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MODELLING PRE-HISPANIC SETTLEMENT PATTERNS IN *ALTO DE TOCHE,* COLOMBIA

MODELACIÓN DE PATRONES DE ASENTAMIENTO PREHISPÁNICO EN ALTO DE TOCHE, COLOMBIA

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Highlights:

- The research contributes to a better understanding of the forms of settlement in the ancient landscape of *Alto de Toche*, influenced by *Cerro Machin* Volcano disaster risk.
- A terrain modelling reconstructed a geoarchaeological mountain landscape, composed of massive systems of terraces at *Alto de Toche* Wax Palm cloud forest.
- From digital photogrammetry in fieldwork, three sites were detailed. A DEM of the settlement pattern projected 37 possible new terraces. The resulting map is accessible in an ArcGIS-online web application.

Abstract:

The enhancement of the archaeological terraces on the *Alto de Toche* and the Wax Palm forest is unprecedented. The Toche region in Colombia contains an outstanding anthropised ecosystems presence (8000 BP), characterised by complex inherited cultural patterns, according to the evidences on the eastern margin of the Andes Central Cordillera. The research focused on i) the cultural landscape of the Premontane and Montane Cloud Forests of the *Alto de Toche*, built by the *Toches*; ii) its high-altitude settlements, interpreted as a strategy of ecological knowledge, deeply linked to their symbolic understanding of the landscape. Fieldwork in three sets of *tambos* (terraces for habitational settlements) in *La Carbonera*, *Gallego*, and *Las Cruces* sites was analysed using remote sensing, drone digital photogrammetry, and on-site data. Their interpretation projected a settlement pattern; a typological-topological *tambos* classification inferred its possible functions such as sighting, funerary, and dwelling, from 2600 MASL to biggest sites at 3000 MASL, related to the sun-moon proximity presumed for gatherings. The authors conclude that the patterns respond to a territorial understanding of its resources and the vertical exploitation of the agricultural thermal floors and micro-watersheds, associated with the east-west solar illumination over both sides of the *Tochecito* River basin; linked with the transit between ridges and steep slopes, through the network of pathways that originated the *Quindío* Trail. Data were projected crossing field-data photogrammetry with GIS spatial analysis; this resulted in a terrain model that reconstructs a geoarchaeological landscape composed of massive systems of *tambos*. Thirty-seven new sites were classified, twenty of them above 2800 MASL. The resulting terrain model facilitates a non-invasive previous prospection for fieldwork planning and a more feasible knowledge of accessibility, due to on-site transit difficulties (steep slopes and very unstable soil due to cattle ranching). Finally, the terrain model was uploaded in an easy-to-access ArcGIS-online web application for sharing with community stakeholders and visiting scientists.

Keywords: landscape archaeology; symbolic archaeology; geoarchaeology; geographic information system (GIS) web app; terrain modelling

Resumen:

La puesta en valor de las terrazas arqueológicas del Alto de Toche y del bosque de Palma de Cera no tiene precedentes en la investigación arqueológica en Colombia. El área conocida como Tochecito, contiene una destacada presencia de ecosistemas antrópicos (8000 BP) caracterizados por complejos patrones culturales heredados, de acuerdo con las evidencias documentadas en sitios cercanos en el margen oriental de la Cordillera Central de los Andes. La investigación se concentró en el paisaje cultural de los bosques de niebla premontanos y montanos del Alto de Toche, así como en sus terrazas en altura creadas por los Toches. El trabajo de campo se realizó en tres conjuntos de "tambos" (terrazas para asentamientos habitacionales), en los sitios La Carbonera, Gallego y Las Cruces, a partir de datos *in situ*, fotogrametría digital mediante drones y análisis satelital. Se analizó un patrón de asentamiento primero por una clasificación tipológico-topológica por altura, superficie, orientación solar, ubicación, y pendientes; de ello inferimos un sistema de posibles usos:

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defensa y avistamiento, funerario, vivienda, desde los 2600 m s. n. m., hasta las terrazas más grandes y elevadas a 3000 m s. n. m.; en éstas, la proximidad solar posiblemente estaba relacionada con prácticas colectivas. Concluimos que los patrones responden a una estrategia de asentamiento que indica un conocimiento ecológico prehispánico profundamente vinculado a i) su comprensión simbólica del paisaje; ii) la explotación vertical de los pisos térmicos agrícolas y de las microcuencas, asociadas a la iluminación solar este-oeste sobre las vertientes de la cuenca del río Tochecito; iii) al tránsito entre las crestas y las laderas escarpadas a través de la red de senderos que originaron el Camino del Quindío. El análisis espacial SIG arrojó un modelo de terreno que reconstruyó un paisaje geoarqueológico compuesto por sistemas masivos de *tambos*. Se clasificaron 37 nuevos sitios; 20 de ellos están por encima de los 2800 m s. n. m. de elevación. El modelo resultante permite una mejor planificación previa del trabajo de campo y de la accesibilidad, debido a las dificultades de recorrido in situ (causadas por las muy pronunciadas pendientes y suelo muy inestable, consecuencia de la ganadería). Por último, el modelo se cargó en una aplicación web ArcGIS-online para compartirlo con la comunidad y científicos visitantes.

Palabras clave: arqueología del paisaje; arqueología simbólica; geoarqueología; aplicación web con sistema de información geográfica (SIG); modelado del terreno

1. Introduction

The oldest evidence of human settlement in the eastern slope of Andes Central Cordillera has been found in the Tolima region, Colombia. Sites located at *Chaparral*, *Saldaña*, and *Roncesvalles* have material evidence of early human activities between 3000-7000 and 11000 BP (Rodríguez, 1987, 1989, 1990; Gnecco & Salgado, 1989; Romero, 1996; Salgado, 1998; Salgado & Varón, 2019); by end of the Pleistocene to the beginning of the early Holocene (Romero, 1996; Rodríguez, 2008; Posada Restrepo, 2017). Similar settlements along the Andes are linked to volcanic landscapes between Colombia and Ecuador (Patiño & Monsalve, 2019; López et al., 2020, López-Soria & Serrano-Ayala, 2020). Those are relevant, considering the oldest sites dated 12500 years BP in South America by Dillehay (1979, 2006; Meltzer et al., 1997).

Tolima's Central Cordillera settlements are influenced by the *Cerro Machín* Volcano (CMV) geoheritage, with multiple stratigraphic evidence of its highly explosive activities (Figs. 1, 2, 3, 4, & 8) every 900 years and a pyroclastic deposits area of approximately 1000 km^2 (Thouret et al., 1995; INGEOMINAS, 2003; Murcia et al., 2008, 2010; Vega Mora, 2009, 2013; Laeger et al., 2013; Londoño, 2016; Inguaggiato et al., 2017; Posada Restrepo, 2017; Monsalve-Bustamante, 2020; Piedrahita et al., 2018; Montenegro et al., 2021; Galvis et al., 2022). Near CMV's northbound, *Alto de Toche* is known for high biological endemism and the discovery of Wax Palm forests, described since the conquest by Spanish chroniclers. They also emphasised the strategic importance of controlling the *Quindío Trail* as a communication route between *Santafé* and *Quito* in the *Nueva Granada* Kingdom (Acevedo & Martínez, 2005; Bernal et al., 2015; Domínguez Ossa, 2022).

