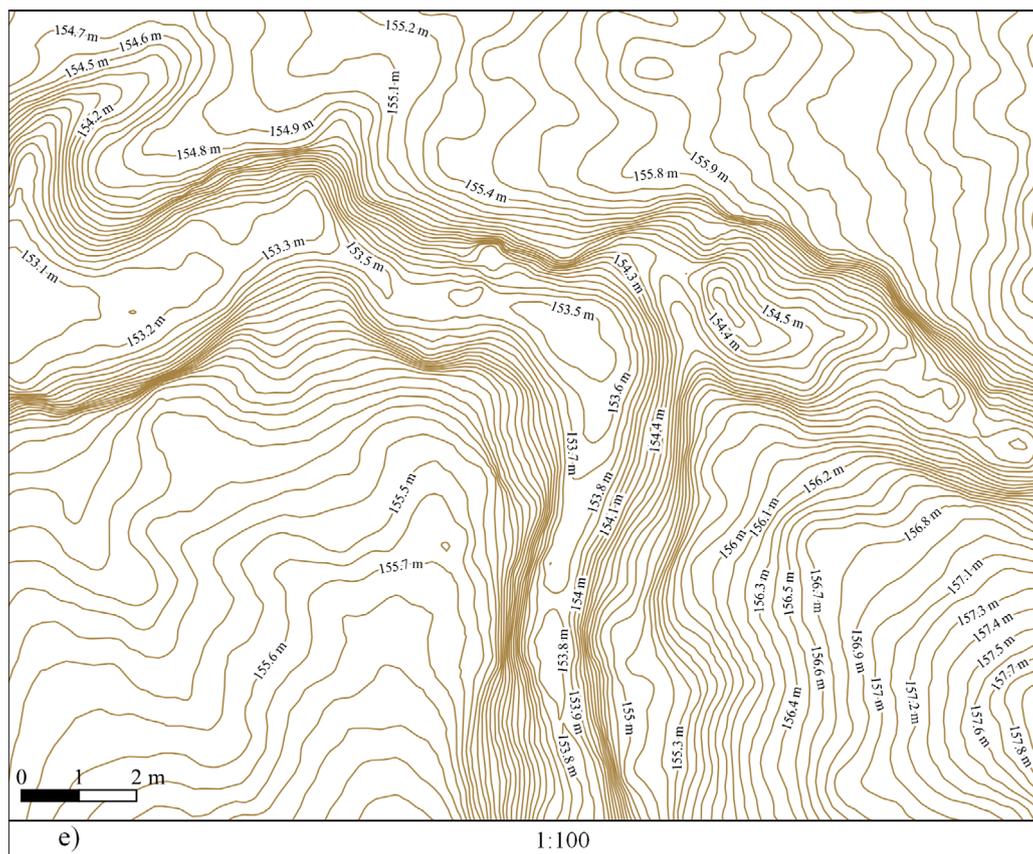


Figure 9.2: Ravine: e) contour lines at 1:100 scale.

Figure 10 shows the cartographic representation of the micro-residual hill at different scales. The micro-residual hill indicates the original surface elevation before the erosion process (Verdum and Soares 2010, Suertegaray et al. 2008). The sediments and the micro-residual hills' surface vegetation are more resistant to the erosion processes (Suertegaray et al. 2008).

Figure 10a shows a micro-residual hill, number 4 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. The micro-residual hill's geomorphological characteristics are better represented by a 1:500 scale (Figure 10c) and larger ones. The contour lines at a 1:100 scale (Figure 10e) have a proper level of detail to represent this landform. It is possible to represent both the lower and the higher elevation of this relief feature and the areas with the highest slope at this scale. At a 1:200 scale (Figure 10d), the contour lines still represent the contour lines' characteristics at a 1:100 scale. At a 1:500 scale (Figure 10c), the contour lines represent the same geomorphological characteristics one can see in the larger scales, but with a much lower detail level. However, even with a low level of detail, the contour lines still represent this micro-relief feature's main geomorphological characteristics, such as the areas with high slope and the base and the top of the micro-residual hill. At a 1:1,000 scale (Figure 10b), the contour lines cannot represent this landform's geomorphological characteristics. At this scale, the contour lines can delineate only the micro-relief feature's spatial location by the representation of its top. The same situation happens at a 1:5,000 scale (Figure 6), where the contour lines depict only the spatial location of the geomorphological characteristics of this landform, that could be represented as a point symbol, therefore, with a lower level of detail than contour lines at a 1:1,000 scale.

