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Original Research Articles

Designing optimal agrosilvopastoral landscape by the potential for conservation use in Brazil

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A R T I C L E I N F O

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A B S T R A C T

Land classification offers decision-makers a baseline to act assertively, improving the relationship between production and the conservation of natural resources. This work characterises the potential of land use concerning agrosilvopastoral use, soil conservation, and water production through a proof of concept to support landscape planning at the State level. The indexes range from low (1) to high (5) aptitude for agrosilvopastoral or conservation use in Google Earth Engine. We crossed land use classification from MapBiomas, Collection 5 (2019) with the PCU map to obtain areas suitable for agrosilvopastoral use (PCU$\geq$3) or conservation use and the percentual of used land considering administrative, watershed, and municipality divisions. The balance observed between administrative regions regarding the potential for conservation use does not repeat when analysing watershed districts or municipalities, reinforcing that hydric management committees and cities must plan territorial use. Livestock has the highest percentage of land use in low PCU areas, followed by silviculture and agriculture, indicating the priority to include conservation use in the sustainable agriculture agenda. In Brazil, Minas Gerais State provides ecosystem services related to water supply beyond the state borders. Payment for environmental services is an alternative to increasing agrosilvopastoral activities' environmental performance. Well-designing the landscape use may promote productivity and reduce pressure under new areas for crop production.

1. Introduction

Conciliating agricultural production and conservation of natural resources is necessary to guarantee current and future generations' well-being (IPBES, 2016; Martin et al., 2016; Oliveira et al., 2020). It is essential to develop and improve methods to understand the landscape (BPBES, 2019; Stevance et al., 2020). The classification of land use is pointed out by the Food and Agriculture Organization of the United Nations (FAO) as a mechanism that offers decision-makers a baseline of opportunity to act assertively, enhance local characteristics, and

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improve the relationship between the production and conservation of natural resources (Garnica, 2005; Ziadat et al., 2021). Moreover, a large and growing body of evidence shows that nature protection supported by scientific theory can improve food production and sustainable development (BPBES, 2018; IPBES, 2018; González-Chaves et al., 2021; Campbell et al., 2022).

Global studies are thinking about tools for territorial planning and considering the ecology of landscapes for decision making (Izakovicová et al., 2018; Khoroshev, 2020; Hersperger et al., 2021; França et al., 2022a). Different methodologies may guide local efforts to implement global pacts and initiatives, such as the 17 Sustainable Development Goals proposed by the United Nations (Fu et al., 2019; United Nations, 2020). In Brazil, the business sector is becoming more concerned and sensible about environmental issues (BPBES & PMBC 2018; Better Food Better Brasil, 2021). Countries and states must identify the more appropriate tools to support their political decisions. Among the land-use regulatory instruments, Environmental Zoning (EZ) stands out as a helpful methodology for orienting and conducting socioeconomic and conservation activities (Qi et al., 2018; Xu et al., 2020).

The core of the EZ methodology currently recommended by Minas Gerais State (Brazil) composes three main stages: landscape units' delimitation, use of water resources assessment, and land use mapping (Minas Gerais, 2020). The landscape analysis considers lithology, soil type, topography, and natural vegetation to determine the area's potentialities, aptitudes, and limitations regarding agrosilvopastoral or conservation use.

A set of landscape characteristics with higher relevance resulting from the interpretation of its physical features defines a Landscape unity (Zonneveld, 1989). The key elements to determine the potential, skills, and restraints are soil conservation and water production. The landscape unity concept, however, has some limitations. The most important is the subjectivity due to analyst interpretation and the intensity of field surveys (Costa et al., 2019). Those limitations can prohibit the application of the methodology for large areas, such as national and state levels. Among the scalable and less subjective methods to integrate an EZ in landscape units, the Potential for Conservation Use (PCU) stands out (Costa et al., 2017, 2019). The PCU proposes calculating an indicator considering three abiotic components: lithology, soil class, and slope. The methodology assumes that these physical variables influence the potential for agrosilvopastoral use concerning soil conservation (resistance to erosion) and water dynamics (surface runoff and groundwater recharge) (Costa et al., 2019). The novelty of our research lies in the proposition of scalable tools to support landscape and land use planning considering the physical attributes, land use, and conservation use at the state level. Landscape modeling and ordering are promising research areas (França et al., 2022a).

The assessment of large areas is essential to subsidize consistent action plans, prevent potential conflicts and ensure the effective development of public policies. This work aimed to apply the PCU methodology in a large-scale proof of concept, assessing the suitability of areas destined for agriculture, livestock, silviculture, and conservation in different regional divisions. The assumption behind the manuscript's objective is that sustainability has also been promoted by fomenting land vocation.

2. Material and methods

2.1. Study area

The study area is the Minas Gerais state, southeast Brazil, with approximately 586,528 km^2 between the latitudes -14° 10′ and -22° 55′ and longitudes -39° 52′ and -51° 00′ (Fig. 1A). The State is more extensive than many European countries. The altitude ranges from 79 to 2890 m above sea level. The climates, considering Köppen's classifications, are: As and Aw (Tropical Savanna), Cfa (Humid subtropical), Cfb (Oceanic), Cwa (Dry-winter humid subtropical), and Cwb (Dry-winter subtropical highland) (Fig. 1B) (Alvares et al., 2013). The state covers three Brazilian biomes: Caatinga (North), Cerrado (Central North and West), and Atlantic Forest (East and South) (Fig. 1C); the last two are considered the world's biodiversity hotspots (Myers et al., 2000).

Minas Gerais is recognised as a state with mineral resources. Still, the land use in Minas Gerais state comprises livestock, agriculture, and silviculture. The livestock is more expressive (Strassburg et al., 2014) with extensive land change use in Cerrado biome in the last three decades (Souza et al., 2020).

2.2. Data source

We obtained the lithology data from the geological map of Minas Gerais on a scale of 1: 1000,000 (available at http://www.portalgeologia.com.br/, accessed on 01/12/2020). This map improved the geological base compiled by the Minas Gerais Economic Development Company (CODEMIG) in 2003, incorporating the knowledge of other mineral research agencies and numerous existing projects, publications, and regional maps.

The soil map of Minas Gerais at a scale of 1:650,000 provided the soil classes (UFV, 2010). According to the Brazilian Soil Classification System, this map represents the spatial distribution of soils for the Minas Gerais State (Santos et al., 2018). We obtained the slope from the Shuttle Radar Topography Mission (SRTM) elevation. NASA JPL distributes the used version of the SRTM (v3) with a resolution of 1 arc-second (approximately 30 m). The slope values were then categorised into a plane (0 to 3%), smooth wavy (3 to 8%), moderately wavy to wavy (8 to 20%), strong wavy (20 to 45%), and mountainous to steep (> 45%) (Costa et al., 2017). The lithology and soil class layers were initially supplied in vector format and converted to a raster format at 30 m (same as the elevation layer).

We used the 2019 land use classification provided by MapBiomas, Collection 5 (https://mapbiomas.org/, accessed 12/1/2022), crossed with the PCU map. The silviculture layer comprises forest plantations; the agriculture layer comprises sugarcane, perennial crops, soy, and other temporary crops. The livestock layer comprises pasture and a mosaic of agriculture and livestock. The other land-use types associated with agriculture were not present in the Minas Gerais state (Souza et al., 2020).