The historiography states that the district of *Toche* belonged to the *Mariquita Province* during the conquest and colony periods (Ortega Ricaurte, 1949, 1952; Friede, 1976; Triana, 1993; Clavijo, 1993; Guzmán, 1996; Carvajal & Velandia Silva, 2019). Spaniards struggled with continuous and fierce resistance by the local ethnic groups generically called *Pijaos* (Ortega Ricaurte, 1949; Bolaños, 1995; Montoya, 2022). The *Toches* group withdrew to the highlands, then began a harshly long process of conquest and colonization, as almost pre-Hispanic groups disappeared when incorporated as uprooted labour of *Mita* mining and the *Encomiendas* of the *Magdalena Valley* during the 17th and 18th centuries (Randolph, 1888, 1889; Restrepo, 1888).

At the beginning of the 19th-century, explorers such as von Humboldt, Bonpland, Boussingault, D'Orbigny, Holton, and André crossed the *Quindío Trail* (André, 1884; von Humboldt, 1982; Boussingault, 1994; Sanín & Galeano, 2011; Bernal et al., 2015). They made a series of observations and naturalistic descriptions of their journeys in whose chronicles they remarked on the exuberant beauty of the Wax Palm (*Ceroxylon quindiuense*) forests (von Humboldt, 1982; Boussingnault, 1994, Boussingnault & Roulin, 1849). Von Humboldt and Bonpland travelled by the *Quindío Trail* in 1801. Also, it was the last return route of *Simón Bolívar* from *Quito* to his death in *Santa Marta* in 1830 (Larrichio, 2008; Bernal et al., 2015). Historically, the *Quindío Trail* represented a unique transversal communication channel of the pre-Hispanic world through Peru and was the origin of a profuse network of roads that communicated dispersed settlements in the region. It allowed the exchange of goods and knowledge between cultures that inhabited the southern part of Colombia from the Pacific coast to the high mountains and down to the eastern plains of the *Orinoco* and *Amazonas* (Langebaek, 1987, 1991; Ramírez, 1996) (Fig. 3).

The main objective of this paper is the modelling of a cultural landscape in the *Alto de Toche* Wax Palm cloud forest composed of a massive system of "tambos" (terraces for habitational settlements). Based on remote sensing and digital photogrammetry of three clusters of *tambos* in the sites of *La Carbonera*, *Gallego*, and *Las Cruces*, it is proposed an interpretation of this landscape between 2500 and 3000 MASL (Barrero, et al., 1997; Ramírez, 1996; Bernal et al., 2016; Domínguez Ossa, 2022) (Figs. 1, 2, & 3a).

1.1. Alto de Toche study area

Alto de Toche is about 2503 ha at the north-western end of the municipality of *Ibagué* and *Cajamarca*. It is defined by the steep narrow basins of the *Tochecito* River on the south side, the *Campoalegre* Creek on the north, and the *Toche* River on the northeast side, which surrounds the CMV western side flowing into the *Coello* River major basin (Figs. 4, 5, & 6). The study area belongs to the buffer zone of *Los Nevados* National Natural Park (PNNN). This is the most profuse water source of rivers that irrigate both sides of the Central Cordillera. *Alto de Toche* and "Wax Palm Sanctuary" shares the denser wax palm population with an estimated population of 600,000 individuals (Bernal et al., 2015; Resolution 046/2019; Sanín & Galeano, 2011; González-Rivillas et al., 2018; Castillo et al., 2021) palm trunks are up to 60 m tall and 200 years old. The wax palm is declared Colombia's National Tree (Law 61/1985).

The study focused on three sites in cattle ranches in the district known as *La Carbonera*, *Gallego*, and *Las Cruces* according to the field and overflight by remote sensing drones. An approximate area of 400 ha was covered (in gray) georeferenced *tambos* in range altitude between 2666 and 2971 MASL, facing the *Tochecito* river basin, which is fed by the *La Ceja*, *La Leona*, *El Delirio*, *Pajarito*, *La Glorieta*, *San Rafael*, and *Dantas* streams (Figs. 2 & 3).

2. Materials and methods

Recent modelling research revealed massive agrarian inhabited landscapes in volcanic soils by terraces construction (Dorison & Siebe, 2023). This Pre-Hispanic terracing interpreted landscape management practices to control soil erosion, water retaining, and rainfall flowing water control (Chase & Weishampel, 2016). But paleoenvironmental research works are scarce on *Alto de Toche-Ibagué*. Its morphology characterizes by steep slopes, sharp edges, dendritic drainages, and volcanic tephra coverings from intensive igneous activity during the Tertiary (Miocene) (Barrero et al., 1969).

Their emplacement due to magmatic activity occurred until the Quaternary (Pleo-Pleistocene) (Herd, 1974). Its lithology consists of metamorphic schists of the *Cajamarca* Group by CMV-Tolima Volcano magmatic discharges (ash, lapilli, lahars, bombs, and pyroclastic flows) during the last 14000 BP (Cano et al., 2016, Cano, 2019; Posada Restrepo, 2017; López et al., 2020). According to Holdridge, the Toche subregion settles into Low Montane Humid Forest life zone, locating the wax palms forests relicts. (Holdridge, 1982; Pomar & Vargas, 1985). Also, it belongs to the MGA unit (M: Mountain Landscape; G: Cold and Humid Climate; A: Pluvial Subnival Climate), where cattle ranching, *arracacha* (*Arracacia xanthorrhiza*) and bean crops predominate (Peláez-Martínez & Santamaría-Ayala, 2010).