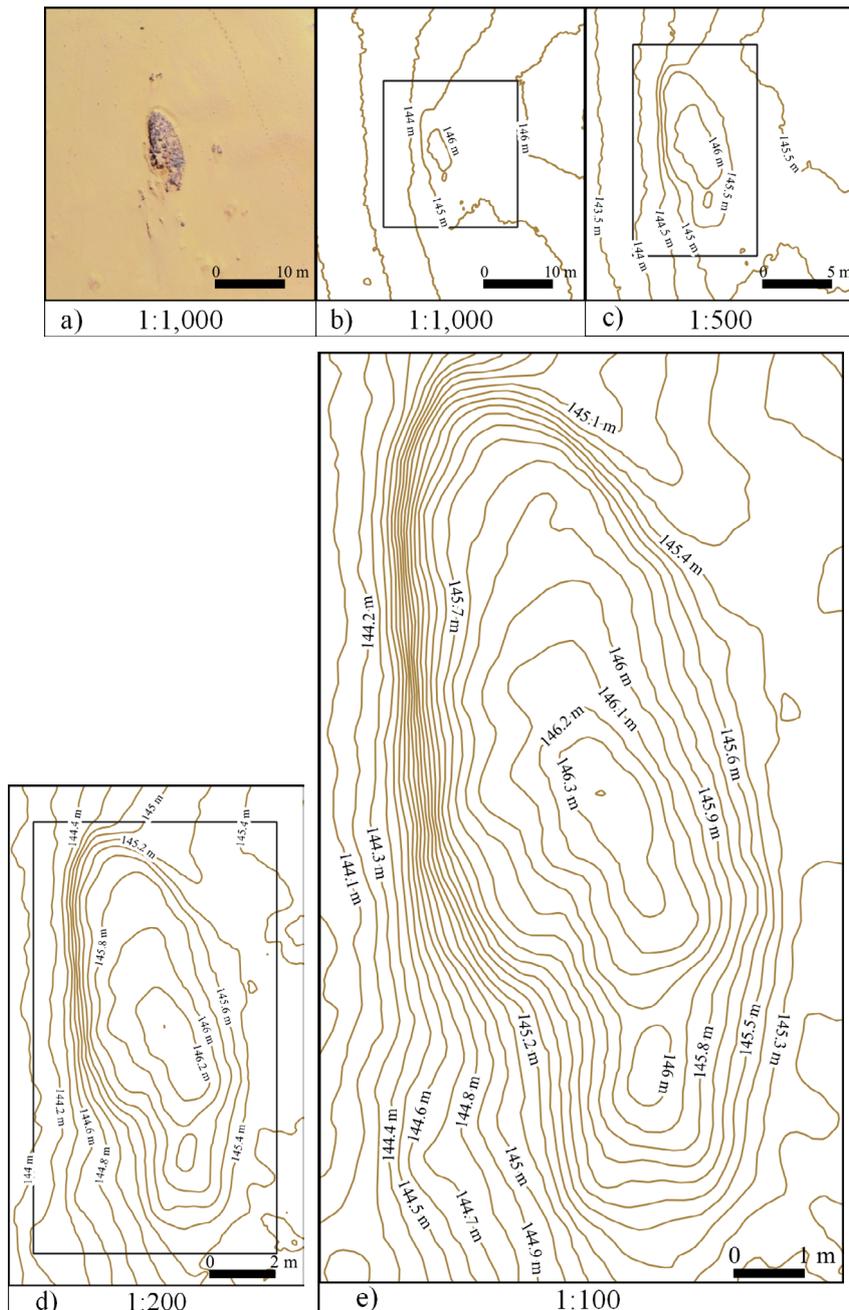


Figure 10: Micro-residual hill: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

Figures 11.1 and 11.2 show the cartographic representation of the dune. The dune of the study area is formed by a high accumulation of sand sediments due to the eolian process of sandyization (Verdum and Soares 2010). Figure 11.1a shows a dune, number 5 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. At a 1:100 scale (Figure 11.2e), the contour lines can depict the dune's geomorphological characteristics by showing in detail the boundary of the sand accumulation. The boundary can be defined by the surface slope because it is established by the sand sediment flow direction. At a 1:200 scale (Figure 11.2d), the contour lines still show the same characteristics of the dune represented at the 1:100 scale. Even though in a 1:500 scale (Figure 11.1c), the contour line representation is at a lower level of detail, it still can represent the same characteristics of the dune. Therefore, at 1:100, 1:200, and 1:500 scales, the representation of the slope's variation makes it possible to limit the extension of dunes formed by the accumulation of sand sediments. At a 1:1,000 scale (Figure 11.1b), the contour lines have a too low level of detail to characterize the area with sand accumulation, but it is still possible to identify some geomorphological

characteristics as the boundary of the dune. At a 1:5,000 scale (Figure 6), one can only identify the region of sand accumulation, but with a low level of detail to delimit the dune and the sand accumulation.

