Legacies of Colonial Dislocation:

Resettlement, Agricultural Deintensification and Infrastructural Reclamation in Huarochirí, Peru

By

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precedieron, porque por su fuerza y empeño
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Chapter 1

Introduction: The Changing Landscapes of Huarochirí

"Puede creerlo señorita Gabriela, estamos tan cerca de Lima, pero acá es otra realidad, acá las cosas no llegan"[1]
Woman at Tupicocha plaza de armas,
Junio 2017, Tupicocha Huarochirí.

1 Introduction

The *Reducción General de Indios* (General Resettlement of Indians, hereafter "Reducción") implemented in the Viceroyalty of Peru during the 1570s CE was one of the largest mass resettlements ever undertaken by a colonial power. The Reducción affected approximately 1.4 million indigenous people (Mumford 2012), forcing communities to abandon their previous settlements to build and inhabit compact, nucleated, Spanish-like towns (referred to as "reducciones"). The Reducción was part of a comprehensive set of colonial institutional reforms by the Viceroy Francisco de Toledo to foster Catholic evangelization, facilitate tribute collection, and monitor the social practices of Andean communities (Málaga Medina 1972, 1975; Mumford 2012; Saito 2012; Mumford 2015). Frameworks for understanding the effects of the

[1] *"Can believe it, Miss Gabriela? We are so close to Lima, but here there is a different reality. Things don't get here"*. Comment made by a woman at the Tupicocha main plaza about how uncared-for and isolated they feel when Lima is so close and has everything and they cant get the basics. (Translation by the author)

reducciones on Andean communities emphasized the agro-ecological, demographic, and logistical crises they created. In this reading, already declining populations were stressed further as they were displaced from their ancestral lands, irrigation systems, and sacred landscapes (Murra 1972; Málaga Medina 1975; Gade and Escobar 1982; Denevan 1986, 1987). Moreover, indigenous communities were further "reduced" by exacerbated disease transmission and social disruption in the close quarters of the reducciones. In this scenario, Reducción is portrayed as a failure—it exacerbated both demographic collapse and agricultural deintensification. However, this picture is not complete. More recent frameworks approach the Reducción as an improvisational process of demographic concentration met by indigenous responses that led to varied patterns of migration and the emergence of new kinds of colonial Andean communities and landscapes (Mumford 2012; Zuloaga 2012; Wernke 2013; Saito et al. 2014; Penry 2017; VanValkenburgh 2017; Zuloaga 2017).

This research combines archaeological and ethnohistorical data and satellite remote sensing techniques to reconstruct the resettlement sequence in relation to agricultural deintensification and reclamation patterns in the region of Huarochirí (Lima, Peru) from the late 16th century to the late colonial era (early 19th century). Historical research shows that during the middle colonial period (1580-1650), some inhabitants fled reducciones to reclaim their ancestral lands (Spalding 1984), while some reducciones were abandoned completely (VanValkenburgh 2012). In other cases, post-reducción villages splintered from the original reducción towns and were re-established in new locations (Spalding 1984; Zuloaga 2012, 2017). Common underlying political, economic, and ecological factors mediated such inherently local dynamics. However, the material and social consequences of such intra-regional movement and the creation of colonial towns with indigenous understandings of displacement and land tenure have not been studied in situ beyond a handful of case studies (Wernke 2007b; VanValkenburgh 2012; Wernke 2015).

At the same time, archaeological research has not examined the relationship between intensive agricultural infrastructure and changing settlement patterns through the colonial era. This research builds on this recent scholarship and bridges these concerns through combined archaeological and image analysis approaches – informed by already published colonial-period documentation – to explore mutual impacts between colonial-era population movement and agricultural landscapes. Through an imagery-based survey in the Huarochirí Province, this research explores the agro-ecological and sociopolitical processes involved in the forced resettled of communities from the reducciones and their subsequent splintering into smaller settlements (post-Reducción villages) across local landscapes. Huarochirí is located in the semiarid western slopes of the central Peruvian highlands (to the adjacent southeast of modern Lima), in the upper section of the Lurín Valley. This area was the home of the Yauyos ethnic polity under Inka imperial rule. The Yauyos Inka province was divided into Anan Yauyos ("Upper Yauyos") and Lurín or Hurin Yauyos ("Lower Yauyos"). Lurín Yauyos, extending from the Rímac valley to the north to the Mala river valley to the south, later became the Huarochirí Province (Spalding 1984).

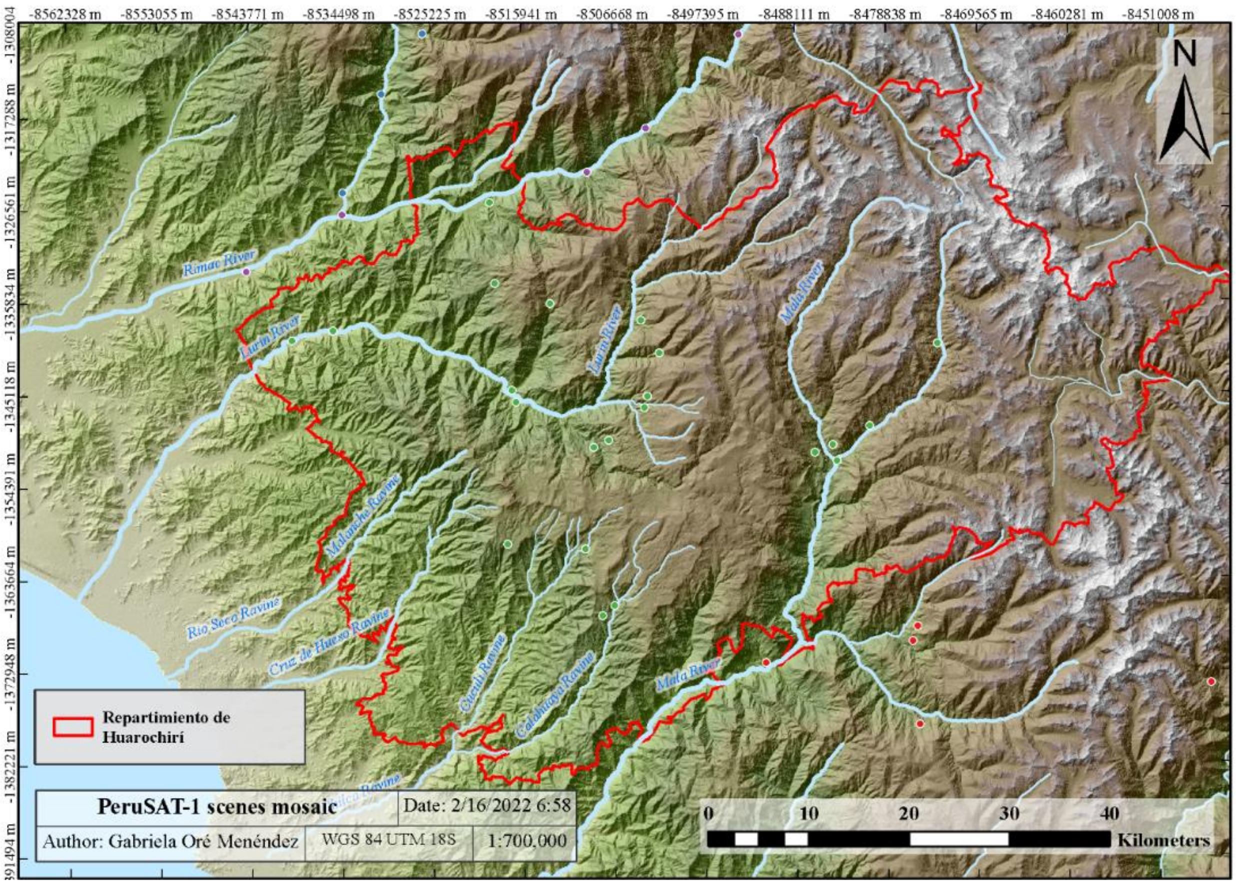

Figure 1. Research area in the Huarochirí region.

Building on the concept of landesque capital, *sensu* Brookfield (1984), I will examine how the labor-intensive, anthropogenic landscape features (terraces, agricultural fields) that sustained highland Andean communities influenced decision making regarding agro-ecological logistics and whether communities would splinter from their reducción towns to reclaim abandoned agricultural landscapes. Concerning reducciones, I consider push and pull factors that acted on communities to remain in the reducciones or pursue better living conditions. I model landesque capital as an attractor or pull factor for Andean communities to move away from reducción towns and settle in new villages close to extant fields and irrigation systems. The oppressive and sometimes squalid conditions within reducciones, on the other hand, acted as push factors.

This research project has two main components: ethnohistorical data and remote sensing. The ethnohistorical component collects and digitizes spatial data from published and unpublish historical documents regarding the foundation of towns within Huarochirí during the colonial period. The location of reducción towns and post-reducción villages aided in establishing cost distance and energy use when moving across the landscape towards agricultural fields. The remote sensing component identifies and locates agricultural fields and terraces in the entire region of the Huarochirí repartimiento. Additionally, several visits to the upper Lurín and Mala valleys in the Huarochirí region allowed me to be familiar with the landscape. Most importantly, the descendant communities of the original Huarochirí inhabitants offer invaluable information about their relationship with the landscape and how they travel from fields to towns.

The core motivation of this research is the dissemination of satellite remote sensing and image analysis tools in archaeological research, in particular in the central Andes. I have created a replicable workflow that can be reproduced and adapted to other research questions and geographical areas. Multispectral satellite remote sensing (MSRS) analysis in archaeological practice allows for a new type of regional-level research that expands and transforms the type of question we can ask, the scale of the research, and how archaeological sites and monuments are monitored (Lasaponara and Masini 2012; Lasaponara et al. 2014; Lasaponara and Masini 2014). Additionally, recent global events like the 2020 pandemic halted all activities; MSRS analysis allowed many archaeologists to continue archaeological work when others depending on fieldwork, could not. However, despite the advantages that MSRS offers, the archaeological community is not widely taken advantage of it.

I demonstrate how a simple-to-follow workflow is a basis for large-scale regional analysis. The workflow steps are based on field observations and archaeological and ethnohistorical data. The ultimate goal is to contribute to the widespread of multispectral image analysis, so it becomes an additional tool in archaeological research, especially in times of constrained budgets and travel restrictions. Nevertheless, there are two main roadblocks when using MSRS: computer power and technical knowledge. I propose that creating accessible workflows offers a replicable tool that can be used, adapted, and improved with essential multispectral and image analysis functions, making the tool more accessible to archaeologists from regions with fewer resources available to researchers.

Creating a replicable workflow includes discussing and explaining the steps taken and the data used. For the case study presented here, we will describe a detailed workflow, including data from different sources (archival, archaeological, geomorphological, and ethnohistorical), the methodologies, and tools included in the analysis.

The approach proposed here focuses on sequentially reducing the area's extent to direct the analyses only in particular sections of the image. The reduction of the analysis area restricts data variability and lowers the amount of computational resources needed. For the case study, each analysis stage is grounded on decision-making derived from archaeological observations and information on the region. Using a case study from the highland region of Huarochirí (Lima, Peru), I apply MSRS to identify agricultural terraces using stone walls marking the boundaries of agricultural plots or *chakras* as a proxy for agricultural infrastructure (terraces and agricultural fields) in the context of a broader research question: How the labor-intensive, anthropogenic landscape features as agricultural infrastructure that sustained Andean communities and that was already in place, influenced decision-making regarding agro-ecological logistics, and whether it will act as a pulling factor for indigenous communities when founding new settlements after the

Reducción, or mass resettlement of Indians in the 1570s, in the viceroyalty of Peru, as I will explain later.

2 The Reducción and agricultural de-intensification

Before the Spanish invasion of Peru, most highland Andean groups lived in dispersed settlements and practiced limited seasonal mobility or maintained access to altitudinally-dispersed resources through intra-ethnic, kin-based exchange networks (Murra 1972). A generation after the Spanish invasion, those systems were disrupted by the vast Reducción resettlement program of the 1570s. Viceroy Francisco de Toledo's reforms attempted to reshape colonized populations, infuse Spanish Catholicism, institute regimes of surveillance, and inculcate a culturally-specific notion of civilized urbanism. Spanish authorities forced people living dispersed in the Andean landscape to live in nucleated, gridded towns around churches and plazas (Durston 1999; Cummins 2002). Toledo instructed Spanish officials that the new towns should be located in accessible areas, with good weather, and away from pre-Hispanic shrines and settlements (Málaga Medina 1972, 1979; Mumford 2012). In doing so, resettlement affected variable disruptions in access and maintenance of the labor-intensive agricultural infrastructure of Andean communities. The new towns forced people away from their *wak'as* (*huacas* or shrines) fields and pre-Hispanic agricultural infrastructure (as terraces and irrigations systems) resulting in the progressive abandonment of remote agricultural systems (Van Buren 1996; Wernke 2007b, 2010, 2013; VanValkenburgh 2015).

Reducción dislocated many communities far away from the labor-intensive agricultural systems that provided their means of subsistence (Denevan 1987) while living in close proximity worsened infectious disease transmission and mortality (Cook 2004; Wernke and Whitmore

2009). In these harsh living conditions and abuse by Spaniard authorities, some inhabitants fled reducciones (Mumford 2012) and went back to their ancestral lands (Spalding 1984; Mumford 2012). In some cases, reducciones were abandoned altogether, and communities established new compact villages, some reproducing the gridded layout of a reducción.

Reducción has long been identified as a prime mover in the mass abandonment of irrigation systems and agricultural terracing complexes, both because of population collapse exacerbated by settlement concentration and because of the logistical strains, the Reducción caused for Andean communities (Málaga Medina 1972, 1974a, 1975; Donkin 1979; Málaga Medina 1979; Denevan 1987, 2001). In essence, colonial magistrates were also forcing people away from their agricultural infrastructure by forcing people away from their original settlements. Intensive agricultural infrastructure (of pre-Hispanic origin) required regular inputs of communal labor for their maintenance and intricate systems of hydrological apportionment for their ongoing operations (Murra 1972; Málaga Medina 1975; Gade and Escobar 1982; Guillet 1983; Denevan 1986, 1987; Treacy 1994; Zimmerer 1999; Gelles 2000; Zimmerer 2000; Denevan 2001). Andean communities' demographic decline and political destructuration caused by Reducción impeded their ability to maintain and even operate these labor-intensive systems, leading slowly to an agricultural deintensification, with impacts experienced asymmetrically by land-impoverished families within Andean communities (Wernke 2007b; Wernke and Whitmore 2009; Wernke 2010).

Given these logistical stressors, indigenous communities often abandoned productive land and agricultural infrastructure when they were resettled to the reducciones. Distance from reducción towns to agricultural fields was a significant factor, sometimes leading to the abandonment of distant field systems. Reducción created a situation where distinct ensembles of push and pull factors acted on communities, producing variable outcomes of agricultural deintensification and the (partial or complete) abandonment of reducciones to establish post-reducción settlements. This project seeks to delineate how push–and–pull factors produced new kinds of colonial communities and landscapes in the central highland Andes.

To understand how communities abandoned or reclaimed their ancestral agricultural infrastructure when splintered from the Reducción towns, I revive the concept of landesque capital, as developed by Brookfield (1984). Landesque capital is the labor investment on durable improvements to the land and its constant maintenances as a productive landscape (Widgren 2007; Clark and Tsai 2012; Håkansson and Widgren 2014a, b). Examples of landesque capital include agricultural terraces and irrigation systems. The creation of landesque capital implies a decision-making process where societies need to evaluate the benefit of investing labor in infrastructure (or their improvements) and how that will affect them in the long term. In terms of agricultural infrastructure, landesque capital describes how allocating energy and labor works in securing a steady supply of goods.

While archaeology has traditionally paid more attention to issues such as agricultural intensification (Godoy 1984; Erickson 2006; Williams 2006), land tenure (Guillet 1981; Adler 1996; Mayer 2004; Assies 2008), labor organization, and rural life-ways (Voss 2008; Van Buren and Weaver 2012; Mayer 2015; Hirsch 2016; Smit and Coello Rodríguez 2016), it has partially ignored the approach to infrastructure using the concept of landesque capital (Widgren 2007; Clark and Tsai 2009, 2012; Bayliss-Sith 2014; Håkansson and Widgren 2014a; Hornborg, Eriksen, and Bogadóttir 2014; Myrda 2014; Arroyo-Kalin 2016). Landesque capital offers a tool to examine the causes, implications, and consequences of societies investing in modifying the landscape and how and why, in some cases, that investment is abandoned.

3 The concept of landesque capital

Landesque capital was first defined by Sen (1959) in his paper about the choice of using different agricultural techniques in underdeveloped [sic.] countries. Sen discusses how investment choices are affected by how productive that investment will be. He distinguishes between the investment in upgrades that replace labor and those that replace (or improve) land. Sen's reflection on capital invested in agricultural production differentiates between two types of capital: *laboresque* and *landesque*. On the one hand, *laboresque* is the type of capital that could replace labor, like the investment in machinery (i.e., tractors); on the other hand, investment on the land, landesque, increases the productivity of the land (i.e., terraces, fertilizers, or irrigation systems)(Sen 1959, 280). A similar concept was used by Marx, who was aware of the role that infrastructure played as a type of capital, describing it as la *Terre-capital* or land-capital when referring to improvements "fixed in the land, incorporated in it" either permanently or just temporarily (Marx 1959, 618).

Harold Brookfield reintroduced the term twenty-five years later and used it to discuss innovations in agriculture over long time horizons[2] that "once created, persists with the need only of maintenance" (Brookfield 1984, 16). Brookfield's use of the concept reorients its purpose to talk about past agrarian societies, land transformation, changes in practice, and its impacts on societies from a Longue-durée approach. For example, once a new improvement is adopted, the "improver" has to adopt other types of changes around it for the change to be substantial (i.e., organization of labor, production, and maintenance); otherwise, the initial investment becomes a waste of energy (labor and resources). Brookfield's re-orientation of the

[2] Brookfield also points out that the term is better applied to societies with non-technified agriculture.

concept makes room to discuss broader social changes and not only political economy top-down decisions.

There is a disagreement in the literature about society's complexity and its capacity to have/create landesque capital. From an evolutionary point of view, on the one hand, complex societies are the natural default by which landesque capital is accumulated, but others suggest that landesque also exists in more egalitarian societies (Håkansson and Widgren 2007). In the first case, highly hierarchical groups from non-industrial societies create changes in the landscape, forming extensive infrastructure that requires considerable human labor inputs. Accordingly, the accumulation of landesque capital often favors *"demographic concentration and socio-economic complexity*" (Hornborg 2014, 15), with urbanization processes, landscape transformation, and the creation of productive land (Clark and Tsai 2012; Hornborg, Clark, and Hermele 2012; Bayliss-Sith 2014; Håkansson and Widgren 2014b). This statement fits well when considering any complex society in the Andes, even more, when we look at the Inka empire (1490–1532 CE). The Inka built the largest empire in South America (Kolata 2013; D'Altroy 2014). It made a significant investment in building complex terrace systems that actively changed the landscape, in particular in the Cuzco region, which enabled cultivation in the highland mountain slopes (Santillana 1999) and also were a statement of the new political order brought into the Andes (Acuto 2005; Farrington et al. 2013).

On the other hand, landesque capital can also be traced in less complex societies, such as the communities from the late pre-colonial and early colonial Tanzania mentioned by Håkansson and Widgren (2007). In their discussion about political economy and landesque capital in four relatively densely populated communities, Håkansson and Widgren stated that *"landesque investments occurred in cases where agriculture was the main source of long-term wealth flow* *irrespective of whether or not hierarchical political systems were present" (Håkansson and Widgren 2007:235).* Under this interpretation, investment in agricultural infrastructure occurs regardless of the societies' complexity; the difference is that in smaller-scale societies, the amount of labor and energy invested is smaller as the infrastructure constructed is small. As Widgren explains: *"irrigation canals and agricultural terraces are the most obvious forms of landesque capital, but the clearance of stones and the improvement of agricultural soils over the years are other, albeit less spectacular, examples" (Widgren 2007).* The spectrum of landesque capital practices in coupled human-environment systems varies from creating intensive soil management in the Amazonian rainforest (Wood et al. 2009), to terrace systems in the Philippines (Acabado 2012). Similar insights have emerged from the Maya region, in which we now understand what used to be considered a primeval jungle as an intensively managed forest (Chase et al. 2011; Hixson 2013; Chase et al. 2014), or in North America, native peoples managed temperate forests, prairies, and savannah environments (Whitney 1996).

This project builds upon and expands the concept of landesque capital to investigate whether and under what conditions Andean communities first abandoned agricultural infrastructure following the Reducción and then reclaimed some of it back with the establishment of post-Reducción villages. It asks, first, what are the spatial and temporal patterns of the abandonment of some field systems and the spatial and temporal patterns of those that were later reclaimed after post-Reducción villages were established? Thus, tracking the distributions of these post-Reducción villages closer to agricultural field complexes is crucial for understanding the processes of deintensification and reclamation. Building on Brookfield's definition, I expand the concept of Landesque capital, adding that decision-making happens at the community level and that its use–abandonment–reclamation moments are part cycles rooted in path dependencies. A foundational concept in evolutionary economics, path dependence means that current actions or decisions depend on the path of previous actions or decisions (Page 2006), and the relative benefits of those decisions increase over time (Arthur 1994). For the upper Lurín valley and the rest of Huarochirí, agricultural fields and terraces are prominent in the landscape but are more simple and smaller in size and extension. Terraces are formed by irregular and quadrangular plots of land over hillslopes between the elevations of 1800 up to 4000 m.a.s.l. Each agricultural field (*chacra*) is delimited by stone walls of *pirca*[3] masonry with a height of 1 m to 1.20 m and a width of 40 cm[4]. Most of the terraces in Huarochirí are located over slopes of 25 to 50% (Agro RURAL 2021).

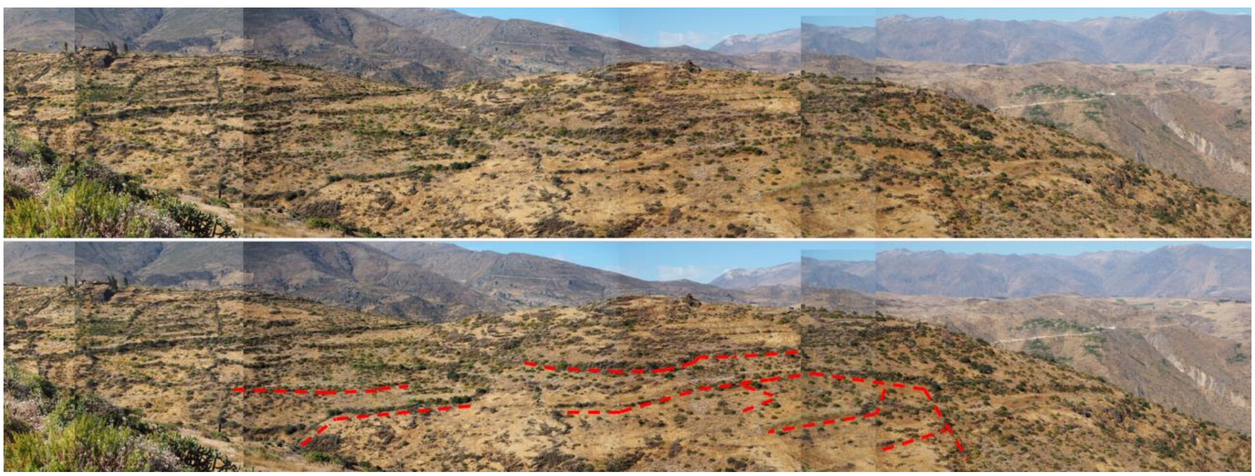

Figure 2. Top: Terraces over hillslopes in Tupicocha, Huarochirí. Bottom: terraces' walls marked by the red line (Photo by the author)

The labor needed to build terraces and provide adequate maintenance in Huarochirí is less than the one needed in places with substantial agricultural systems in the western range of the Andes, such as the Colca Valley in Arequipa (Denevan 1987, 2001). Therefore, the amount of labor needed to build and maintain Terrazas in Huarochirí should be less than the amount

[3] Undressed dry fieldstone masonry walls made of locally available stone.
[4] Observations made during field seasons

needed for terraces with masonry over steep slopes. In smaller systems where less labor investment is necessary, decision-making could happen at the local community level and not from a top-down mandate with the need for state sponsorship.