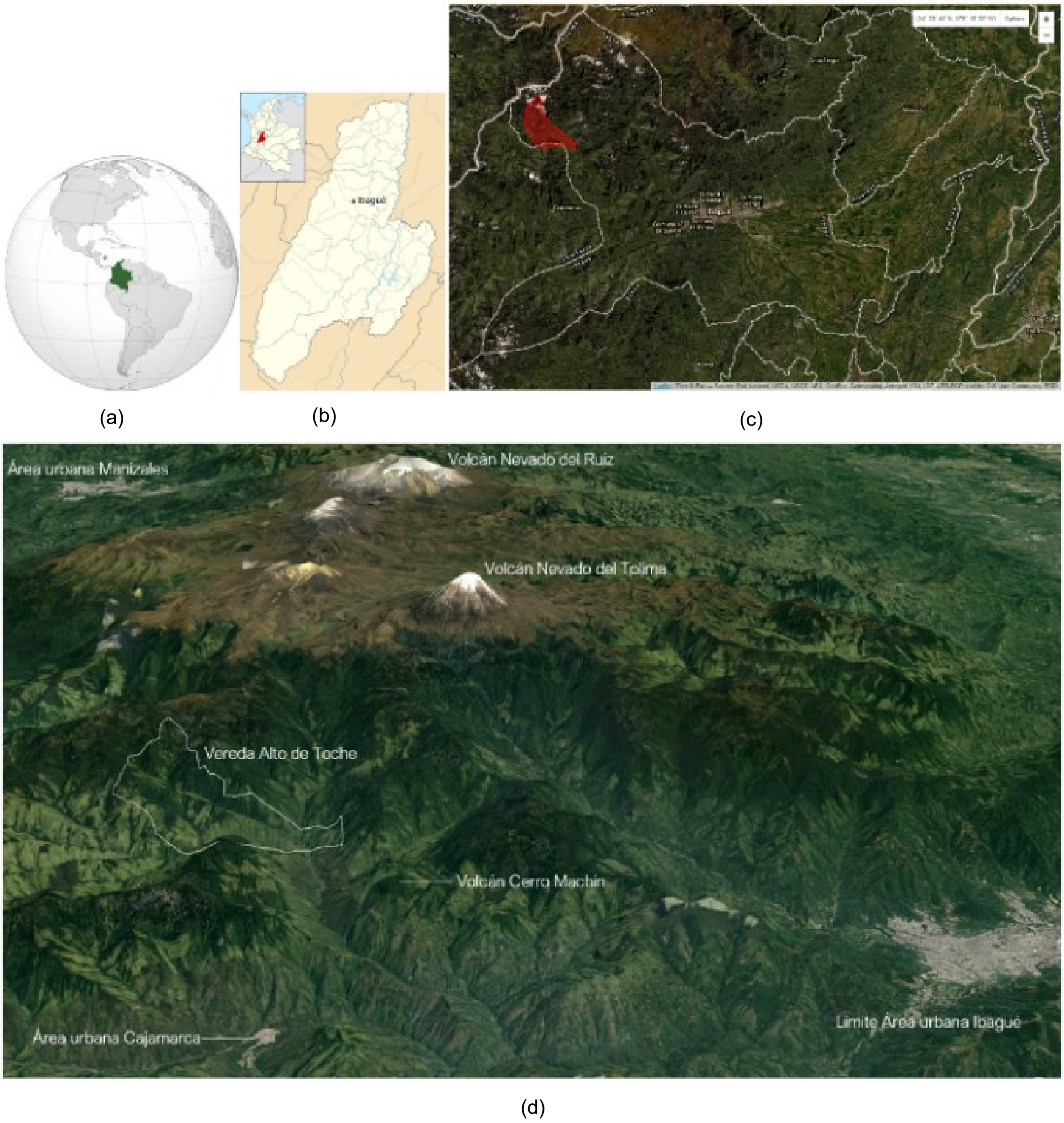
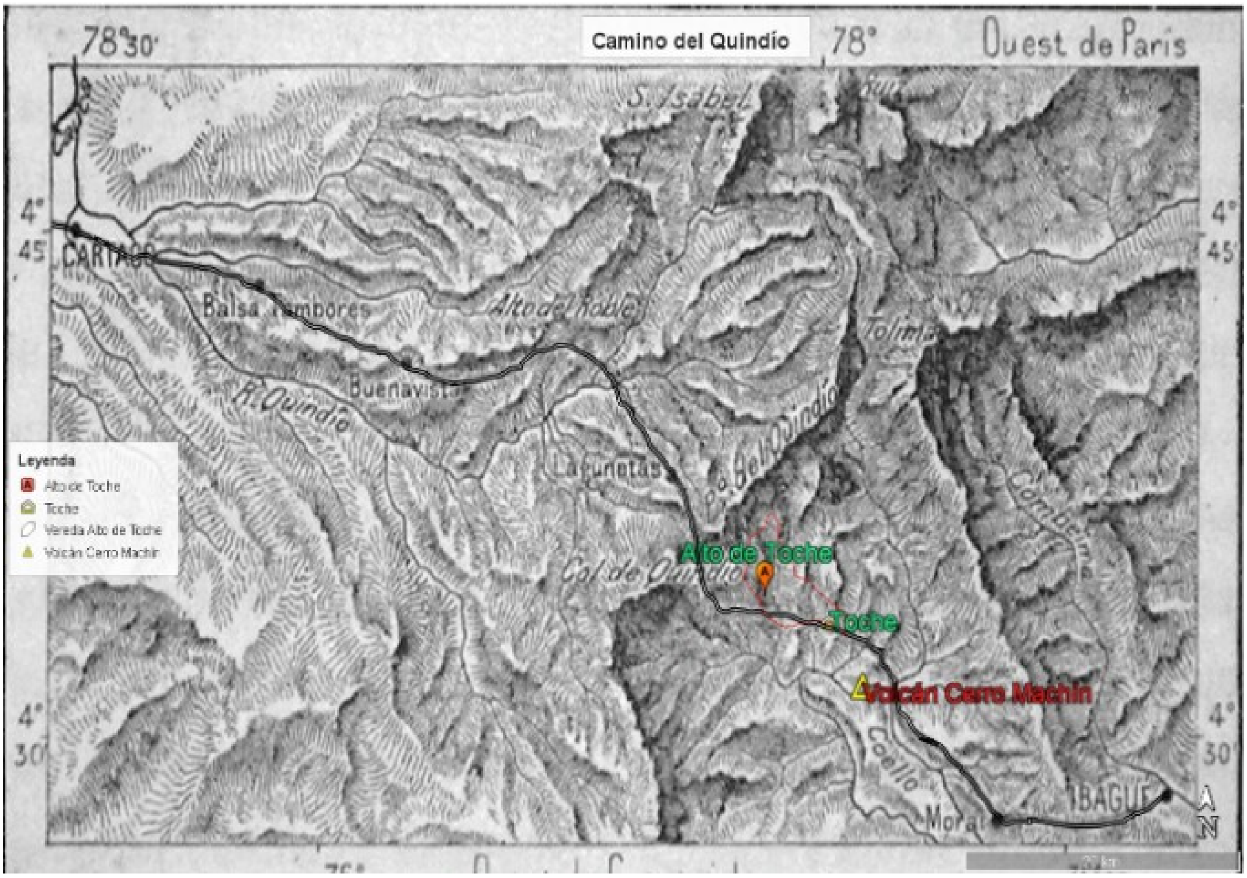


Figure 1: Location of *Alto de Toche*: a) Source: Milenioscuro - Addicted04 CC BY-SA 3.0. b) Source: https://creativecommons.org/licenses/by-sa/3.0. c) Source: USGS Earth Explorer. d) Source: Authors from Google Earth Pro software.