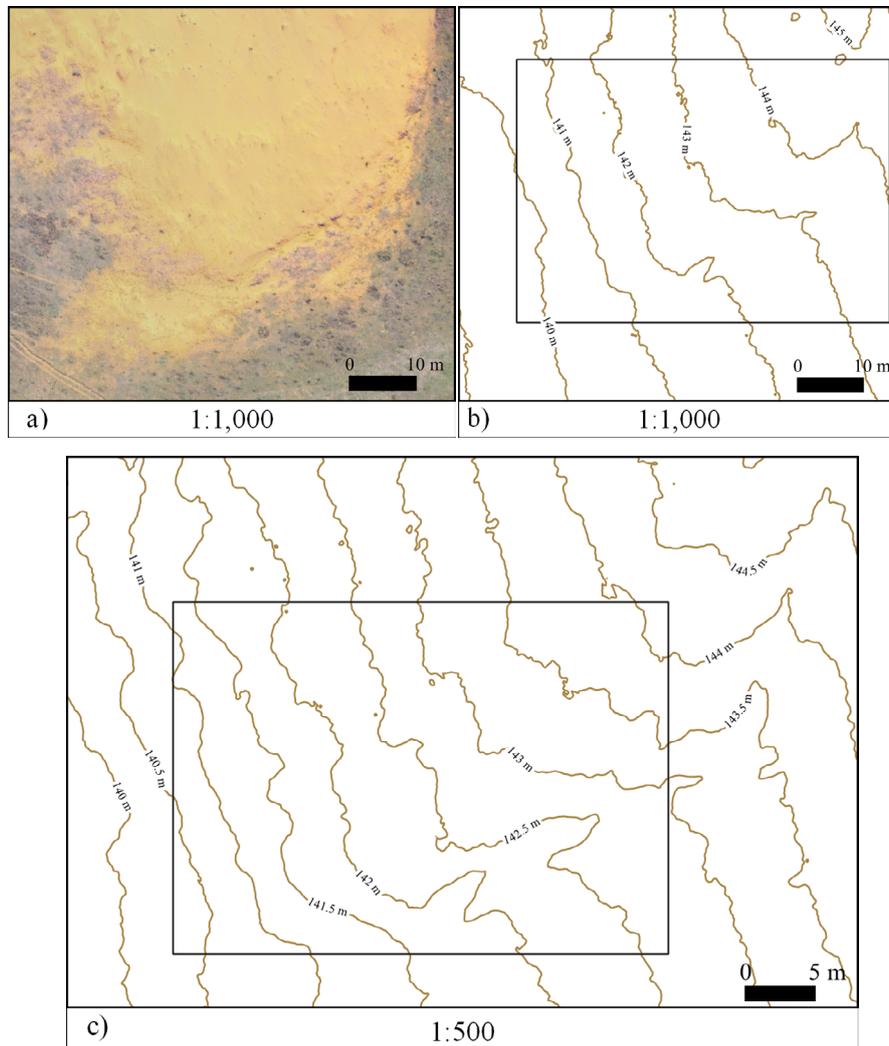


Figure 11.1: Dune: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale.

