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Research Article

Methodological considerations and proposed integrated legend for anthropogenic geomorphological mapping

Considerações metodológicas e proposição de legenda integrada para mapeamento geomorfológico antropogênico

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Abstract: The present work aims to propose methodological considerations for the realization of geomorphological mappings focusing on anthropogenic relief forms with the presentation of an example of an integrated legend designed to be used in this type of mapping. The main issues surrounding the realization of geomorphological mapping are discussed, especially those aimed at identifying, classifying, and recording the forms resulting from human action. A broad bibliographic and methodological review of research on anthropogenic geomorphology and on geomorphological mapping under development in Brazil and abroad was carried out. Based on this conceptual and methodological review, this work proposes to create a new methodological proposal for geomorphological mapping with a focus on anthropogenic landforms and an integrated legend.

Keywords: Anthropogenic Geomorphology; Anthropogenic Landforms; Geomorphological Mapping.

Resumo: O presente trabalho tem por objetivo propor considerações de cunho metodológico para a realização de mapeamentos geomorfológicos com foco em formas de relevo antropogênico com a apresentação de um exemplo de legenda integrada elaborada para ser utilizada neste tipo de mapeamento. São discutidas as principais problemáticas acerca da realização do mapeamento geomorfológico e, principalmente, daqueles voltados para a identificação, classificação e registro das formas resultantes da ação humana. Realizou-se uma ampla revisão bibliográfica e metodológica de pesquisas sobre a geomorfologia antropogênica e sobre mapeamento geomorfológico em desenvolvimento no Brasil e no exterior. Com base nesta revisão conceitual e metodológica propõe-se, neste trabalho, criar uma proposta metodológica de mapeamento geomorfológico com foco em formas de relevo antropogênico e uma legenda integrada.

Palavras-chave: Geomorfologia Antropogênica; Formas de Relevo Antropogênico; Mapeamento Geomorfológico.

1. Introduction

The landforms of anthropogenic origin can be called anthropogenic relief or technogenic relief (PELOGGIA, 1996, 1997, 1998, 2003, 2005). As Gerasimov (1979) informs, the term anthropogenic was proposed by Pavlov (1922) and can be used to qualify events of the "probable" new geological period that appears in the literature under different names, such as Quinary (TER-STEPANIAN, 1988), Technogenic (OLIVEIRA and QUEIROZ NETO, 1994), Anthropocene (OLIVEIRA, 2014), (BELLESA, 2018), among others.

Within geomorphology, several authors have produced research on landforms resulting from human activities, such as Brown (1971), Haigh (1978), Nir (1983), Peloggia (1997), Csima (2010), Brown et al. (2017), Pica et al. (2017), Cooper et al. (2018), Lundershausen (2018), Barbosa et al. (2018) and Barbosa et al. (2019). Such studies have increasingly contributed to the advancement of the conceptual field of anthropogenic geomorphology and to the area of anthropogenic geomorphological cartography.

Anthropogenic geomorphological mapping consists of the act of mapping forms, processes, and general characteristics of the relief resulting from the human geomorphological agency. The term "agency" is used in this work to replace the term "action", because as Peloggia (2019) describes, agency (and not simply action) implies not only simple relations of cause and effect, process and result, but a complex context of imponderable circumstances, determinations, options and occurrences, both natural and cultural, that lead individuals or social groups to relate in a particular way with the ecological and landscape supports, resulting in processes that reconfigure them in geological and geomorphological terms.

For the study of the relief resulting from the anthropogenic agency, mapping has been a very important tool, not only in mapping, delimiting, and identifying forms derived from human activity, but also its use in environmental and urban planning according to Furrier and Barbosa (2016), Furrier et al. (2017), and Barbosa et al. (2018). By mapping the relief, it is possible to register the most varied anthropogenic landforms and analyze them quantitatively and qualitatively through field verification and analysis of their typical morphology.

The geomorphological map can contain several approaches that show certain forms of relief and morphogenetic processes, according to the objectives of each researcher. One of the great exponents in the theme of geomorphological mapping in Brazil is Geographer Jurandyr Ross, mainly for his work from 1992, which brings a division of six relief taxa addressed in the methodological building developed by the author, which can be used in general studies on the geomorphology of a given area, explaining from the great morphostructure to the quaternary relief forms, including the anthropogenic landforms. Other works addressing geomorphology and geomorphological mapping were also published by the author, such as Ross (1985, 1994, 2014), and in partnership with other researchers such as Ross and Moroz (1996), Ross and Dell Prette (1998), Vervloet and Ross (2012), among others.

Other authors with more recent works have brought different methodologies for the specific geomorphological mapping of urban and anthropogenic forms, among which the following can be cited: Rodrigues (2005), Ford et al. (2010), Peloggia et al. (2014a), Del Monte et al. (2016), Brandolini et al. (2018), Barbosa et al. (2018) and Cappadonia et al. (2020). Peloggia (2018) makes a very pertinent comparative analysis between anthropogenic geomorphological mapping methodologies developed in Brazil and abroad. This author makes it clear that there is no unanimity regarding the most usual and applicable methodology, requiring, therefore, greater methodological and technical contributions.

However, despite geomorphological mapping being considered a great tool for studies of anthropogenic geomorphology, and environmental and urban planning, it is known that mapping landforms are not as simple a task as mapping "concrete objects" that can be found on the earth's surface and represented in several thematic maps. When mapping relief, one maps the aspect, shape, and behavior of the most superficial part of the Earth, which is dynamic, even more, when it comes to anthropogenic forms.

Even amidst so many questions about the difficulty of mapping relief, the geomorphological map is indispensable in some situations and its importance in geomorphological studies has been discussed for decades. Tricart (1965), the geomorphological map represents the basis of research in geomorphology. At the same time, it is the instrument that directs the research and, when concluded, becomes its synthesis product. Penteado (1983) emphasizes that Geomorphology has two very important aspects to analyze, which are: (i) the description of relief forms and (ii) the genesis of relief forms. On the map, there are possibilities of occurrence of these two analyses.

1.1 Geomorphological mapping in Brazil

Geomorphological cartography constitutes an important instrument in the spatialization of geomorphological facts, allowing to represent of the genesis of relief forms and their relationships with the structure and processes, as well as the dynamics of the processes, considering their particularities (CASSETI, 2005).