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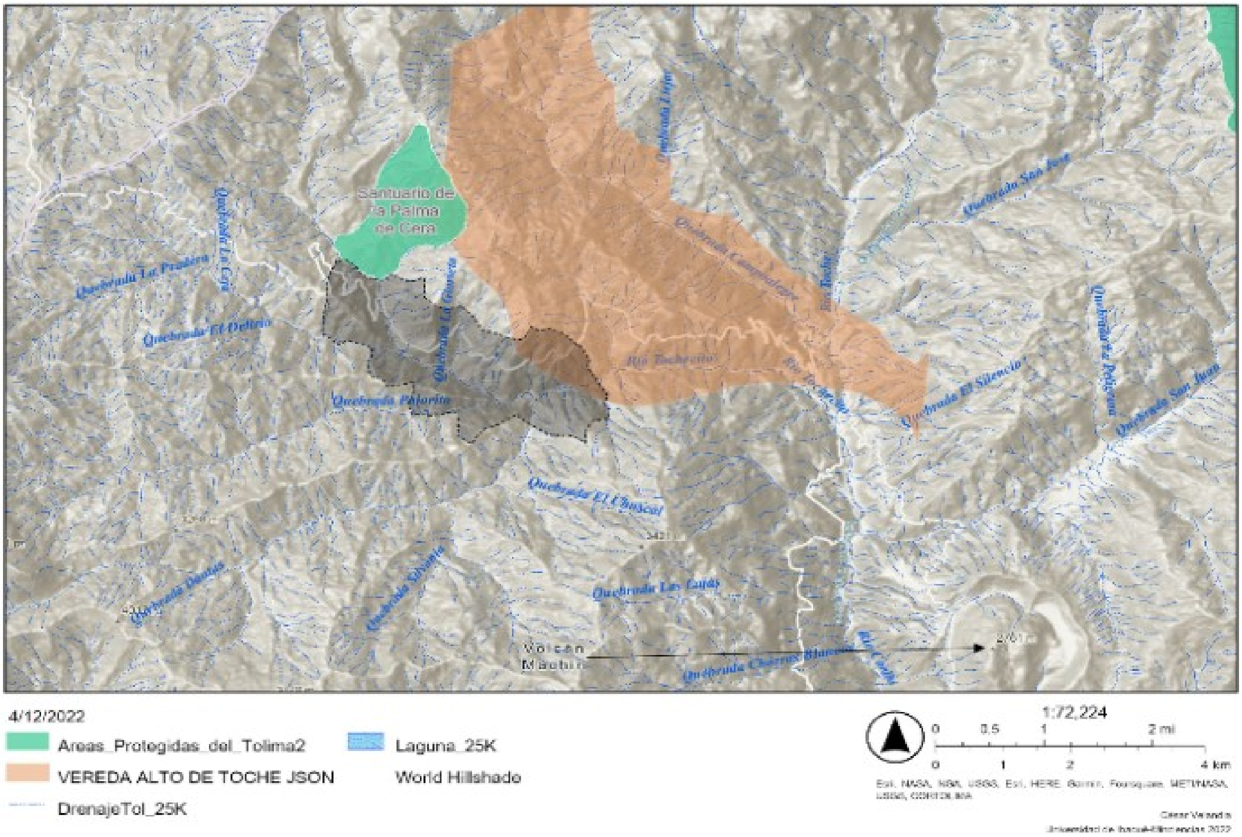
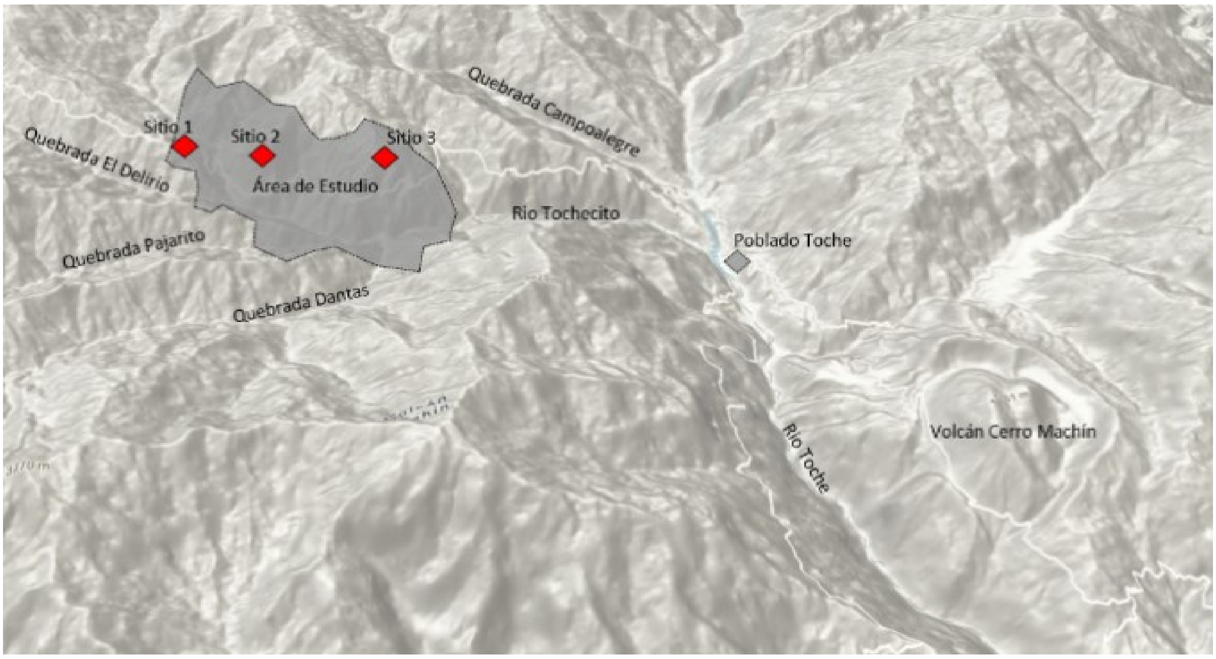


(b)

Figure 2: a) Map of the *Quindío Trail*. Source: Authors from 1893 Reclus' map (Martínez-Rivillas, 2021); b) Location of study area. Source: Authors from Esri Geoserver Web Map Service.



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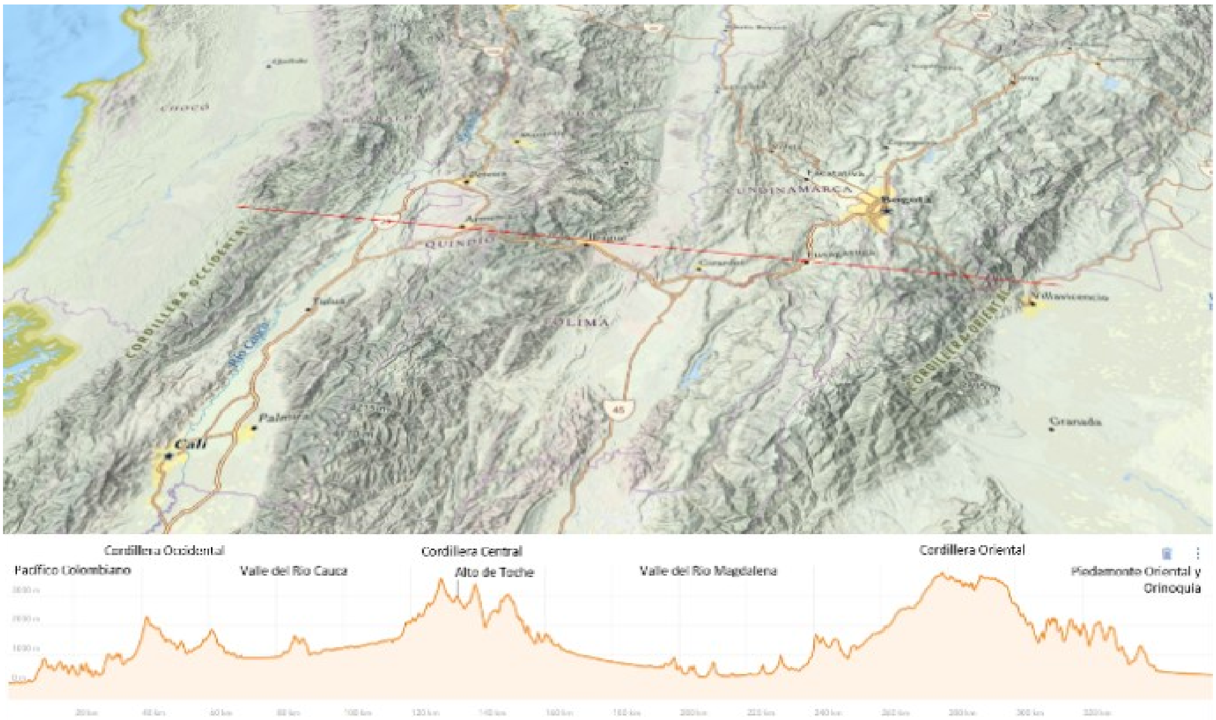


(b)

Figure 3: a) Detail of study area and prospected sites. b) East-West elevation profile of Andes Cordillera of Colombia. Source: Authors from The Human Reach Atlas. https://www.arcgis.com/apps/instant/atlas/

2.1. An archaeology of cultural landscape

Conceptually, every landscape is cultural (Jackson, 1984; Cosgrove, 1985; Norton, 1989; Deetz, 1990; Ingold, 1993; Anschuetz et al., 2001, Tress & Tress, 2001; Mujica & Holle, 2002; Rössler, 2003; Liu et al., 2007); and among recent cases, this value is reaffirmed in agro-productive tropical landscapes (Kołodziej, 2017; Velandia Silva, 2017; Isaza & Velandia Silva, 2018; Velandia Silva & Ospina-Tascón, 2020; Suárez-Rubio et al., 2020; Sleptsov et al., 2021; van Lanen et al., 2022; Rombe et al., 2022; Velandia Silva et al., 2023). However, despite the archaeological pre-existences, management, and provisioning of forest resources studies developed concepts such as “adaptive systems” (Borrero, 1988), “environmental symbiosis” (Condarco & Murra, 1987), “micro verticality” and “vertical archipelago” (Murra, 1975, 1981; Deza & Delgado, 2018).