2.3. Processing and classification of image acquisition for PCU

To compute the PCU, we implemented a script of the methodology developed by Costa et al. (2017) in Google Earth Engine (available at https://code.earthengine.google.com/76a7d9abc9109a6de575fe155ac7dee9). The PCU was calculated from three layers of information: lithology, soil class, and terrain slope (Fig. 2). Each layer was associated with a score related to the aptitude for agrosilvopastoral use ranging from 1 to 5. Small scores (close to 1) represent the low potential, and the big scores (close to 5) describe the high potential (Table 1).

The principle for lithological classification considers the potential of nutrient supply and susceptibility to weathering. Thus, lithological classes are more susceptible to weather processes, and greater capacity to provide nutrients receive higher grades. Soils are weighted according to drainage attributes, texture, effective depth, and fertility. Soils with drainage balance, more clayey texture, and more profound and fertile had notes closer to five (Costa et al., 2019). The slope varies with the degree of inclination of the relief. The flattest reliefs receive higher scores, and the bumpiest reliefs have smaller notes (Costa et al., 2017). The colours of PCU score intervals from 1 to 5 follow the methodology of Costa et al. (2019).

After being weighted, the variables are (re)calculated in the GIS environment through map algebra and multicriteria evaluation, Analytic Hierarchy Process (AHP). In the AHP method, the variables are arranged in a paired sequence, being placed in comparison according to the degree of importance (Saaty, 2008). The layers were then combined,

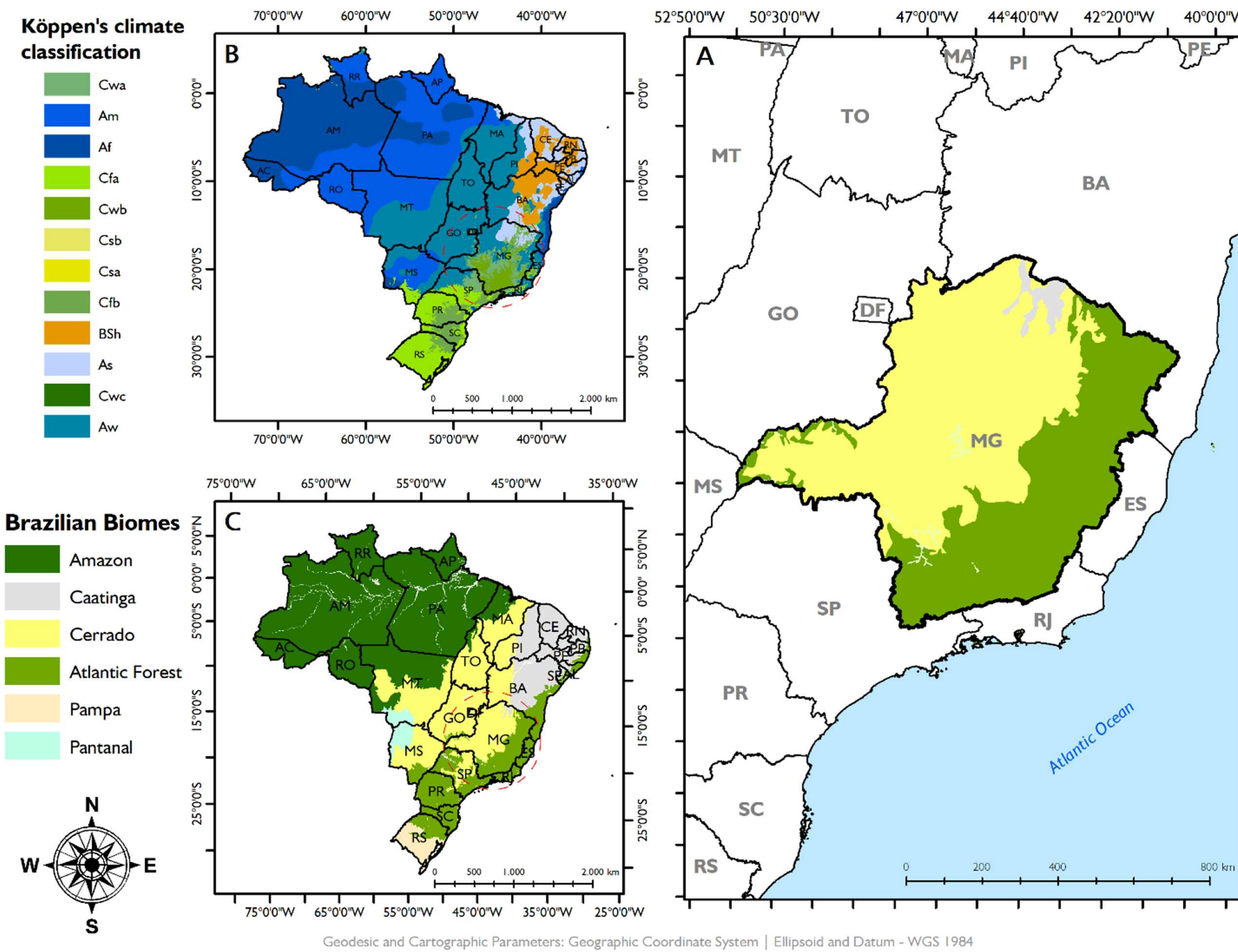

Fig. 1. (A) Study area location, Minas Gerais, Brazil; (B) Koppen's climate Brazilian classification and (C) Brazilian Biomes.