Geomorphology studies developed with the support of geomorphological cartography in Brazil are largely the result of the theoretical contribution of Gerasimov and Mescherikov (1968), and fundamentally of the ideas of Penck (1953). These authors brought as their main contribution to geomorphological mapping the concepts of morphostructure (geological foundation) and morphosculpture (featured or typology of forms generated on one or several morphostructures), which were later adopted by several researchers within the geomorphological cartography developed in Brazil.

Barbosa et al. (1984) portray the methodological evolution of geomorphological mapping in Brazil, from Ab' Saber (1969) and Moreira (1969) to the RADAMBRASIL project, in which geomorphological cartography had a great technical and scientific impulse. In this project, geomorphological cartography was developed based on images generated from the SLAR remote sensor, an active side-view sensor that was attached to an aircraft.

There is no denying that the images produced by the SLAR remote sensor in the RADAMBRASIL project, later used as a master tool in the most varied thematic maps prepared in this project, were of fundamental importance for the advancement of geomorphological cartography in Brazil, both from a methodological point of view as a technician (FURRIER, 2007) (SOUZA & FURRIER, 2019). In fact, the geomorphological mapping methodology developed by Ross (1992), previously mentioned as one of the most used in Brazil, was based on the images produced and used in the RADAMBRASIL project.

Since then, a series of researchers have started to carry out geomorphological mapping using this methodological basis, and adding their own modifications, according to the objective of each research carried out, as can be seen in Carneiro e Souza (2003); Fujimoto and Schmitz (2004); Amaral and Ross (2006); Freitas et al. (2013), Barbosa et al. (2018), Furrier and Vargas Cuervo (2018), Barbosa et al. (2019), Souza and Furrier (2019), Botelho and Pelech (2019) among others.

The development of methodologies and techniques in geomorphological mapping in Brazil from the beginnings of the RADAMBRASIL project to the present-day places Brazil in a privileged position in the world, being, therefore, a reference in this subject.

2. Materials and Methods

Through an extensive national and international bibliographic consultation on geomorphological mapping and anthropogenic geomorphological mapping, this work seeks to build its own and usual methodology for geomorphological mapping together with an informative and integrated legend. The municipality of João Pessoa, located in the state of Paraíba - Brazil, was chosen as a test area because this municipality contains important works on geomorphology and previous general geomorphological mappings.

Bibliographic and cartographic research was carried out using geomorphological mapping as a tool for the study of geomorphology and anthropogenic geomorphology. Such works were analyzed and compared in terms of their methodological approaches and later a new methodology was proposed for mapping anthropogenic landforms based on previous methodologies and developed during this research.

2.1 Some methodologies for geomorphological mapping

Of the methodologies related to geomorphological mapping, the objective was to analyze three different methodologies: two developed by Brazilian researchers and one developed by researchers from the United Kingdom. There is no doubt that Brazil is a world reference in geomorphological mapping, thanks in part to the RADAMBRASIL project that lasted 15 years (1970 – 1985). Based on the three methodologies chosen, it was possible to propose the creation of a new methodological proposal and an example of an integrated legend for use in anthropogenic geomorphological mapping. Such methodologies were disseminated by the authors Ross (1992), Peloggia et al. (2014a, 2014b, 2017, 2018), and Ford et al. (2010).

To support the methodology developed by Ross (1992) it is said that there are essential elements to be considered in geomorphological mapping. According to Ross (2012), such elements would be the identification and classification of forms, considering genesis, age, and active morphogenetic processes.

In short, morphometric, morphographic (forms resulting from evolutionary processes), morphogenetic (processes responsible for elaboration), and chronological (period of feature formation) data should be included. Such elements can be identified by determining the six taxonomic levels of the relief spread by Ross (1992), described as follows (Figure 1):

- 1st taxon – it is called morphostructure, which corresponds to the geological basement.
- 2nd taxon – are the morphosculptural units generated on the morphostructure.

- 3rd taxon – units of patterns of similar landforms: they are sets of smaller landforms that present distinctions from each other. They can be forms of aggradation or denudation.
- 4th taxon – individual landforms within each unit of patterns of similar shapes. They are distinguished by topographic roughness or relief dissection index.
- 5th taxon – slopes and slope sectors belonging to each of the individual relief forms: they can be concave, convex, and rectilinear.
- 6th taxon – minor forms produced by current erosion processes or current deposits: gullies, ravines, landslide scars, current sedimentation banks, siltation, and other forms that are the result of current natural or anthropogenic processes.