4 Hypotheses

Mobilizing the concept of landesque capital in the colonial landscape of reducciones, abandoned agricultural infrastructure, and post-Toledan villages, this research elucidates the interplay of an ensemble of push and pull processes acting on Andean communities, whose ability to react and improvise was also constrained by variable coercive colonial state power in this regional setting, especially right after the Reducción. Given these factors, my hypotheses are structured around two distinct ideal/typical scenarios:

Scenario one: If landesque capital of agricultural infrastructure was a pull factor for Andean communities, with better and more productive lands away from reducciones, then post-Toledan villages will be located in close proximity to areas of higher concentration of highly productive agricultural infrastructure (terraces and irrigations systems). I will concentrate on variables like distance (through walking and connectivity models) and terrain, elevation, and cost to move from and to agricultural fields to model the productivity/marginality of the agricultural fields around the post-reducción villages. Scenario two: If agricultural complexes away from reducciones were of marginal productivity, whether due to poor soil, high slope angles (creating small terraced planting areas), high elevation (and thus, high frost risk), poor access to irrigation water, or some combination of these factors, then we will expect a zone of agricultural deintensification around a reducción, with proportionally more deintensification with increasing distance and elevation. In both scenarios, reducción internal push factors varied independently and were observable primarily through written historical documentation.

These are ideal/typical scenarios, and a spectrum between the types is expected in the larger regional scale context. Understanding these different patterns at a regional scale aims to understand how these interactions happened in different areas in the region and to elucidate the interaction of different ensembles of landscape endowments and liabilities relative to changing settlement patterning through the terminal pre-Hispanic and colonial occupational sequence.

I investigated these scenarios through large-scale spatial analysis of connectivity through the cost of moving across the landscape between agricultural infrastructure and reducción towns and post-reducción villages.

5 Structure of the Dissertation

This dissertation is divided into five chapters, corresponding to three articles that elaborate further about three aspects of the research presented here: multispectral satellite methods, ethnohistory and digital cartographies, and landesque capital and agricultural deintensification, introduction, and conclusion.

Chapter two, "Agricultural Infrastructure Detection to Multispectral Satellite Remote Sensing and PeruSAT-1 imagery in Huarochirí, Peru," discusses the use of multispectral satellite remote sensing analysis to archaeological research reflecting on the broader use of image analysis tools through equity issues. This discussion suggests that one way to shrink the gap in highly technical tools is to assure know-how and technology transfer through the broad sharing of established and understandable workflows that can be replicated for different geographical areas and research questions. I apply multispectral satellite remote sensing analysis to identify agricultural terraces' walls as proxy for agricultural infrastructure. I examine how the labor-intensive, anthropogenic landscape features (terraces, agricultural fields, irrigation systems) that sustained Andean communities and that were already emplaced influenced decision-making regarding agro-ecological logistics and whether communities would splinter from the nucleated towns where they were forced to resettle to reclaim their abandoned agricultural infrastructure.

Chapter three, "Reimagining Colonial Landscapes through Geospatial Digital Visualization: An Example from the Peruvian Andes," touches on the subject of spatial modeling tools, particularly Geographic Information Systems (GIS), and the critics for reinforcing a static and cartesian rendering of the landscape and a limited point of view through which communities filter rich spatial experiences. On the contrary, I argue that through geospatial analysis of Huarochirí's settlement pattern from historical documents, it is possible to reconstruct changes in the geopolitical boundaries in the region during the colonial period and offer a perspective of these changes from the experienced landscape.

Incorporating historical, ethnohistorical, and archaeological data, on the one hand, and information registered during personal visits to the research area and satellite images, I define the boundaries of Huarochirí's region through settlement patter change during the colonial period from the 1570s to 1815. Moreover, I discuss how the reconstruction of political landscapes through "spatial reading and translation[5]" of documents offers a perspective that centers local communities push in the constant bending of colonial mandates instead of complying with the Spanish urbanist view of the space. Additionally, I reflect on how tools, like spatial analysis, can

[5] To obtain geographical information (coordinates and also descriptions) from documental sources.

be used to reconstruct peasant[6] communities' histories by centering local narratives associated with the landscape rather than westernized expectations of cartographic standardization.

Finally, through the concept of landesque capital, chapter four explores the impact of labor investment and agricultural infrastructure as communities' prime motivators for abandoning colonial towns and reclaiming their ancestral productive lands. Again, I use a cross-disciplinary approach that incorporates multispectral satellite remote sensing technologies, geospatial analysis, and ethnohistoric research to investigate processes of agricultural reclamation carried out by indigenous communities. The approach here challenges colonizers' utopic narratives claiming to have established "order" while demonstrating indigenous ingenuity and agency challenging such colonial impositions.

[6] The term officially used by the Peruvian government and by communities themselves is *comunidad campesina* (peasant community) since indígena (indigenous) was closely associated with *indio* (indian), and it has a pejorative tone (Remy 2013).

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Chapter 2

Agricultural Infrastructure Detection through Multispectral Satellite Remote Sensing and PeruSAT-1 imagery in Huarochirí, Peru

Abstract

This paper discusses the implications of applying multispectral satellite remote sensing analysis to archaeological research and reflects on the broader use of image analysis tools. Satellite remote sensing remains a specialist methodological domain associated with frameworks that approach environmental factors as prime movers in past social dynamics. Here I suggest that satellite remote sensing can be incorporated in diverse research agendas, and that perceived barriers to entry into the field can by surmounted through development and sharing of replicable workflows. Using a case study from the highland region of Huarochirí (Lima, Peru), I apply multispectral satellite remote sensing analysis to identify agricultural terrace walls as indices for agricultural infrastructure in the context of a broader research question related to a Spanish colonial resettlement program and processes of agricultural de-intensification. I examine how the labor-intensive, anthropogenic landscape features (terraces, agricultural fields, irrigation systems) of prehispanic origin that sustained Andean communities influenced decision-making regarding colonial era agro-ecological logistics. The analysis also examines whether communities would splinter from their planned colonial towns (reducciones) to reclaim their abandoned ancestral agricultural infrastructure.

1 Introduction

Multispectral satellite remote sensing (MSRS) analysis in archaeological practice allows for a new type of regional- and even inter-regional scale research that expands and transforms the type of questions we can ask, and how archaeological sites and monuments are monitored (Lasaponara et al. 2014; Davis 2020b). Additionally, recent global events like the 2020 pandemic have made fieldwork much more difficult to undertake; MSRS analysis can allow many archaeologists to continue archaeological research despite these challenges. However, despite the advantages that MSRS offers, it remains a niche specialization within archaeology.

There are two main challenges when using MSRS: it requires advanced and specialized software skills and high computational power to process large amounts of high-resolution image data. Unfortunately, this high-skill and high investment approach makes this methodology less accessible to the broad archaeological community and is limited to specialized circles. The capacity to invest time and energy in training individuals and the investment in powerful computational resources are constrained by the limited funding opportunities in archaeology (Davis 2020a). The gap in technical skills between expert and novice users can be targeted more efficiently by exploring open-source and collaborative archaeological practices that center on access, training, and research design. This paper proposes that creating accessible workflows offers a replicable tool that can be used, adapted, and improved with essential multispectral and image analysis functions, making the tool more accessible to archaeologists from regions with fewer resources available to researchers. Creating a replicable workflow includes discussing and explaining the steps taken and the data used. For the case study presented here, we will describe the methodological approach, the steps in the workflow, including data from different sources (archival, archaeological, geomorphological, and ethnohistorical), and analytical tools included in the analysis.

Each analysis step is grounded on decision-making derived from archaeological observations and information on the region. Using a case study from the highland region of Huarochirí (Lima, Peru), I apply MSRS to identify agricultural terraces using stone walls marking the boundaries of agricultural fields or *chacras* as indices of agricultural infrastructure (terraces and agricultural fields) in the context of a broader research question: How the labor-intensive, anthropogenic landscape features as agricultural infrastructure that sustained Andean communities, influence decision-making regarding agro-ecological logistics? Did they act as "pull" factors influencing decision-making by indigenous communities to (partially or completely) abandon the planned colonial towns (reducciones) to which they were resettled as part of the *Reducción General de Indios* (General Resettlement of Indians) in the 1570s. The proposed approach sequentially reduces the area of interest within the imagery, leaving only sections with attributes consistent with the target features (field and terrace walls). The reduction of the analysis area also reduces data volume and variance, thus lowering the computational power needed to run the analyses.

The transferable workflow described here is set to identify agricultural terraces located in the central Andean highland, where rough terrain with deeply incised valleys, steep slopes, and high glaciated peaks makes landscape feature detection very difficult in the field or with standard three band (RGB) imagery. The advantage of using multispectral satellite images (MSI) over other types of freely available satellite visualization platforms—such as Google Earth Pro or

Worldwind[7] – lies in their capabilities to register objects beyond the perceptive capabilities of human vision.

MSRS is an ideal methodology to get regional information at high resolution and low cost. Its resolution offers the possibility to move from the regional to the site scale; additionally, it can incorporate data from different sensors and scales, making it a very versatile tool when data comes from different sources. Nevertheless, there is much input that goes into the analysis that is based on the researcher's choices. The following section offers an example of choosing and incorporating different variables into the analysis.

2 Multispectral Satellite Remote Sensing Analysis

In addition to high-resolution capabilities, many satellite sensors also register images in different segments of the electromagnetic spectrum. The electromagnetic spectrum refers to the many types of radiation released by the sun. The frequency of waves is particular to each type of radiation and can be measured in function of the distance between waves (wavelengths). The electromagnetic spectrum divides the different types of radiation into bandwidths based on the wavelength—measured in nanometers (Figure 3). Humans can perceive the reflected radiation as colors only in a small section of the electromagnetic spectrum (the visible color section between 400 to 700 nm). In contrast with standard photographs, multispectral images capture light beyond the visible light and register the amount of light reflected from objects on the Earth's surface (reflectance[8]) in specific bandwidths in separate single band (or "channel") images. In a multispectral image, bands that are not visible to humans are added to either end of the spectrum

[7] https://earth.google.com/web & https://worldwind.earth/explorer/
[8] Reflectance is the fraction of the emission rate of radiant energy incident upon a surface that is reflected, and that varies according to the wavelength distribution of the incident radiation.

beyond visible light—such as infrared bands (closer to the red band) at the longer end of the wavelength (lower frequency) spectrum, and the ultraviolet bands (close to the blue band) at the shorter end of the wavelength (higher frequency) spectrum.

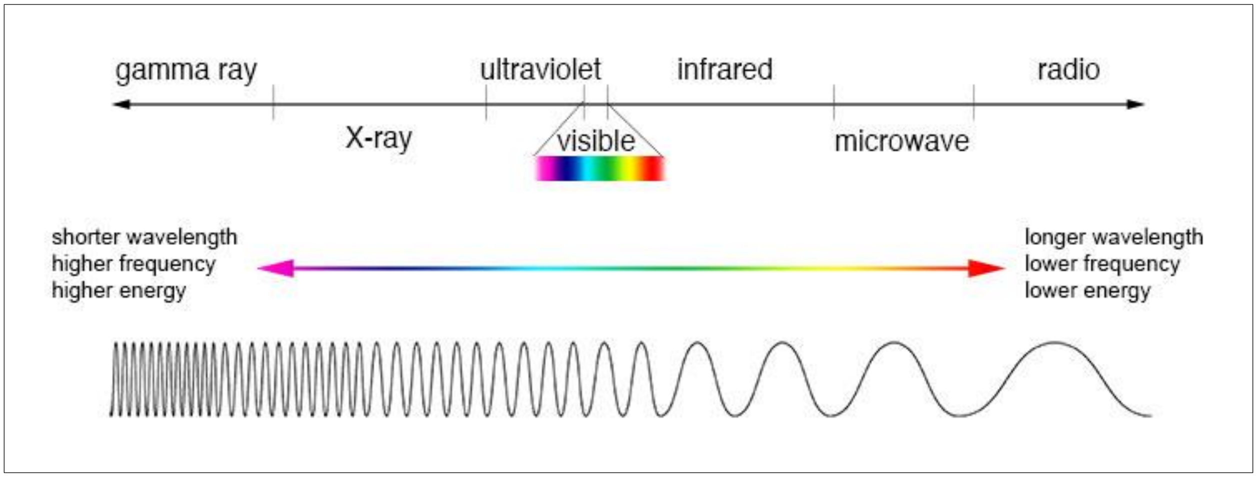

Figure 3. Comparison of wavelength, frequency, and energy for the electromagnetic spectrum (NASA 2013)

A multispectral image has reflectance values for each band; that is to say, in a four-band image, there are four separate images that are spatially co-registered, so that any given location will have four separate layers representing intensity values – in each pixel – from each of the four spectral bands: Blue, Green, Red, and Near-Infrared. A Landsat-8 image, for example, has eleven bands: Coastal aerosol, Blue, Green, Red, Near Infrared, Shortwave Infrared 1 and 2, Panchromatic, Cirrus, Thermal Infrared 1 and 2. Image analysis software like ENVI, Orfeo, Sentinel, and more commonly available ArcGIS or QGIS, use each pixel reflectance value and location to perform spatial statistics, band combinations and transformations, and classification functions to distinguish different objects on an image. Usually, pixels representing an object have similar reflectance values. Therefore, multispectral analysis groups all the pixels of the same objects and assigns them to a particular class (a process referred to as image classification).

Remote sensing and image analysis are primarily used in environmental research, urban planning, and commercial or humanitarian actions. For example, they detect changes after natural disasters, provide information about wildfires' progress, or track urban growth. Therefore, most algorithms and tools are designed to identify specific elements: buildings, roads, fires, and floods, among others. Additionally, all these elements (modern structures and areas of different land use) have defined edges and boundaries that help their identification. Archaeology, on the contrary, does not have the resources to dedicate teams of engineers to design specific tools for our needs. Moreover, feature detection in archaeology has a considerable disadvantage: archaeological elements are usually covered by vegetation, soil, debris or are lost in the background where building materials are made largely of the same materials as the surrounding landscape, making them indistinguishable and with poorly defined edges or boundaries; ultimately, archaeological features are often difficult to isolate from the background in standard RGB imagery due to their low spectral contrast and lack of crisp edges. However, through MSRS analysis, subtle features can be detected. Below a workflow for an MSRS approach is presented.

3 Case study: Huarochirí and agricultural infrastructure after the Reducción

This case study focuses on identifying and isolating agricultural infrastructure as terraces and agricultural fields in the region of Huarochirí, Peru. The study corresponds to the *repartimiento*[9] of Huarochirí (Davila Briceño 1881[1586]; Hernández Garavito and Oré Menéndez ms) during the colonial period (Figure 4).

[9] In the post-Reconquista, in Spain, *Repartimiento* was an allocation of Muslim lands to Christian landowners. Repartimientos preceded the *encomiendas*, which entrusted populations and labor force to Spanish administrators (Lockhart 1969; Varón Gabai 1998).

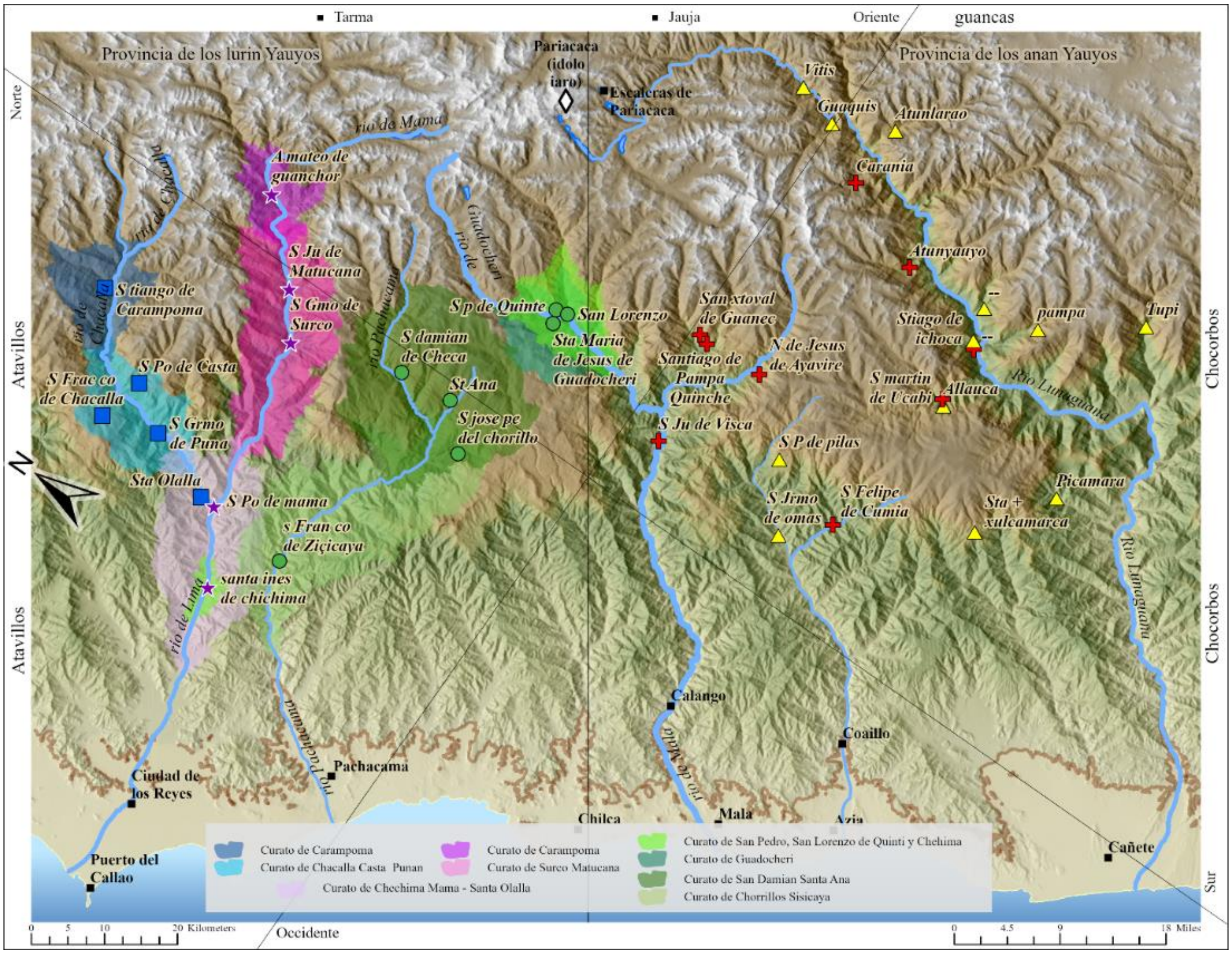

Figure 4. Mapa based on Davila Briceño's map of the Yauyos (1586) showing curates or doctrinas from Lurin Yauyos (Hernández Garavito and Oré Menéndez ms)

On the eve of the Spanish invasion, most highland Andean groups lived in dispersed settlements and maintained access to altitudinally-dispersed resources through intra-ethnic, kin-based exchange networks (Murra 1972). After the Spanish invasion, those systems were disrupted by the *Reducción* resettlement program of the 1570s. Viceroy Francisco de Toledo implemented a mass resettlement project, forcing indigenous populations to move to compact grided towns (called *reducciones*) and abandon their original settlements dispersed in the Andean landscape. This mass resettlement project was known as *Reducción General de Indios* (General resettlement of Indians, hereafter *Reducción*) (Murra 1972; Málaga Medina 1974a; Gade and Escobar 1982; Mumford 2012; Saito and Rosas Lauro 2017). Toledo's reforms attempted to reshape colonized populations, infuse Spanish Catholicism among indigenous daily lives, institute regimes of surveillance, and inculcate a culturally specific notion of civilized urbanism (Mumford 2015; Saito and Rosas Lauro 2017). Reducción has, as one of its consequences, the abandonment of vast areas of agricultural infrastructure (Denevan 2001).

Andean communities, decimated by infectious diseases and relocated far away from their original pre-Hispanic settlements and lands, lacked sufficient communal labor necessary to maintain their extensive terraces and irrigation systems (Cook 2004). Andean communities, decimated by infectious diseases (Cook 2004) and relocated far away from their original pre-Hispanic settlements and lands, did not have the organized communal labor necessary to maintain terraces and irrigation systems. Theoretically, this scenario left the surviving population with higher per capita landholdings, the problem became one of infrastructural maintenance: terracing and irrigation systems require frequent maintenance (punctuated by major annual cleanings and renovations). Lacking the labor base required to maintain these systems, which had reached their maximal extents under Inka rule in many areas, communities were faced with decisions about which terraces and canals to abandon (Treacy 1994; Denevan 2001; Wernke and Whitmore 2009). In these harsh living conditions and the abuse by Spaniard authorities, some inhabitants fled reducciones (Mumford 2012) and went back to their ancestral lands (Spalding 1984; Mumford 2012).

In some cases, reducciones were abandoned altogether, and communities established new compact villages, reproducing the gridded layout of a reducción, and building churches on plazas. In other cases, reducción towns splintered into smaller post-reducción villages, hamlets, or high-altitude *estancias* (ranches)., communities abandoned fields and terraces (Wernke and Whitmore 2009). In these harsh living conditions and the abuse by Spaniard authorities, some inhabitants fled reducciones and went back to their ancestral lands (Mumford 2012). In some cases, reducciones were abandoned altogether, and communities established new compact villages, reproducing the gridded layout of a *reducción*, and building churches on plazas. In other cases, reducción towns splintered into smaller post-reducción villages, hamlets, or high-altitude *estancias* (ranches).

My main objective is to locate and identify the agricultural infrastructure of Huarochirí and reconstruct agricultural landscape change from the era of the reducciones to the era of post-reducción villages. Moreover, I seek to build on our understanding of how Andean communities built new settlements after the forced resettlement, prioritizing areas closer to previously built agricultural infrastructure (Denevan, Mathewson, and Knapp 1987; Wernke and Whitmore 2009).

The research area spans parts of the modern districts of Santiago de Tuna, San Andrés de Tupicocha, Espíritu Santo de Antioquia, San Damian, Lahuaytambo, Huarochirí and Langa, over a total area of 525 km^2, in the province of Huarochirí, in the highlands of Lima. According to Davila Briceño (1881[1586]) in his account of *La Provincia de Yauyos* in the *Relaciónes Geográficas*[10], this area coincides with the *doctrina* de Santa Ana y San Damián (Hernández Garavito and Oré Menéndez ms), part of the *repartimiento de Huarochirí*, in the Province of Lurín Yauyos (Figure 5).