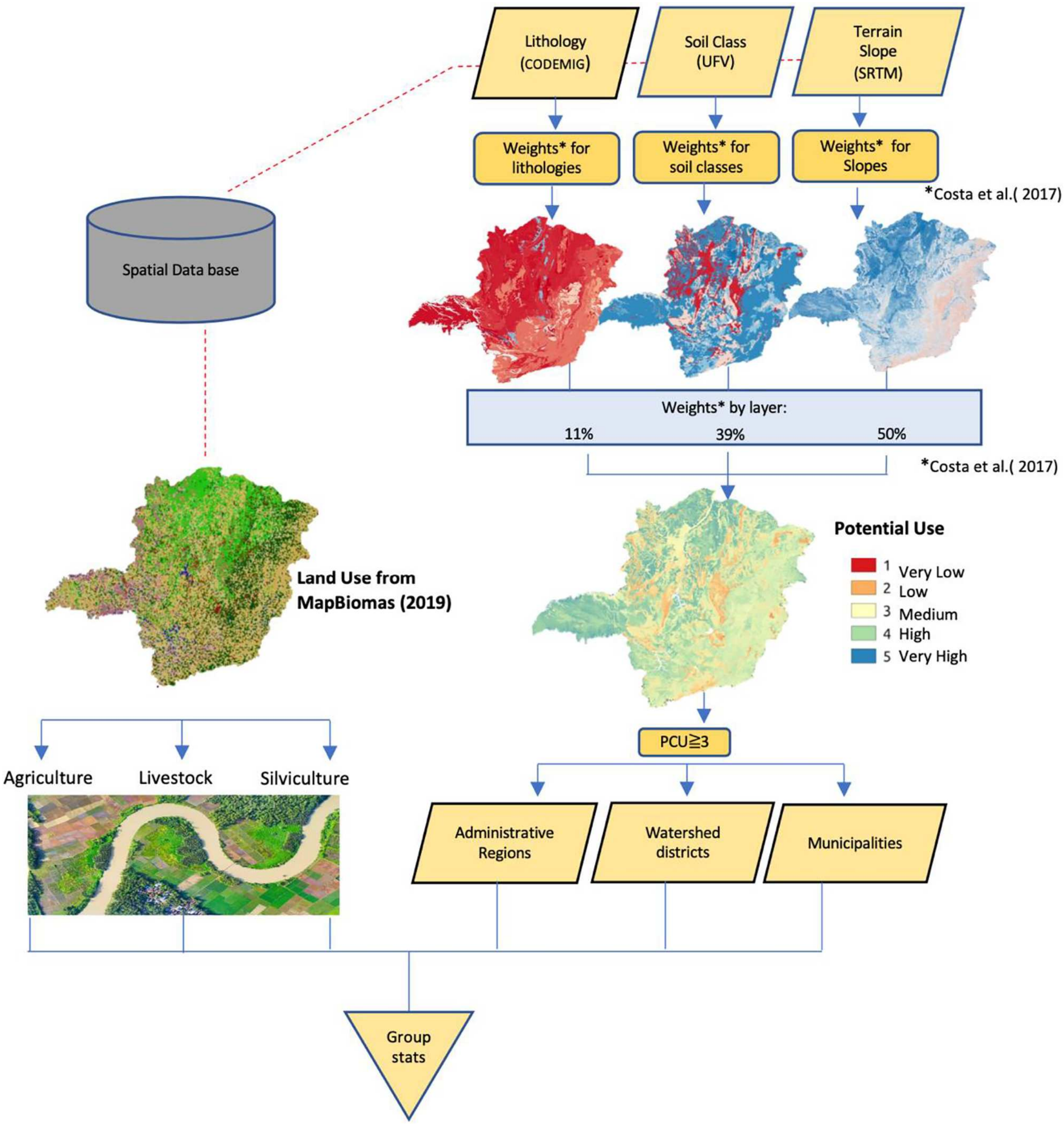

Fig. 2. Flowchart of the methodological procedures for analysing.

Table 1
Scores related to the aptitude for agrosilvopastoral use ranged from 1 to 5.

PCU Scores	Information Plans Lithology	Soils *	Slope (%)
1.0 to 1.8	Quartzite, (meta) arenite, (meta) greywacke (meta) conglomerate, arkose, (meta) diamictite, banded iron formation, itabirite, (meta) siltite, argillite, slate, phyllite, unconsolidated sediments, clastic metasediments and sediments, gneiss, granite, charnockite, rhyolite, schist	Spodzols, Histosols, Entisols (Arenosols), Alfisols	> 45
1.8 to 2.9	Monzonite, tonalite, enderbite, syenite, trachyte, dacite, phonolite, granulite, diorite, anorthosite, alkaline ultramafic, andesite, volcanic breccia and bomb, meta ultramafic, kimberlite, peridotite, amphibolite, dunnite, gabbro, migmatite, meta basic, metavolcanic, diabase	Vertisols, Entisols (Gleysols), Alfisols, Ultisols (Plinthic), Chernosols, Inceptisols	20.1 to 45
3 to 3.4	Basalt, pyroxenite	——	8.1 to 20
3.5 to 4.2	Dolomite, evaporite, limestone, marble	Ultisols	3.1 to 8
4.2 to 5	Calcschist, marble	Oxisols, Nitosols	0 to 3

*FAO and Soil Taxonomy.

Table 2
Intervals are used to classify aptitude based on Potential for Conservation Use (adapted from Costa et al., 2017).

Potential for Conservation Use	PCU Score	Aptitude for agrosilvopastoral use	Description
Very Low	1.0 to 1.8	No	Unstable areas, with severe restrictions on land use and relevant interest to conservation and biodiversity.
Low	1.8 to 2.9	No	High restriction on land use, requiring careful evaluations for use to minimize impact or prioritize conservation or protection.
Medium	3 to 3.4	Yes	Moderate restrictions on the use of natural resources and anthropic use.
High	3.4 to 4.2	Yes	Stable morphodynamical conditions in the landscape.
Very High	4.2 to 5	Yes	High resilience potential and dynamic balance.

considering weights of 50% (w_1= 0,50) for slope, 39% (w_2=0,39) for soil class, and 11% (w_3= 0,11) for lithology (Costa et al., 2019) (Fig. 2) following the equation:

$$PCU = \sum_{n=1}^{3} (n * w_i) \quad (1)$$

Where: PCU = Potential for Conservation Use; n = environmental variables (Lithology, Soils and Slope); Wi = Weights obtained in the AHP operation.

We overlapped the PCU map with the administrative boundaries (Minas Gerais, 2021), watershed districts (IGAM, 2016), and municipality divisions (IBGE, 2020a) (Fig. 2). The combination of the multi-criteria considered in the study was standardised to a common scale, with the weights technically assigned. The data had their spatial resolutions and scales harmonised, aiming at the normalization and adequacy of layers of different scales (Tobler, 1987). Besides, we used the 2019 land use classification crossed with the PCU map (Fig. 2) to obtain the land use assessment.

We adapted the indexes of agrosilvopastoral aptitude from the PCU classes (Table 2) which the scores reflect the potential for water recharge, agricultural use, and resistance to erosion (Costa et al., 2017). The PCU is associated with drainage, fertility, and soil depth. Drainage is related to the capacity to supply water and oxygen to the soil; fertility is associated with the natural availability of the soil to provide nutrients, and adequate depth is related to space for the development of the root system and internal drainage profile. The water recharge and the erosion resistance considered the runoff rate and the time to water infiltration.

3. Results

3.1. Biophysical parameters of the landscape of Minas Gerais

The highest lithology scores are (meta) limestone rocks at the central, northwestern, and southwestern portions (Fig. 3a). The soil order has a high potential for agrosilvopastoral use since Oxisols dominate it. Low weights (Fig. 3b) occur associated with Entisols order (e.g., center, northwest, and in some river valleys) whose origin is related to quarzitic and ferriferous rocky substrate central region (e.g., *Espinhaço* range). In the northwestern, low weights are associated with sand river deposits (Fluvisols). Inceptisols areas have intermediary scores (Fig. 3b). The high slopes are associated with the mountainous regions, mainly in the east and southeast of the state (e.g., *Mantiqueira, Espinhaço, Canastra*, and *Caparaó* ranges), resulting in low scores for agrosilvopastoral use. The high scores are in the flat regions from the northwest and west portion of the study area and the plains of large rivers (e.g., *São Francisco, Jequitinhonha, and Doce*, among others) (Fig. 3c).

3.2. PCU to Minas Gerais state

After combining the lithology, soil class, and slope (weights of 11, 39, and 50%, respectively) to create the PCU map, the State showed an average PCU score of 3.5, ranging from 1.078 to 4.989 (Fig. 4). The highest PCU score of "number" was recorded in the state's west and northwest portions. However, the low PUC score of "number" was observed in mountainous regions. The eastern and southern areas have intermediate values primarily conditioned by the slope resulting from the wavy terrain.

The west portion of the state presented lower weights widely formed by acidic and chemically poor soils (Red Yellow Oxisols, Red Oxisols, and Ultisols). Entisols with a low score for PCU are striking in areas formed by structurally resistant rocks, such as quartzites and itabirites. The slope is the main layer in the PCU spatial distribution. In addition to the high weight (50%), it is the layer with the highest resolution and detail and the only layer derived from numerical and continuous information (i.e., SRTM).