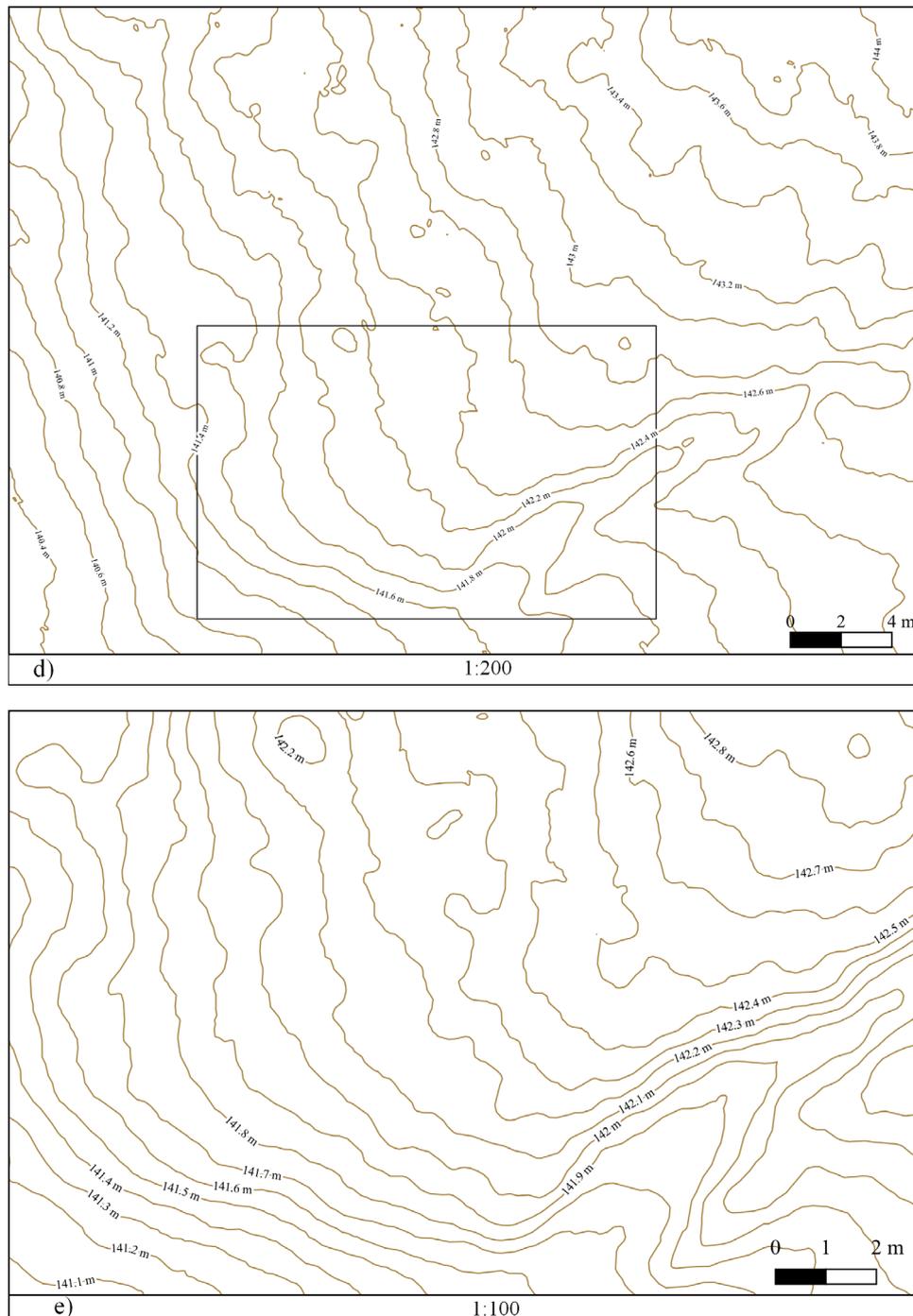


Figure 11.2: Dune: d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

Figure 12 shows the cartographic representation of the depositional fan at different scales. The depositional fan occurs due to the transport of sediments by surface runoff in torrential rain episodes in the sandyization process area (Suertegaray 2011). These features occur at the base of ravines and gullies (Suertegaray 2011). Figure 12a shows a depositional fan, number 6 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. At a 1:100 scale (Figure 12e), the fan shape is depicted by representing the directional flow of sediments' deposit with a high level of detail. At a 1:200 (Figure 12d) and 1:500 (Figure 12c) scales, the contour lines still represent the directional flow of sediments' deposit in a fan shape of the depositional process that characterized this landform. At a 1:1,000 scale (Figure 12b), the contour lines represent the area of the deposit of sediments, but the fan shape is not visible, only the main depositional flow direction. At the 1:5,000 (Figure 6), the contour lines can represent only the region's point spatial location where the deposit of sediments occurs.