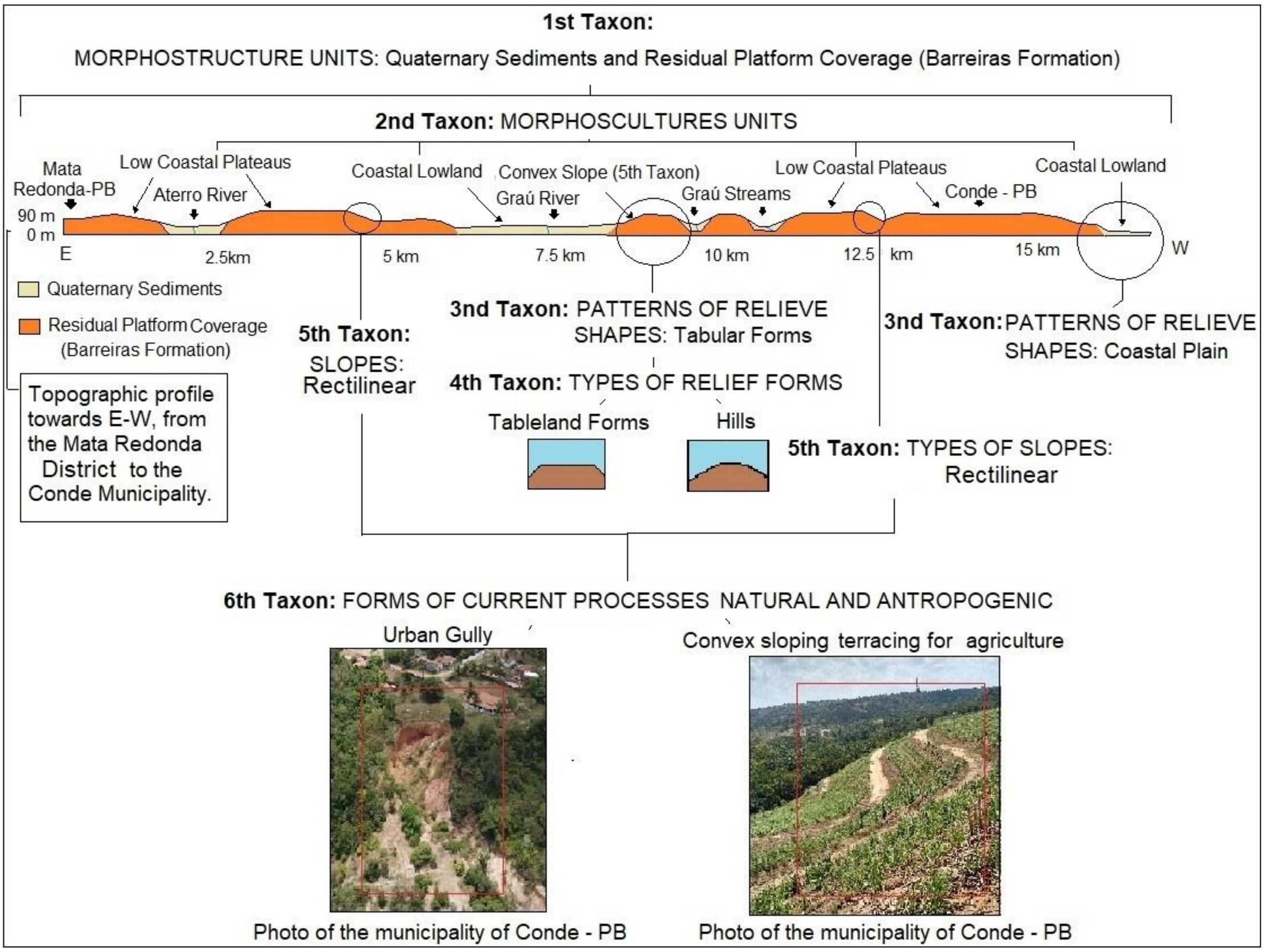

Figure 1. Example of the taxonomic proposal for the classification and mapping of landforms considering the six taxa by Ross (1992). Elaboration: authors.

In this last taxon of the geomorphological mapping proposed Ross (1992), the current natural and anthropogenic landforms are concentrated, therefore, it would be the most evident taxon in a mapping of anthropogenic landforms. Some authors who use this methodology generally adapt it to serve the purposes of their research, such as those by Furrier et al. (2017), Nóbrega et al. (2011), Barbosa (2013), Souza and Furrier. (2014), Barbosa (2015), Lima et al. (2017), Barbosa et al. (2018), Barbosa et al. (2019) and Silva (2020).

In the case of mapping anthropogenic or technogenic landforms, the methodology proposed by Ross (1992), alone, is limited, as this methodology prioritizes macroforms and large structures, giving little emphasis to current and anthropogenic landforms. Therefore, it is a very useful mapping methodology for small and medium scales. When it comes to large scales or scales of detail, several adjustments in this methodology must be elaborated to encompass more precisely and comprehensively the anthropogenic forms.

For anthropogenic geomorphological mapping, it is necessary to use a mapping methodology that prioritizes the 6th taxon, proposed by Ross (1992). Although the methodology developed by Ross is limited to the study of anthropogenic landforms, it is quite useful, as it delimits the morphostructure and morphosculpture where anthropogenic landforms were developed. Therefore, keeping the larger taxonomies proposed by Ross and improving the smaller taxonomies using anthropogenic mapping methodological proposals developed by Ford et al. (2010) and Peloggia et al. (2014a, 2014b, 2017), can be an interesting methodological path.

As Peloggia (2017) points out, for each technogenic feature, particular types of ground are defined, which may include: produced ground, with its technogenic deposits induced or remobilized; ground of an erosive or excavated nature; filled grounds; complex grounds, etc. In addition to the ground, technogenic soil layers and more superficial general alterations are also identified.

Peloggia et al. (2018) present a technogenic ground classification framework to be used in the anthropogenic geological and geomorphological mapping. This framework was proposed by Peloggia et al. (2014b), with subsequent collaborations by Peloggia (2015) and Vitorino et al. (2016) (Table 1), and is of great importance in the classification of anthropogenic landforms.

Table 1. Classification of technogenic grounds for geological and geomorphological mapping.

Class	**Geological category**		**Types**		**Layer or technogenic feature**
Technogenic aggradation ground	Anthropogenic surface formations	Technogenic deposits	Produced ground	Grounded terrain	Built technogenic deposits
				Accumulated ground	Successively accumulated cultural technogenic layers
			Filled ground		Technogenic deposits built over excavated terrain
			Sedimentary technogenic ground	Alluvial	Valley bottom-induced technogenic deposits
				Colluvial	Slope-induced technogenic deposits
			Slip technogenic ground		Induced technogenic deposits created by mass movements
			Remobilized technogenic ground		Technogenic deposits formed by the remobilization of pre-existing technogenic deposits
			Mixed technogenic ground		Technogenic deposits built, induced, or remobilized forming an

				undifferentiated package
Modified technogenic ground		Technogenic soils	Altered composition ground	Natural soils with the incorporation of chemical contaminants or organic material
			Geomechanically altered ground	Compacted or turned natural soils
Degradation technogenic ground	Exposed or moved substrate		Eroded ground	Erosion scars created by induced processes
			Slipped ground	Slip scars created by induced processes
			Moving or sunken ground	Subsidence depressions created by induced process
			Excavated ground	Excavation surfaces
Complex technogenic ground	Technogenic landscape		Complex ground	Grounds formed by the aggregation or complex overlapping of deposits or technogenic soils or substrate exposure surfaces, not differentiable in the mapping scale adopted

Source: Peloggia et al. (2018).

Ford et al. (2010) brought as a major methodological contribution to research related to geological and geomorphological mapping, a new configuration of classification of artificial grounds and technogenic landforms established in three main hierarchies: Class, Type, and Unit. Within these hierarchies, the authors distinguish the different types of artificial terrains, the aggradational, degradational, and/or disturbed forms, as shown in Figure 2.