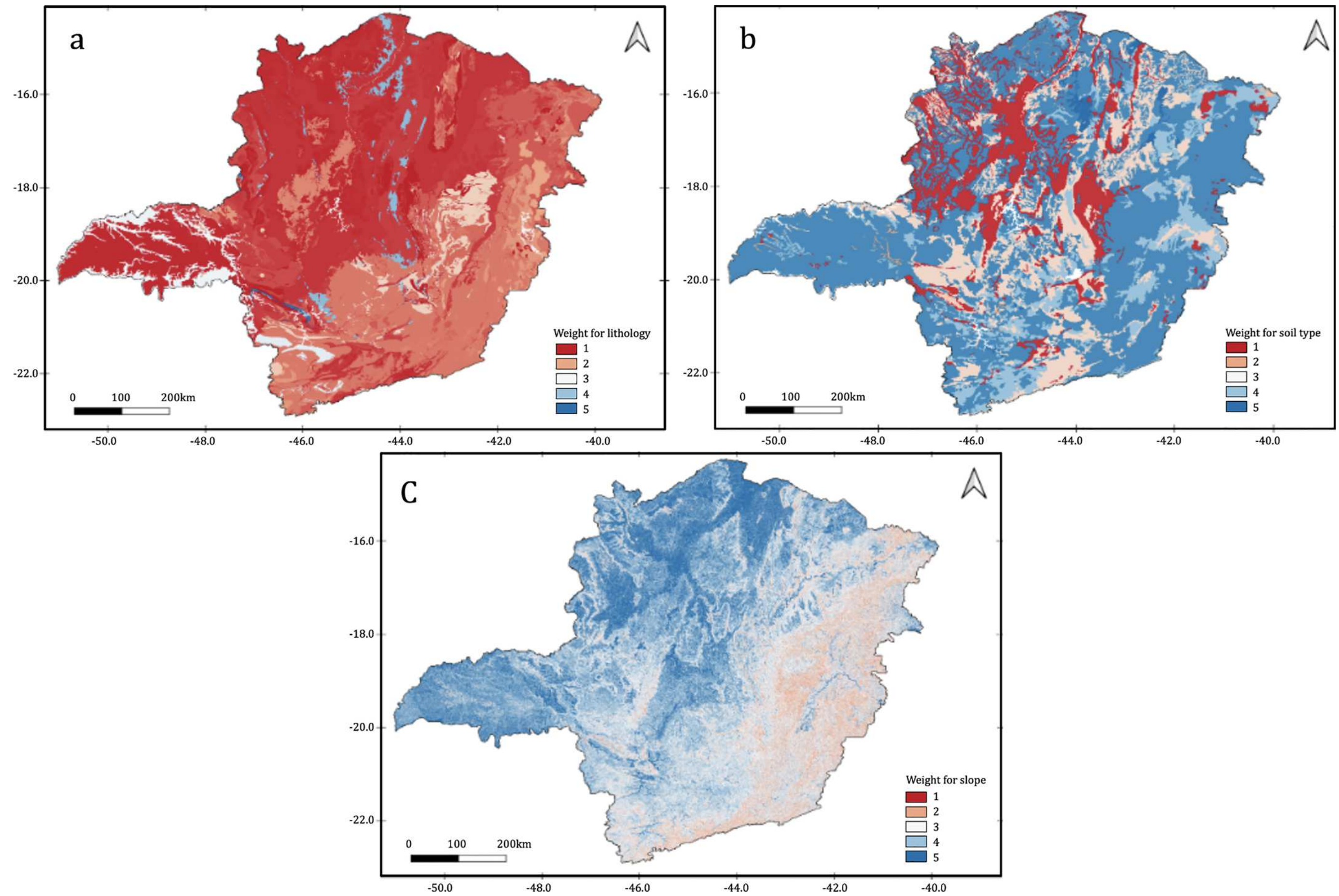

Fig. 3. Scores reflect the potential for water recharge, agrosilvopastoral use, and resistance to erosion for a) lithologies, b) soil, and c) terrain slope classes.

3.3. Agrosilvopastoral land use in Minas Gerais state

Based on the land use classification carried out by MapBiomas (2020) for 2019, livestock is the principal land use with economic purpose in Minas Gerais state, covering 29.7 million hectares, followed by agriculture with 4.1 million and silviculture with 2.3 million. Livestock has the highest percentage of land use (17.9%) in areas with low potential, followed by silviculture (8.6%) and agriculture (3.9%) (Table 3).

3.4. Administrative divisions – PCU and agrosilvopastoral land use

Considering the 12 administrative divisions of the Minas Gerais state (Fig. 5), the results of PCU have a similar percentage of land with adequate potential for agrosilvopastoral use (PCU$\geq$ 3) combined with land use data (Table 4). The highest potential is in the *Mucuri* valley division, with 98.3% of the area with PCU $\geq$ 3 (average score = 3.52), followed by the *Triângulo Mineiro* division (96.7%) and *Doce* Valley (96.6%). The *Triângulo Mineiro* presented the highest average PCU (3.87), while the *Jequitinhonha* region had the lowest average PCU (3.26).

Land use data subdivided by administrative regions indicate lower use than suitable areas (Table 4). However, part of the eligible areas consists of Permanent Protection Areas (PPA), regulated by federal laws (Brazil, 2012). Regions in the north-central of the Minas Gerais state (North, Northwest, *Jequitinhonha, Mucuri*) have lower land use percentual compared to the other areas.

3.5. Watershed districts – PCU and agrosilvopastoral land use

The balance observed between the PCU administrative divisions is not repeated when analysing the watershed districts (Fig. 6, Table 5 - *supplementary material*) and the municipal divisions. The results showed the average PCU for the primary 43 watershed districts whose scores ranged from 2.07 to 4.27, with a percentage of areas with adequate PCU between 0.44 e 98.02%, respectively.

The *Itapemirim* watershed district (1) is eastern of the studied region (Fig. 5), on the board of another Brazilian state. This portion has the lowest PCU score and presents only 11% of the PCU area due to the Caparaó Range. The aptitude for agrosilvopastoral ranges from 82 to 88% in seven watershed districts and 90 to 98% in twenty-six watershed districts. Eight watersheds showed PCU>99%, especially those with large territories: Low *Grande* tributaries (36), Low *Paranaíba* (40), and *Mucuri* (38) (Fig. 6, Table 5 - *supplementary material*).

3.6. Municipalities

The analyses of municipal divisions amplified the inequalities (Fig. 6), showing an even more significant variation in PCU values between units. Many municipalities had an average PCU score between 3