[10] Documents send to the Spanish court answering a questionnaire about American colonies as part of Spain general mapping project of its colonies

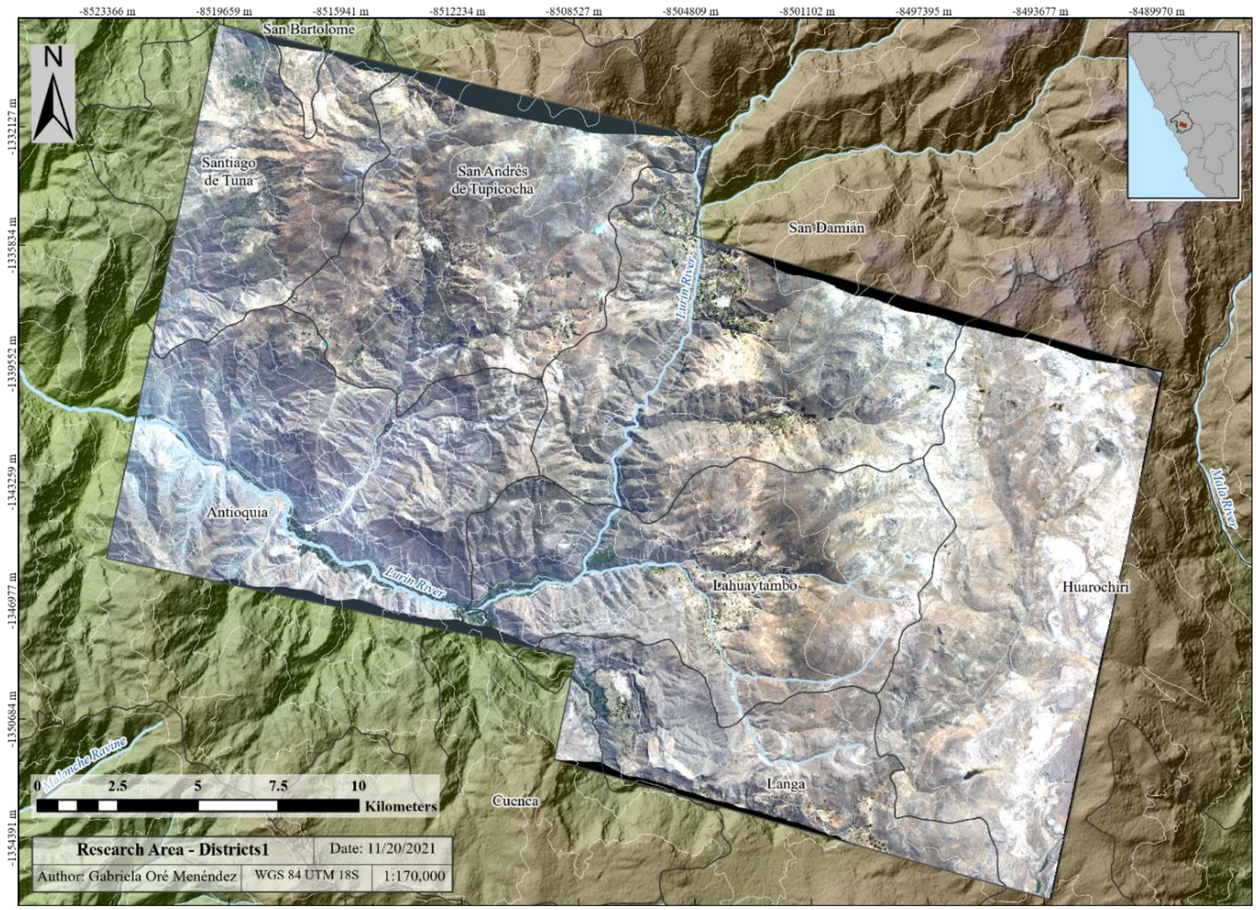

Figure 5. Research Area

4 Methodology: sequential reduction of the area of analysis (SRAA)

To investigate spatial relationships among agricultural terraces, reducción towns, and post-reducción villages, it is necessary to accurately locate settlements and agricultural infrastructure (terraces). The area selected for the analysis was 525.53 km^2, a section of the Lurín and Mala valleys where terraces and agricultural fields were detected through a preliminary field survey. The features of interest are larger than the Ground Sample Distance (that is, the ground-level dimensions that each pixel represents) of the imagery, making their detection possible. Pedestrian survey of a 500 km^2 area would require several field seasons. Furthermore, the scale and resolution needed to locate agricultural fields do not require the level of precision a pedestrian survey would yield. Therefore, high-resolution satellite imagery covering the research area is enough to identify and map terrace extension. Given the large extent of the area of analysis the granularity of the research question, the most efficient and cost-effective method is MSRS analysis.

The application of MSRS to answer archaeological questions presents many challenges; nevertheless, benefits like reducing field costs and potentially dramatic upscaling outweigh its potential downsides. As mentioned in the introduction, those downsides include computational power, complexity of analysis, and a steep learning curve. To overcome those limitations, I focus on creating an accessible workflow that aims to limit the variables present on an image and reduce the area of interest (AOI) for each analysis iteration until there is a satisfactory result.

The workflow used to identify agricultural terraces and fields was divided into two stages to avoid overloading the workflow: 1) Pre-Classification and 2) Classification. The pre-classification stage reduced the AOI to only sections where agriculture is detectable through low and mid-resolution satellite data: ALOS PALSAR for terrain information and Landsat 8 for low-resolution multispectral data. I used Landsat 8 in the Pre-Classification stage because it requires less computational resources and takes less time than a high-resolution image like PeruSAT-1. In addition, the results' resolution is ideal since the main goal for this stage is to reduce the area to avoid complex analysis. Finally, as long as the images are similar (same season), the results between the two data sets are roughly the same.

The strategy chosen for the workflow narrows the more complex and computationally demanding analysis (classification) to selected sections of the satellite image mosaic to maximize resources (computer power and processing time). Furthermore, since the selected sections share similar characteristics (variables that allow spaces where agriculture is possible), the variability within the area is also reduced and, as such, the complexity of the classification analysis.

4.1 Getting the data: Satellite Imagery

Depending on the research question and the scale of a project, some satellite images are more suitable than others. For example, the highland Andes present many challenges when using satellite images effectively; the features of interest—agricultural terraces and field walls—are below the Ground Sample Distance of public domain medium-resolution satellite images like Landsat or Corona unsuitable for feature detection in the Andes. Additionally, the lack of contrast between structures (built out of mud bricks or stone) and the Andes backdrop makes it particularly difficult to use satellite imagery without extensive manipulation to detect and isolate archaeological features. Using high-resolution images will help avoid part of these issues, given that a higher resolution image will be better at defining objects' edges and elements smaller than 4 to 5 meters in width.

A significant deterrent to using high-resolution images is the high cost of commercially imagery such as WorldView[11], Ikonos, or Pleiades, even after educational or academic discounts. Thankfully, national spatial agencies from various countries (US., Japan, the EU, or Peru) have semi-open-source online repositories with research and educational access to high-resolution data (i.e., Sentinel-2 from the ESA12). In addition, some national repositories, like USGS, have archives with images dating back to the first satellite photos taken during the cold war by spy satellites from the US (Braasch 2002). For example, we used PeruSAT-1 from the National Commission for Aerospace Research and Development in Peru (CONIDA for its Spanish

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[11] Both satellites are part of Digital Globe one of the largest and oldest satellite image providers in the world.
[12] European Space Agency https://earth.esa.int/eogateway

acronym), Landsat 8 from the Landsat Program run by NASA-USGS, and ALOS PALSAR from the Japan Aerospace Exploration Agency.

a) ALOS PALSAR

The ALOS[13] mission of the Japan Aerospace Exploration Agency (JAXA) is a Phased Array type L-band synthetic aperture radar (SAR) sensor that produces single band elevation rasters with a resolution of 12 m. The instrument is an active microwave sensor that uses L-band[14] frequency to achieve cloud-free and day-and-night land observation. The primary use of SAR data is to generate digital elevation models (DEM) since its signal is responsive to surface characteristics like structure and moisture. As an active method, SAR sends its energy (B and C, wavelength between 7.5–3.8 cm) and then records the energy reflected back by an object on the Earth's surface. The DEM obtained from ALOS PALSAR was used to get terrain information and derived calculations, such as elevation and slope.

b) Landsat 8

The Landsat program (previously called Earth Resources Technology Satellite) consists of nine sensors (the last one, Landsat 9[15], launched on Sept 27, 2021), collecting information from the Earth's surface and its resources since 1972. The Landsat program brought new insights into land-use surveys, allowing fields like geology, natural resource management, agriculture, and even archaeology to have highly detailed data about land surface and stimulating new data analysis approaches. Landsat is especially valued as the longest continuously running platform, with some 40 years of earth observation data; however, it has a lower resolution (15 to 60

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[13] Advanced Land Observation Satellite https://asf.alaska.edu/data-sets/sar-data-sets/alos-palsar/
[14] The L-band (1565 nm to 1625 nm) or long-wavelength band
[15] https://landsat.gsfc.nasa.gov/satellites/landsat-9/

meters), making it more suitable for regional research. One example of Landsat multispectral capabilities used in archaeology is the Roots of Agriculture in Southern Arabia research project to differentiate between land-covered features like canals and silts (Harrower, McCorriston, and Oches 2002). The project also used spectral classification to identify different types of land cover associated with paleo soils and past agricultural activities. Landsat has also been used for monitoring Islamic sites in Ethiopia, where the use of open access images allows government heritage offices to control endangered archeological sites (Khalaf and Insoll 2019).

I am using Landsat 8, a ten-band multispectral image with two sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Landsat 8 has a spatial resolution of 30 meters in its multispectral bands (visible, NIR, SWIR[16] , as shown in Figure 6), 100 meters in its thermal band, and 15 meters in its panchromatic one. This resolution is too coarse to detect structures and terraces directly; nevertheless, the approach used to identify agricultural terraces— the sequential reduction of the analysis area (SRAA) used Landsat 8 to narrow the analysis to areas that present moisture in vegetation. Landsat 8 multispectral bands can help determine vegetation moisture indices and health, as well as water bodies over the surface. Band 6 is particularly useful for distinguishing between wet and dry soil (SWIR bands are not present in PeruSAT-1) and is used to calculate the Normalized Difference Moisture Index (NDMI) over the terrain (amount of moisture present in vegetation).

[16] Short Wave Infrared has two bands and correspond to a subdivision of the Infrared band

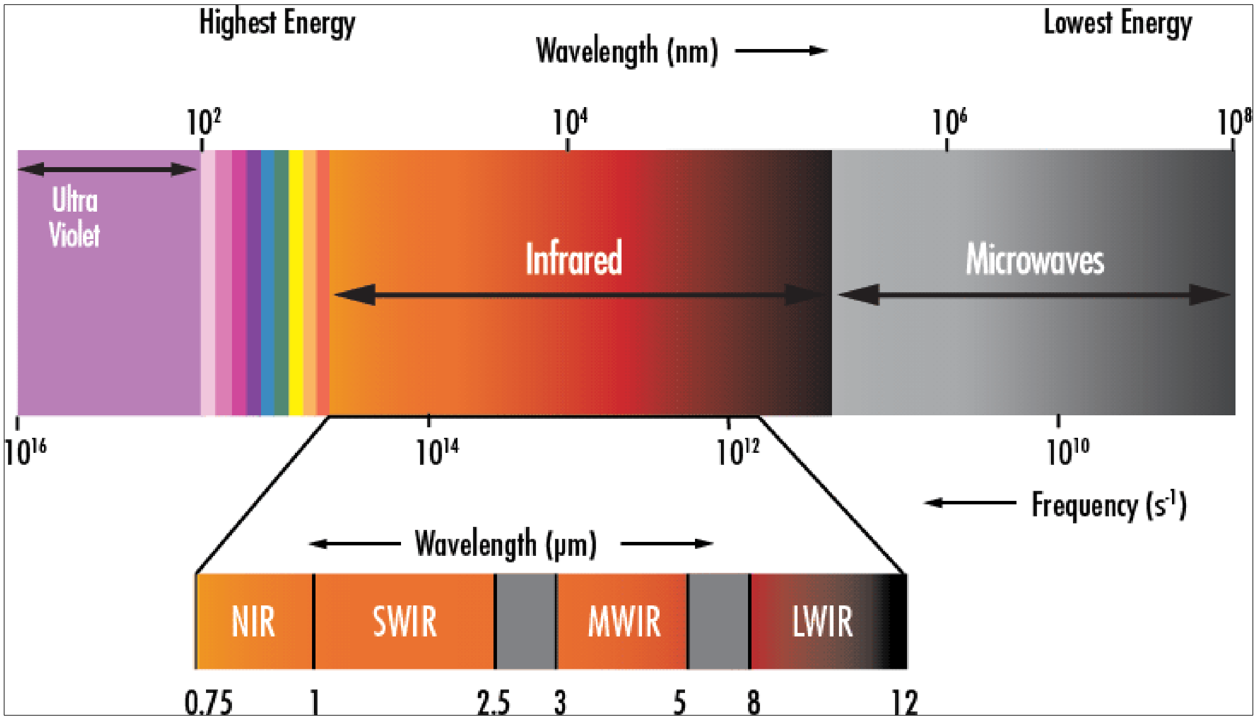

Figure 6. Electromagnetic Spectrum Illustrating SWIR Wavelength Range (Edmund Optics Inc 2022)

c) PeruSAT-1

The Peruvian State launched PeruSAT-1 in 2017, the most advanced high-resolution satellite in Latin America as of 2022. PeruSAT-1, built by Airbus Defense and Space, uses the powerful sensor NAOMI (New AstroSat Optical Modular Instrument) capable of capturing images of the entire Earth every 48 hours. In addition, this satellite has stereo capabilities and offers data with 0.7 m resolution in the panchromatic band and 2 m in its multispectral bands (4 bands RGBNIR, see Table 1).

The panchromatic band detects intensity by combining red, green, and blue bands. The combination offers a brighter image allowing for more detail (or higher resolution). On the other hand, multispectral bands record light's energy only in certain sections of the electromagnetic spectrum, registering less brightness and, as such, requiring larger areas to compensate for it.

To better take advantage of both the high-resolution panchromatic image and the lower resolution multispectral images, I combined them both using the pansharpening transformation tool. All the subsequent stages of the analysis used the pansharpened image version of the image since it has higher resolution (0.7 m) and multispectral values (Vrabel 1996).Two scenes from PeruSAT-1[17] (Table 2) cover the entire area of research, 525.53 km². The scenes were already corrected[18], and orthorectified. We created pansharpened images and mosaicked the two image tiles.

The climate of Huarochirí is characterized by marked wet and dry seasons, resulting in drastic vegetation land cover changes (Figure 7). Because of this, it is essential to consider the time of year that the images were captured. I only chose imagery from the same season (dry season May – December), with zero cloud cover, allowing for consistency across the imagery mosaic to minimize such seasonal effects. Images from the same season but different years tend to be more similar than those from the same year and different seasons.

The pansharpened image is a multispectral four-band mosaic with a resolution of 0.7 meters, resulting in a raster array of pixel dimensions X Y. Therefore, it is essential to ensure enough computer power to handle the extensive processing required for the analyses. Alternatively, splitting the image into tiles is a viable option that helps to reduce the processing times and the risk of overloading the computer system. PeruSAT-1 images are available through purchase or at no cost for research purposes through Peruvian institutions[19].

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[17] Scenes were part of an in-kind grant given by the National Commission for Aerospace Research and Development Conida | Agencia Espacial del Perú - CONIDA and its National Satellite Image Operation Center

[18] Atmospheric correction removes the effects of the atmosphere that alter the reflectance values capture by satellite sensors.

[19] https://www.gob.pe/8392-solicitar-acceso-al-portal-de-imagenes-satelitales

Figure 7. Wet (left) and dry seasons in Huarochirí. San Pedro de Casta, Rímac valley. (photo: Municipalidad Distrital de San Pedro de Casta)

4.2 Workflow

The objective for an efficient workflow is to reduce the AOI using simple sequential tasks. There are three stages in the analysis (Figure 8):

- Pre-classification: Creates a mask or single polygons that contain the final AOI. We use elevation (ALOS PALSAR) and NDMI (Landsat 8) data to target the AOI.
- Classification: Classifies the PeruSAT-1 image within the boundaries of the AOI using segmentation and then unsupervised classification.
- Post-Classification or Polygon manipulation: Simplify and manipulate polygons to get the closest result to agricultural fields walls

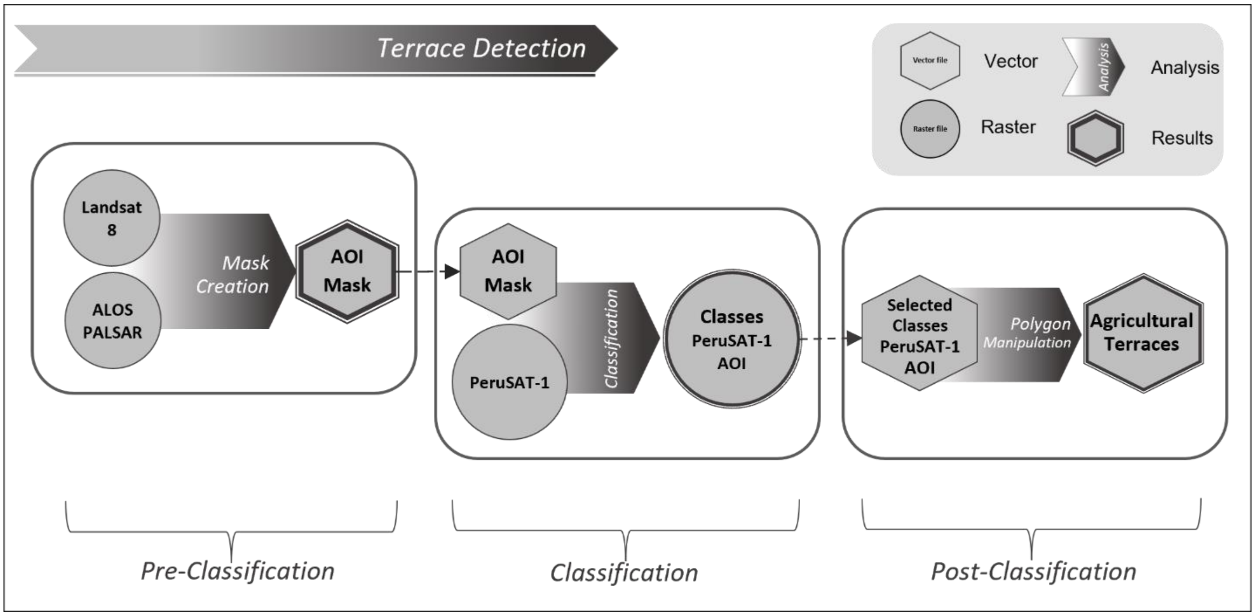

Figure 8. Workflow for terrace detection

1.1.1. Pre-Classification: Mask creation

A mask is a polygon restricting the analysis to an AOI within the image. Specifying an AOI decreases processing time, and most importantly, limits the number of feature types present in the image (see flowchart Figure 9). The AOI mask restricts the analysis to sections of the image suitable for agriculture, including areas with high moisture index in vegetation, with a slope less than < 30°, and below 4000 m.a.s.l.

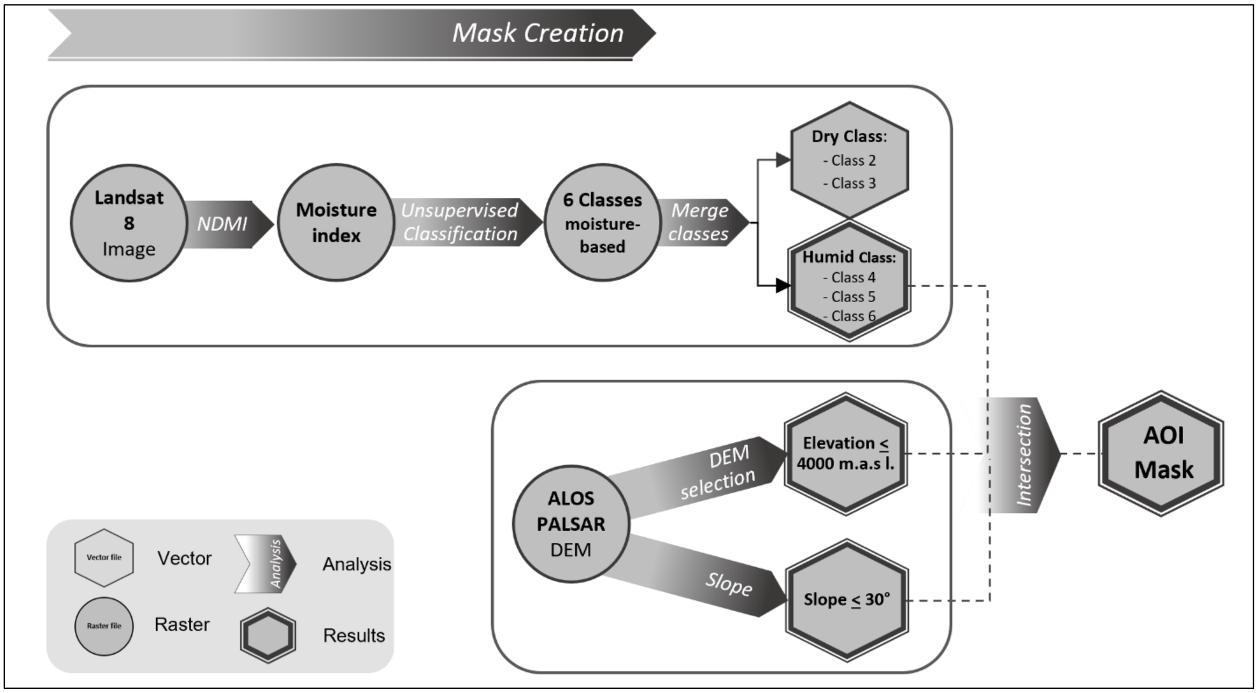

Figure 9. First stage – mask creation workflow

The upper Lurín and Mala valleys in Huarochirí depend on irrigation canals and agricultural terraces to maintain crops. The pronounced slope, seasonal rain, erosion, and loss of soil nutrients caused by washout rainwater make agricultural land very scarce (Yakabi Bedriñana 2015). According to FAO, the soil in the region is classified as *dystric leptosol,* a shallow soil over hard rock, usually over a pronounced slope with a soil base saturation (or how fertile the soil is) lower than 50 – which is not suitable for productive agriculture (Sheng 1990; Balci, Sheng, and Dembner 1992). The very few areas where agriculture is possible have been mostly covered by valley floor fields or agricultural terraces (in areas with slopes higher than 5°). Considering these characteristics and following ethnographic and agricultural research in the region, the best place to build terraces and *chakras* in Huarochirí is in areas under 4000 m.a.s.l where nighttime frost cannot harm crops, over hillslopes lesser than 30°, and in areas with high vegetation moisture since during the dry season only areas purposefully irrigated will present high moisture indices (Soler Bustamante 1954; Salazar Diaz 1983; Taboada and Dolorier 2014; Yakabi Bedriñana 2015; Agro RURAL 2021).

a) Elevation and slope

Areas under 4000 m.a.s.l and areas with slope angles lesser than 30° were extracted from the 12 meters resolution elevation raster ALOS PALSAR. Figure 10 shows the regions below 4000 m.a.s.l (357 Km^2, approx. 71% of the original research extent), and Figure 11 shows the areas with soft slopes (373 sq. Km. approx. 75% of the actual research extent).

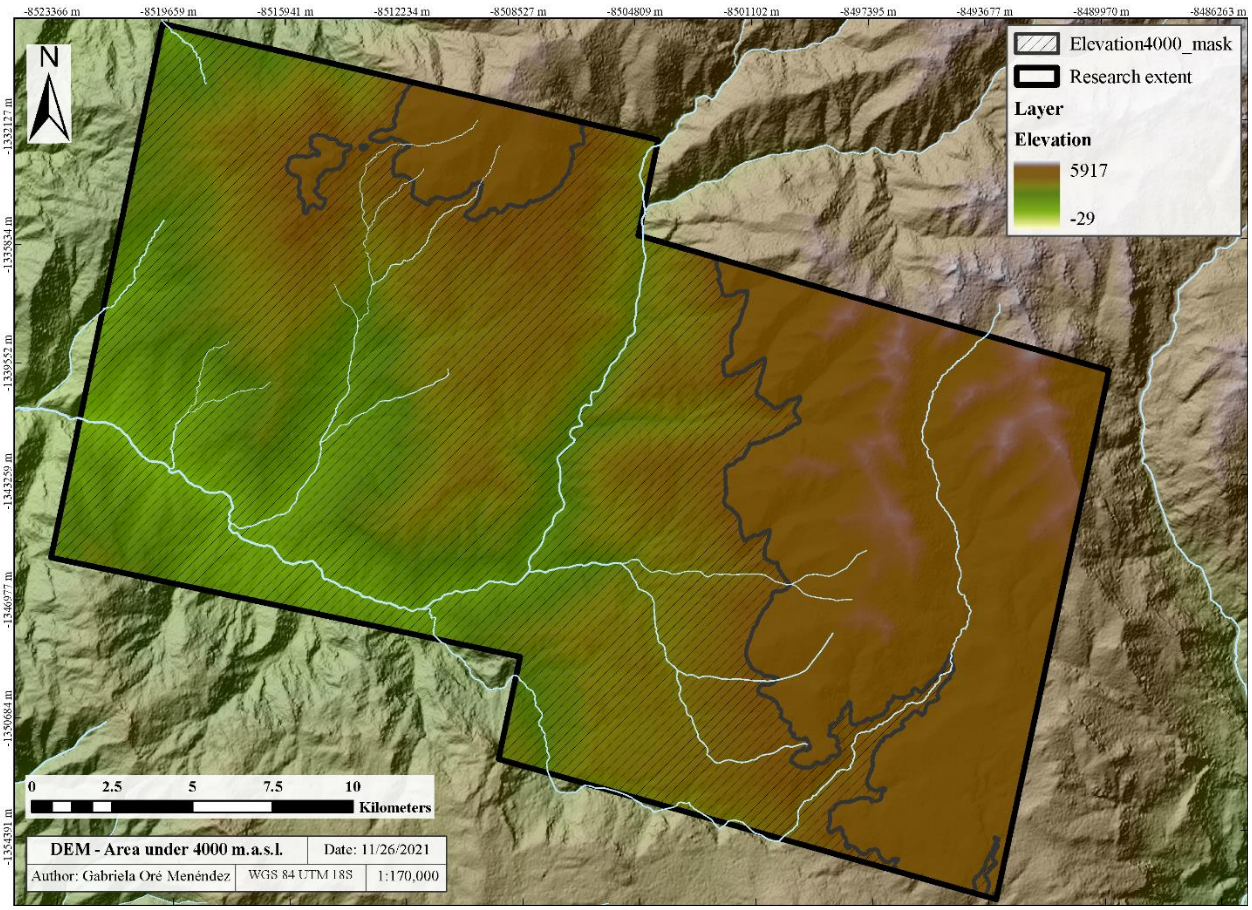

Figure 10. Elevation under 4000 m.a.s.l.