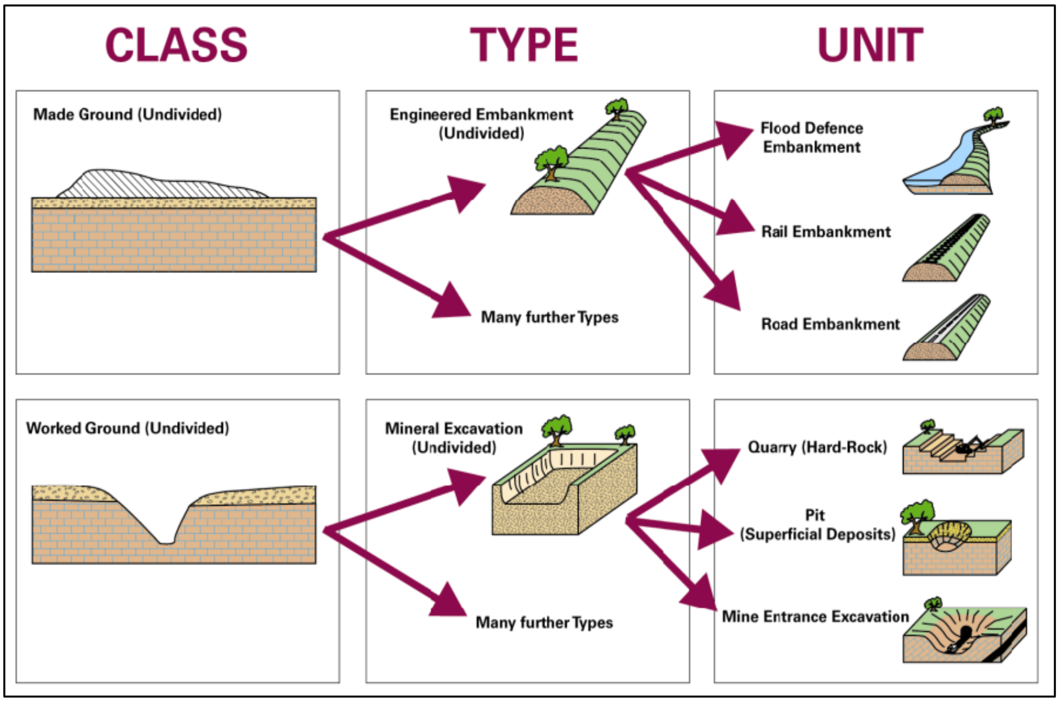

Figure 2. Examples of a hierarchical classification of anthropogenic landforms. Source: Ford et al. (2010).

The hierarchy presented by Ford et al. (2010) has typical and intuitive usage, and is described below:

- Unit – the highest level of detail, e.g.: a specific type of landfill, ideal for scales of 1:10,000 or greater.
- Type – moderate level of detail, e.g.: undifferentiated deposits or excavated areas, ideally identified at scales of 1:10,000 or greater.
- Class – corresponds to the level of detail existing in the classification of the five terrains described above, and the optimal mapping scale is 1:50,000 above.

In the case of Complex Terrain, the classification is not subdivided beyond the Type level. When there is not enough information to reach the subdivision to the Unit level in any of the Sites, the classification may stop at the Class or Type hierarchy (FORD et al., 2010).

Analyzing the three methodologies presented, they could be combined, with due caution and adjustments, so that there would be greater use in the elaboration of a geomorphology map with a focus on anthropogenic landforms, as they complement each other in several areas. In this way, a new mapping methodology could be developed from the methodologies presented and certain adjustments made to them, as well as the presentation of an integrated legend as a model for use in mappings with a focus on anthropogenic landforms.

It is important to highlight two things: (1) the methodology constructed here is not a simple sum or superposition of the three methodologies analyzed above. There is a huge amount of work in adjusting each methodology to the methodology being developed in this work, excluding non-compatible proposals and adding new propositions. (2) to develop an integrated and completely new legend that is a primordial tool in the correct reading and interpretation of the final map.

3. Results

For mapping and analysis of morphometric data, thematic support maps can be elaborated, such as hypsometry and slope maps, which offer a range of morphometric data about the relief of a place. In addition to the production of these thematic support maps, the relief dissection index can be applied to the analysis of the types of landforms, following the methodology of Ross (1992).

The relief dissection index is applied taking into account the notching and the interfluvial dimension average of the valleys and provides important morphometric data of the relief (Frame 1). When calculating river notching, it is relevant to consider the regional geological/geomorphological structure and the hierarchy of the drainage network, as explained by Souza and Furrier (2019).

Frame 1. Relief dissection index matrix.

Interfluvial Dimension (classes) / Incising of the valleys (classes)	Very large (1) (> 1500m)	Large (2) (1500-700m)	Middle (3) (700 - 300m)	Small (4) (300 - 100m)	Very small (5) (< 100m)
Very low (1) (< 20m)	11	12	13	14	15
Low (2) (20 - 40m)	21	22	23	24	25
Middle (3) (40 - 80m)	31	32	33	34	35
Strong (4) (80 - 160m)	41	42	43	44	45
Very strong (5) (> 160m)	51	52	53	54	55

Source: Adapted from Ross (1992).

The relief dissection index matrix shows values in Arabic numerals that represent areas that contain interfluvial dimension from very large (1) to very small (5), and areas of very weak (1) to very strong (5) average valley notching. When these values are combined (vertical column + horizontal column), the relief dissection index is obtained. Therefore, a relief with a value of 31 means that it has a valley incision of 40 to 80 meters and an interfluvial distance greater than 1500 meters.

It should be noted that the relief dissection index is part of the 4th taxon according to Ross's methodology (1992) and is always grouped with the 3rd taxon (relief patterns). The relief patterns are divided into accumulation and dissection relief and are designated by the letters A (accumulation) and D (dissection). Grouped with these capital letters are small letters that designate the specific shape of the landform such as: Amp (Accumulation – marine plain) and Dc (Dissection – convex form). The accumulative forms are not accompanied by Arabic numerals, as they are not originated by dissection processes.

Therefore, the following situation can be cited as a practical example: a certain area of the geomorphological map will contain convex denudational forms (Dc) (3rd taxon) with relief dissection index 42 (4th taxon). This means that the area contains convex forms arising from erosive processes with a large interfluvial dimension (1,500 – 700 m) and strong notching of the valleys (80 – 160 m).

For quantitative data corresponding to the evolutionary process of anthropogenic landforms, satellite images from different periods and old aerial photographs can be very useful, as anthropogenic forms can be extremely changeable in short periods of time. Therefore, temporal analyzes are important tools in the study of anthropogenic landforms.