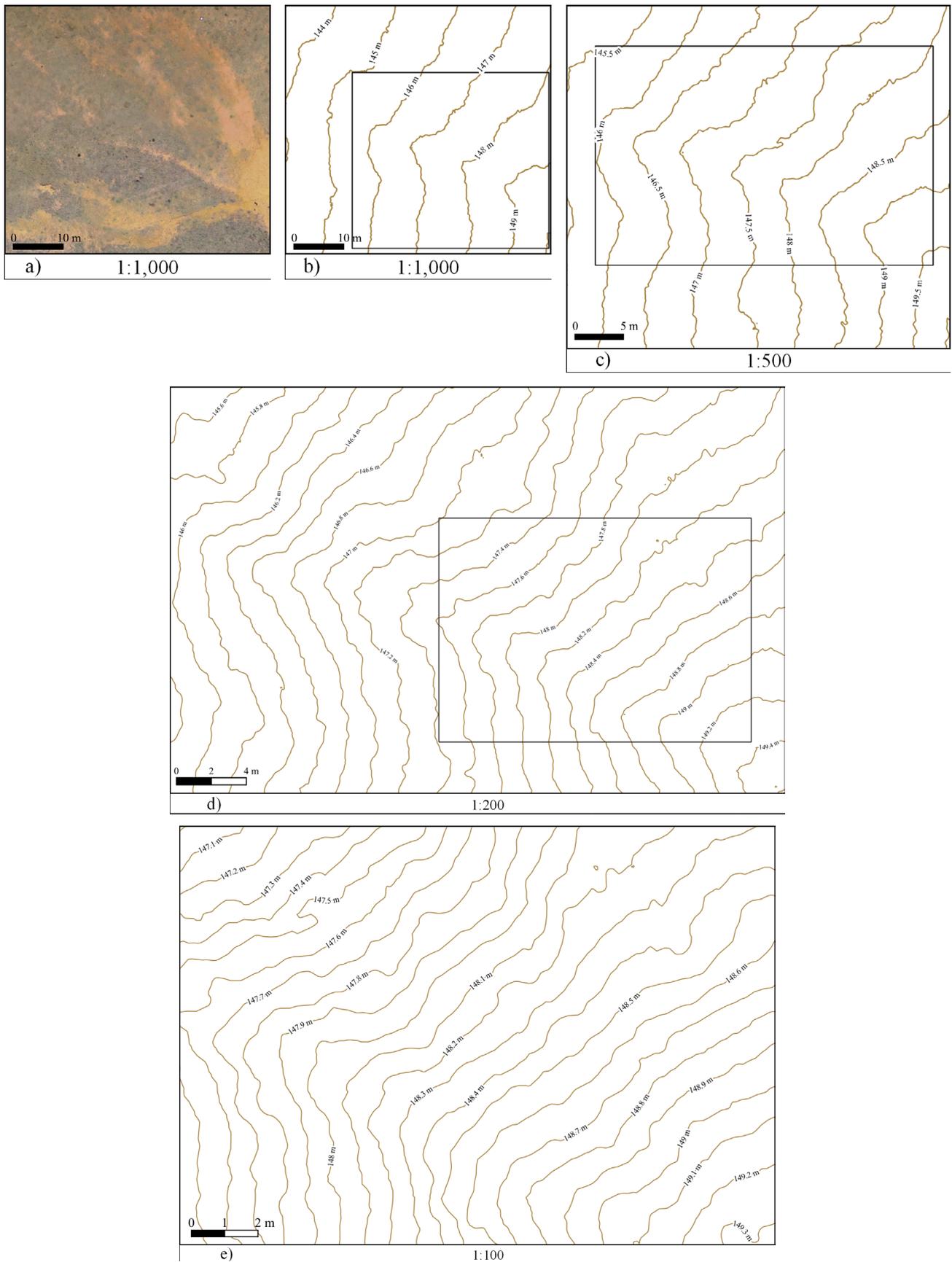


Figure 12: Depositional Fan: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

According to Suertegaray and Verdum (2008), the surface runoff by concentrated flow is responsible for exposing, transport, and deposit the sand sediments in the sandzation process. The concentrated flow represented in Figures 13.1 and 13.2 is part of the landform responsible for transporting the sediments, which means the transition between the denudational and depositional processes, present in the ravine and depositional fan, respectively. Figure 13.1a shows a concentrated flow, number 7 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. At a 1:100 scale (Figure 13.2e), the contour lines represent this landform's geomorphological characteristics at a high level of detail. The concentrated flow is represented by the main channel of the sediment flow. At 1:200 (Figure 13.2d) and 1:500 scales (Figure 13.1c), the contour lines represent the same geomorphological characteristics one can see at a 1:100 scale. The main channel has a lower level of detail at a 1:500 scale, but the contour lines still represent it. The region of transition between the denudational and depositional processes is also represented at this scale. At a 1:1,000 scale (Figure 13.1b), the contour lines make it possible to identify the concentrated flow and the region of transition between denudational and depositional processes. However, fewer contour lines represent the main channel characterizing this landform, which means insufficient detail to delineate the channel. At a 1:5,000 scale (Figure 6), the contour lines represent only the spatial location of this landform, and the limits of the channel are not represented. The region of transition between denudational and depositional processes is provided only by a point spatial location.