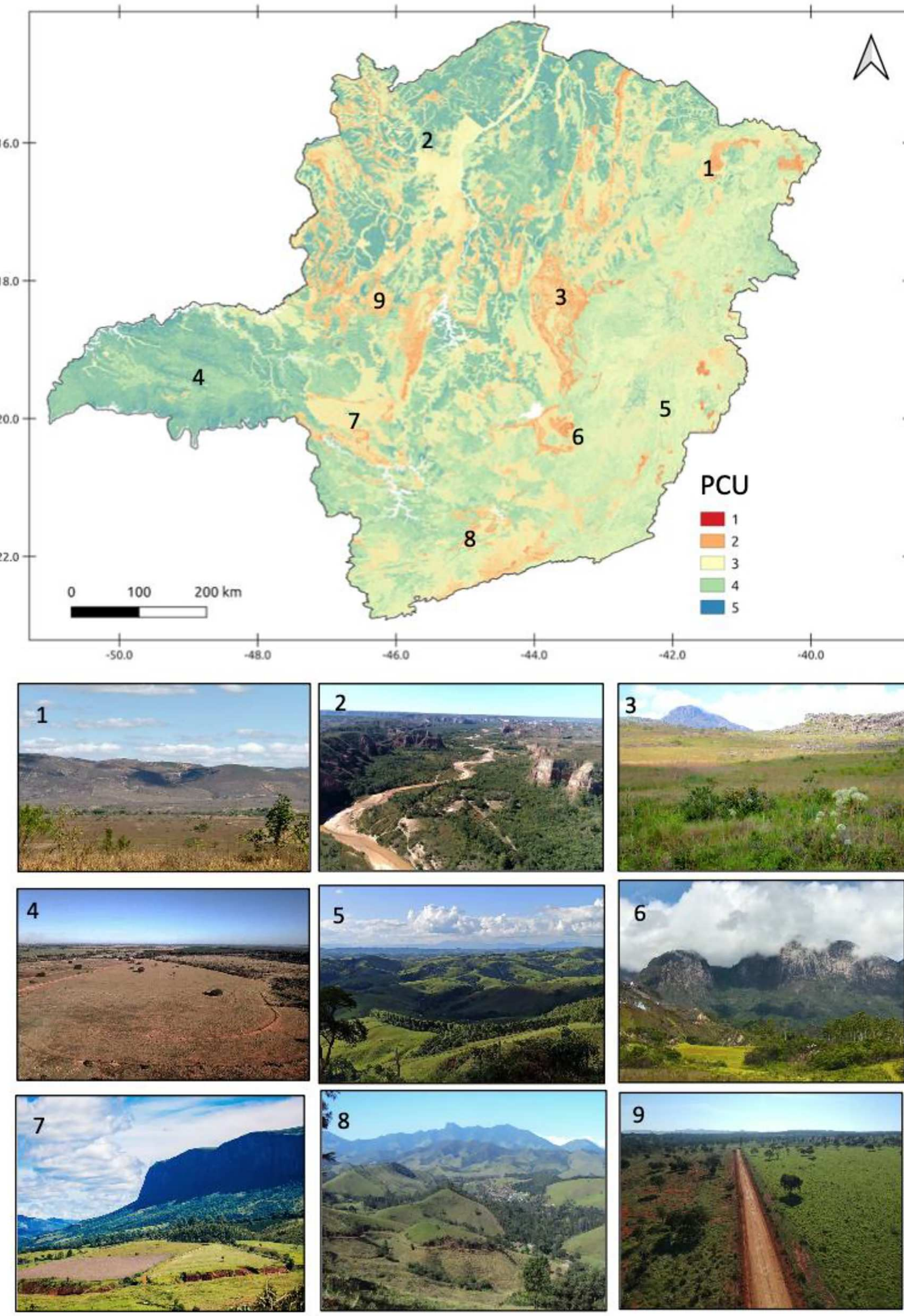

Fig. 4. Potential for Conservation Use (PCU) resulted from the combined layers: lithology, soil class, and slope. Some photos that characterize the diversity of landscape in Minas Gerais state: **1**) Almenara municipality, Low Jequitinhonha Valley; **2**) Northern Minas Gerais State landscape; **3**) Espinhaço Range and Itambé Peak (2052 m of altitude); **4**) Triângulo Mineiro, western portion of Minas Gerais state; **5**) "Mares de Morros" – eastern portion; **6**) Caraça Range; Iron Quadrangle; **7**) Canastra Range with cultivated areas; 8) Mantiqueira Range with cultivated areas; **9**) Western portion (Paracatu municipality region).

Table 3
Current land-use area and percentage over low Potential for Conservation Use.

Land use	Area (ha)	Low PCU (%)
Livestock	29,724,881	17.89
Silviculture	2381,596	8.61
Agriculture	4188,472	3.91

and 4 (Fig. 6), and some from the west and north regions concentrated on high PCU scores (4 to 5). A high concentration of 2 to 3 PCU score municipalities is related to the ranges (Espinhaço, Iron Quadrangle, Mantiqueira) in a North-South trend. Cedro do Abaeté had the lowest percentage of area suitable for agriculture (31%) and an average PCU of 2.25 (standard deviation of 0.40) (Fig. 7 and Table 6 - *supplementary material*).

4. Discussion

Global land use has increased considerably in recent decades and Brazil is one of the countries with the largest change from native to the anthropic area (Winkler et al., 2021). Methodologies aimed at the agrosilvopastoral aptitude are necessary for establishing public policies that enable sustainable land use (Briassoulis, 2019; Chasek et al., 2019) as well as conservation use areas (Ghoddousi et al., 2022; Jiang et al., 2022). The EZ must be combined with several other components, such as legislation, endangered species, tourism interest, etc. Even if a region has a high potential for agricultural use, it is essential to have a portion of conserved areas for storing reservoirs of native species and for providing ecological services like pollination, pest control, water production, etc.

Concerning the PUC environmental factors, Minas Gerais lithology shows a predominance of low scores considering PCU, represented by gneisses, metapelites, granites (eastern and southwest), quartzite (central) slate, siltite (central/ northwestern), and arenite (west) portions. The (meta) limestones conditioned the highest weight scores for potential use in the state territory (Costa et al., 2017). The Red Yellow Oxisols, Red Oxisols, and Ultisols, widely present in the Minas Gerais, conditioned the medium to high PCU due to the advanced weathering stage, deep, good drainage conditions, and low cation exchange capacity (Bünemann et al., 2018). Entisols, with a low score for potential use, are associated with resistant rocks (Taveira et al., 2021), such as quartzites and itabirites. The vegetation formed in these shallow and lithic soils has high endemism (Schaefer et al., 2016) and must be preserved (Silveira et al., 2016; Colli-Silva et al., 2019). The ecological features claim protection creating double enforcement for conservation and promoting ecosystem services as indicated by the Brazilian law (Brazil, 2021).

Although Minas Gerais state lithologies present low PCU scores, the soil and the slope provide an ideal PCU for developing agrosilvopastoral activities in a significant portion of the area. However, low PCU regions highlight the importance of studies to understand the ecosystem's fragilities. They must also be combined with other surface characteristics related to the biota or other uses that may lead to other than agricultural land destinations. This affirmation aims to enhance the responsible use of natural resources, following Brazil's national and international commitments, such as the 2030 Agenda (UN, 2015). Methods aiming at agricultural zoning (Minas Gerais, 2021), environmental fragility mapping (Ross, 2012; França et al., 2022a), and the potential use evaluation (Costa et al., 2017) tend to encourage and promote appropriate agricultural practices in areas with high aptitude. On the other hand, those methods should also promote natural vegetation recovery in low potential regions and discourage low potential land for agrosilvopastoral use (BPBES, 2019; Brazil, 2021).

The terrain slope is the main layer, with a high weight (50%) and the highest resolution and detail layer in the PCU spatial distribution. The slope determines the intensity of processes such as erosion and redistribution of sediments, local drainage capacity, and the amount and power of solar radiation (Abate and Kibret, 2016). At regional scales, topographic heterogeneity contributes to soil moisture's spatial heterogeneity (Chadwick and Asner, 2016) which can also shape species distribution and habitat diversity (Engelbrecht et al., 2007; Comita et al., 2009; Jucker et al., 2018). Water availability in tropical soils severely limited vegetation growth and productivity (Silva et al., 2013). For these reasons, the slope layer defines the transitions and details of the PCU. Although the soil type and lithology maps have lower spatial resolution than the slope, the PCU calculation can be continuously updated and improved as more refined scale maps become available.