For morphogenetic data, when working with anthropogenic geomorphology, data about the morphogenesis of forms can be inserted into the map, indicating whether they have undergone direct or indirect anthropogenic morphogenetic processes. The direct processes are related to the activities of construction, excavation and change of river courses, while the indirect ones are related to erosion acceleration, land subsidence by human activities, slope ruptures and even the triggering of earthquakes by human causes. These classifications of anthropogenic landforms based on direct and indirect anthropogenic actions are considered the simplest, and are also used by Brown (1971), Goudie (1994), Vita-Finzi (1993), Goudie and Viles (2010).

The forms resulting from direct anthropogenic processes are more easily recognized on the ground. They tend to clearly demonstrate their origin and are deliberately produced, taking as examples the forms produced by civil construction activities, excavation, hydrological interference, etc. Indirect anthropogenic processes are more difficult to have their origin recognized, because, generally, it is not about new geomorphological processes being created, but the acceleration or alteration of natural geomorphological processes by anthropic activity (GOUDIE, 1993).

A classic example of an indirect anthropogenic form is the formation of "deltas" at the headwaters of water reservoirs. The river waters, upon encountering the reservoir, abruptly lose their energy and sediments can be deposited forming an accumulation area. Therefore, there is an indirect anthropogenic form.

Therefore, for the mapping of indirect forms, in addition to a careful temporal analysis of satellite images and aerial photographs, it is also necessary to have a reasonable study of the sequence of events that occurred until the generation of this new landform. It is necessary to understand the form and process involved in the generation of this new anthropogenic landform. In order to insert this type of shape in the mapping legend, it is necessary to analyze whether the form will be present in an anthropogenic ground of accumulation, erosion or filled.

The proposal presented in this work aims to divide Ross's (1992) taxa down to the 4th taxon (see example in figure 3), so that there is greater contextualization of anthropogenic landforms in the reality of local and regional relief, and thus, if possible, for example, understanding and mapping the direct and indirect forms more easily, given that the anthropogenic forms are on a certain geology and on a larger morphosculpture.

In addition to this determination of taxa, it was also considered good to propose the use of the classifications and nomenclatures defined by Peloggia et al. (2014a, 2014b, 2017, 2018), Peloggia (2015) for mapping technogenic terrains, anthropogenic landforms and technogenic deposits, making major adjustments to the local reality and the types of anthropogenic landforms that will appear on the ground. And finally, to use the idea of hierarchy of land and anthropogenic reliefs spread by Ford et al. (2010). In which, one can divide the current forms into Classes, Types and Units (Figure 4).

For the division of Ross's (1992) taxa, the following methodological approach can be adopted, which is exemplified in Figure 3:

- **1st step** – determination of the morphostructure (1st taxon): it is necessary to have information about the geological composition of the area in question, such as, for example, the geological map of the area and complementary fieldwork.
- **2nd step –** determination of the morphosculpture of the large relief forms that predominate in the area (2nd taxon): in this step, vectorized topographic maps, 3D images that demonstrate the terrain modeling, in addition to satellite images can be used.
- **3rd step** – determination of relief patterns (3rd taxon): to determine this taxon, DEM image can be used in a GIS environment, in addition to satellite images and fieldwork, where patterns can be visualized so that the relief presented, from the forms of denudation as well as those of accumulation.
- **4th step –** determination of landform types (4th taxon): in this step, the dimensions and average notching of the valleys in a given area are verified morphometrically. The aggradational forms do not have this hierarchical level, as they do not have dissection.

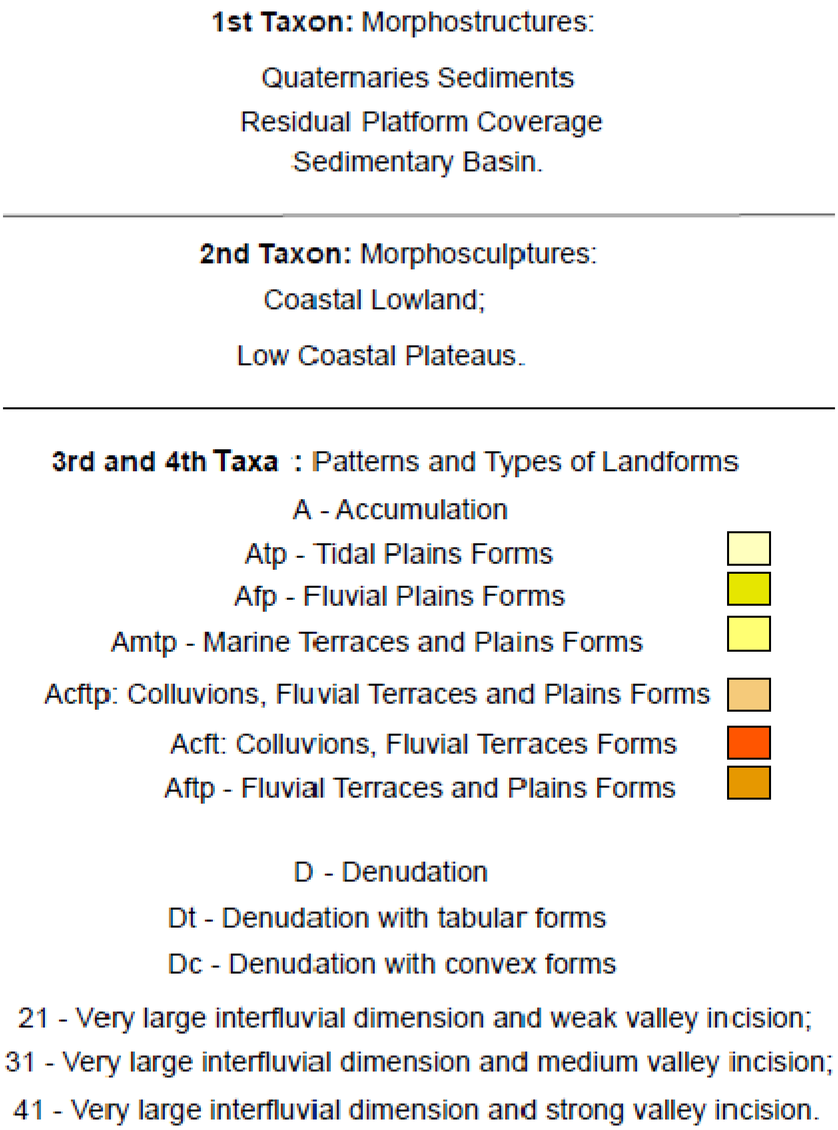

Figure 3. Examples of Ross's (1992) 1st to 4th taxon division applied to a mapped region. Source: authors.