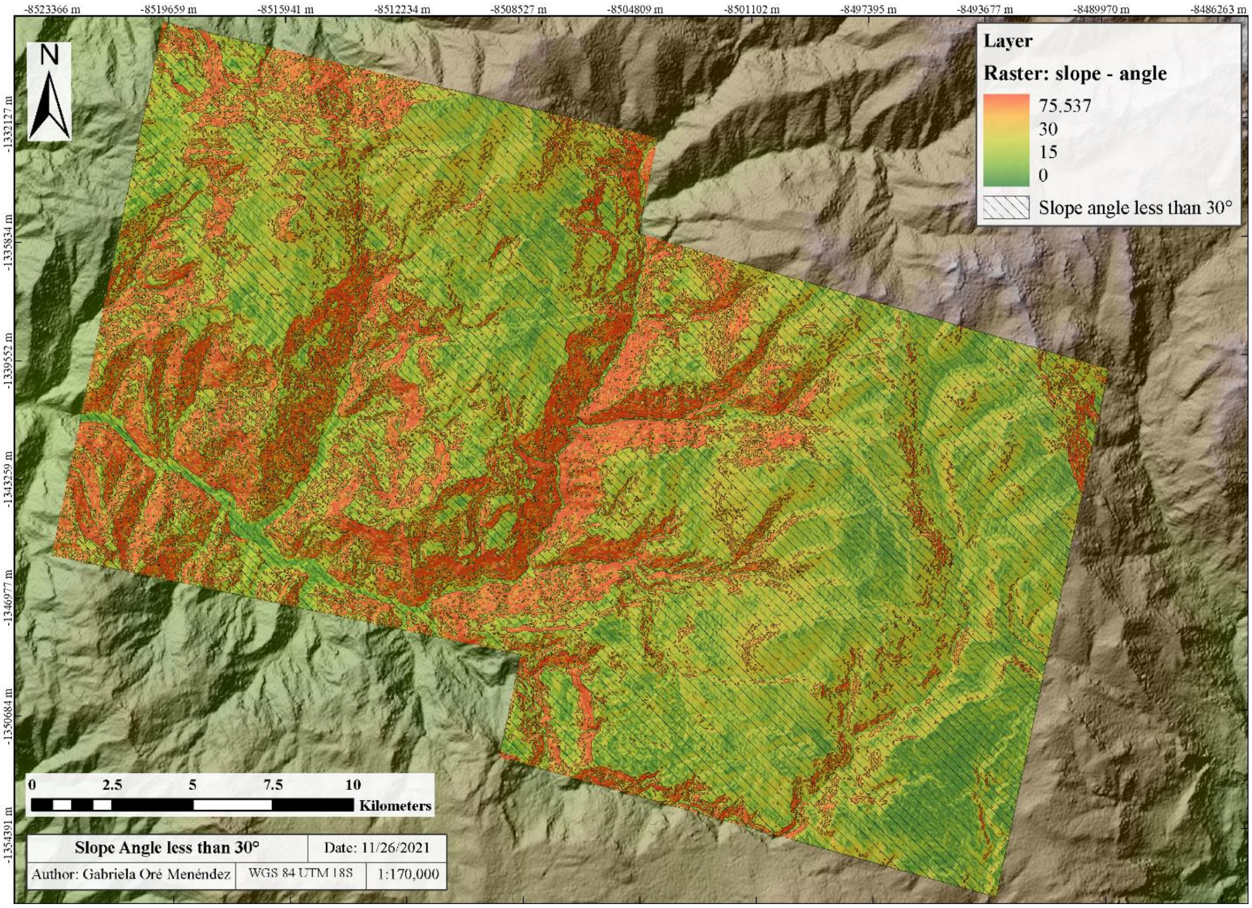

Figure 11. Slope angles lesser than 30°

The final mask or AOI for the analysis intersects the polygons extracted from the three previous calculations. The intersected area forms the primary mask or area of interest (AOI) that reduces the area of PeruSAT-1 high-resolution classification analysis to 138 km^2, 26.26% of the total image area of 525.53km^2 (Figure 12).

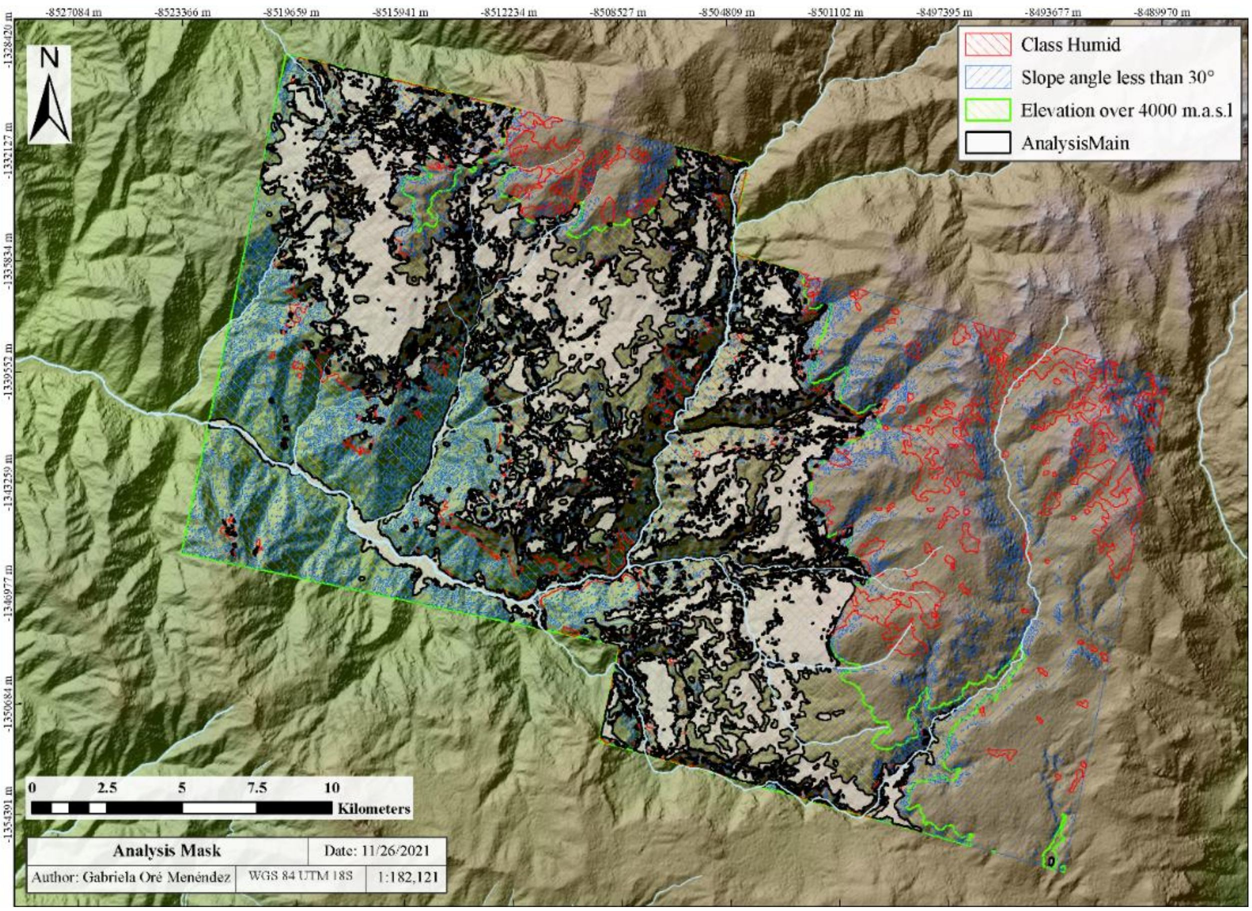

Figure 12. Area intersecting the selected NDMI, elevation, and slope sections

b) NDMI and Unsupervised classification

The Highlands of Huarochirí landscape is composed of natural vegetation, agricultural fields, exposed bedrock, and inert soil. As such, agricultural fields and terraces will be located over areas where moisture in vegetation can be detected since during the dry season, even if there are no agricultural fields present, much of the topsoil remains covered with dormant vegetation that maintains humidity. Areas such as bedrock or inert soil have different NDMI[20] values compared to agricultural fields or areas suitable for agriculture

[20] NDMI Normalize difference moisture index.

The NDMI determines moisture index in vegetation by calculating the ratio between the NIR and the SWIR bands to assess water content in vegetation through a normalized difference index (Gao 1996):

$$NDMI = \frac{(SWIR - NIR)}{SWIR + NIR}$$

Landsat 8, with its IR (band 5) and SWIR (band 6), allows NDMI calculation, and its values for the research area range from -0.5875 to 0.6897; according to industry standards,[21] -0.5 corresponds to: “poor canopy cover” and 0.6 corresponds to “very high canopy cover, no water stress” (Table 5). As the map shows, the areas with higher moisture index are located next to rivers or active ravines and in elevations between 2500 and 4000 m.a.s.l. in the Lurín and Mala upper valleys (Figure 13).

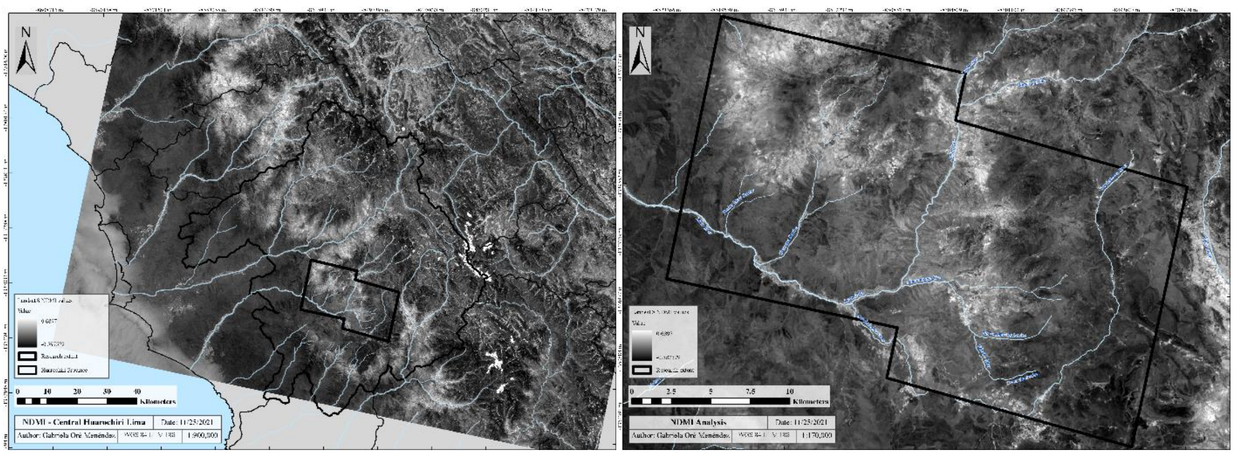

Figure 13. Landsat 8 NDMI results. Light areas show a higher moisture index (close to -0.7), dark areas show a low moisture index (close to -0.5). NDMI Landsat-8 scene extent (left) and research extent (right).

Areas with similar NDMI values were grouped using unsupervised classification analysis to distinguish between high or low moisture index areas. Classification analysis is a pixel-based grouping process where each pixel is assigned to a class. It extracts information from a multiband raster image (Landsat 8 NDMI raster). Then, it analyzes the values (in this case,

[21] NDMI values are used as part of the values measure during crops monitoring.

NDMI) and location (coordinates) of each pixel, organizing them statistically into different categories or classes. There are two main types of classification analysis: 1) unsupervised classification, where pixels are grouped in natural and significant clusters; and 2) supervised, where the user provides examples for each class to be used as a reference (Lillesand, Kiefer, and Chipman 2014).

Unsupervised classification of the Landsat 8 NDMI raster classifies the image in six different groups, showing a clear division between low and high moisture clusters along the valleys. The six classes are:

- Class 1 grouped the unclassified pixels outside the image’s boundary
- Class 2 and 3 grouped areas of bare soil and bedrock
- Classes 4, 5, and 6 grouped areas with healthy crops, dry crops, and natural vegetation. These last three classes were grouped and set to form the “humid class” and classes 2 and 3 the “dry class” (Figure 14 and Figure 15).

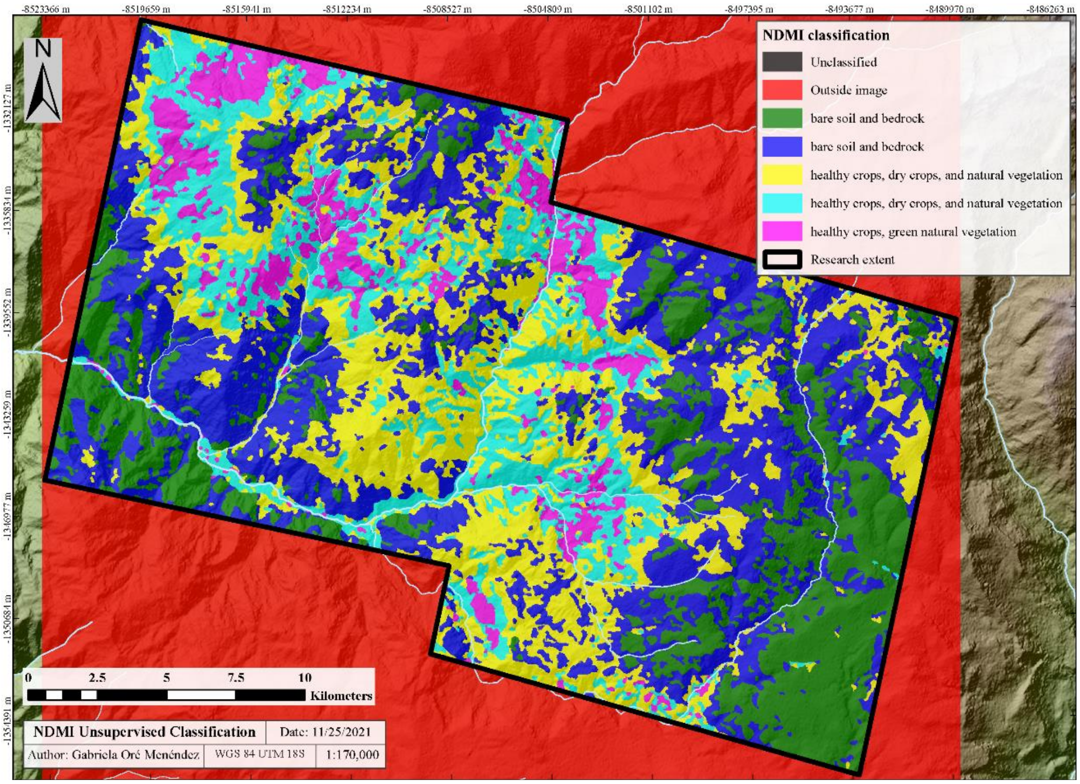

Figure 14. Landsat 8 unsupervised classification: Six classes.

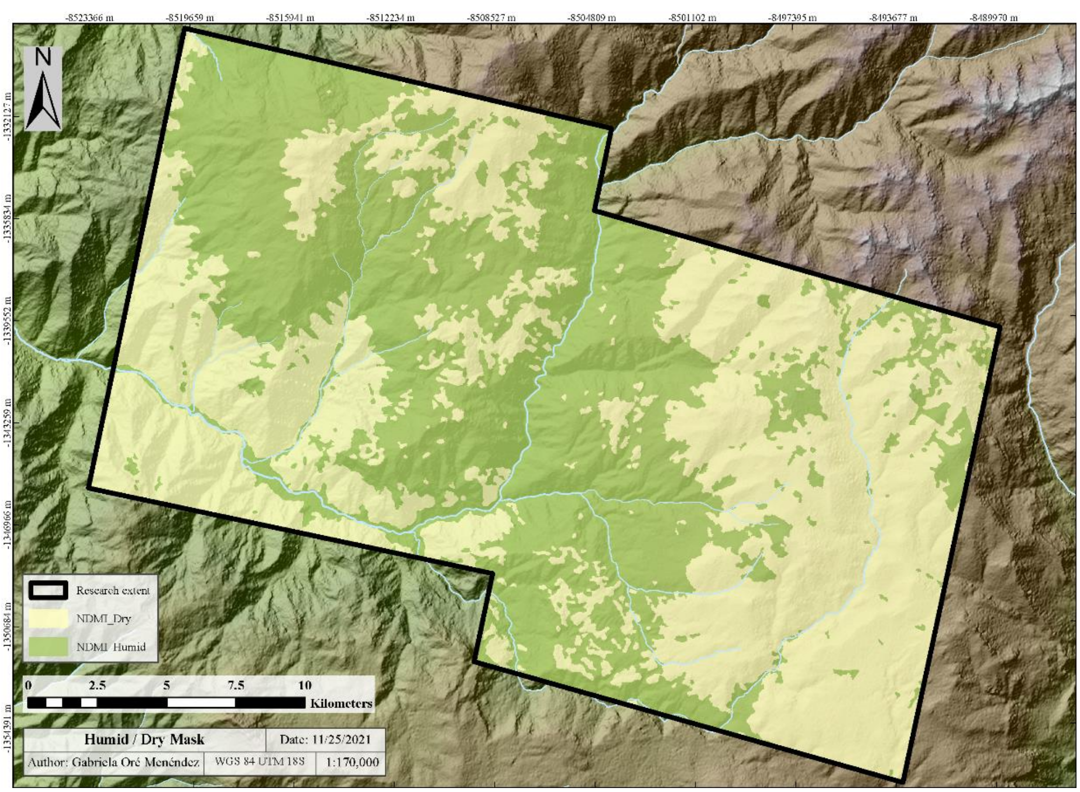

Figure 15. Landsat 8, lasses grouped under Humid or Dry classes.

c) Segmentation Peru-SAT-1 pansharpened mosaic

This workflow aims to reduce processing requirements, and as mentioned before, classification analysis consumes many computing resources and takes a long time. Moreover, processing time grows exponentially based on the image size and resolution, which means the larger the number of pixels, the more extended the processing time. For the case study, creating a targeted AOI with only areas suitable for agriculture has reduced the original area to less than 30%, shortening the processing time and decreasing the risk of overloading analysis. Nevertheless, an additional step will reduce the processing requirements but not the analysis area. Creating a segmented image of the AOI into more manageable small pieces makes the classification analysis less demanding. The segmentation process groups pixels with comparable values (extracted from each spectral band: blue, green, red, and IR) and cluster them together. As part of the process, segmentation analysis creates additional bands to include extra variables into the cluster analysis. For example, on a segmented PeruSAT-1 image, besides its four multispectral bands (RGB and IR), it includes normalized difference[22] and color scheme (hue, saturation, and intensity) bands, totaling eight bands. Image segmentation uses the values of each of the eight bands to assign a label to every pixel; pixels with similar labels are clustered

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[22] The normalized difference that we choose to add to the segmentation is the vegetation index known as NDVI. NDVI quantifies plants' light absorption during photosynthesis. Healthy and or dense vegetation reflects a significant amount of Near Infrared (NIR) light but little Red light as it is absorbed instead. Conversely, on non-healthy vegetation, we see a decrease in the NIR but an increase in the red reflectance as there is less chlorophyll to absorb the red light. NDVI combines the information into a single normalized value: $NDVI = \frac{(NIR-RED)}{NIR+RED}$ NDVI

together, establishing boundaries between elements. Scale and aggregation parameters determine the segmented image level of detail[23].

The segmented image shows a simplified version of the original mosaic, where features are still recognizable, but instead of individual very regular pixel mesh, there are thousands of form-free segments (Figure 16). The segmented 8-band image will be classified using automatic classification in the next step.

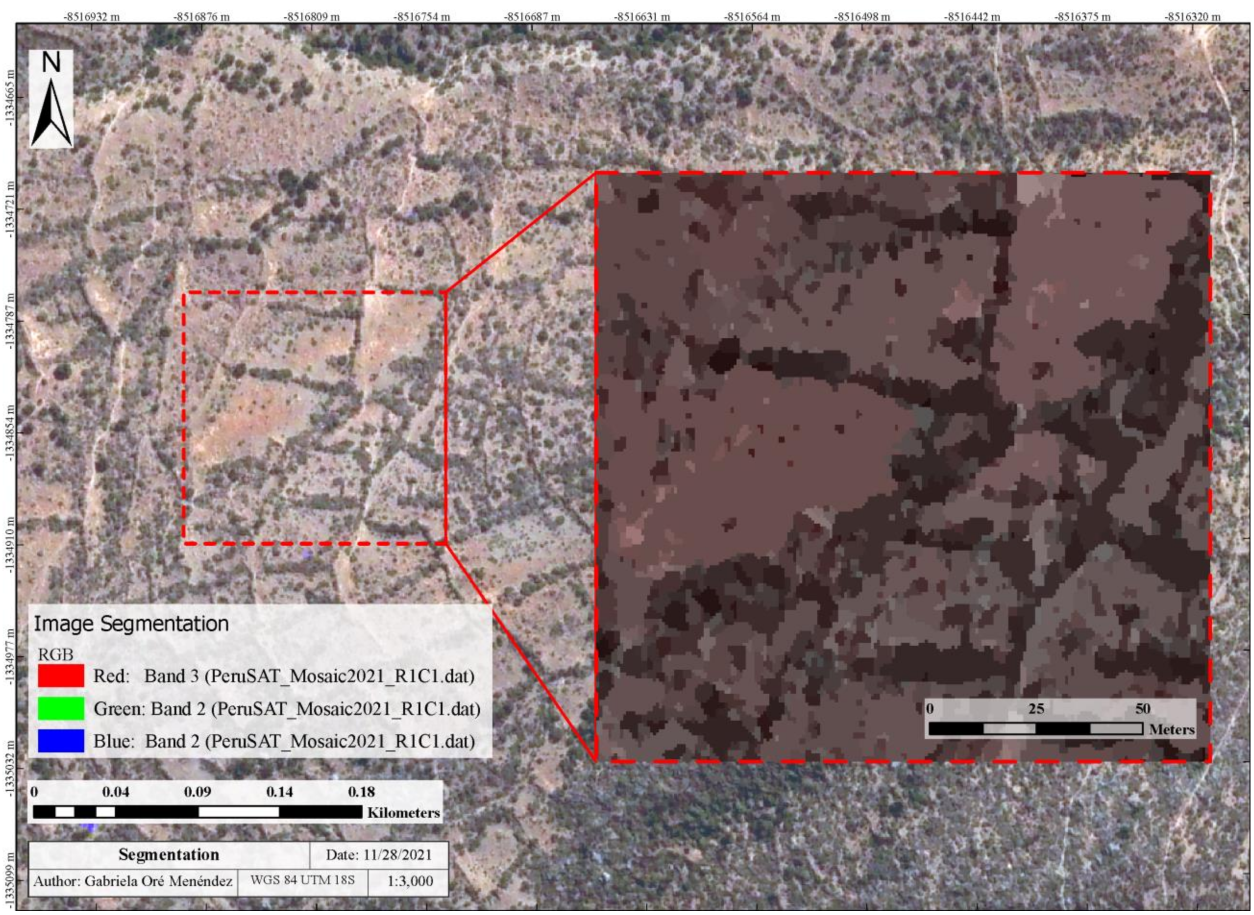

Figure 16. Segment version of PeruSAT-1 mosaic (scale 1:3000)

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[23] The merging process scale can also be managed using only certain bands. For PeruSAT-1 all the bands (spectral, normalized difference, and color scheme bands) were considered to establish an adequate scale; on the other hand, only the spectral bands (RGB and IR) were considered to stablish the aggregation factor since using all the bands will yield no results.