The landscape is also symbolic. It is a material expression of the man-hand working of physiographic landscape revealing formal systems as “categories”; “levels of articulation and compatibility” between “patterns of rationality”, “technologies of construction of the social space”, and “strategies of the cultural landscape" associated with a "specific social formation" (Criado-Boado, 1993, 1999; Santos-Estévez et al., 1997). Lucena Salmoral (1963) reported ethnohistorical observations of solitary dwellings separated one from another, staggered from the middle to highest terraces along the blades ridges of the mountains, and visible from long distance (Ramírez, 1996). Also evidenced by the Chronicles of the Indies by Fray Pedro Simón (1986), when he pointed out that the mountains of Ibagué and the *páramo* of Quindío were occupied by a good number of indigenous dwellings, which were later occupied by coffee and cattle farms (Rodríguez, 1987; Carvajal, 1995; Ramírez, 1996; Barrero, et al., 1997) (Figs. 5 & 7).

2.2. Related archaeological data

Paleogeographic strata on the western slope of the Central Cordillera revealed a temporality in the settlements (Cano, 2018, 2020; Cano et al., 2016; Cano & López, 2017; Fölster et al., 1977; Dickau et al., 2015; Herrera et al., 2016; Patiño & Monsalve, 2019; López, 2019; López et al., 2020; Zuluaga et al., 2019, Zuluaga, 2020). On the eastern slope, it carried out in sites along *Anzoátegui*, *Cajamarca*, *Fresno*, *Ibagué*, *Líbano*, *Roncesvalles*, and *Santa Isabel* during the last four decades, and revealed existence of funeral spaces in high terraces with shaft tombs, shaft with the lateral chamber, and *cancel* tombs (Tovar, 1983; Rodríguez, 1987; Carvajal, 1995; Ramírez, 1996, 1999; Barrero et al., 1997; Salgado, 1998; Salgado & Gómez, 2000; Cely Vargas, 2021). The obtained dates under *Machín-Tolima* volcanic system influence allow a range from 7500 BP to 300 BP with cultural traits well related to the *Cauca* and *Magdalena* valleys pottery.

2.3. Photogrammetry and spatial analysis

The method for the identification of a settlement pattern of terraces is based on the procedure initially proposed for the photogrammetry of the surveyed sites (La Carbonera, Las Cruces, and Gallego). Flight missions were conducted using the DJI Mavic 2 Pro quadrotor at an average altitude of 40 m above ground level. Flight planning executed through Pix4Dcapture, acquiring approximately 300 georeferenced images, each with a resolution of 5472 x 3648 pixels in RGB. Subsequently, the acquired files were processed offline using Pix4Dmapper [Pix4D, July 2022. [Online: www.pix4d.com.] on a computer (Intel(R) Xeon(R) Silver 4114 CPU @ 2.20GHz, 64GB RAM, NVIDIA GP104GL GPU) running Ubuntu 20.04 operating system. The processing time per project was approximately 3 h, and the analysis detected an average of 75942 keypoints and 32712 matches per image. This resulted in a final average Ground Sampling Distance (GSD) of 2.24 cm over an area of 0.080 km^2.

As a first step, photogrammetry provides a Digital Elevation Model (DEM) (Fig. S1) extracted by the terrain contour lines to determine the necessary features. For this, the ArcGIS Spatial Analyst extension helps evaluate the features according to the criteria established for the Digital Terrain Model (DTM) morphometric variables and the DEM. Secondly, a slope map is generated for the existing terraces interpretation. The slope is defined as the angle between the land surface and the horizontal. Its value is expressed in degrees from 0º to 90º or in percentage so that the lower the slope, the lower the susceptibility to mass movements and the possible existence of a semi-flat area for a terrace. For this purpose, the SLOPE geoprocessing function identifies the slope in each raster surface cell. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. Then PERCENT RISE option helps to define the steepness of the slope, calculated as elevation in percent or slope in percent. Thirdly, slope ranges are determined valued in a reclassification from 1 to 8 levels. The natural break classification method (Jenks optimization) best groups data values between classes and is best for mapping non-uniformly distributed values. Considering the above, we propose the Triangulated Irregular Network (TIN) geoprocessing tool and the 3D Analyst extension that better helps to establish ranges of slope values for triangulated surfaces, allowing the improvement of a slope model by adding terrace features obtained for their delimitation and values from the *La Carbonera*, *Las Cruces* and *Gallego* sites. This procedure will be applied under the same parameters for a raster image (IGAC-Colombia, 2022; uncompressed GeoTIFF, TILED 512, Enhanced Compression Wavelet (ECW)) of the enlarged study area (5800 ha), directed to a survey procedure for prospecting new terraces in which we highlight the advantages of the algorithms used.

For this raster geoprocessing, the digital topography first analysis develops the slope model in the same conditions for the reclassification in 8 divisions that will guide us to find the terraces of our interest. The analysis to extract contour lines and the slope map determines a classification by natural cut (Jenks). In this method, the Natural Neighbour interpolation algorithm finds the subset of input samples closest to a query point and applies weights on them based on proportional areas to interpolate a value known as Sibson interpolation (Sibson, 1981) or "area-stealing" (Gold, 1989). One of its basic properties is that it operates locally since it uses only a subset of samples surrounding a query point and ensures that the interpolated heights will be within the range of the samples used. In natural neighbour interpolation is determined in which data points are neighbours of a given location, typically using Thiessen (Voronoi) polygons rather than simply employing a distance metric. The values of the points are used to interpolate a value for the location of interest.

Second, from the input raster TIN interpolation excels in more efficient handling of irregularly spaced data points and contributes to a detailed and accurate TIN model. It is especially advantageous in photogrammetry (first method) when there are captured terrain features with varying densities of data points. In addition, the algorithm's ability to adapt to different terrains and topologies makes it a versatile tool for TIN generation, providing reliable results in diverse landscapes. TIN interpolation helps to create new elevation points using information from a discrete set of known elevation points useful for surveying new terraces. It creates also irregular flat terraces on the ridge lines and valleys resulting from the different triangle faces or "facets" connection. The Delaunay triangulation creates a surface using triangles of nearest neighbouring points that it circles the selected data points creating their intersections and connecting to a network that is as compact and non-overlapping as possible. Delaunay triangulation ensures a more natural surface interpolation, especially in areas with irregularly distributed data points. TINs adapt to the topographic changes often associated with the heterogeneity of many land surfaces. Therefore, TINs are a more reliable source when dealing with specific surface details (Kidner & Smith, 1993; Lim & Pilesjö, 2022). The TIN method is useful for processing the rugged topography of the study area because of its complex data structure.