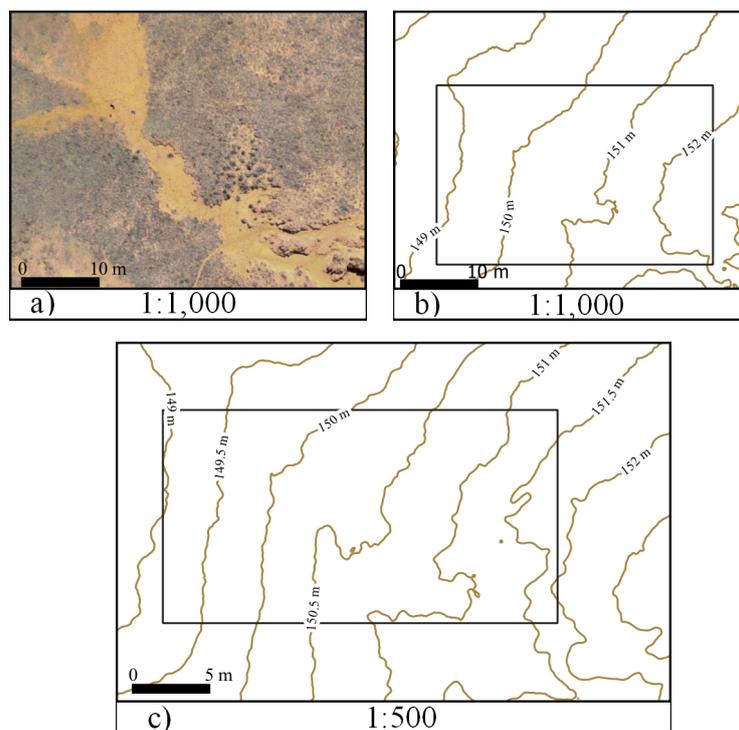


Figure 13.1: Concentrated Flow: a) orthophoto mosaic at 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale.