1.1.2. Classification Analysis

As mentioned before, classification analysis groups pixels with similar values. It extracts information from a multiband raster image (PeruSAT-1) and analyzes its multispectral values (pansharpened data in four bands: RGB and IR) and location (coordinates) for each pixel, organizing them statistically into different categories or classes. Within classification analysis, the two main types are unsupervised and supervised classification. Deciding to use supervised or unsupervised classification depends on the type of feature needed to be identified, the image type, computational resources, and the research question.

Supervised classification allows for the direct creation of classes informed by examples, or training data, from the different features or classes to be identified (Canty 2014; Lillesand, Kiefer, and Chipman 2014). The success of a supervised classification then rests on the quality of the training data. At a glance, it seems that supervised classification is the most straightforward method to detect specific elements on an image; nevertheless, the classification of archaeological features requires controlling many more variables when creating an adequate data set. Some first efforts in taking classification analysis for archaeology to the next step include the use of neural networks to identify archaeological structures in the southern highlands in Peru (Zimmer-Dauphinee and Wernke 2021).

Additionally, there are some challenges in creating a training data set, especially in archaeology. For example, archaeological architecture and features tend to be in a poor state of preservation, usually do not have roofs, and are partially covered by vegetation or soil. All these elements difficult the creation of boundaries between features making the classification harder and not very precise. Moreover, some elements have very low obtrusiveness (Banning 2002) and are challenging to isolate and represent within one training class.

d) Unsupervised classification

For the case study in Huarochirí, supervised classification is not the best methodology for agricultural infrastructure detection since the training input (stone walls as terrace boundaries) present too much variability: walls covered by healthy vegetation, walls covered by dry vegetation, wall remodeled for modern use, walls where only the base is still present. Nevertheless, supervised classification can be beneficial when their training data is collected on the field and familiarity with the landscape and its multispectral representation. One of the easiest ways to explore the multispectral data and the image is to perform an automatic classification first to understand the natural groups formed and informed the creation of training data.

Other types of supervised classification that can be performed after an initial exploration of an image are object-based image analysis (OBIA). However, OBIA bases its classification process not only on spectral information but also on the location of each pixel in the image (Lillesand, Kiefer, and Chipman 2014). clusters, size, shape, proximity, directionality, context, and repetition to train the algorithm Artificial Neural Networks and Machine learning are much more complex analyses; both processes self-train after initial data input and create very accurate results after several iterations, have become ubiquitous tools for commercial and research agendas[24]

The workflow for the classification stage includes unsupervised classification of the last AOI and then class selection and simplification of the resulting classes and polygons known as post-classification (Figure 17).

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[24] Davis (2019) presents a timeline of developments of analysis OBIA as a method in archaeology from 2000 to the present.

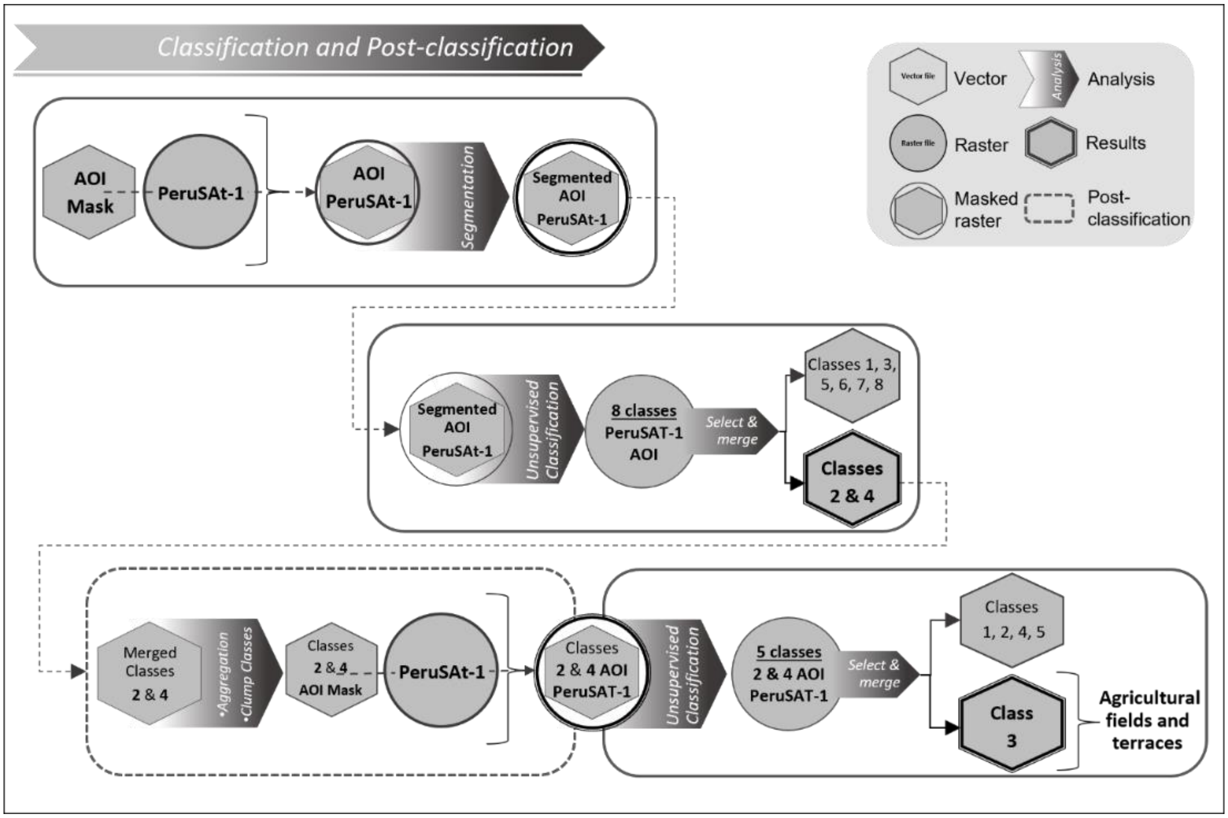

Figure 17. Workflow for Classification and Post-classification

For the case study discussed here, terraces present two main issues that example-based classification cannot overcome easily—at least while using simple classification and not deep learning processes: the obtrusiveness of the built material (made from local stone), and the wild vegetation present next to and on top of the terrace's walls. That is why it is imperative to understand and have enough information about the main characteristics and particularities of the research area and in particular the elements to identify; for this case study terraces and terrace boundary walls. Many of the decisions made during image classification are based on descriptions made during field reconnaissance. Terrace characteristics, like wall width, terrace vegetation types, field types, terraces and fields locations with landscape elements, support decision making during the classification process. Fields and terraces within the Huarochirí region are made of *pirca*[25], and located within a landscape mosaic composed of similar elements (exposed bedrock, soil, and natural vegetation). Terraces are located over hillslopes and plateaus, thus having irregular distribution and orientation, and are partially covered with natural vegetation or present vegetation growing along walls (Figure 18).

Figure 18. Wild vegetation growing along terraces' walls (Photo by the author, 2017)

In the previous step, the PeruSAT-1 mosaic was reduced to the AOI extent and then simplified (using segmentation). The classification analysis of the Landsat 8 NDMI resulting image consisted on just one band, on the contrary, the classification of the PeruSAT-1 scenes analyze not only the 4 bands from the original PeruSAT-1 images, but also uses as references, additional layers of information offer by supporting data (either from this or different sensors). In total the classification analysis uses the four original spectral bands from PeruSAT-1 (RGB=IR) plus the additional four bands created by the segmentation process (one band per segmented layer). In addition, the AOI mask area shares very similar geomorphological characteristics within its area; as such, it contains a limited number of features (i.e., roads, terraces, ravines,

[25] Crude dry masonry wall made from locally available stone.

towns, and modern structures, in use and abandoned agricultural fields), reducing the complexity of the analysis.

The unsupervised classification process of the upper Lurín valley yielded eight classes (Figure 19). The most abundant class corresponds to Class 3, closely matched by Class 4 with almost 24% of the entire AOI (Figure 20) that grouped similar characteristics under the same class:

- Class 1 – Boundary outside the mask
- Class 2 – Wild vegetation, trees, vegetation over hillslope covering stone walls
- Class 3 – Vegetation covering stone walls. Included areas dryer than class 2
- Class 4 – Area inside fields and wild non-healthy vegetation
- Class 5 – Fields of healthy vegetation
- Class 6 – Soil is slightly humid and areas next to stonewalls.
- Class 7 – transited hillslope surface – moderate use, the interior of some in use agricultural fields
- Class 8 – Transited hillslope surface – intense use (usually found within towns, roads, and modern structures. It also features the interior of clean fields.

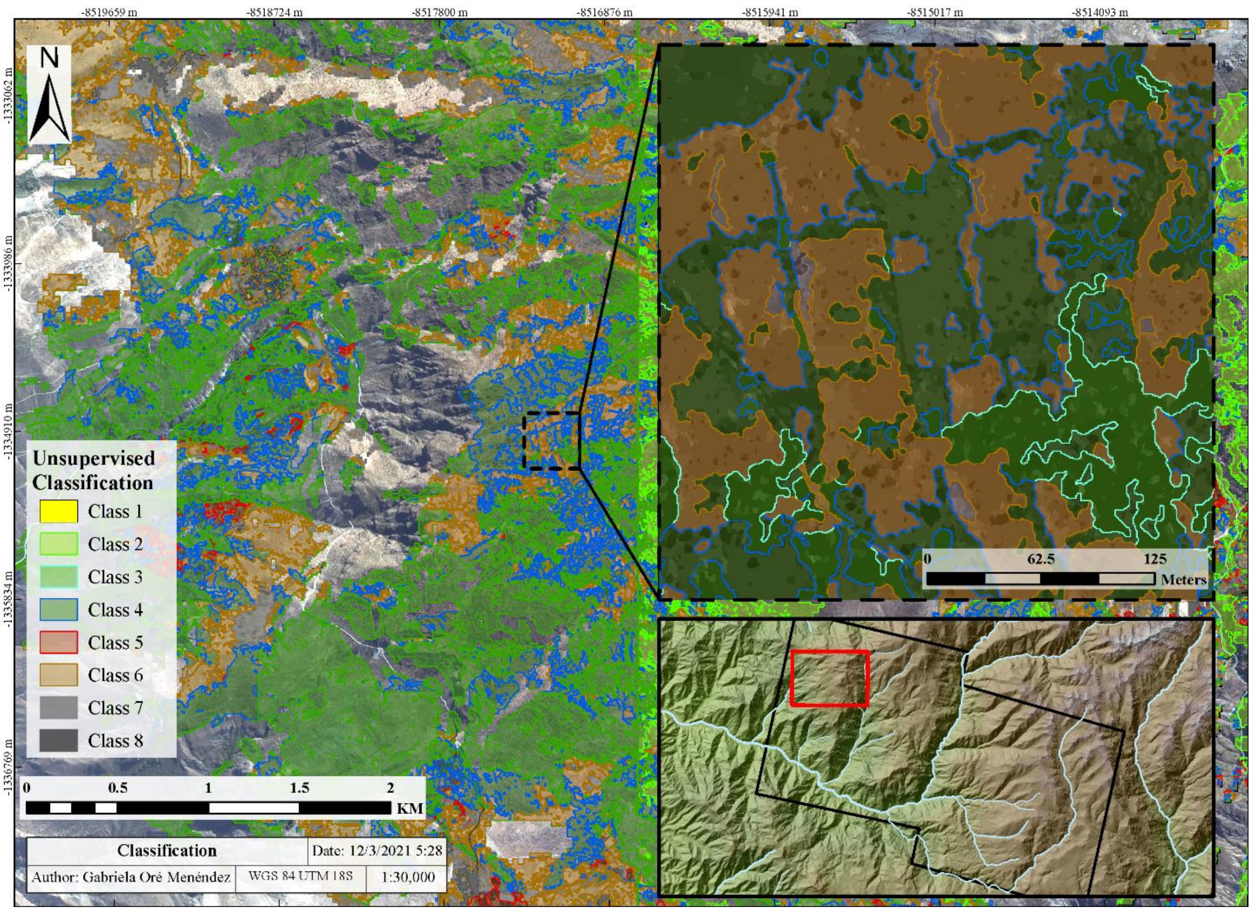

Figure 19. Unsupervised Classification result

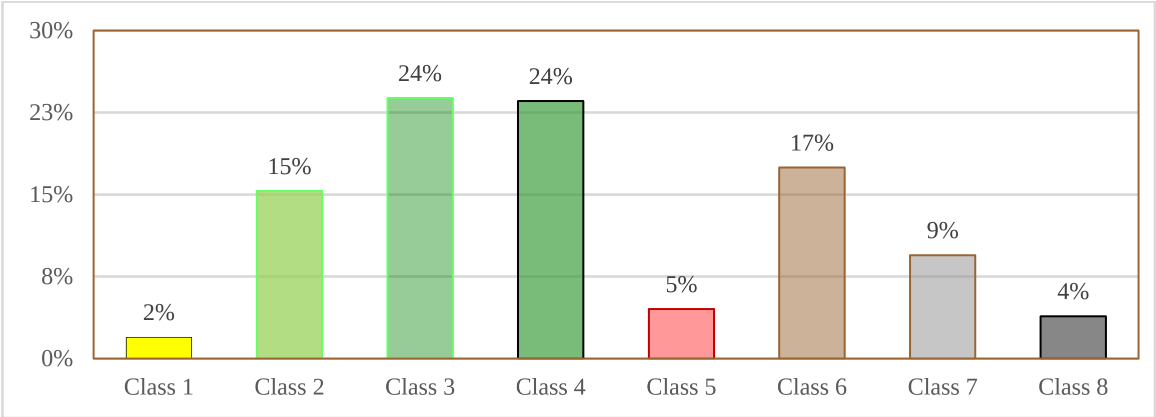

Figure 20. % pixel by class PeruSAT-1 segmented mosaic automatic classification

Close observation shows that Class 2, Class 3, Class 4, and Class 5 contain part of agricultural terraces. Most classes achieved separation between features; for example, classes 7 and 8 correspond to in-use surfaces, including roads and areas next to structures like modern corrals. Classes 2 and 4 include stone walls vegetation covering stone walls; both classes formed the next AOI (Figure 21).

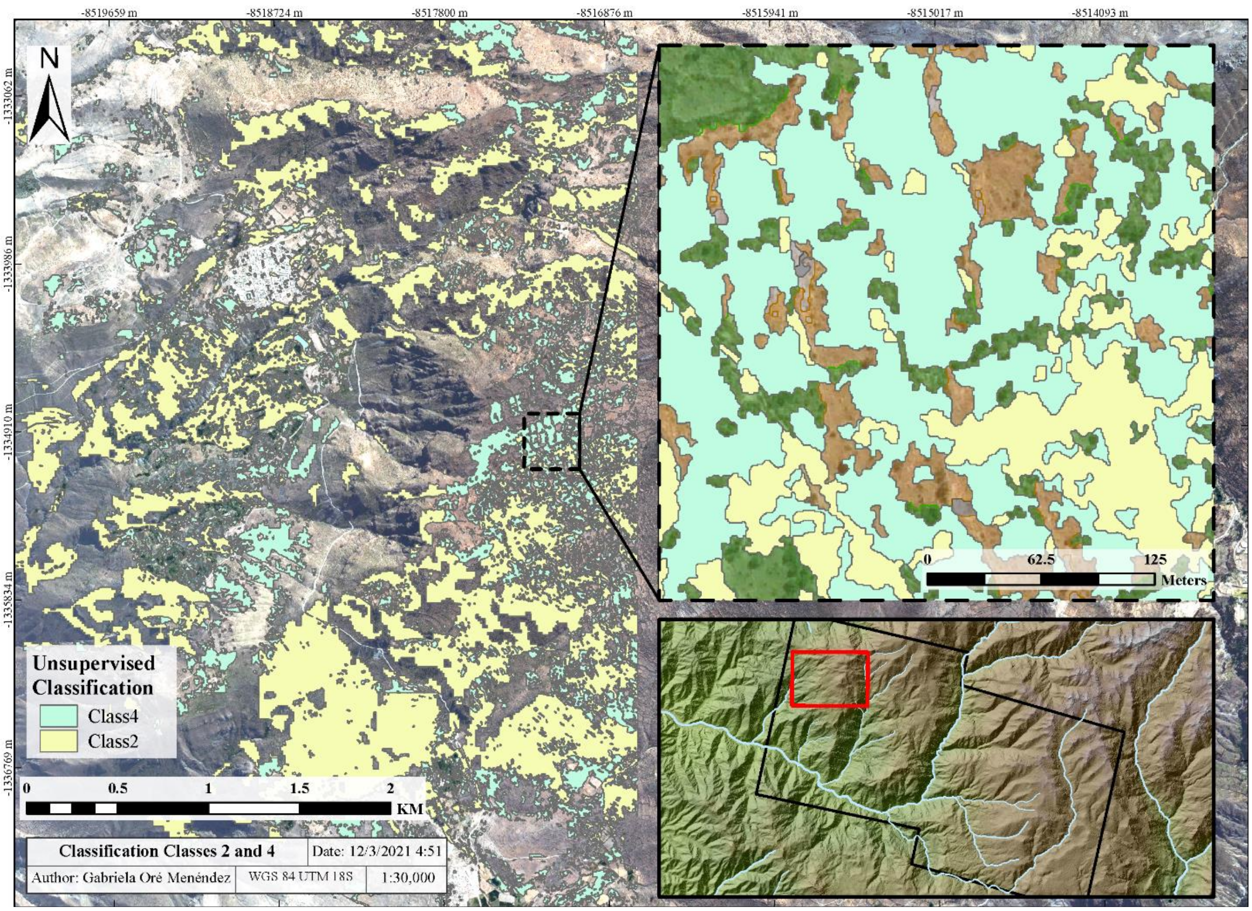

Figure 21. Classes 2 and 4 will form the new AOI

Classification analysis can also use complementary data to improve feature detection. Usually, the data comes from direct observation and information collected during visits to the research area and archaeological data. For example, Class 2 and Class 4 correspond to wild vegetation. From fieldwork observations and close examination of the satellite image, we can infer that some vegetation covers part of the stone walls. These walls delimitate agricultural field extensions and terraces and are usually covered by scrub growth[26] growing next to and on top of

[26] Ludwigia peploides sp., Mutisia acuminata sp., Senecio cantensis sp., and Senecio richii sp. (Gonzáles et al. 2015)

the terrace and field walls (Figure 21). These bushes benefit from the conditions created by the walls. Walls offer the plants protection against the sun and wind and allow water retention. Thus, stone walls create a suitable growing environment (Manenti 2014; Agnoletti et al. 2015). Therefore, we can correlate the presence of seemingly aligned wild herbaceous plants as a proxy for the fields and terrace walls. Nevertheless, the use of wild herbaceous vegetation as a variable need to be carefully monitored since these bushes also grow dispersed in hillslopes and small ravines. The difference is that when the vegetation grows next to the stone walls, they follow the alignment of the walls, whereas when they grow on hillslopes, they tend to cluster together in ovoid patterns.

1.1.3. Post-Classification

The classification process resulted in a raster image composed by pixels with values corresponding to each of the identified classes. Those pixels were transformed and grouped into measurable polygon vector file (shapefile) containing two classes represented by thousands of irregular complex polygons. Given the high resolution of the imagery and the lack of clear boundaries for features like agricultural terraces, it is necessary to standardize and simplify the results through data clean-up. There are two reasons for this step: the higher the number of complex polygons with a high number of vertices covering small areas (less than 50 m^2 over the terrain is considered a small area for our objectives), the higher the processing time computational resources need it.

Some of the basic operations of the post-classification routines consist of decreasing polygon complexity. For example, the basic geometric operations eliminate classes that do not contain data of interest, combine those that remain, and smooth and simplify them (eliminate extra vertices and points). The AOI classes 1, 3, 5, 6, 7, and 8 (37.28% of the AOI) were not included in the second classification, and no further action was performed. Classes 2 and 4 were combined (62.72% of the AOI) as the two classes present wild herbaceous vegetation, agricultural fields, and stone walls. However, all these elements show in both two classes. Therefore, to adjust the classification, I decided to run one more unsupervised classification only in areas part of Classes 2 and 4 as the new AOI. Unsupervised classification of Classes 2 and 4 created five classes. Out of those five classes, two very similar classes contained terraces and agricultural fields subclasses 3 and 4.

As Figure 22 and Figure 23 show, subclasses 3 and 4 mark the stone walls delineating agricultural fields and terraces. A repetition of the geometrical simplification tasks will yield much more manageable polygons.