The 5th taxon by Ross (1992) consists of the analysis of slopes, where the construction of topographic profiles can be used, or the analysis of the DEM. However, the 5th taxon should be added to the anthropogenic geomorphological map only in areas with highly dissected reliefs, where the study of slopes is important for understanding the general relief and anthropogenic forms. Therefore, in the mapped study area, the 5th taxon will not be used. It is also interesting to note that a good map is not necessarily one that has more information, but one that is easy to read and has good practical employability.

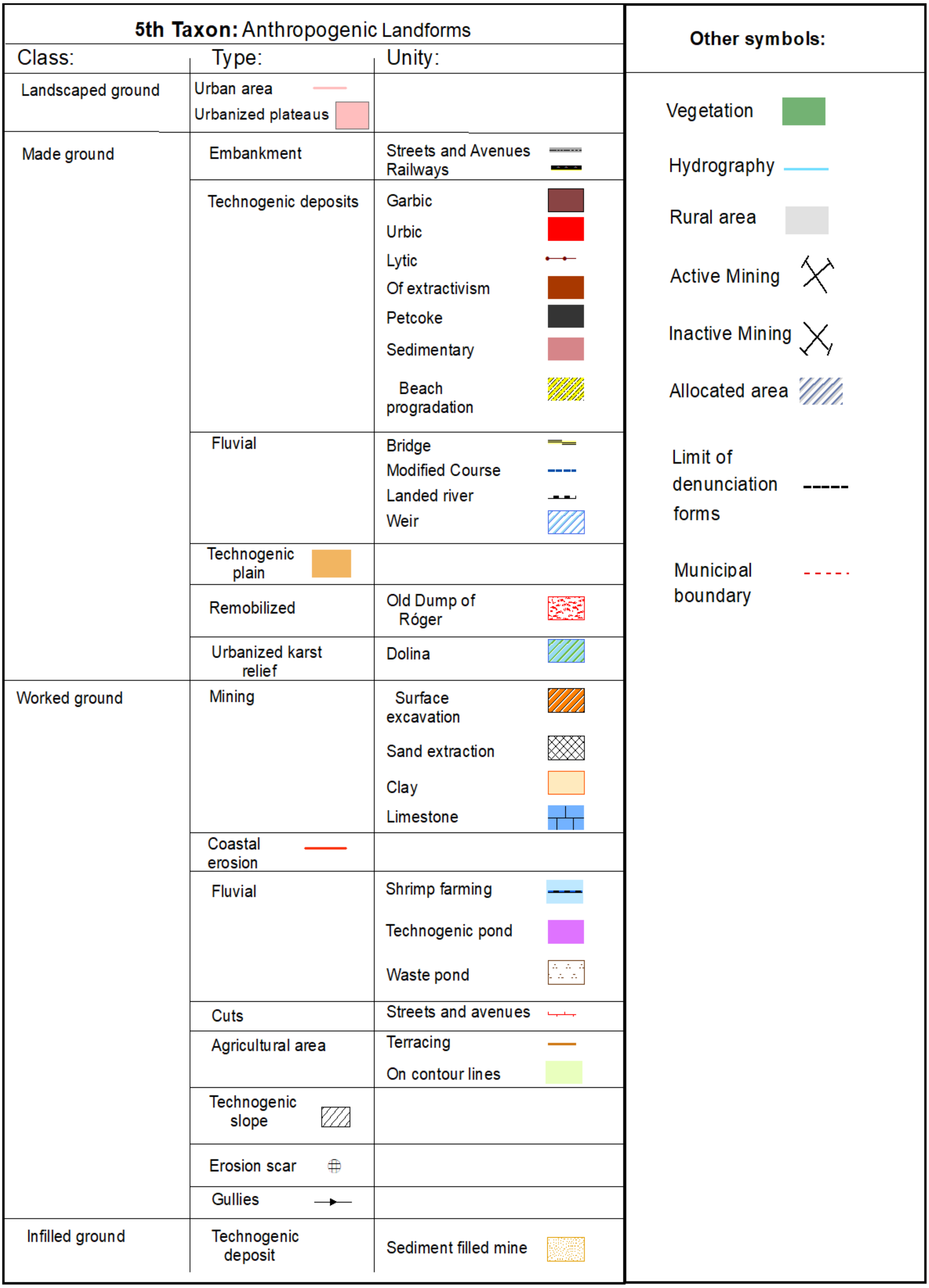

Figure 4. Example of a hierarchy in Class, Type and Unit, and classifications of land and anthropogenic forms. Source: authors.

To determine what the 6th taxon of Ross (1992) would be, the hierarchical divisions proposed by Ford et al. (2010) and classifications of grounds and forms from the work of Peloggia et al. (2014a, 2014b, 2017, 2018), Peloggia (2015). The anthropogenic landforms of a particular location to be mapped can be obtained through data collected in the office and in the field and through remote sensing instruments. For the quantification and measurement of areas of anthropogenic relief, the data processed in a GIS environment can go through processes of metric operations and thus offer more morphometric data about the area.

Table 2. Classifications and nomenclatures for mapping Anthropogenic Geomorphology.

CLASS	TYPE	UNITY
Aggradation Terrain (produced, filled, alluvial or colluvial sedimentary and remobilized)	Technogenic deposits	Lithic; Sedimentary; Garbic and Urbic.
Degradation Terrain (eroded, slipped, moved or excavated)	Modified slopes; Modified fluvial landforms etc.	Erosion scar; Excavation surfaces (mines); Induced gullies etc.
Modified Terrain (chemically or mechanically altered)	Chemically altered soil layers, plowed soil layers.	Leaking gas station
Mixed terrain (overlapping or complex terrain)	Urbanized area	Not applied

Source: Adapted from Ford et al. (2010), Peloggia et al. (2014a); Del Monte et al. (2016), and Cappadonia et al. (2020).

Therefore, in the mapping process, after the identification of the first four taxa by Ross (1992), a hierarchy of anthropogenic landforms of the 6th taxon can be constructed, grouped into Class, Type and Unit, with Unit being the group corresponding to the highest level. of detail and the Class to the lowest level of detail. Consequently, as a practical example, one can cite: Class: aggradation ground; Type: landfill; Unit: railroad landfill.