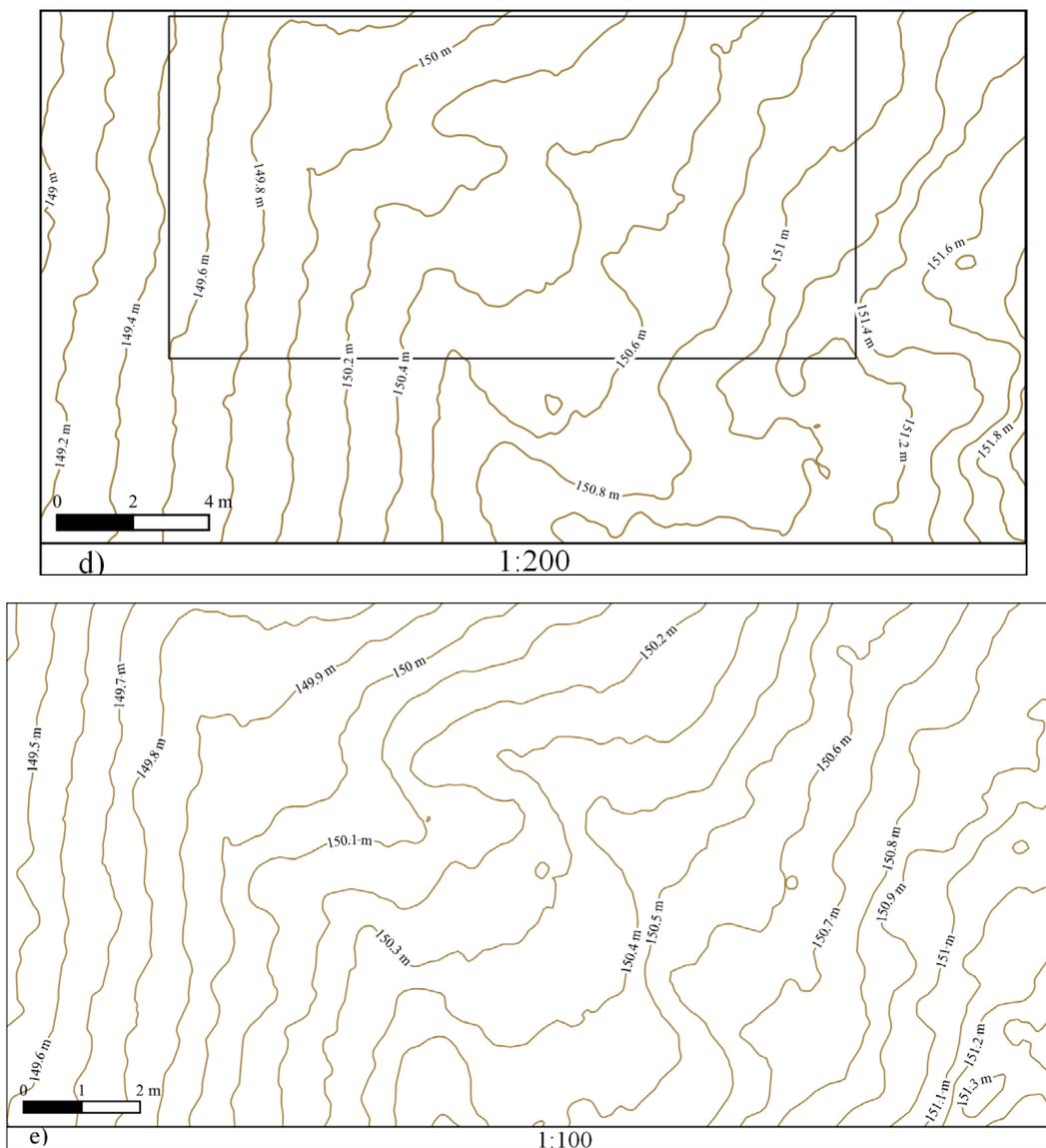


Figure 13.2: Concentrated Flow: d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

Figure 14 shows the cartographic representation of the gully. The gully is described as a landform with an advanced erosion process and a high slope (Suertegaray et al. 2008, IBGE 2009). The gully covers a considerable portion of the study area. This landform is the only one analyzed in this study that is out of the area’s limits with exposed sand in the floodplain compartment. Besides that, the gully is associated with the areas with sandzation process, and it is related to the instability of the landscape (Suertegaray et al. 2008, Guasselli and Evers 2012). Figure 14a shows the gully, number 8 on the orthophoto mosaic (Figure 5), at a 1:1,000 scale. At a 1:100 scale (Figure 14e), the contour lines represent gully characteristics at a high detail level. Some gully characteristics are high slopes and channels, with location and direction of concentrated flow of sediments. At a 1:200 scale (Figure 14d), it is still possible to represent the same geomorphological characteristics that one can see on a 1:100 scale. Although the 1:500 (Figure 14c) and 1:1,000 scales (Figure 14b) have a lower level of detail, the gully’s geomorphological characteristics are still represented. At a 1:500 scale, it is possible to identify high slopes and channels with the direction of the concentrated flow at the gully base.