Costa et al. (2019) divided the PCU into five classes regarding the potential for conservation use. This work adopted the most straightforward division for analysing the fitness for use: PCU ≥ 3 indicated aptitude for agrosilvopastoral activities and PCU<3 for biodiversity conservation (Table 2). The methodology allows rapid reprocessing allowing different divisions readily. Although, we do not ignore the need for conservation initiatives inside the productive landscape to ensure adequate supplies of pollinators, seed dispersers, herbivores, natural enemies, and so on (Nelson and Burchfield, 2021). Moreover, it is also necessary to consider conserving the streamflow margins and other areas demanded by law (Brazil, 2021).

We emphasize that other factors such as climate (Gomes et al., 2020), the capital and technology applied to land use (Taveira et al., 2021), logistic network (Lupinetti-Cunha et al., 2022), and distance to markets can also affect the land use potential and were not considered in this study. It is essential to have regional studies to develop policies for conservation. Levels of agricultural management must be analysed considering the land use capability from the different applications of capital and technology (Taveira et al., 2021) or even considering the roadless and railroad-less opportunity for conservation (Tisler et al., 2022). Besides restoring degraded areas and mitigating forest degradation, measures to contain deforestation are necessary to avoid drastic loss of biomass and biodiversity (Lima et al., 2020). The challenge to land use planning must be the improvement of land use efficiency and the reduction of new areas opening. The ecosystem services approach in landscape design and accountability may be a great driver to face this challenge, especially at the government level (IBGE, 2020b; Agra et al., 2021).

4.1. Potential conservation use by administrative, watershed, and municipalities divisions

The administrative divisions have a better balance in terms of agricultural aptitude than the watershed districts and municipal divisions. These results highlight the necessity to improve generic programs of land use designed for larger scales before implementation in municipalities or watershed districts. Despite this apparent balance between divisions, a most in-depth analysis becomes recommended since each region has climate and logistical differences beyond the methodology analysed here. For example, the North and part of Jequitinhonha region of the Minas Gerais state, which scored with high PCU, is partly in areas susceptible to desertification, classified as semiarid (IBGE, 2018; França et al., 2022a). The contrast of the suitable regions and land use for the agrosilvopastoral use at the North, Northwest, *Mucuri*, and *Jequitinhonha* valleys can be conditioned to climate conditions and lower populational density from the state (0–25 0–25 inhabitant/km^2) compared with the *Belo Horizonte* region ($>$ 500 inhabitant /km^2) (IBGE, 2010).

Determining the PCU's spatial distribution within a region or watershed district is essential for adequate management and

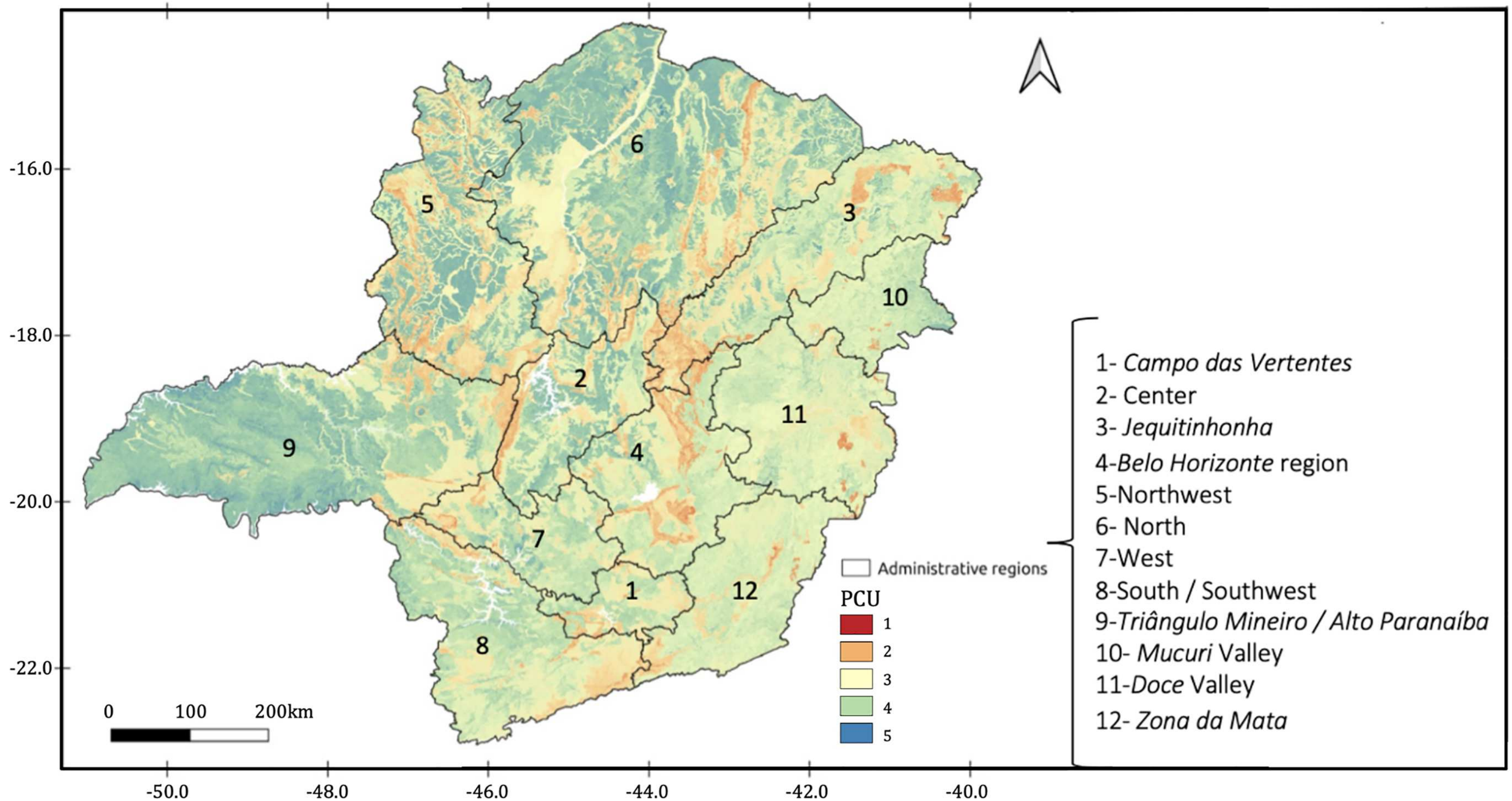

Fig. 5. Potential for Conservation Use index for the Minas Gerais State and the administrative divisions.

Table 4
Resume of the Potential for Conservation Use per administrative divisions: mean, standard deviation, and percentage of the areas suitable for agrosilvopastoral use based on PCU ≥ 3 and the percentual of used land (MapBiomas, 2019).