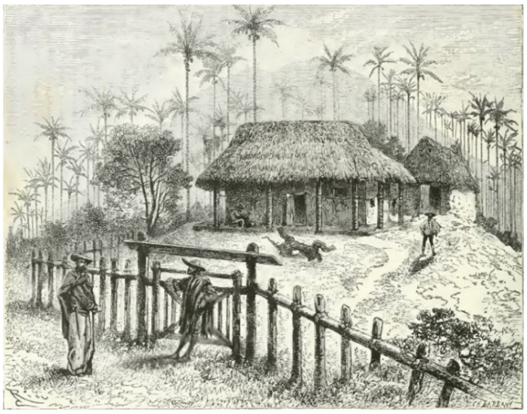
(a)

(b)

Figure 4: a) Montane forest landscape in *Alto de Toche*, Tolima. Altitude 3000 MASL; b) View from the *Cerro Machín* Volcano towards *Nevado del Tolima* Volcano.

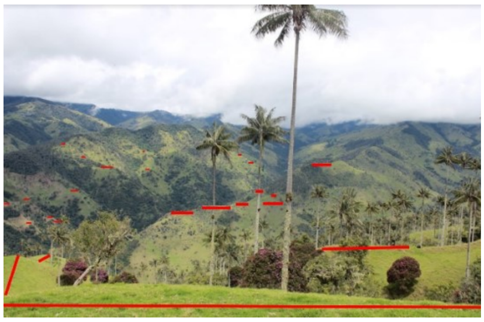
(a)

(b)



(c)

Figure 5: a) Pre-Hispanic indigenous groups of Tolima. Source: Batanelo (1996) & Espinosa (2007); b) Traditional house near *Cerro Machín* Volcano. Source: Photograph by Martin Horst (1933); c) Hacienda Las Cruces by André (1884). Source: Martínez-Rivillas (2021).



(a)

(b)

Figure 6: *Las Cruces* (Site 3): a) Southwest view of terraces; b) West view of terraces.

(a)

(b)

(c)

Figure 7: *Pajarito* site: a) terraces; b) Terrace detail; c) Terraces view from *Gallego-Galleguito* (site 2).

Table 1: Classification of the terraces.

Terrace	*XY Centroids*	*Longitude Latitude*	*Elevation MASL*	*Area m²*	*Solar Orientation*	*Slope range*
Carbonera 1	844.699,900 993.805,800	-75,47681 4,538827	2935	2099	S. (157.5-202.5) SE. (112.5-157.5) NE. (22.5-67.5)	0–12 %
Carbonera 2	844.794,300 993.712,200	-75,47596 4,537983	2900	2218	NE. (22.5-67.5) SE. (112.5-157.5) E. (67.5-112.5)	0–12 %
Las Cruces 1	848.030,500 993.008,100	-75,4468 4,531674	2704	3418	SE. (112.5-157.5) S. (157.5-202.5) SW. (202.5-247.5)	0–10%
Las Cruces 2	848.012,200 993.101,000	-75,4470 4,532514	2744	1530	SE. (112.5-157.5)	10.5–16.5 %
Las Cruces 3	847.511,100 993.402,300	-75,4515 4,535229	2943	1641	SW. (202.5-247.5)	21–26%
Las Cruces 4	847.516,100 993.345,900	-75,4514 4,534719	2935	1437	SW. (202.5-247.5)	10.5-16.5% 16.6-22%
Las Cruces 8	847.738,600 992.935,400	-75,4494 4,531012	2750	394	S. (157.5-202.5)	21-26%
Las Cruces 9	847.706,400 992.875,300	-75,4497 4,530468	2718	403	SW. (202.5-247.5) S (157.5-202.5)	30-35%
Las Cruces 11	847.699,000 992.792,400	-75,4498 4,529718	2680	315	S. (157.5-202.5)	21 - 26%
Las Cruces 12	847.680,800 992.753,100	-75,4499 4,529362	2666	165	S. (157.5-202.5)	21 - 26%
Las Cruces Tomb	847.704,000 992.828,800	-75,4497 4,530047	2693	211	S. (157.5-202.5)	21 - 26%
Gallego 1	845.576,900 993.744,200	-75,46891 4,538287	2707	428	SW. (202.5-247.5) S. (157.5-202.5)	0 - 11%
Gallego 2	845.574,300 993.709,300	-75,46893 4,537971	2695	300	S. (157.5-202.5)	0 - 11%
Gallego 3	845.556,900 993.681,900	-75,46909 4,537723	2684	407	S. (157.5-202.5)	0 - 11%
Gallego 4	845.537,400 993.650,200	-75,46927 4,537436	2668	465	SW. (202.5-247.5) S. (157.5-202.5)	25.3 - 36%

3. Results

Fieldwork documented in *La Carbonera* (Site 1), *Gallego* (Site 2), and *Las Cruces* (Site 3) (Fig. 3.) determined *Las Cruces* the highest site where we found the most density and diversity of terraces in a long-range from 2666 to 2943 MASL. Followed by *La Carbonera* (2218 MASL) with the largest terraces (2900-2935 m^2) and a great view of the *Tochecito* River valley. The analysis yielded an average slope of the terraces of 16.5% and obtained ranges of 8 representative slope levels in the field. *La Carbonera* terraces between 0-12% slope, *Las Cruces* between 10-35% slope and 165 to 3418 m^2 of area, and *Gallego* terraces 10%-25% slope and 300-465 m^2 of area (Table 1, Figs. S1 & S2). The solar orientation of the *Las Cruces* and *Gallego* sites (north side of the *Tochecito* River) is predominantly oriented South-Southwest (S-SW), while *La Carbonera* is oriented Southeast-Northeast (SE-NE).

A diagram of *Alto de Toche* study area explains the structure where groups of terraces in which very high ridges stand out (in red) and the deep ditches of streams micro-basins that tribute to the Tochecito River, the Campoalegre Stream, and the Toche River (in yellow) (Fig. S3). Observed patterns of ridges and streams clearly shows visible average watersheds approximately every 300 m. These conditions also determined location patterns of terraces concentrated on the ridges and banks of the San Rafael, Pajarito, El Chuscal, and Dantas creeks in the Tochecito River Basin. Based on this, the results of schematic graphics projected a view of possible settlement sites (in purple) in Alto de Toche ridges similar to the resulting DEM of projected settlements (Figs. S4 & S5).

Projecting the spatial analysis method for prospecting the settlement pattern of terraces occupation resulted in 37 terraces, 20 of them above 2800 MASL elevation (Table 2, Figs. S4 & S5). For instance, the Pajarito site (visible from the Las Cruces site) belongs to a system of

17 terraces aligned on the Pajarito north and Pajarito south ridges of Pajarito Creek. This information allows us to organise the field survey and the route to access them. It means a non-invasive prospection for fieldwork planning and a more feasible knowledge of accessibility due to on-site transit difficulties (steep and unstable soil due to cattle ranching and strong rains), as well as previously analysed their settlement pattern and solar orientation. Their elevation hierarchies range from 2670 to 2860 MASL, and their bigger terrace areas are located on eleven terraces located on ridge tops (Fig. 7).

4. Discussion

From the data recorded during the *Alto Toche* transect (Table 1), it could be inferred that *La Carbonera* 1 and 2 correspond to the largest terrain removed by *Toches* builders with best topographic location for visibility and sight ability, the highest annual insolation (hours/daylight), and the highest horizontality of the terrace (lower slope); very useful attributes to interpret the data related to the "solar orientation" in the settlement systems of the *Alto de Toche* landscape. The Figure 9 explains the sun exposure in a tropical-ecuatorial zone such as Colombia. Full morning sun and afternoon sun allowed for social organization and observation from high terraces, but also a dominance over low terraces as less exposed to the sun, although zenith stands at 12:00 noon sharp. Patterns in the terrain model also resulted in the arrangement of possible flattened sites built as larger terraces on the highest points of the ridges above the steep basins, as low terraces become smaller.