For the identification, nomenclature, classification, and analysis of the forms that will be mapped, the methodologies of Peloggia et al. (2014a, 2014b, 2017, 2018), Peloggia (2015) (2014) and Peloggia (2017) will be used in this proposal, where the authors define the artificial terrains called: made ground, worked ground, infilled ground, disturbed ground, and landscaped ground.

Regarding deposits, they can be classified into urbics, which are made up of urban debris materials, garbic, which is related to the composition of organic waste and detrital material, and spolic which are earthy materials derived from industrial and extractive activities (PELOGGIA et al., 2014a). And, still, in Peloggia et al. (2018), anthropogenic landforms were delimited intensely linked to technogenic terrains, which are the forms of aggradation, degradation, and disturbed.

Some of the classifications and nomenclatures for anthropogenic geomorphological mapping that this proposed new classification points to can be seen in the example of a legend created for this research presented in figure 4 and some of the classifications presented in Table 2.

It is important to remember that the first part of this legend (Figure 3) contains the division of taxa, from the 1st taxon to the 4th taxon, following the methodology of Ross (1992). The anthropogenic landforms, as proposed in detail, will be represented in the 5th taxon with the modifications proposed in this work. In this work this last taxon is divided according to the hierarchy of Classes, Types, and Units, where the classes contain the types of technogenic terrains, then the types of forms that can be found in each type of terrain are presented, and finally, the units, containing the more specific information of each form. Therefore, the methodology created in this work proposes 5 taxa: morphostructure, morphosculpture, relief patterns, types of relief, and anthropogenic landforms.

The symbols representing areas, lines, and points are considered in the map legend according to the type of presentation that each form can have on the ground (point, linear, or area forms). And they can also be assigned according to the availability of the software used for the mapping.

In summary, the steps of the methodology presented to carry out the anthropogenic geomorphological mapping would fulfill the following steps:

a) Determination of the first four taxa following the methodology of Ross (1992).

b) Observation of satellite images and aerial photographs for the acquisition of technogenic landforms.
c) Acquiring more data from fieldwork and comparing cabinet and field data.
d) Georeference of all anthropogenic landforms verified in the analysis of satellite images, aerial photographs, and in fieldwork and place in a GIS environment.
e) In the GIS environment, a satellite image is placed as a background of the geomorphological map and of the points marked in the field, through which it is possible to identify where the points in the field were marked.
f) New shapes are created in the GIS environment corresponding to the technogenic landforms, which have formats: points, lines, and polygons. Through the satellite image, it is possible to vectorize, with the polygon shape, the most expressive areas of relief forms or anthropogenic morphogenetic processes.
g) After vectorizing the areas and choosing the types of points and lines used, the colors of each area of the polygons can be determined, thus concluding the symbology part of the map. When there are better representation shapes in lines and points or symbols, they should be added according to the purpose of representing the forms that the researcher wants to focus on; and
h) With the map built, the final elements are finally added: hydrography, scale, coordinate grid, north, legends, different nomenclatures, municipal boundaries, and the taxonomic levels of Ross (1992) (from the 1st to the 4th taxon) previously mapped and delimited.

3.1 Methodology application

The area chosen for the application of the methodology developed in this work was the municipality of João Pessoa, the capital of the state of Paraíba, located in the northeast region of Brazil. The choice of this municipality was due to the wide knowledge of this area by the authors, ease in carrying out fieldwork, and for having detailed geomorphological works performed by Furrier (2007), Barbosa *et al* (2015), Furrier and Barbosa (2016) and Barbosa et al. Furrier (2017).

According to the mapping performed, the municipality of João Pessoa has two morphostructures (1st taxon): Residual Platform Coverage represented by the Barreiras Formation (Miocene) and the Quaternary Sediments. These two morphostructures are supported by the Paraíba Sedimentary Basin. On these morphostructures, two morphosculptures are developed (2nd taxon): Low Coastal Plateaus carved on the Residual Platform Coverage, and the Coastal Lowland developed on the Quaternary Sediments. The outcrops of the Paraíba Sedimentary Basin are very small, limited to the bottoms of the valleys of some rivers and do not form considerable morphosculptures (Figure 5).

In the Low Coastal Plateaus, two denudational forms (3rd taxon) were delimited (convex and tabular) with a dissection index of 21 and 31 (4th taxon). In the Coastal Lowland, 6 relief patterns (3rd taxon) were mapped, encompassing all forms of accumulation found, such as Tidal Plains (Atp) and Fluvial Plains (Afp). Due to the scale, some forms of accumulation had to be agglutinated such as Amtp - Marine Terraces and Plains Form, Acftp – Colluviums, Fluvial Terraces, and Plains Forms, Acft – Colluviums, Fluvial Terraces Forms, and Aftp – Fluvial Terraces and Plains Forms (Figure 5). Accumulation forms do not have dissection, so there is no 4th taxon in this relief pattern.