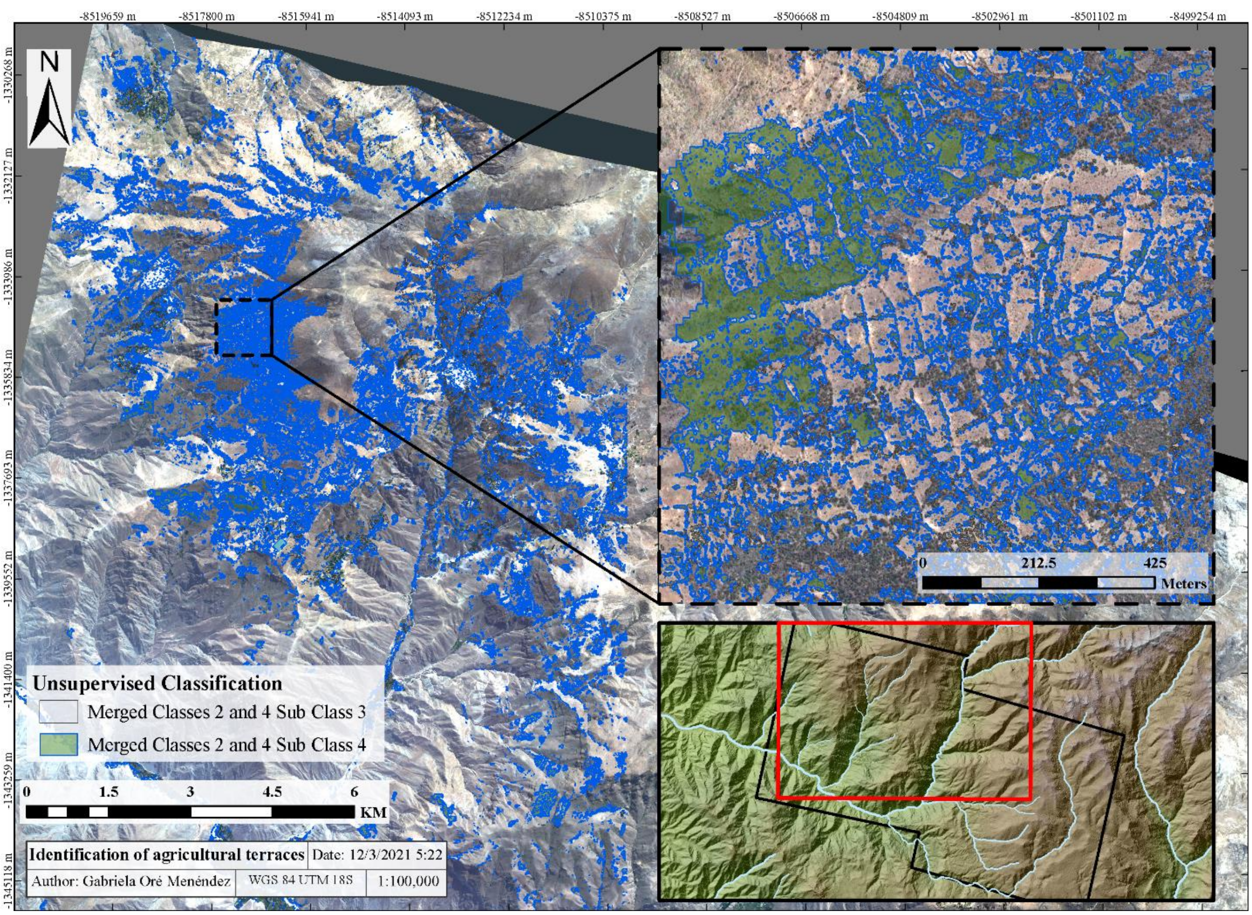

Figure 22. Subclasses 3 and 4 from unsupervised classification applied to the AOI from Classes 2 and 4 showing agricultural terraces (scale 1:100000)

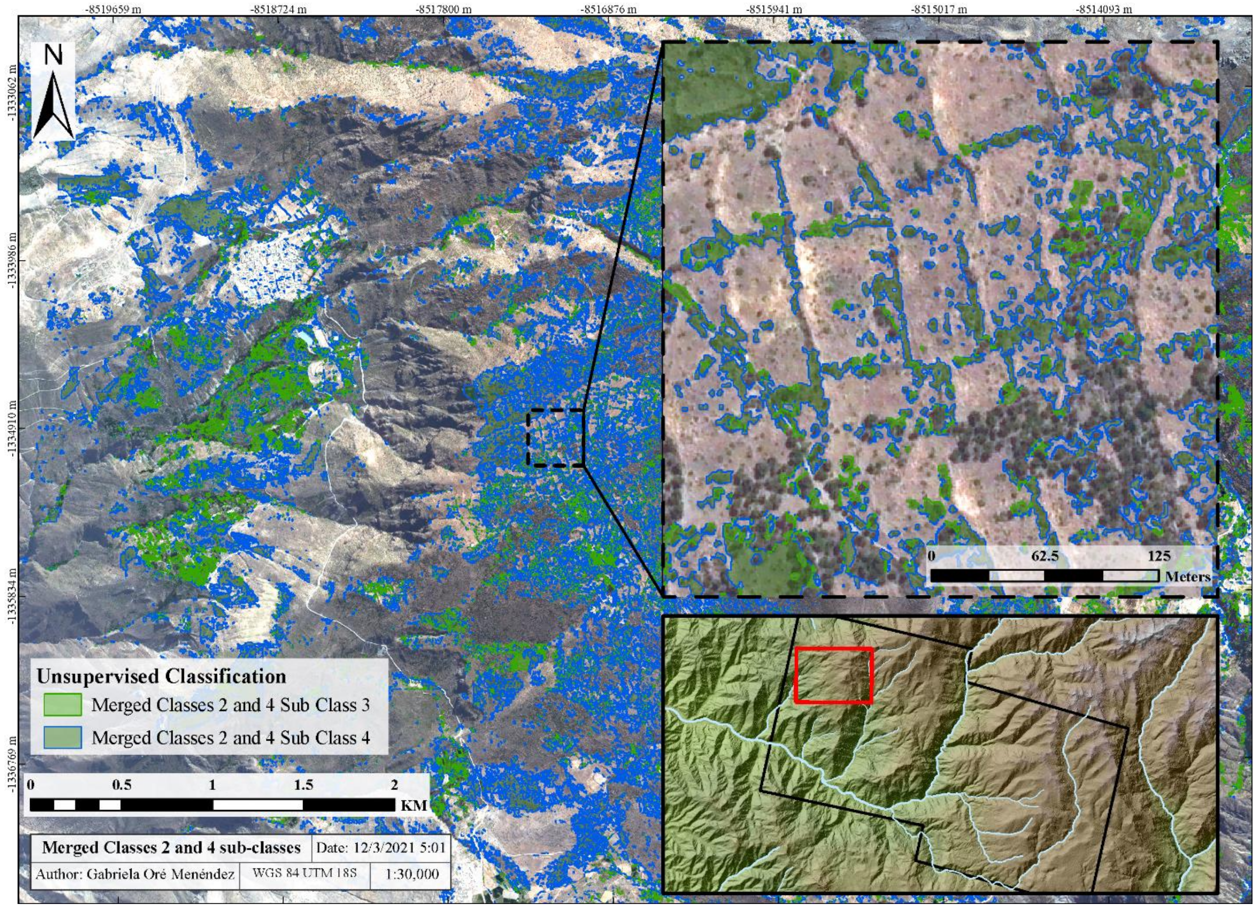

Figure 23. Subclasses 3 and 4 from unsupervised classification applied to the AOI from Classes 2 and 4 showing agricultural terraces (scale 1:30000)

5 Discussion and conclusions

The MSRS workflow presented here requires basic knowledge of multispectral image analysis principles as well as a basic GIS experience. This paper provides a set of instructions, descriptions, and explanations for a transferrable and replicable tool to other regions and research questions. I offer three examples of high-quality satellite imagery and the sources where they can be found. Furthermore, we are often not aware of the availability of free satellite imagery, usually granted to state sponsor research or educational affiliations, for example, PeruSAT-1 from the Peruvian Spatial Agency. They offer free imaging from their satellite and other satellites within the same cooperation network. Multispectral data is not well exploited in mainstream archaeological practice because it requires niche computer expertise, powerful computational capabilities, large amounts of data, and usually expensive software[27]. In that sense, high-resolution satellite images are more commonly used as high-altitude orthophotos instead of taking advantage of their multispectral capabilities. The results show that identifying agricultural fields and terraces can be done through sequential and essential analyses. Even though some variations between the identified walls and their general accuracy exist, the classification analysis yielded excellent results. The process presented many challenges that required changing strategies several times; nevertheless, the proposed workflow and the example presented here offer a practical and clear set of instructions with good results.

Still, the most valuable aspect of satellite image analysis relies on understanding the research area. The constant examination and re-examination of the image and the incorporation of data and variables from historical documents and visits to the area offered additional elements that, once incorporated into the analysis, aided in identifying terraces and fields. There are many different ways to get to the desired results in image analysis; the path that I chose follows a series of easy steps that required basic knowledge of multispectral analysis and a lot of trial and error. Information about the geography and terrain of the research area helps to choose and delineate variables; moreover, the incorporation of variables that come from cultural, historical, and natural understandings of the research area provides additional data that complements the fundamental classification analyses.

The entire image classification process can be a daunting task that seems to be reserved for a small circle of specialized practitioners. That is why I centered my efforts in establishing a

[27] Usually more amicable and also stable software is not freely available (i.e. ENVI from Harris Solutions and ArcGIS Pro from ESRI)

more accessible path to multispectral analysis and widening its use at all levels of archaeological practice. Identifying agricultural features will help reconstruct the agricultural landscape and its changes during the colonial period at a regional scale. However, further analysis is necessary to establish patterns that can explain the creation of new post-reducción villages in Huarochirí. The workflow developed here allows for the incorporation of additional documental and archaeological data to identify agricultural fields and terraces, and as is shown in chapter 4, it will also allow for additional inputs during the spatial analysis.

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Appendices

A. Tables

Type of Band	Band name and number	Wavelength (nm)	Sensor Resolution
Spectral band (PAN)	Panchromatic	450 – 750	0.7 m
Multispectral bands (MUL)	Blue band – 1	450 – 520	2 m
	Green band – 2	530 – 600	2 m
	Red band – 3	760 – 890	2 m
	IR band – 4	760 - 890	2 m

Table 1: PeruSAT-1 bands, resolution, and wavelength

Product Name	VOL_PER1_ORT_001_003561/IMG_PER1_ORT_P/MS_003561	VOL_PER1_ORT_001_000041/IMG_PER1_ORT_P/MS_000041
Dataset ID	ORT_PER1_20170801152549_000	ORT_PER1_20180902152205_000
Acquisition date	2017-08-01 15:25:49	2018-09-02 15:22:05
Panchromatic (P) 1 band	28448 rows x 27016 columns	29884 rows x 27160 columns
Multispectral (MS) 4 bands	29884 rows x 27160 columns	7471 rows x 6790 column
Short name	03561	00041

Table 2. PerúSAT-1 Image tile information

Type of Band	Band name and number	Wavelength (nm)	Sensor Resolution
Multispectral bands (MS)	Coastal / Aerosol – 1	435 – 451	30 m
	Blue band – 2	453 – 512	30 m
	Green band – 3	533 – 590	30 m
	Red band – 4	636 – 673	30 m
	NIR – 5	851 – 879	30 m
	SWIR1 – 6	850 – 880	30 m
	SWIR2 – 7	1570 – 1650	30 m
Spectral band (PAN)	Panchromatic – 8	530 – 676	15 m
Multispectral bands (MS)	Cirrus – 9	1363 – 1384	30 m
Thermal Infrared Sensor	TIR1 – 10	1060 – 1120	100 m
	TIR2 – 11	1150 – 1251	100 m

Table 3. Landsat-8 bands, resolution, and wavelengths

Product Identifier	LC08_L2SP_007068_20130429_20200912_02_T1
Scene identifier	LC80070682013119LGN02
Acquisition date	2013-04-29
Short name for this image	LC08_007068

Table 4. Landsat 8 Image tile information

NDMI range values	Description
-1 to -0.8	Bare soil
-0.8 to -0.6	Almost absent canopy cover
-0.6 to -0.4	Very low canopy cover
-0.4 to -0.2	Low canopy cover, dry or very low canopy cover, wet
-0.2 to 0	Mid-low canopy cover, high water stress or low canopy cover, low water stress
0 to 0.2	Average canopy cover, high water stress or mid-low canopy cover, low water stress
0.2 to 0.4	Mid-high canopy cover, high water stress or average canopy cover, low water stress
0.4 to 0.6	High canopy cover, no water stress
0.6 to 0.8	Very high canopy cover, no water stress
0.8 to 1.0	Total canopy cover, no water stress/ waterlogging

Table 5. NDMI range values

Class	Pixel count	Percentage
Class 1	5472085	1.95%
Class 2	43025534	15.33%
Class 3	66867508	23.83%
Class 4	66097673	23.56%
Class 5	12715379	4.53%
Class 6	49041300	17.48%
Class 7	26523637	9.45%
Class 8	10855002	3.87%

Table 6. Percentage of the AOI assigned to each class. Classes in bold were classified again.

Chapter 3

Reimagining Colonial Landscapes through Geospatial Visualization: An Example from the Peruvian Andes

Abstract

Spatial modeling tools, particularly Geographic Information Systems (GIS), have consistently come under criticism for reinforcing a static and cartesian rendering of the landscape and the limited point of view through which they filter rich spatial experiences. Nevertheless, recent scholarship, mainly coming from indigenous studies, demonstrates the potential of GIS to present more nuanced and multivocal understandings of landscapes, challenging western cartographic conventions as the only possible rendering. This article uses GIS visualization to reimagine the colonial landscape during the late 16th, the early years of the forced resettlement, through the early 19th century in Huarochirí, Peru. Using historical documents and spatial analysis, I will explore how the forced resettlement of indigenous populations during the 1570s set a starting point for the contemporary geopolitical boundaries of Huarochirí. Through analysis of settlement patterning from archival documents, it is possible to reconstruct changes in the geopolitical boundaries in the region during the colonial period.

Incorporating historical, ethnohistorical, and archaeological data with the information registered during field reconnaissance in the research area, I define the extension of the region of Huarochirí and trace its changing spatial settlement pattern through the colonial period from the 1570s to 1815. A dynamic picture of colonial Andean community boundaries thus emerges through GIS-based spatial integration of documentary and field-based evidentiary sources.

Building on these insights, I discuss how spatializing documentary sources enables a perspective that centers local communities' agency in the face of colonial mandates. Additionally, I reflect on how this kind of spatial ethnohistorical approach can be used to represent colonial Andean community histories by centering local narratives of community and landscape. The colonial gaze is not inherent in geospatial tools; they can advance indigenous-centered perspectives on the colonial past and its legacies in the present.

1 Introduction

For years now, the impact of the "spatial turn" of the humanistic social sciences has led to rethinking the role of Geographic Information Systems (GIS) in generating new knowledge of past landscapes. At the core is whether GIS is an appropriate tool to investigate the divergent experiences of different communities withing their enveloping landscapes or whether its value is limited to the production of cartesian maps and spatial analysis to provide etic analytic perspectives on the socio-spatial processes. Much of the criticism has been clear: the cartesian nature of GIS and its focus on environmental rather than experiential features homogenizes human experiences and precludes understandings of most sensorial aspects of landscape-human interactions (Tilley 2009). Nevertheless, many scholars (e.g. Gillings 2012; Llobera 2012; Howey and Brouwer Burg 2017; Supernant 2017) argue that we can approach dimensions of past human experience and the affordances of place through GIS-based modeling of movement and perception. Recent scholarship (Wernke, Kohut, and Traslaviña 2017; Kohut 2018) has demonstrated that the affordances of perception and movement through space can be effectively modeled with GIS. In this context, I am presenting an analysis of the changing landscapes of the Huarochirí territories and their administrative boundaries during the colonial period. I trace landscape and settlement pattern transformation and changing relationships between settlement and agricultural infrastructure. What emerges is a sense of a local “depth of place” embedded in the landscape—a depth of place that lies beneath the superficial boundaries of colonial administrative divisions (Wickens Pearce and Pualani Louis 2008).

I will discuss how the forced resettlement of the *Reducción General de Indios* (hereafter *Reducción*) of the 1570s dislocated entire Andean communities, and at the same time, community responses reshaped the political and agricultural landscape according to their own needs, knowledge, and internal politics. I will determine the transformation to the settlement pattern in the region through the reconstruction of administrative boundaries, from *waranqas* to original Toledan reducciones including its parishes (Davila Briceño 1881[1586]), to the transformation of some parishes becoming heads of the parish as listed by (Bueno 1780), to finally, the last transformation to parishes and doctrines registered on the Ecclesiastic report of Pedro Salvi in 1815 (Torres Tello 2007).

The second line of critique questioning the abilities and limitations of GIS focuses on its ability to incorporate cultural value, local histories, and multiple forms of place-making into analysis and renderings of past landscapes. New research centered on indigenous cartographies and visualization (Wickens Pearce and Pualani Louis 2008; Caquard and Cartwright 2014; Millhauser and Morehart 2016) demonstrates that GIS can allow us to represent the landscape in various and nuanced ways. Consequently, rather than emphasizing its limitations, we should investigate our methods in using the fuller potential of GIS to expand our understandings and challenge our assumptions of the past landscapes we study.

These approaches can be used to understand indigenous community changes and responses when analyzing the representation of local landscapes in the Andes in the context of Spanish colonialism. The research area is in Huarochirí, in the highlands of Lima, Peru.

Archaeological and historical research in Huarochirí reveals a continuously changing landscape through late Prehispanic and colonial times. During the Late Intermediate Period (LIP) in the central Andes, between the 11th – 15th centuries CE, prior to the Inka imperial occupation, indigenous communities occupied the territory in a dispersed pattern, preferentially locating their settlements on prominent hilltops with visual connections to surrounding sacred mountain peaks. In Huarochirí, the glaciated peak Pariaqaqa was the *paqarina* ("place of dawning", i.e., origin place) of the Yauyos ethnic polity. Yauyos communities came together to honor Pariaqaqa during annual ritual cycles (Spalding 1984; Salomon and Urioste 1991; Astuhuamán 2008; Salomon, Feltham, and Grosboll 2009[1588]; Hernández Garavito 2020). Through the Inka occupation of Huarochirí (1438 - 1532 CE), small, these dispersed settlements grew and were subsumed under larger aggregations that constituted Inka administrative units. These units—organized by reference to tributary labor—used the language of kinship that was already part of the local imaginary to scale up a population system that easily fitted within Inka imperial administration (Hernández Garavito 2020). These trends in settlement and land use were violently truncated by invasion and colonization by the Spanish. After a period of initial indirect colonial rule and evangelization, the dispersed hamlets and villages of Huarochirí, as elsewhere in the central Andes, were suddenly abandoned as the population was forcibly resettled into Spanish-style gridded towns during the massive resettlement program instituted by Viceroy Francisco de Toledo in the 1570s (Málaga Medina 1974b; Mumford 2012; Saito et al. 2014; Saito and Rosas Lauro 2017).

The Reducción forced people away from their ancestral lands to live in nucleated towns, in many cases, farther away from their agricultural fields (as discussed in further detail below). Entire communities in Huarochirí were relocated to only seven reducción towns in the 1570s.

However, as we are going to discuss in section 2.2 (on page 99), according to historical documentation, local communities petitioned, for example, to formally be assigned a priest to a new settlement—in practice, they were petitioning for the formal acknowledgment of a new town or village. The new settlements, generally built in the style of the reducciones, were built in areas with easier access to productive lands and agricultural infrastructure already in place.

To reconstruct changes in the settlement pattern in Huarochirí, I used data taken from two well-known colonial-era documents: the *Descripción de la Provincia de Yauyos* (1586) and the Huarochirí Manuscript (1608). These documents reveal different and complementary experiences of the local landscape while grappling with the complex and competing experiences of the colonial era Central Andes. The first document is from the *Relaciones Geográficas* (geographic, historical, economic, and geopolitical report) describing the Huarochirí *repartimiento*[28]; the second document is a compendium of ex-oral histories centered on narrative approaches to the landscape. Additionally, two other documents (Cosme Bueno 1763 and Pedro Salvi 1815) inform transformations in the administrative boundaries in Huarochirí, specifically, the area used as the backdrop for the Huarochirí Manuscript. These documents offer a *longue-durée* reading of top-down colonial mandates (like the Reducción), the constant transformation of the settlement pattern of Huarochirí, and the responses of Andean communities. The Huarochirí Manuscript, on the other hand, offers contextual information from Andean points of view.

These accounts exemplify the competing, complementary, and expansive understandings of the local landscape that were at play in constructing specific spatial narratives. We argue that we can mediate and represent these coexisting and changing landscapes through GIS spatial

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[28] Term used to describe land-based territorial subdivisions.

modeling and visualization capacities. First, using historical documents, I reconstructed the administrative boundaries within the Huarochirí *Repartimiento* and contrasted the settlement pattern changes during the colonial period, from the Reducción project in the late 16th century, the mid-18th century to the end of the colonial rule in the early 19th century and discuss the active engagement of Andean communities in reshaping colonial landscapes. Second, I mapped Huarochirí during the colonial period incorporating historical accounts from archival documents to understand changes in the extents and shapes of administrative and ecclesiastic units[29].

The original Reducción settlement pattern—with just seven reducción towns for the area of Huarochirí—had to be reshaped to meet indigenous communities' subsistence needs. Therefore, I propose that colonized Andean communities created new settlements splintered from the original reducción towns to establish new post-reducción villages closer to their ancestral agricultural fields and terraces.

The broader scope of my research topic—how ancestral agricultural infrastructure influenced indigenous decision-making in response to Spanish resettlement policies—requires a critical characterization of the indigenous landscape. In other words, it is not enough to map out the locations of terraces and settlements; we also need to incorporate the continued interaction between Andean communities' settlement patterns, imposed colonial settlement, and the anthropogenic landscape. To approach this much deeper and broader perspective, I use spatial modeling to make spatially implicit information in historical sources spatially explicit and then describe the transformations in settlement and territory that such renderings enable. Characterizing a fluid, constantly reinvented, multivocal landscape through historical sources

[29] The Provinces of Urin Yauyos (modern Huarochirí province) and Hanan Yauyos (modern Yauyos province) included five repartimientos that were grouped by parishes (Davila Briceño 1881[1586]).

and spatial modeling will help to register and center these transformations as part of communities' agency within the colonial rule.

2 Indigenous Cartographies: Beyond the Cartesian Grid

In recent years, archaeologists and ethnohistorians have started meaningfully incorporating indigenous approaches to academic and applied cartographic research. This impetus was influenced by Tuhiwai Smith's research, where they argued that cartographic practices and conventions were instrumental in objectifying, appropriating, and colonizing indigenous places. Smith illustrates how westernized and cartesian cartographic representations break intrinsic connections between space and time.

Early critical cartographic scholarship on GIS questioned its ability to map non-Western epistemologies and spatial representations. For instance, (Rundstrom 2013) highlights the "assimilationist tendencies" of GIS and its recommended deployment by the Bureau of Indian Affairs (BIA) as a means to "translate" indigenous "geographies" into the standards of federal agencies. In addition, Rundstrom recommended that GIS practitioners include "cross-cultural studies of knowledge transformation and culture change" in their research agendas to avoid potential harm to indigenous peoples. Nevertheless, indigenous practitioners have found new and creative ways to harness the power of GIS to further their objectives and illustrate their cartographic imaginations in ways that are legible to them rather than to a colonial or westernized reader (Chaturvedi 2012; Schneider 2015; Schneider and Hayes 2020).

Indigenous approaches to landscape studies and cartography critically demonstrate how normative post-Enlightenment western mapmaking practices erased indigenous understandings of place and time. Wickens Pearce and Pualani Louis (2008) refer to this as "depth of place" or “knowledge that is not confined to the boundaries of the land but is intimately intertwined with the spiritual realm. Today, we can find several examples of GIS-based mapping that center indigenous cartographic values and expand canonical ideas of mapmaking into the different epistemologies of indigenous communities across the world. For example, Caquard and Cartwright (2014) highlight the use of GIS to map oral stories and narratives—or even audio-visual stories—that are critical in the self-definition of territoriality among many indigenous communities in North America. Likewise, Laidler et al. (2010), employing participatory mapping among the Baffin Island communities, show the centrality of ice and freeze patterns changes in Inuit understandings and mappings of their landscapes. These examples illustrate that GIS is not inherently biased toward a specific type of cartographic practice and is not exclusively oriented toward the production of western knowledge over other epistemologies. Instead, it can be adapted to different approaches depending on whose point of view is highlighted and what variables are prioritized in rendering (Millhauser and Morehart 2016); as Weiland states, “the modeler decides what variables to consider and what weight or influence they have over the model” (Weiland 2022, 184).

In thinking of the colonial Andes, I take the growing practice of indigenous cartographies and indigenous reinvention and appropriation of geospatial methods to push spatial modeling techniques further and address questions such as: Can GIS-based methods help uncover the different and conflicting ideas and practices of the colonized? Can GIS-based technologies facilitate archaeological engagement with past experiences and understandings of local landscapes? In the following pages, I explore these questions through the case study of Huarochirí and its transformation during the colonial periods from the late 16th to early 19th centuries.

2.1 Colonial documents and indigenous landscapes

Using colonial written sources like *visitas* or *relaciones geográficas* it is possible to produce novel cartographic representations of historical landscapes. The written record left by colonial magistrates and church officials offer a window into the perspectives of the colonizers regarding the life, and actions of indigenous peoples. This large register also offers a glimpse into how Andean communities learned to use Spanish judicial and ecclesiastic tools like trials, petitions, complaints to further advanced their own interests.

On the other hand, documents like maps are not very present in Spanish colonial administration. Cartography and mapmaking are often regarded as ways to apprehend and appropriate environmental and social landscapes that fit the expectations and needs of empires and states (Scott 1998). One of the few early cartographic depictions of a large area of the viceroyalty of Peru is a *pintura* or drawing of the Yauyos province that accompanies the *Relación Geográfica* written by Diego Dávila Briceño (1881[1586]). Moreover, as described below, the schematic inscribed in this map represents the imperfect, top-down perspective of the state. In this sense, it reveals the limits of the territorial knowledge of colonial officials—it represents a vast simplification of a much more complex indigenous reality. But an anthropologically-informed reading of this map may admit to a diversity of readings, or the "hidden transcripts" of multiple histories in a single shared space.