According to Aceituno & Loaiza (2007) and Gnecco & Aceituno (2004), the groups that populated the premontane forests of the Northern Andes manipulated the environment to increase their carrying capacity, thus creating anthropic landscapes that were laboratories for the domestication and cultivation of plants, from the late Pleistocene and during the early and middle Holocene. Settlement *tambos* are strategic. It potentially communicated ideas and principles for the planning and environmental management of the forest as well as conceptions of the symbolic world involving the social reproduction of ethnic kinship segments (Service, 1975; Ramírez, 1996; 1999; Velandia Jagua et al., 2014, 2019; Velandia Jagua, 2018; Zuluaga et al., 2019). Also, there are "funereal spaces" (Velandia Jagua, 2018) designed to bury the deceased in the high hills and to approach an "astronomical vision" (von Hildebrand, 1984, 1987). The possibility of settlements as stellar observatories at higher sites has been raised (Zuluaga et al., 2019, Zuluaga, 2020). In the *Bermellón* and *Anaime* River basins near *Toche* and *Tochecito* basins, Cely Vargas (2021) documented demographic changes in the population of pre-Hispanic settlements. A greater number of *tambos* were found between 1600 and 2100 MASL. The number of *tambos* decreased between 2600 and 2900 MASL although they tend to be larger. An extended work may intend to develop a regional pre-Hispanic demography from basins settlements in Central Cordillera.

It can be stated that there is much concordance with the work in nearby sites of *Cajamarca* and *Anaime*, but this is the first work in Tolima of high-altitude archaeology in *Toche*. It is relevant because the whole region presents evidence of the CMV disaster. Other developed works in volcanic soils are contrastable in *Santa Isabel*, *Fresno*, and *Roncesvalles* near the *Nevado del Ruiz* Volcano (Carvajal, 1995; Ramirez, 1999).

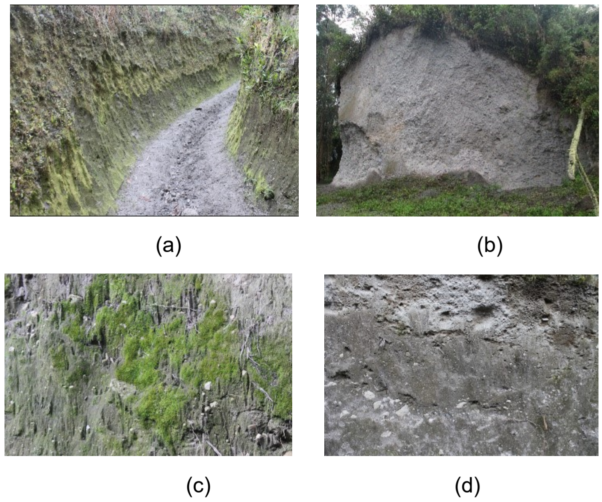
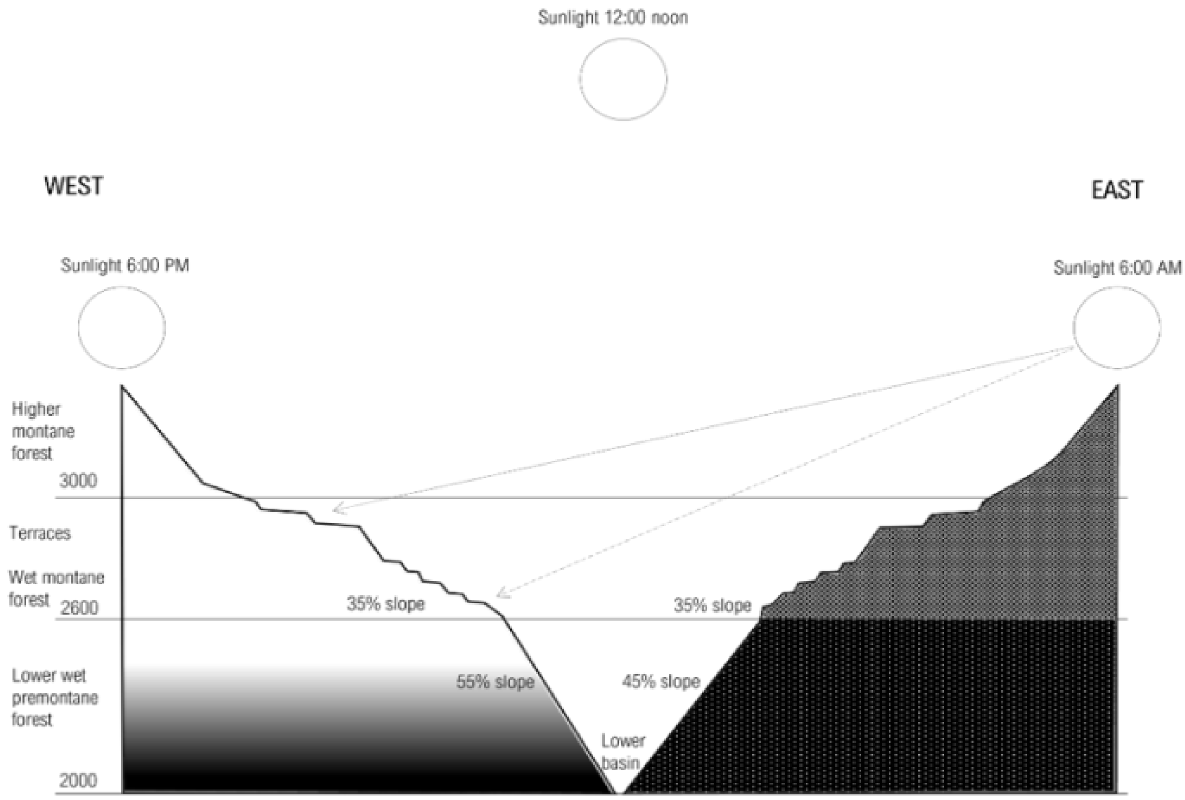