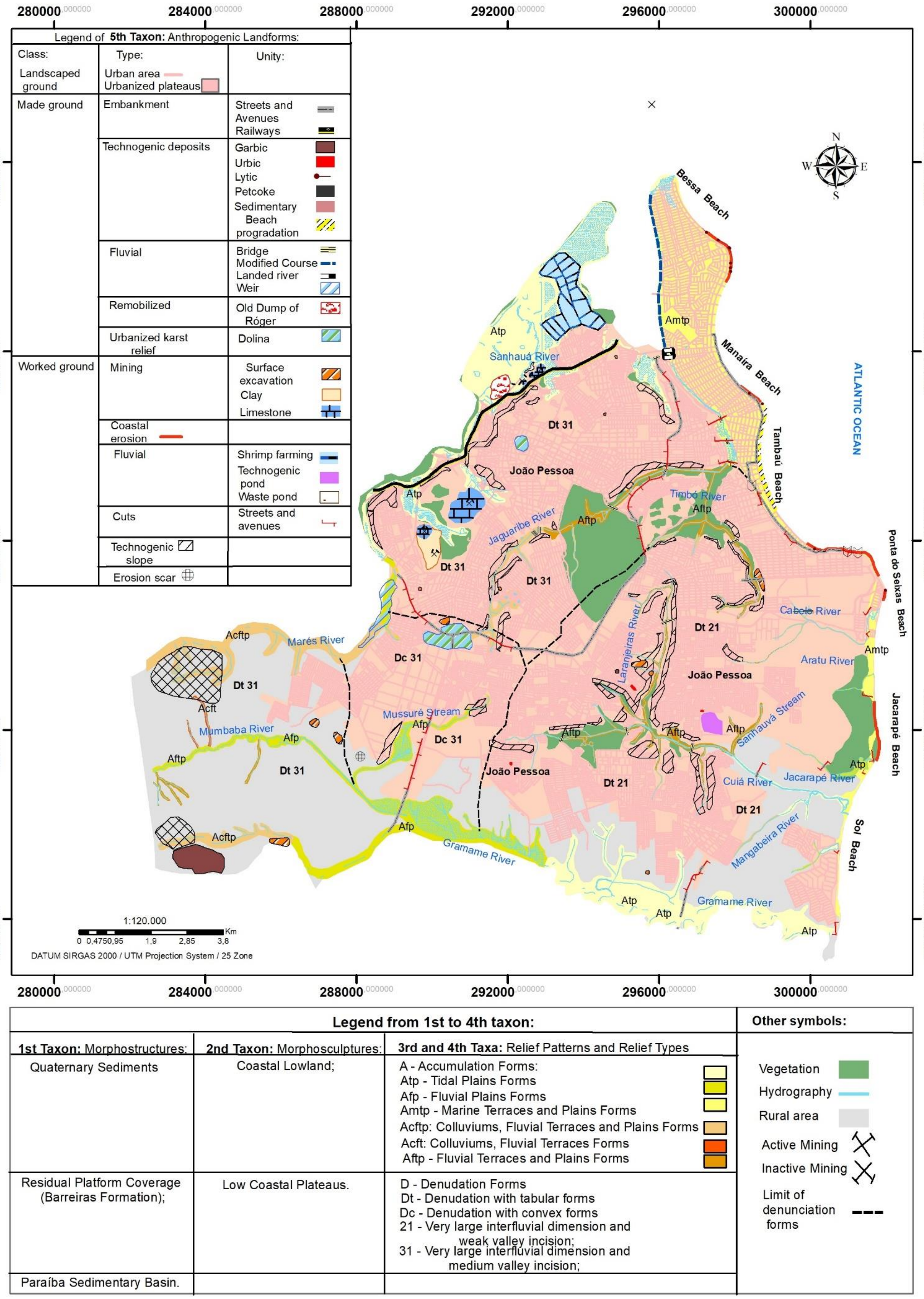

Figure 5. Geomorphological map of the municipality of João Pessoa. Elaboration: authors.

Anthropogenic landforms were delimited in the 5th taxon and were ranked in Class, Type, and Unit. Three classes of anthropogenic landforms were mapped: Landscaped ground, Made ground, and Worked ground. Eleven types of anthropogenic landforms were mapped. These 11 types were divided into 21 anthropogenic landform units (Figure 5). As an example, one can cite: an anthropogenic Unit called garbic (garbage dump) is part of the anthropogenic Type technogenic dump that is part of the Made Ground anthropogenic Class. An important highlight in the anthropogenic landscape of the area is the shrimp farming Unit which is part of the cut Type which is a kind of Worked Ground.

The final map presents unprecedented geomorphological detailing and, therefore, for better visualization of all mapped anthropogenic landforms, this map must be viewed at a scale of 1:50,000 or greater. The final map presents 5 taxa from the morphostructures present in the area to the anthropogenic landforms, the latter being hierarchized in Class, Type, and Unit (Figure 5).

4. Discussion

The methodological proposal presented in this work seeks to provide guidelines in relation to anthropogenic geomorphological mapping, considering the mapping of grounds, forms, and anthropogenic deposits in detail. It also seeks to divide the types of forms present in certain classes of anthropogenic reliefs, allowing a more detailed and complex visualization, since anthropogenic landforms have extensive heterogeneity.

In this proposal, the mentioned map brings information about the great geological structures present and the general relief of the area represented by the morphosculpture. This brings the possibility of comparative analysis and causality about the human geomorphological agency on natural surfaces. In fact, anthropogenic landforms are on top of geological structures and broader morphosculptures that cannot be neglected in geomorphological mapping.

There are numerous issues to be considered when proposing to carry out a mapping of this type. And each of these questions may dictate the best methodological path to be used in accordance with the characteristics of the area to be mapped. Methodological adjustments will always be necessary according to regional and local peculiarities. Some of the questions that may arise are the size of the mapped area, which scale of work will be used, which are the best representation symbols, and which is the best data processing software to work with, among others.

When applying the methodology proposed in this work, there is a broader general approach, counting on the characterization of the great geological morphostructures present in the area, their morphosculptures, patterns of reliefs, types of reliefs, and anthropogenic landforms. Therefore, it can be well suited and adapted for scales of 1:50,000 and greater.

In short, the diffusion of methodologies for anthropogenic geomorphological mapping has at present, haughty importance, considering that humanity has been an important geological and geomorphological factor and, in some regions of the planet, preponderant. Human agency, in this sense, has gained prominence, and with it comes the great need for a study to obtain the best ways to manage space, execute plans, and direct human actions when they interfere with geological and geomorphological bases.

5. Conclusion

Brazil is a world reference in geomorphological mapping and the great impetus began in the early years of the RADAMBRASIL Project in the early 1970s. Although most of the geomorphological mapping was used in large areas, therefore, generating maps at small and medium scales, the methodology of hierarchical landforms can be very well used to support anthropogenic geomorphological mapping. Anthropogenic landforms were developed over larger morphostructures and morphosculptures that are broken down into smaller relief patterns and relief forms.

The methodology proposed here is not just a sum of methodologies developed in Brazil and Europe. It is an exercise in application and techniques to adjust, adapt, and create propositions and integrated legend. Of course, it is not the intention to propose a new permanent methodology devoid of mistakes and the need for adjustments since it is a relatively new subject and in full development in the world.

The primary intention is to show the feasibility of maintaining, with adjustments, the methodology developed by Ross (1992) already widely used and tested in Brazil and Colombia, adding methodologies and techniques from other Brazilian and foreign researchers. It is undeniable that this work is pioneering and, therefore, it should be scrutinized by other Brazilian and foreign researchers who work with anthropogenic geomorphological mapping.

The result achieved showed the broad feasibility of this methodology, producing a detailed map of the general and anthropogenic geomorphology of the municipality of João Pessoa, Brazil. The map produced, in addition to being a synthesis instrument of the research, can be considered an important tool for future environmental and urban planning works, thus going beyond the walls of the scientific community, and can be used by environmental, planning, public works and infrastructure departments.

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