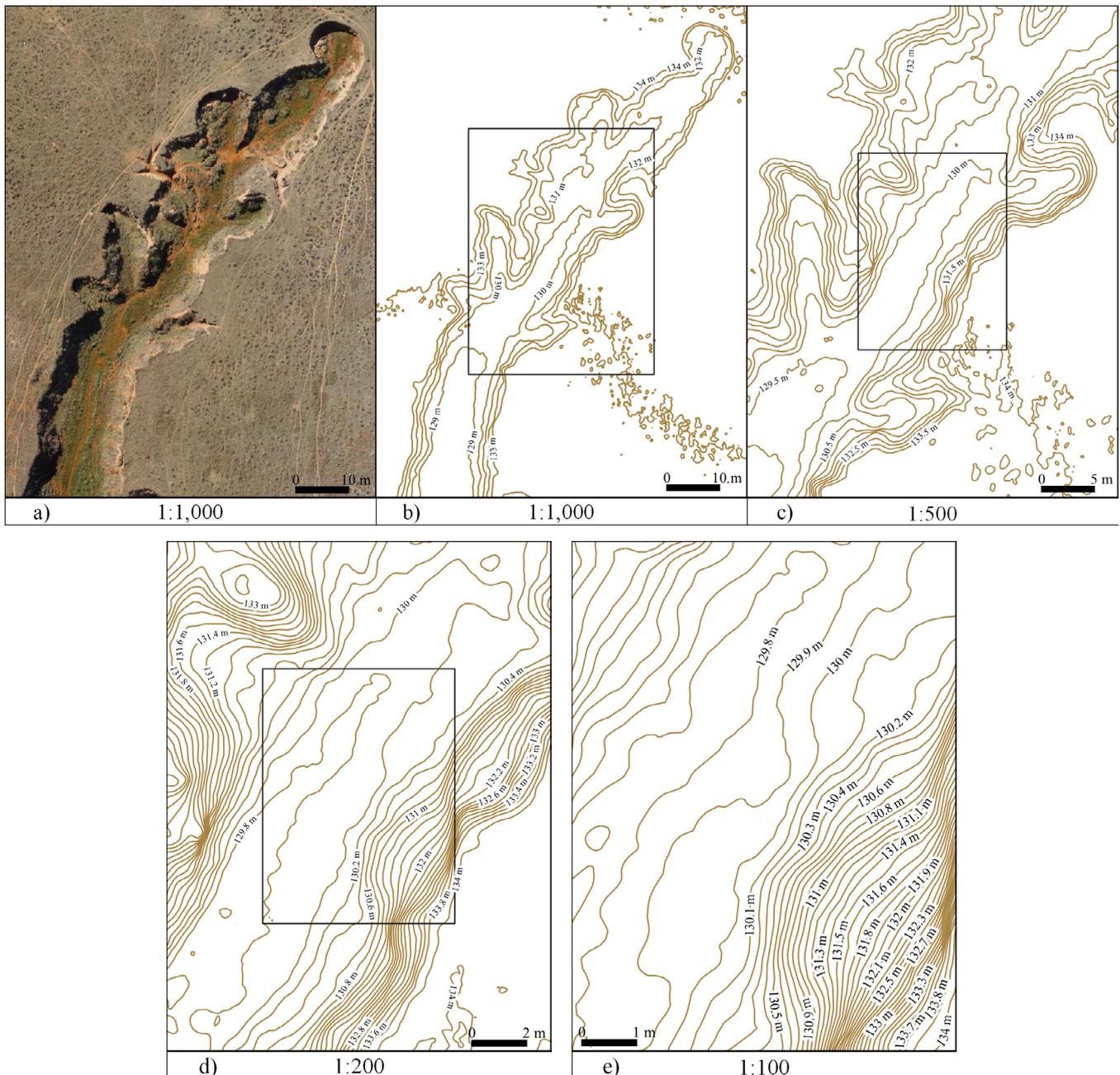


Figure 14: Gully: a) orthophoto mosaic at a 1:1,000 scale; b) contour lines at 1:1,000 scale; c) contour lines at 1:500 scale; d) contour lines at 1:200 scale; e) contour lines at 1:100 scale.

4. Conclusion

The erosion caused by hydric and eolian dynamics in areas with sandization process forms relief features that expose the sandy soil and highlight the landscape's fragility. These features are not exclusive of this process but are related to it. Mapping these landforms is important to support geomorphological studies in sandization areas and also to understand this process. In this study, we defined the suitable scales for the cartographic representation of landforms associated with the sandization process. To achieve our goal, we first defined the representative landforms of the study area, based on the literature review that describes the geomorphological characteristics of the landforms. This step was important for defining the level of detail required for the relief representation. In the second step, we described the aspects of data survey using RPA to generate the high spatial resolutions DSM and

orthophoto mosaic. The orthophoto mosaic allowed us to identify the landforms arising from the sandyzation process in the study area. We used the DSM to extract contour lines at 1:5,000, 1:1,000, 1:500, 1:200, and 1:100 scales. With the contour lines intervals stated for each scale, we defined the level of detail required for the relief representation. This research analyzed eight landforms: denudational landform, rill, ravine, micro-residual hill, dune, depositional fan, concentrated flow, and gully. Because of the known characteristics of the relief features, we could verify if the geomorphological characteristics of these landforms are cartographically represented and at which scale.

The results showed us that the landforms such as denudational landform, rill, and dune have their geomorphological characteristics better represented by contours lines at 1:200 scale and larger ones. At 1:500 scale and smaller ones (1:500 to 1:5,000), the contour lines generalize these landforms' cartographic representation but still depict their spatial location. The geomorphological characteristics of the micro-residual hill, depositional fan, and concentrated flow are better represented at 1:500 scale and larger ones. The contour lines at smaller scales (1:1,000 and 1:5,000) can represent these landforms' spatial location, except the depositional fan. These scales represent the main direction of the transport and deposition of sediments. Ravine's geomorphological characteristics are better represented by contour lines at 1:1,000 scale and larger ones. At a 1:5,000 scale, this landform can be represented only by point symbols. The gully is the only feature we analyzed with the geomorphological characteristics represented by contour lines at 1:5,000 and larger.

The main result we achieved in developing this study was to show the level of detail required for the cartographic representation of the erosive landforms associated with the sandyzation process. The results also showed us that different geomorphological characteristics of the analyzed landforms require a different level of detail; therefore, different scales. The choice of the best scale depends on the main goal of the research work. Since there is no scientific reference for suitable scales for the cartographic representation of landforms related to the sandyzation process, this study can contribute to geomorphological researches in areas where this process occurs.

ACKNOWLEDGMENT

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001, and by Bolsa Produtividade em Pesquisa do CNPq - Brasil.

AUTHOR'S CONTRIBUTION

All the authors contributed equally to make the writing of this paper possible.

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