In Huarochirí, two early documents served as an example of this type of manifold text: The *Descripción de la Provincia de Yauyos* (1586) and *El Manuscrito de Huarochirí* (1608). The Both provide insights into the origins, organization, traditions, and history of the peoples of Huarochirí (Taylor and Acosta 1987[1608]; Salomon and Urioste 1991; Arguedas and Uzquiza González 2011). Additionally, two other accounts from the mid-18th and the early 19th centuries described political and administrative divisions in the colonized territories: the *Relación Geográfica*[30] 1763 Dr. Cosme Bueno, Vicar Pedro Salvi report concerning Huarochirí, 1815.

The first two documents have been the subjects of extensive research (Salomon 1984; Taylor and Acosta 1987[1608]; Adelaar 1994; Sternfeld 2004; Bonavia and Monge 2007; Durston 2007; León-Llerena 2007; Sagredo 2008; Santa Gadea 2010; Arguedas and Uzquiza González 2011; Campos 2014; Durston 2014; Espinoza 2014; Hyland 2017; Ramón 2017). Bueno's *Relación* and Salvi's report, however, are not very well known. Accordingly, our knowledge base for the two types of documents is quite disparate. Both Bueno's 1763 and Salvi's 1815 accounts of Huarochirí territories and towns offer a list of Huarochirí's administrative divisions. Comparing these two lists, it is possible to infer which new settlements were founded since the late 16th century and which ones were abandoned or lost status. In the following sections, I describe these documents, their historical context, and the information they provide.

2.1.1 The *Descripción de la Provincia de Yauyos* 1586[31]

The *Descripción* of 1586 centers on the modern provinces of Huarochirí and Yauyos in the eastern boundaries of Lima, Peru, encompassing the upper courses of the Rímac, Lurín, and Mala rivers (Figure 24). Penned by the Corregidor Diego Dávila Briceño in 1586, the

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[30] A geographic description of colonial territories required by the Spanish Crown, based on a questionnaire administered by the local *corregidor* (magistrate).

[31] Dávila Briceño, Diego 1881[1586] Descripción y relacion de la provincia de los Yauyos toda, Anan Yauyos y Lorin Yauyos, hecha por Diego Davila Brizeño, corregidor de Guarocheri [Description and inventory of the entire Yauyos province, Anan Yauyos and Lorin Yauyos made by Diego Davila Brizeño. governor of Huarochirí]. In Relaciones geográficas de Indias - Perú. Pp. 155-165. Madrid: Ministerio de Fomento.

Descripción was first published in Marcos Jiménez de la Espada's compilation of the *Relaciones Geográficas* (1881:61–78).

The *Relaciones Geográficas* are the product of a campaign by the Spanish Crown to produce a general accounting of colonial holdings in the Americas during the sixteenth century (Cline 1964). Accordingly, questionnaires were sent from Spain to the different colonial jurisdictions in the Americas, many of which went ignored. The limited numbers of responses sent back from New Spain and Peru's Viceroyalties are jointly known as *Relaciones Geográficas de Indias* (RGI). In the Andes, most RGI responded to fifty questions posed by the 1577 *Instrucción y Memoria de las Relaciones que se han de hacer para la descripción de las Indias, que Su Majestad manda hacer para el buen gobierno y ennoblecimiento de ellas* (Instruction and Memory of the Relations to be made for the description of the Indies, which His Majesty commands to be made for the good government and ennoblement of them). The tenth question requests a pictographic companion to the written answers, and no further guidelines were given.

Dávila Briceño was a diligent observer in the written section of the *relación*. In the introduction, he emphasizes his personal knowledge of the region, stating he had been *en estas partes* (in these lands)[32] for more than forty-five years and served as Corregidor (Provincial Magistrate) in Yauyos for thirteen years. His major accomplishment was "reducing" the population from over 200 dispersed hilltop settlements into thirty-nine Spanish-style towns.

[32] "En estas partes"; it is unclear if he means Peru or Huarochirí.

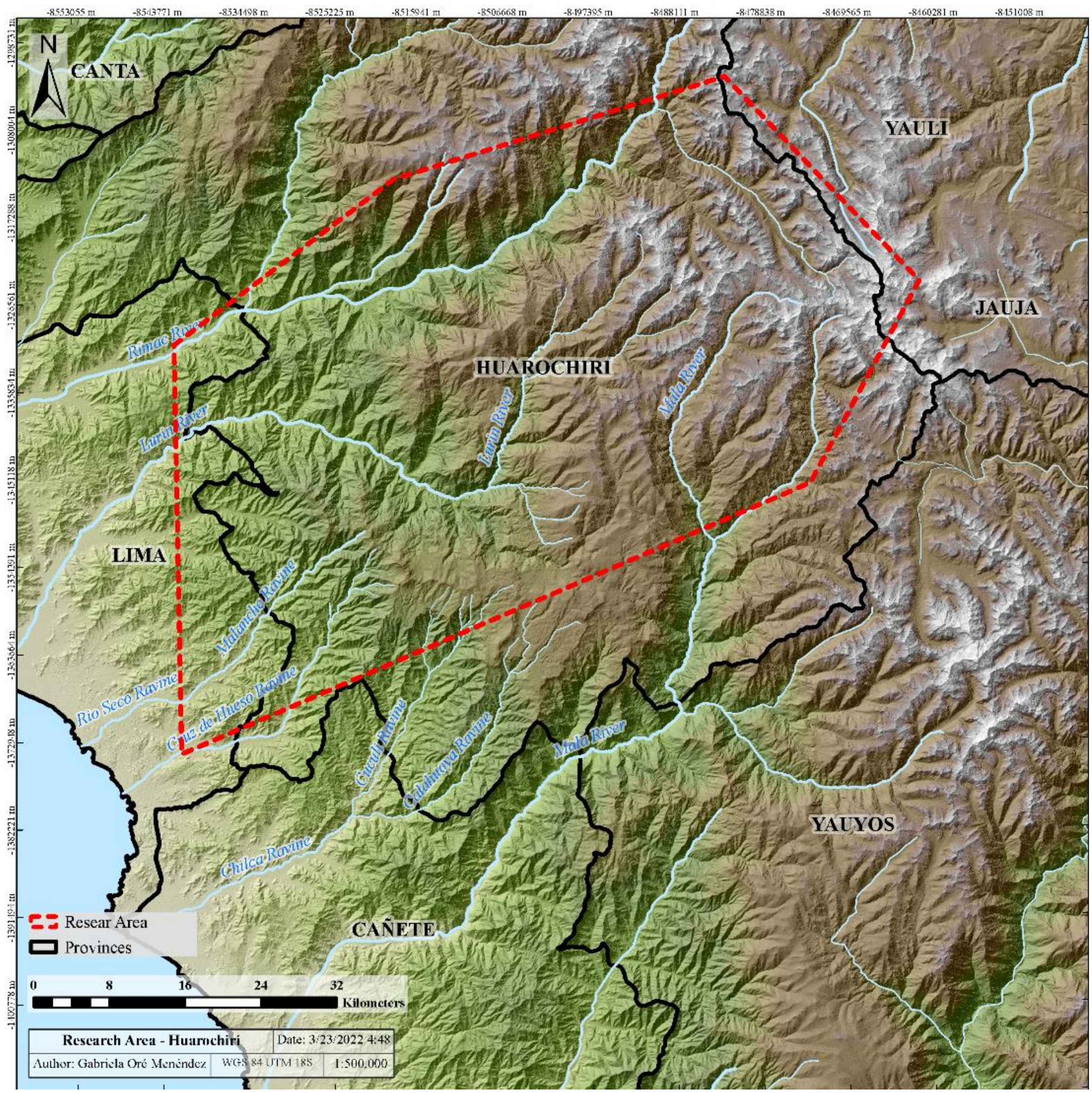

Figure 24. Research area.

Dávila Briceño first details the history of the region, including the origin of the names of the province, neighbors, number of tributaries, geographic location and extent, the position of the province in relation to the sea and Andean mountains (*cordillera)*, and the impact of the Inka conquest. Next, he addresses specific questions by each geographic division, first by river valley and then by *repartimiento*[33]. The close examination and digital mapping of the Yauyos' *Relaciones geográficas* reveal specific mention of such collaboration in the production of the texts in different Andean regions, and Spanish authorities either consulted with indigenous leaders (*kurakas*) or held broader forums with members of the community to answer the questionnaire (Hernández Garavito and Oré Menéndez 2021).

While the questionnaire stated the topics to be addressed in the text, the execution of the paintings showed the lack of standardization. The lack of guidance, the assumption that colonial administrators and Peninsular officials shared symbolic abstractions for graphic representations, their scale, and ongoing tensions between indigenous and colonial constructions of place led to a cold reception of the final products in Spain (Mundy 1996, 213). Citing quality and security issues, Philip II asked the Council of Indies to keep the paintings guarded under lock and key (Kagan 2000, 75–76).

a) The pintura (painting or map)

The associated painting is never directly referenced in the text, but the document's title was noted on the back. The map is currently housed in the Biblioteca de la Real Academia de la Historia in Spain (signature C-028-004), (Figure 25). Out of the small corpus of paintings associated with the Andean Relaciones geográficas, the map of the Yauyos province is among the most detailed. While the map's authorship is unclear, the text notes the vital role of the local kuraka, don Sebastian, "ques hombre ladino en nuestra lengua española y de mucha razon,"34 in

[33] *Repartimientos* were an allocation of Muslim lands to Christian landowners in post-Reconquista Spain. This land-based unit preceded the *encomienda*, which entrusted populations and labor force to individual Spanish administrators. Both arrangements were imported to the Americas by the Conquerors (Carballo 2020, 90).

[34] "A man that can speak our Spanish language and is of great reason" (translation by the author) (Jiménez de la Espada 1881, 70)

the colonial administration (Spalding 1984). This again suggests the need for an exploration of indigenous collaboration in producing the Relaciones geográficas.

Figure 25. Map of the Descripción de la Provincia de Yauyos Toda…, 1586. Courtesy of the Biblioteca de la Real Academia de la Historia, Madrid.

There is a clear correspondence between the text and the pictorial depiction. While the painting follows the request of the Instrucción to mark North (symbolized here with the Fleur de Lys in the left border of the painting), the general orientation of the drawing is to the 40° East, characteristic of the Mapa Mundi (Edson 2007, 231). The single-point orientation of the towns also mimics European mapmaking (Mundy 2011, 52). Natural and geographic boundaries frame the urban space. The outer boundary of the map represents mountains to the North, South, and East, marked as a broad ochre stripe with the names of the antagonistic neighbors enumerated in the text. The western edge is bordered by a blue band peppered with nautical ships, representing the Pacific Ocean (Mar del Sur) to the West. Near the coast running parallel to the ocean, a broad brown line marks the geographic boundary between the middle valley and the highland region. The line also represents a boundary between the Yauyos and the lower and middle valley "Yungas," the original population of their lands expelled by their forefather, Pariaqaqa, as the most famous mountain and idol in the region is represented as the central mountain in the cordillera. The symbol for Pariaqaqa includes the notation " Pariaqaqa ydolo yaro" and a stairway rising from a lake to the top, with the notation "escaleras de Pariaqaqa." The Yauyos province is between these two lines: the cordillera and the middle valley. The text mentions four of the five rivers depicted in the painting. Descriptions of the river courses are carefully rendered in the painting and are generally well-scaled, with only the Pachacamac River (currently Lurín) showing a significant error in its orientation. Parallel to the rivers, yellow lines depict the Qhapaq Ñan[35] or Royal Road (Hyslop 2014).

[35] Qhapac Ñan´s webmap GIS service by the Ministry of Culture, Peru: https://www.arcgis.com/home/webmap/viewer.html?url=http%3A%2F%2Fsigda.cultura.gob.pe%2Fsigda%2Frest%2Fservices%2FServicios_GIS%2FRedinca%2FMapServer&source=sd

Figure 26. Close up of Pariaqaqa in the Descripción painting (upper left). View of Escalerayoq (upper right) from Google Street View (Image July 2021, X2GV+FR, Tanta District, Peru – plus code). Mullucocha (bottom) (Photo from Twitter.com @QhapaqNanPeru, May 13, 2020, X24M+93, Tanta District, Peru)

The text of the *Relaciones Geográficas* mentions specific features such as the stairs and lake. The stairs, currently known as *Escalerayoc,* are a well-known regionally archaeological feature (Figure 26). They are among the best-preserved sections of the Inka Road that connect the province to Lima (Ciudad de los Reyes). Pariaqaqa is in the top-center of the painting, overlooking his people's lands, a visible remnant of a sacred indigenous landscape that the Spanish sought to eradicate. At the same time, Pariaqaqa itself and its central place in the painting opposes the central narrative of both text and map in the domestication of "uncivilized spaces"; as mentioned before, Spanish colonialism was grounded on urbanism. In the text, the

Corregidor enumerates thirty-nine towns organized first by repartimiento and then by parishes Curates or parishes refer to the towns grouped under the care of a single priest.

2.1.2 The Huarochirí Manuscript - 1608

The *Huarochirí Manuscript* (HM) is of unique importance in colonial Andean studies as the only known surviving book-length source written in Quechua. It was written as a compilation of ex-oral testimony in the context of an extirpation of idolatries campaign around 1610 (Salomon 2008), about 20 years after the RGI. As Salomon (2008, 296) states: "The anonymous, undated, untitled, and composite work known as the Quechua Manuscript of Huarochirí is the only known colonial text that explains an Andean religious tradition in an Andean language." The HM's compiler was mestizo priest Francisco de Avila, who compiled the manuscript amidst abuse leveled by his indigenous parishioners. The goal of the document was to gather information about idolatrous practices that the members of his parish continued to practice (Acosta RodrÍguez 1979). Following (Durston 2007, 2014), one Cristobal Choquecaxa, an indigenous man and son of a *kuraka* (ethnic lord), was likely the primary Andean interlocutor in gathering information about local beliefs and practices.

The manuscript is structured as an exposition of the deep history of the sacred landscape of Huarochirí. It contains the charter myth of the major ancestor deity of the province, the snow-capped mountain, Pariaqaqa—the same feature represented in the RGI painting. Pariaqaqa is also the protagonist of the HM, where he is a *wak'a* (HM Chapter 1), a place and animated being with a birth (HM Chapter 5), and a history (HM Chapter 6). The document tells the foundational myth in which Pariaqaqa starts as an ancestral hero that comes into Huarochirí to expel the original population, the Yungas, and claim the lands for "his children." the manuscript presents the history of the world from an Andean ethnic polity expressed through colonial means in a way that becomes legible to Spanish authorities. It consistently presents a narrative of movement where space and place are created through the narrative description of the main deities moving around the landscape(Taylor and Acosta 1987[1608]; Salomon and Urioste 1991; Salomon 2008; Arguedas and Uzquiza González 2011; Cerrón-Palomino 2021).

In contrast with the *Relaciones Geográficas*, the manuscript was not concerned with geographical and administrative boundaries per se. Instead, the description of the landscape is intertwined with the narration of movement by mythical ancestors through it. For example, in the manuscript's narrative, Pariaqaqa moves through Huarochirí's landscape, generating a link between different places and himself (Salomon and Urioste 1991), creating a narrative of cohesion in the region.

2.1.3 Relación Geográfica by Dr. Cosme Bueno - 1763

Dr. Cosme Bueno, an Aragonian born in the early 18th century, arrived in Peru in 1730, where he became a well-respected physician and intellectual. In 1748, the Spanish Crown, now under the house of Bourbon, asked Mexico and Peru for a detailed description of the territories. However, it was not until 1751 when Peru answered after a second request from the Crown, and it was not until 1758 when Dr. Cosme Bueno, as the viceregal cosmologist, was appointed to carry out the Descripción Geográfica[36]. Then, with the help of his nine sons (some of them part of the church and working in different prelatures), they compiled, revised, and standardized the information provided by priests and Corregidor from across the Peruvian territory. Bueno, a recognized intellectual in Lima, made very clear in a letter to Phillip V that an accurate *relación* required professional cartographers (Gala 2017). The *relación* was circulated later by Bueno

[36] A Descripción Geográfica is a different name for a Relación Geográfica

himself in a publication called "El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780]"[37]

2.1.4 Vicar Pedro Salvi report concerning Huarochirí, 1815

Pedro Salvi, the vicar of Huarochirí, submitted to Lima's Archbishopric a report of its inhabitants, churches, priests, and area extents of the eleven parishes of the province. Unfortunately, little information has been recovered about Pedro Salvi. However, Salvi does appear in the Archbishopric catalog "Parroquias y Doctrinas de Indios del Arzobispado de Lima, Siglos XVI-XIX" (Tineo Moron 1997). As published by (Torres Tello 2007) from Salvi's account, in 1815, there were eleven doctrines in Huarochirí—Mama and Huarochirí repartimientos (Table 7).

2.2 Digital mapping and territory allocation: 1586, 1763 and 1815

To understand how Andean communities continuously transformed the Huarochirí repartimiento in their efforts to improve their living conditions, I will estimate the areas of waranqas, reducción, parishes, and doctrines based on descriptions found in the archival documents. Spanish administrators and priests needed to move between towns within a given jurisdiction, collect taxes, and take care of their assigned parishes. That is why the description of roads, travel time, and the difficulty of movement between places is always present in texts like the *Descripción de Yauyos*. To establish the potential extension of each repartimiento, I

[37] The complete publication name is: "El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780] : en que van puestos los movimientos de la luna y los principales aspectos de los planetas con ella y entre si... : con calendario de las fiestas y santos..."
[The knowledge of the ephemeride times of the year 1763 [-1768, 1775-1780]: in which the movements of the moon and the main aspects of the planets with it and with each other are set...: with a calendar of festivals and Saints...]

developed a workflow of analysis that uses moving between reducción towns as the primary variable to establish administrative divisions of the landscape.

We limit the analysis to the area corresponding to the Repartimiento de Huarochirí, that is, the settlements included and grouped under the repartimiento as stated by Dávila Briceño. This area includes the upper Lurín valley and the northern branch of the Mala River valley. Modern political divisions are a product of constant transformations of the landscape, particularly those that occurred during colonial times, in which political institutions authorized the creation of repartimientos, reducciones, curates, and parishes (by the colonial administration and the church). For example, in an ecclesiastical document (AA, Legajo 13, Exp. 3), we can trace the events behind the creation of the annexes of Chatacancha and Caraguaya between 1594 and 1617. According to archival texts, the communities of Chatacancha (reduced to Chorrillos) and Caraguaya (reduced to Huarochirí) stated that they had to travel five and seven hours respectively from their ancestral agricultural lands to the twice a week mandatory mass, making it impossible for them to continue to do so. In that context, the people from Chatacancha took it upon themselves to build a chapel with the Spanish requirements of ornamentation and dedication and asked the Spanish administration to assign a priest to the new chapel, so they did not have return to their assigned reducciones[38]. This document shows how Huarochirí communities transformed the original Reducción settlement pattern to fit their needs and how Spanish and Ecclesiastic authorities subsequently formalized these relocations.

The following section describes the steps taken to establish the administrative boundaries and the changes that transformed Reducción in Huarochirí into the modern province. First, I will digitize the map presented in the RGI to incorporate the location of the original reducción towns.

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[38] Document translation by Carla Hernández Garavito

Second, I will establish the administrative boundaries in the Huarochirí repartimiento during three different times: when the Reducción was established in 1570, right before the changes that marked the end of the colonial rule in the mid-18th century (1763), and right before the independence in the early 19th century (1815).

3 Digital Mapping: Visualizing the Huarochirí Landscape 1586

The digitization of the RGI offers a geospatial and digital version of the Reducción in Yauyos in 1586; this version of the Reducción is the ideal materialization of the Reducción project as planned by the Spanish administration. Additionally, in contrast with the painting from the *Descripción*, the digital map offers the real-world location of the reducción towns and the possibility to establish spatial relationships that explain the transformations in Huarochirí. (See Table 3, Table 4, and Table 5 for the detailed information gathered from the documents.)

The first step of our analysis was to locate the RGI's map into its geographic setting through georeferencing the illustration. First, we located all the elements present in the Dávila Briceño illustration in a GIS, including towns and significant landscape elements like Pariaqaqa mountain peak and Escalerayoq, Hanan/Urin, and Yunga/Yauyos divisions. Then, we conducted a digital survey using Google Earth Pro, OpenStreet Map, Bing Maps, and GEOIDEP – Peruvian Fundamental Geospatial Data Portal[39] to confirm the location of the colonial towns mentioned on the RGI. We prioritized toponyms and information taken from archaeological research (Aguirre-Morales 2008; Hernández Garavito 2010; Enríquez 2014; van Dalen Luna 2014), ethnohistorical research (Matos Mar 1953; Soler Bustamante 1954; Gentile Lafaille 1977), local history

[39] Instituto Geográfico Nacional - Infraestructura de Datos Geoespaciales Fundamentales https://www.idep.gob.pe/

publications (Suyo Rivera 2019) and historical documents (Bueno 1780; Davila Briceño 1881[1586]). In some cases, the location corresponded to modern towns, while in others, we found the remains of abandoned colonial-era structures. For example, the original town of Guaques (Huaquis) was abandoned and later declared national patrimony by the Peruvian Ministry of Culture[40] (Figure 27).

Figure 27: View of the relict village of Huaquis. The picture shows the colonial temple and the freestanding bell tower (Photo: Rafael Schmitt, 2014, Wikicommons)

The result of the located towns is a cartesian representation of the landscape (Figure 29). However, I retained the original elements from the painting that adds cultural dimensions to the map, like the division lines marking upper and lower moieties (Hanan/Urin), highland and lowland territories (Yungas/Yauyos), and markers with a profound meaning like the iced capped mountain Pariaqaqa as well as textual information consigned in the borders. As a result, the digitized version offers a cartographically accurate map with information that enriches the understanding of the Huarochirí space (Hernández Garavito and Oré Menéndez ms) (See Appendices Figure 30). Additionally, I color-coded the repartimiento affiliation of each of the towns, which communicates the province's colonial inner classification and division.

[40] Pueblo Antiguo de Huaquis located at 12°16'43.60"S, 75°49'29.22"W P5CG+H3 Miraflores District, Peru (plus code for Google maps)

3.1 Estimating Huarochirí territories through Distance Allocation

To better visualize how the repartimiento de Huarochirí went from seven reducciones (all of them also parishes heads) to twenty-one settlements (between parishes and head of annexes), I recreate the inner boundaries in the Huarochirí territory, using the parishes and its annexes division listed in historical documents. Within ESRI ArcGIS Pro, I used the Distance Allocation function to determine the areas in the region that are the easiest to reach from a specific location. If we assumed that the administrative boundaries are established considering logistical costs for administrators and clergy to move between towns, then it can be inferred that the territory was divided into areas that allow for the same overall cost to reach one town or the other. Distance allocation modeling divides the area of the Huarochirí repartimiento into smaller sections (parishes) using the cost of moving across the landscape to determine the easiest areas to reach from each reducción town or post-reducción village.

Distance Allocations analysis considers the cost of moving across the landscape over the terrain using variables like destination points, elevation, slope, cost of movement, barriers or paths, and the maximum distance a traveler can travel. Destination points are all the places of interest (towns and annexes) found in the documents and located on the digital map. Elevation and slope (the change in elevation percentage per pixel) are determined by the terrain's 12m resolution digital elevation model (ALOS PALSAR). The cost of moving over the terrain is determined by a function that transforms the slope of the terrain into walking velocity; in this case, we use Tobler's hiking function from a to the destination (Tobler 1993). Other hiking/walking models offer slightly different results (Márquez Pérez, Vallejo Villalta, and Álvarez 2015), but Tobler's offers solid modeling and works well with archaeological data (Tripcevich 2004).

The model offers the opportunity to include barriers in the analysis. It is meant to incorporate elements that affect or block the travel across the landscape. While it is true that there are no physical boundaries across Huarochirí, the western area of Huarochirí limits with the Yunga or lowlands territory, creating a de-facto boundary. In that case, the westernmost edge of Huarochirí presents as a barrier the *chaupiyunga*. The *chaupiyunga*[41], or piedmont, corresponds to the middle section of the coastal valleys and marks the highest boundary for the Yunga people (Murra 1972, 11; Dillehay 1976; Rostworowski 1988a). For the Lurín Valley, the *chaupiyunga* is located between 500 and 1500 m.a.s.l (Feltham 1983; Román Godines 2013). We agree with Hernández Garavito's (2019) valley division, where the lower and upper valley limit corresponds to the area around Cerro Orcocoto (1800 m.a.s.l). Nevertheless, we have moved the boundary between Yungas and Yauyos to 1000 to include Sisicaya as the Inkas, and later the Spanish included in their reorganization of Huarochirí.