Administrative Region	State representation (%)	PCU Mean	PCU StdDev	Suitable for agrosilvopastoral (%)	Land Used %
1 - *Campo das Vertentes*	2.14	3.29	0.626	91.83	78.77
2 - Center	5.41	3.45	0.736	91.58	68.85
3 - *Jequitinhonha*	8.55	3.26	0.658	89.53	37.07
4 - *Belo Horizonte* Region	6.75	3.23	0.699	86.34	49.13
5 - Northwest	10.64	3.42	0.839	88.10	53.46
6 - North	21.89	3.62	0.753	94.25	40.78
7 - West	4.10	3.45	0.615	95.39	73.71
8 - South/Southwest	8.45	3.43	0.614	93.98	74.63
9 - *Triângulo Mineiro/Alto Paranaíba*	15.44	3.87	0.650	96.71	79.48
10 - *Mucuri* Valley	3 43	3.52	0.494	98.33	59.72
11 - *Doce* Valley	7.11	3.35	0.501	96.60	67.13
12 - *Zona da Mata*	6.09	3.35	0.507	95.13	72.40

development of effective public policies for soil conservation, water conservation, biodiversity, and land use regulation. Applying the EZ at the watershed scale is recommended for potential environmental and territorial management and planning (Minas Gerais, 2020). Crossing data on current land use and potential for conservation use makes it possible to identify conflict points and define priorities for maintaining a balanced natural ecosystem (França et al., 2022b). This study improves environmental management established by the Brazilian policies (Brazil, 1981; 1997) and contributes to actions linked to biological diversity (CBD, 1992) and Climate Change Conferences (COP 21 - 21st 2015; COP 25 - 25st 2019).

The PCU score showed a good agreement with cultivated production related to the municipalities (IBGE, 2019). For example, some cities with lower PCU (e.g., Cedro do Abaeté, Bocaina de Minas, and Rio Acima) have inexpressive cultivated areas (< 150 ha) (IBGE, 2019). In contrast, municipalities with higher PCU values (e.g., Uberlândia, Uberaba, and Sacramento) presented cultivated areas over 100,000 ha (IBGE, 2019). Other factors can affect agribusiness activities, including climate conditions and non-climate factors. Further research may include new elements to model the potential for agriculture, livestock, silviculture, and conservation use for species protection or ecological intensification of the productive landscape.

4.2. Potentiality for payments of environmental services

Areas with lower PCU should primarily be maintained, with native vegetation becoming suitable to provide ecosystem services. In this direction, we highlight some international actions, such as the Espinhaço Range Biosphere Reserve declaration (Andrade et al., 2018). When a low PCU region presents some agrosilvopastoral use, it is essential to adopt appropriate soil conservation practices and mitigate impacts by implementing environmental services necessary to recover the ecosystem services required by the productive landscape. Such action is needed as they are fragile and more susceptible to degradation when subjected to inadequate management practices (Costa et al., 2019).

Some municipalities with low PCU have a strong economic dependence on non-agriculture activities, such as mining or industrial. In contrast, cities with low agrosilvopastoral capacity and no alternative economic activity have the lowest Gross Domestic Product (GDP) (Table 6). The land aptitude should guide actions and public policies that seek the best possible use for the land, searching for harmonious and sustainable use of resources without compromising its quality (Garnica, 2005).

With a considerable part of the area presenting an intermediary to high PCU, adequate soil and water management and conservation techniques are even more critical for maintaining the sustainability of agrosilvopastoral activities. The practices adopted reflect directly on the soil's physical, chemical, and biological properties (Reichardt and Timm, 2004). Regardless of the PCU, management must always ensure the maintenance of soil and water quality.

The rural sector has undergone intense changes due to migration, traditional activities abandonment, deforestation, technification, and intensification of use. Initiatives that seek to organize the landscape and develop affirmative actions are essential and need to be based on the best possible resolution of environmental and temporal spatially explicit data (Lomba et al., 2015; BPBES, 2019). Initiatives like PCU make it possible to identify the potential of areas for agrosilvopastoral use from a soil conservation perspective and are in line with similar initiatives that are already occurring in Europe. This compatibility can help open new markets and promote transparency in the sector, allowing a scalable, replicable, and auditable methodology. Lomba et al. (2015) point out that owners could also benefit from some payment mechanism for environmental services based on a method to prioritize areas.

Payment for environmental services is a great alternative to increase the environmental performance of agriculture, livestock, and silviculture (Brazil, 2021). One option is payment for land taken out from the production process (Bullock et al., 2011), giving up areas with low productive potential, and directing their use to natural vegetation by ecological restoration (Bullock et al., 2011; Lomba et al., 2020). Associating the agriculture sector with an image of "biodiversity producers" is a significant social and environmental impact. The preservation of low PCU areas is essential for biodiversity conservation, creating natural corridors, protection against natural disasters, and water regulation (Lomba et al., 2020). Moreover, environmental services can also be paid when agricultural activities have improved sustainable indexes by ecological intensification measures even inside highly suitable areas for agriculture, silviculture, or livestock (Brazil, 2021; Nelson and Burchfield, 2021).

Based on the knowledge of soil capacity, it is possible to propose not only a planning of use and occupation, of guided planning but also a set of policy recommendations, studies, and practices for the conservation of natural resources, soil, water, and irrigation. The use of land, in natural resources, can avoid cases of underutilization or overutilization, with serious socioeconomic and environmental adjustments.