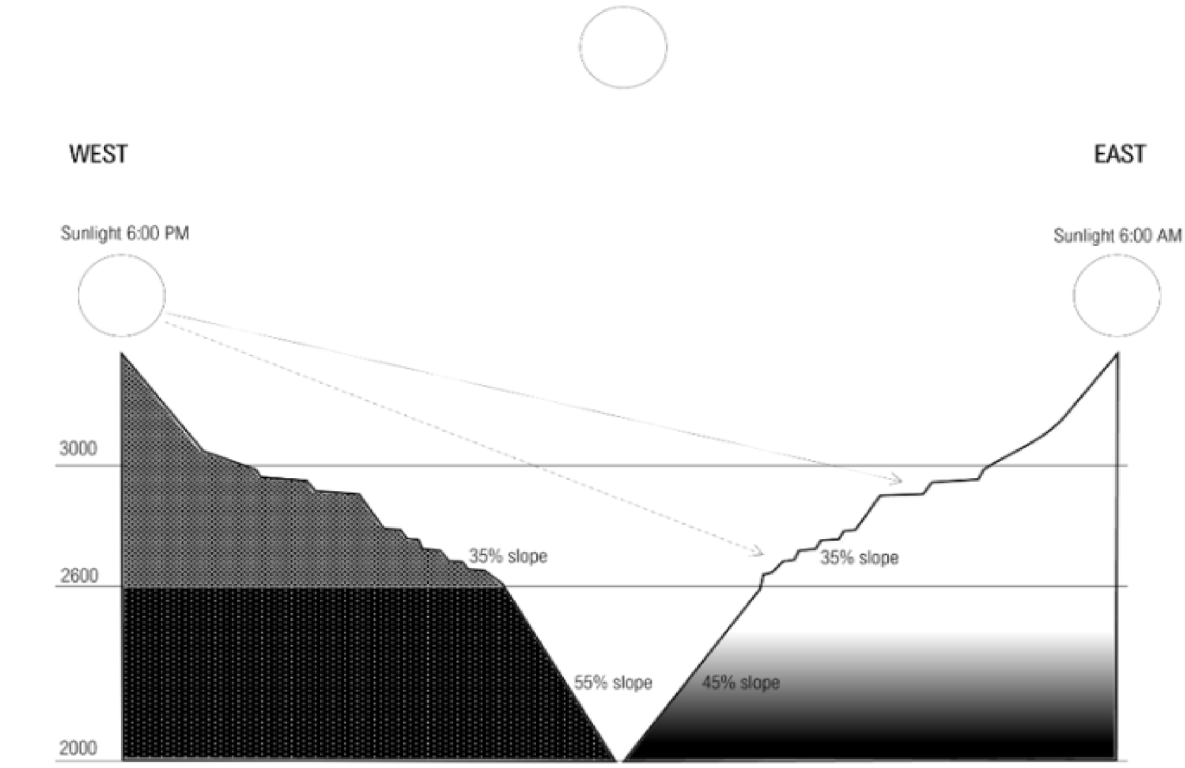
Figure 8: a) Mule path (part of *Quindío Trail*) between *Toche*-Cemetery with ash and pumice deposits. b) Deposits of pyroclastic material in the *Cerro Machín* Volcano-*Toche* Road. c) & d) Ash and pumice deposits at mule path (*Quindío Trail*) between *Toche*-Cemetery.

Table 2: Classification of possible identified terraces.

Terrace ID	*Terrace name*	*Elevation MASL*
1	Possible Terrace Campamento 1 Creek	2809
2	Possible Terrace Campamento 2 Creek	2884
3	Possible Terrace Campamento 3 Creek	2759
4	Possible Terrace Campamento 4 Creek	2679
5	Possible Terrace Campamento 5 Creek	2602
6	Possible Terrace Dantas 1 Creek	2847
7	Possible Terrace Dantas 2 Creek	2804
8	Possible Terrace Dantas 3 Creek	2769
9	Possible Terrace El Chuscal 1 Creek	2843
10	Possible Terrace El Chuscal 2 Creek	2869
11	Possible Terrace El Chuscal 3 Creek	2840
12	Possible Terrace El Chuscal 4 Creek	2756
13	Possible Terrace El Chuscal 5 Creek	2789
14	Possible Terrace El Chuscal 6 Creek	2756
15	Possible Terrace El Chuscal 7 Creek	2709
16	Possible Terrace El Chuscal 8 Creek	2613
17	Possible Terrace El Chuscal 9 Creek	2691
18	Possible Terrace La Pradera 1 Creek	2893
19	Possible Terrace La Pradera 2 Creek	2890
20	Possible Terrace La Pradera 3 Creek	2781
21	Possible Terrace Pajarito 1 Creek	2851
22	Possible Terrace Pajarito 2 Creek	2857
23	Possible Terrace Pajarito 3 Creek	2822
24	Possible Terrace Pajarito 4 Creek	2824
25	Possible Terrace Pajarito 5 Creek	2860
26	Possible Terrace Pajarito 6 Creek	2801
27	Possible Terrace Pajarito 7 Creek	2803
28	Possible Terrace Pajarito 8 Creek	2742
29	Possible Terrace Pajarito 9 Creek	2779
30	Possible Terrace Pajarito 10 Creek	2623
31	Possible Terrace Pajarito 11 Creek	2725
32	Possible Terrace Pajarito 12 Creek	2864
33	Possible Terrace Pajarito 13 Creek	2785
34	Possible Terrace Pajarito 14 Creek	2875
35	Possible Terrace Pajarito 15 Creek	2795
36	Possible Terrace Pajarito 16 Creek	2810
37	Possible Terrace Pajarito 17 Creek	2803



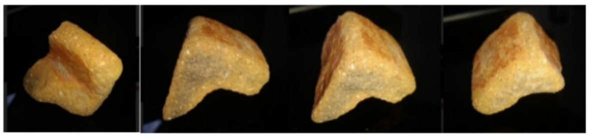
(a)



(b)

Figure 9: Sunlight explanatory diagram of solar incidence in the terracing system: a) 6:00 AM; b) 6:00 PM.

(a)



(b)

(c)

Figure 10: *Las Cruces* site: a) Evidence of a tomb; b) Fragment of red-slip ceramic rim on both sides; c) Human scale and perception of terrace slope.

5. Conclusions

Mapping geoforms associated with CMV is new as well as the study of their archaeological-cultural landscape. Ancient farming dynamics and its cultural implications hypotheses of agricultural resources management do not necessarily imply sophisticated agrarian features but certainly imply a conscious effort to the knowledge of drainage and to communicate terraces and develop an interpretation of its relationship with nature.

The study of *Alto de Toche* allowed the systematic observation of a paleo-landscape. Based on 40 years of experience in the *Arqueoregion* research group, it can be concluded that the patterns found in the field and projected by the terrain model respond to a settlement strategy due to an ecological knowledge deeply linked to a symbolic understanding of resources. It is possible that terraces were used for sighting, funerary, dwelling, and gathering at higher altitude terraces related to the east-west solar illumination.

The Toches people displayed a conscious effort by managing the hydrology, sighting and defence, and inner -interregional commercial interchange, due to an extensive trail network transit between the ridges and the steep slopes, which becomes the Quindío Trail. The vertical exploitation of the landscape suggests that the lower and middle zones were the catchment sites where raw materials, clay, wood, and natural watering places for hunting herds; in the middle zones occurred the transit and movement zones between the micro-watersheds and were the most diverse areas of production or agricultural spaces. The high zones were places of observation of clear skies for decision-making. That means a complex knowledge of nature features such as the luminosity of the rising and setting sun, water sources, soils, humidity, and winds.

Additionally, in fieldwork, we found a ceramic piece border characterised by the red slip and the core of dark material of Tolima ceramics (an indicator of a ceramic dump) (Fig. 10b); as well as a prospect tomb in the *Las Cruces* site, georeferenced at an altitude of 2963 MASL (Fig. 10a). We can affirm that we carried out an archaeological interpretation of the landscape and the vertical management of the settlement patterns in a non-invasive approach since we did not carry out any excavation. Likewise, the resulting terrain model will help with a previous prospection for fieldwork planning and a more feasible knowledge of accessibility due to on-site difficulties. The result can be viewed in detail using an ArcGIS-online web app, easily accessible for sharing with local residents and stakeholders. Also, it can be useful for visiting scientists and birdwatchers. (https://unibague.maps.arcgis.com/apps/webappviewer/index.html?id=9e48026546654de0bd834cee6fb38b83).

Despite the regional work, more specific efforts are needed in this area, as we believe they are just beginning. In such a way they contribute to a better understanding of the forms of settlement in the ancient landscape. Currently, the wax palm forest is threatened by cattle ranching and adventure tourism. We hope to continue to educate the community about the need for the conservation of the forest and the ancient terraces, in addition to the importance of the CMV disaster risk that currently looms as we have entered the 900th year of volcanic activity since 2006. Therefore, understanding the cultural landscape of *Alto de Toche* links and integrates the conservation of biodiversity, geoheritage, and archaeology of the territory.

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Supplementary files

This article contains supplementary files accessible via https://doi.org/10.4995/var.2024.20145.

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