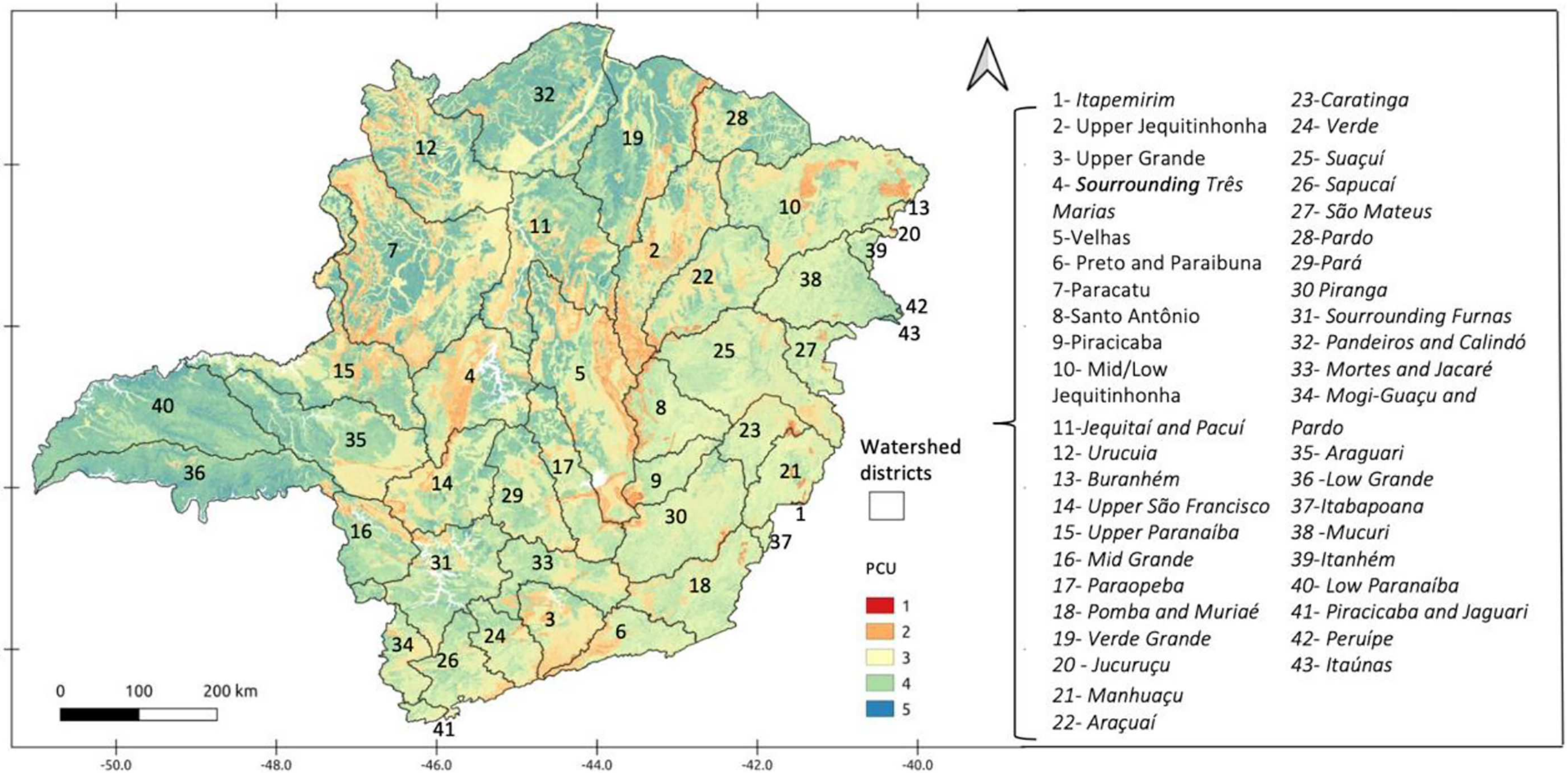

Fig. 6. Potential for Conservation Use index for the Minas Gerais State and the watershed districts.

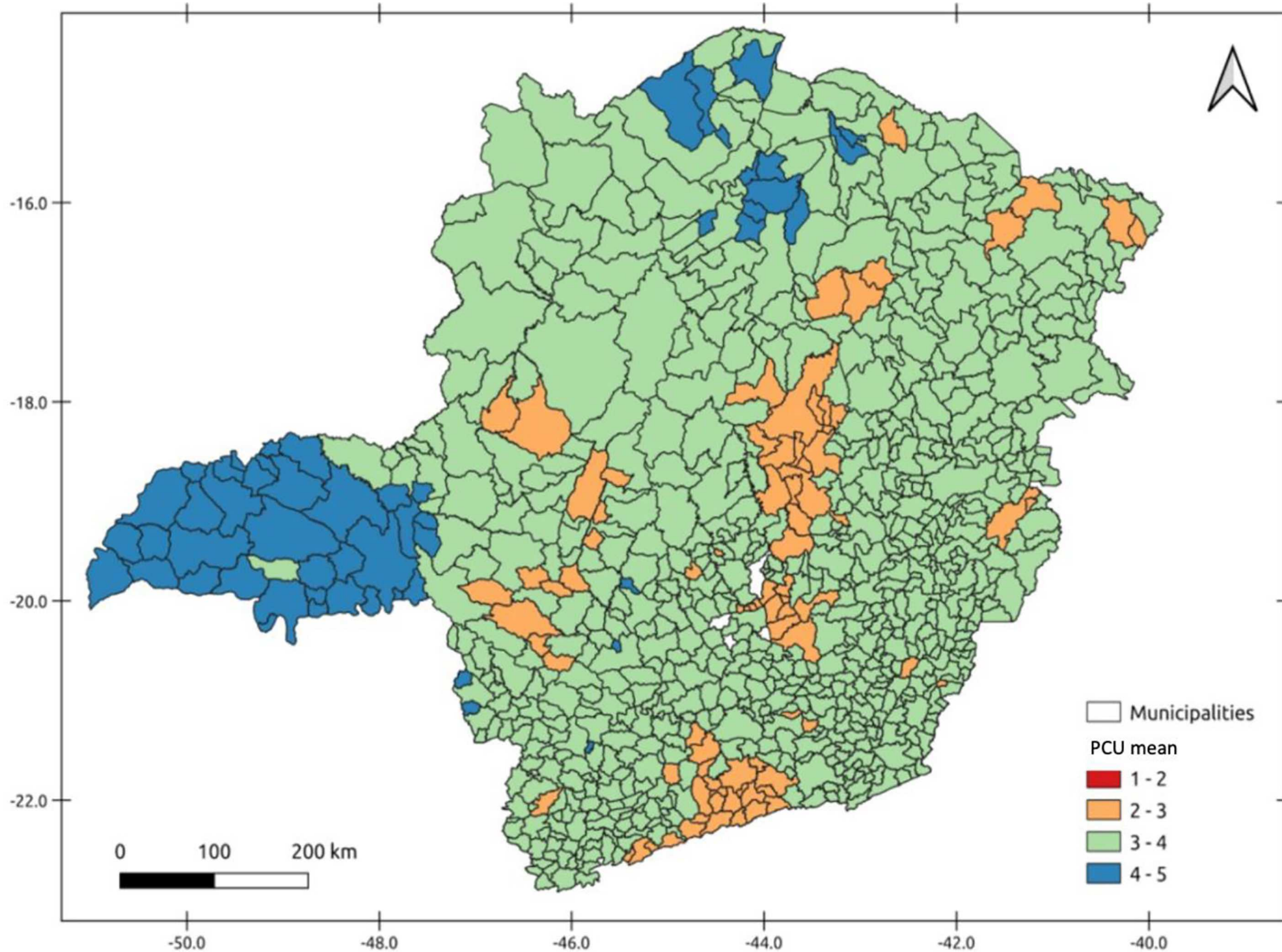

Fig. 7. The mean of the Potential Conservation Use Index to the municipalities.

5. Conclusions and perspectives

Many countries rely economically on agriculture, including livestock and silviculture sectors. Therefore, it is essential to recognize the sector's strengths and weaknesses to develop public policies that need to enhance the agricultural vocation of municipalities with high PCU areas. However, in the same way, it must also provide alternatives for cities with low or without agribusiness land aptitude. Besides, the PCU could also be an indicator while evaluating a new economy activity authorisation's potentiality. This perspective may be enormously improved if the productive landscape is designed considering biodiversity sources and sinks to provide ecosystem services necessary to ensure the best productive potential of each managed crop.

It is important to note that multiple factors condition land use in each region. Implementing the PCU methodology can assess two of them: soil conservation and water production. Many other factors can also affect the land use potential, such as climate conditions, the logistic network, distance to markets, and environmental restrictions imposed by law or local biodiversity idiosyncrasies.

Strengthening the interface between science and public management to support efficient policy formulation is essential and urgent. Developing policies that integrate agricultural production, land use, environmental conservation, and income distribution is necessary to encourage the legalization of land. Consequently, reducing migratory flows, supporting local communities, and using land to its potential, ensuring healthier landscapes capable of securing long-lasting resources for the next generations.

CRediT authorship contribution statement

Danielle Piuzana Mucida: Conceptualization, Visualization, Data curation, Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing. **Eric Bastos Gorgens:** Conceptualization, Visualization, Data curation, Formal analysis, Methodology, Project administration, Validation, Writing – original draft, Writing – review & editing. **André Rodrigo Rech:** Visualization, Writing – original draft, Writing – review & editing. **Cristiano Christofaro:** Visualization, Validation, Writing – original draft, Writing – review & editing. **Ricardo Siqueira da Silva:** Visualization, Writing – original draft, Writing – review & editing. **Israel Marinho Pereira:** Visualization, Writing – original draft, Writing – review & editing. **Marcelino Santos de Morais:** Visualization, Writing – original draft, Writing – review & editing. **Adriana Monteiro da Costa:** Visualization, Writing – original draft, Writing – review & editing. **Luciano Cavalcante de Jesus França:** Visualization, Writing – original draft, Writing – review & editing.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.horiz.2022.100045.

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