Finally, the last variable, the cost surface raster, is calculated as the weighted cost of combining slope and roads as a weighted average of each variable. Experience of walking across the landscape in Huarochirí on frequent visits to the region and during survey seasons (Hernández Garavito 2010) suggested that the presence of roads or paths take precedent over how steep the path is (Figure 28). Therefore, the importance (weight) of the roads will be greater than the slope when a traveler decides which route to take. The weighted cost of moving

[41] "This zone [Chaupiyunga] is geographically, as well as sociopolitically and economically, intermediate between highland and coastal populations. The Quechua term chaupi yunga indicates that the middle valley zone is part of the yunga or "warm land," and the word chaupi, "middle," indicates that these lands lie between the sierra and the coast." (Rostworowski 2004, 3)

horizontally is the average of a slope raster[42] (with a weight of 25%) and a raster indicating the walkable paths (with a weight of 75%).

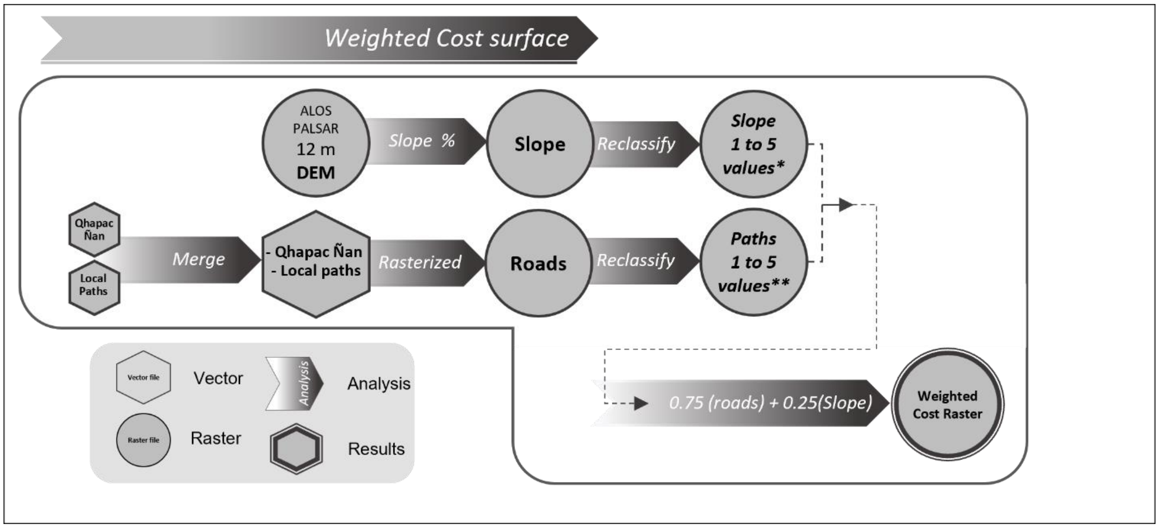

Figure 28. Weighted cost surface raster workflow.

Additionally, Distance Allocation analysis includes the option to add to the calculation the maximum distance a traveler can travel. After conversations with community members in the towns of Lahuaytambo, Tupicocha, and Antioquia (Huamansica in early documents), they suggested that the maximum distance traveled during a day is the equivalent to four hours walking. Historical documents describe distance in *leguas* (distance traveled in an hour. One *legua* = 5.56 km [43]), and as imagined, it is not very accurate since it varies depending on the terrain, the traveler's speed, and the road conditions. Therefore, using this as a baseline, the maximum distance will be the distance traveled after a jornada (daytrip). A four-hour travel day equals 22 km as the maximum distance a traveler covers on a *jornada*. Then, each administrative unit will cover the territory within the boundary marked by a "*jornada*" of four-hour travel time.

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[42] We use the (Agro RURAL 2021) report about agricultural terraces classification in Perú to reclassify the percentage slope into a 1 to 5 intensity

[43] There are different values for a *legua* according to the region. For Perú a legua is considered 5,56 km (Garza Martínez 2012).

Using these variables, I calculated the Distance Allocation to each of the towns grouped within different *waranqas*, curates, and doctrines where the entire area is divided between each town or annex according to how easy it is to get to that area from a particular location.

3.1.1 Results from the reconstructed extents

a) Waranqas

This division of the territory is based on the waranqas created by the Inkas when they arrived at Huarochirí (See Appendices Figure 31). Waranqas correspond to an Inka-based unit of approximately 1,000 taxpayers. This was the preferred terminology they used to reorganize people within their empire. While there is some debate about identifying pre-colonial and colonial waranqas, research in Huarochirí suggests they represented an indigenous pre-colonial grouping of people and land (Chase 2014; Hernández Garavito 2020).

b) Toledan Reducciones and its curates

Using the original seven reducción towns and the four parishes they belonged to, we can observe that the areas belonging to each parish do not follow the region's natural watershed divisions. On the contrary, this arbitrary subdivision of the area makes the movement between reducción towns from the same parish very difficult to navigate (See Appendices Figure 32).

c) Modeling Mid-Colonial Parish Jurisdictions (1763)

The listing of parishes by Cosme Bueno contrasts sharply with the one presented by Dávila Briceño. After 177 years of colonial rule, communities of Huarochirí re-accommodated their territories and changed the settlement pattern first emplaced by the Reducción. The most noticeable changes between 1586 and 1763 are the status change of some of the original reducción towns. Two became annexes out of the seven reducciones, Sisicaya and San Pedro de Huancayre, and one disappeared out of the official list: Santa Ana de Chaucarima.

By 1763 the original curates had imploded, and fifteen new settlements were created. Some of the more notable changes are the foundation and growth of Santo Domingo de Los Olleros. The town (including two annexes Matará and Chatacancha), is the only settlement that became head of a parish and was not part of the original reducciones). On the other hand, the parish with more new annexes was Chorrillos (San Joseph del Chorrillo). As we can see in Figure 10, the area that the Chorrillos's parish serves (See Appendices Figure 33 purple) is smaller than the other ones, and also is the one located right in the middle of the entire repartimiento, having direct access to the Qhapac Ñan road and the Lurín valley connecting it to Lima in less than two days.

d) Curates before the independence 1815

Finally, the parishes described by Pedro Salvi in 1815 show small changes in the composition of Huarochirí – very similar to the modern composition of the province. The area from the Chorrillos parish (including the towns of Lahuaytambo, Cochahuayco) did not change much; only Sisicaya lost its status as an annex and was not even mentioned in the document. San Damián parish (See Appendices Figure 34, orange), composed mostly of the Checa waranqa, lost San Bartolome de Soquiacancha that until 1763 was part Huarochirí. The loss of San Bartolome immediately removes the territory on the Rímac valley's northern margin and naturally maintains its boundaries on the southern margin. Olleros, continuously growing, incorporates the annex of Calahuaya from Huarochirí, and at the same time, Huarochirí incorporates Santa María de Alloca as an annex. Alloca, the southernmost town in Huarochirí in the Mala Valley, was not part of

Huarochirí, and its incorporation as part of the main curate in the region, the capital of the repartimiento and later the capital of the province, is notable.

4 Discussion

The change to the extension and administrative divisions of the Huarochirí repartimiento offer a broader view on how communities in the region transformed the imposed colonial settlement pattern (Toledan reducciones) and transformed in a configuration that resembled more the pre-Hispanic waranqas than the Spanish reducciones. In that context, historical accounts of Huarochirí territories—a Spanish perspective—always presents and describes administrative divisions like parishes or repartimientos. These taxonomical explanations of Andean regions tried to apprehend Huarochirí territories by using legible concepts for the crown like regions, parishes, or head towns. One major difference in the construction of this territoriality between the mainly Spanish accounts like *visitas, relaciones* or *descripciones* and those with a clear indigenous perspective like the Huarochirí Manuscript is that the second one features and describes the repartimiento of Huarochirí in terms of its interactions with elements of the landscape, fauna, mythical creatures and does not even mentions administrative division, even though for 1608 the original Reducción towns were already there.

The repartimiento of Huarochirí is identified in several colonial sources, particularly those in which indigenous communities forwarded claims to the Spanish judiciary, as the "Five Waranqas of Huarochirí," which encompassed Colcaruna, Quinti, Checa, Langasica, and Chaucarimac. Modeling the waranqas territories, we find an overlap in the designated territories of the waranqas and the ones from 1815 (Figure 31 and Figure 34), but this aligns with the principle of a shared landscape, where irrigation canals are built and maintained along with micro and macro basins.

Along the colonial period the Huarochirí repartimiento changed configurations, but at large it maintained part of its original area. On the contrary, the internal subdivision of the province went through periods of adjustment before establishing its current districts. After the Spanish invasion and the Reducción, the most significant change was the establishment of the post-reducción villages, in which the towns and villages were grouped under parishes with no clear knowledge of movement dynamics and terrain in the region. If we compared the distribution of the *waranqas* with the distribution of parishes from the early 19th century—already including the post-reducción villages—we noticed a closer resemblance in the territory divisions, than if we compare them with the late 16th century settlement distribution—when the reducciones were founded.

The area of the repartimiento maintains its relative extension and distribution from 1763, with only the settlement of Sisicaya disappearing from the official lists. Sisicaya was located in a prime section of the valley with access to roads, good weather, and productive land. Nevertheless, the settlement was not even mentioned as an annex in the 1815 account. Capriata Estrada and Zambrano Anaya (2021) point out that the church bell in Sisicaya has an inscription that reads 1720. Maybe the town's abandonment happened after that and before Bueno's account[44], and its multiethnic nature did not pull people into the town.

[44] Sisicaya now is a small town with about 60 inhabitants (Capriata Estrada and Zambrano Anaya 2021) part of the district of Antioquia (Huamansica).

5 Conclusions: GIS and the Visualization of Colonial Landscapes

In both the graphic and narrative aspects of the documents used in our analysis, one thing is clear: even while embedded in colonial institutions and demands, indigenous points of view are discernable and were active in reshaping the jurisdictions, settlements, and agricultural landscape of Huarochirí. Wernke, after his research in the Tuti reducción in the Colca valley Arequipa, highlights the role of negotiation of community and landscape (Wernke 2013, 2018). In other cases, like the reducciones in Huaylas, northcentral highlands of Peru, communities created new settlements to expand its political and economic influences in the region, Zuloaga (2017) in response to the Reducción in Huaylas. In Charcas Penry (2017) observes that the *composiciones de tierras*—a colonial mandate that expropriates all (nominally) unused land for the crown and then sells it to any buyer—forced indigenous communities to purchase their own land. A deeper comparison using similar data could be done for the Huaylas region to see how economic forces and resources push the fissioning process in the northcentral highlands.

The Huarochirí landscape was transformed is not only about territory but also about history and time. Landscapes are constantly reinvented through interaction, while the shifts in socio-political trajectories can transform these interactions. Huarochirí is a clear example of a landscape in which different stories and histories coexisted and were embedded cartographic and textual forms the early colonial period, during which secular and ecclesiastical authorities depended on indigenous collaboration to fulfill their tasks. Later, Spanish accounts of the territories show how the communities re-ordered the landscape to fit their needs, and the changes between the 17th and 18th centuries resembled the *waranqas* more than the Reducciones.

In the Andes, the landscape was not depicted through maps but experienced through constant movement and the rich visual canvas allowed by vantage of hilltop settlements.

Reducciones affixed populations to towns and shifted this perspective, but that shift left some space to remake the landscape in Andean terms.

In using a multilayer approach using data from different documental sources, ethnohistorical accounts and archaeological research and bringing them together through geospatial analysis to show Andean´s communities push during the colonial period. I have demonstrated how spatial analysis tools aids in the explorations of the divergent experiences of different communities withing their enveloping landscapes and is not only limited to the production of cartesian maps and geospatial statistical analysis. It provides an etic analytical perspective on the socio-spatial processes happening in Huarochirí. Indigenous understandings, the colonizing gaze, and present-day interactions can be overlaid and compared in a GIS environment. Further exploration of GIS visualization tools and the use of open-source platforms should be put to the service of communities so they can do their own exploration and tell their own understanding of the landscape—their sense of the “depth of place” of the past territories and peoples.

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Appendices

A. Figures

(See next page)

Figure 29. The updated version of the Descripción map. Note that the original painting bears a striking similarity to the natural landscape, while, on the other hand, the cartesian location does not correspond with the represented location.

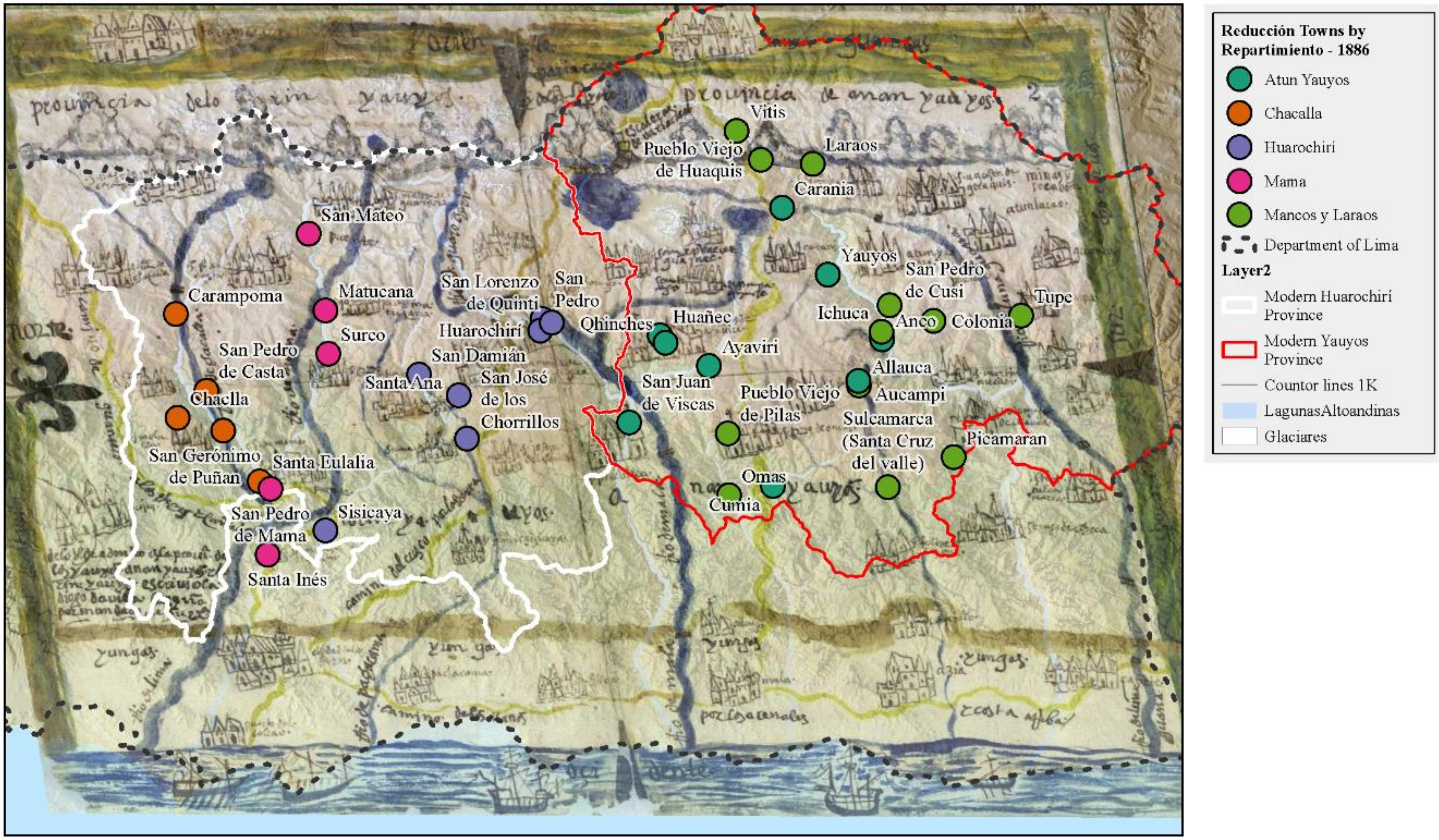

Figure 30. Georeferenced raster of the RGI map. The actual location of towns is indicated, in contrast to where they were placed on the original map.

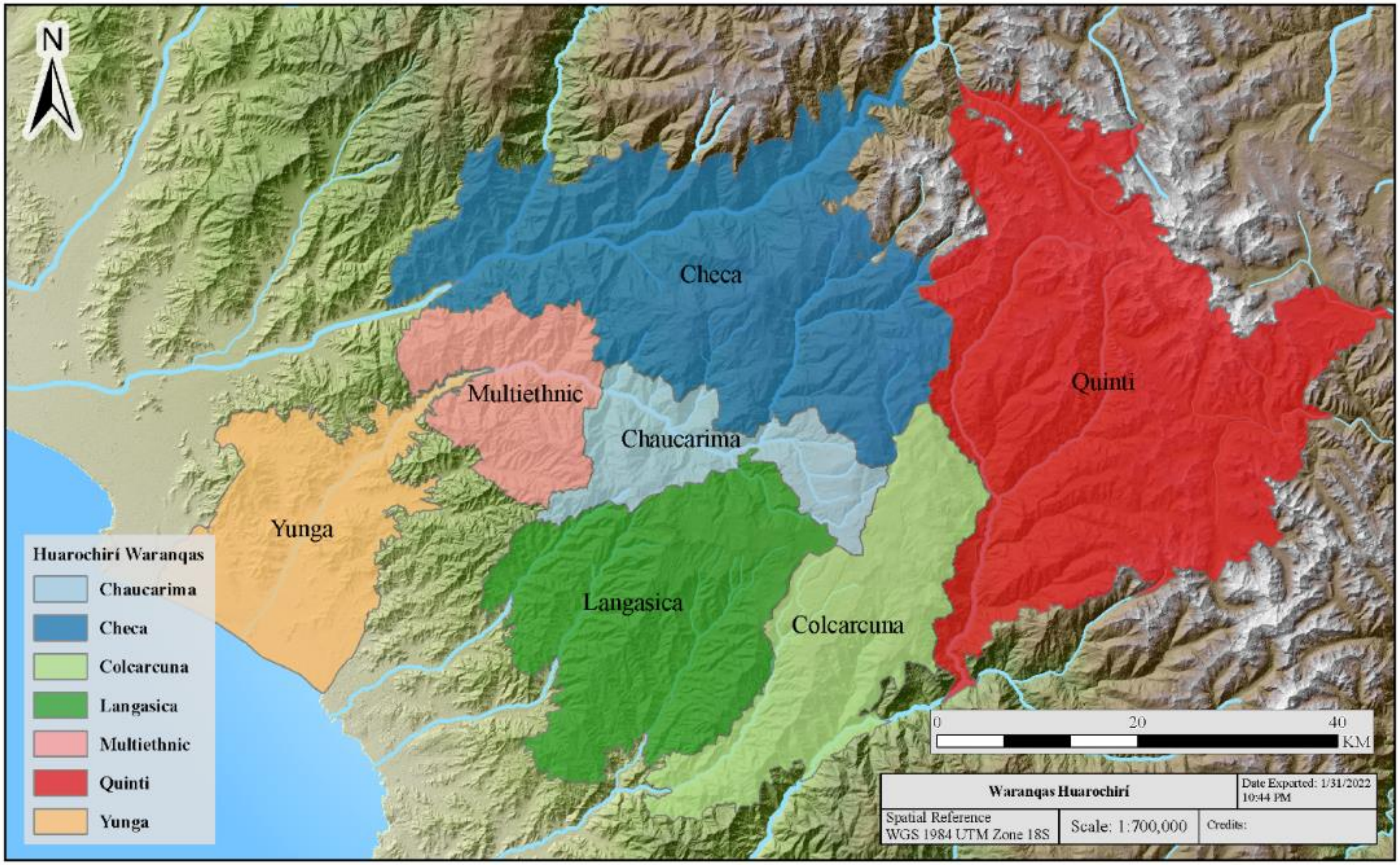

Figure 31. Distance Allocation result for the calculated waranqas territories.

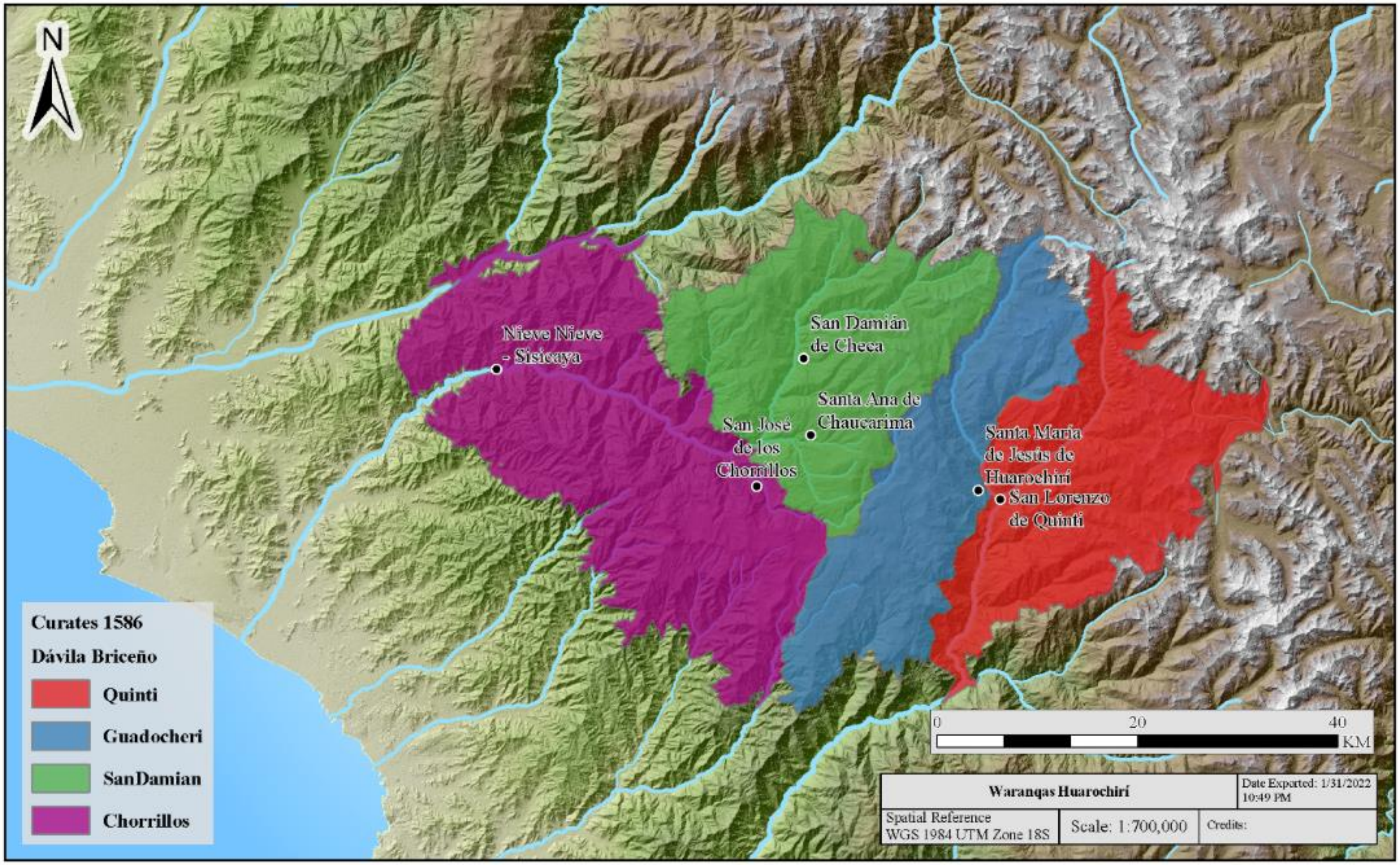

Figure 32. Distance Allocation result for the Toledan reducciones.

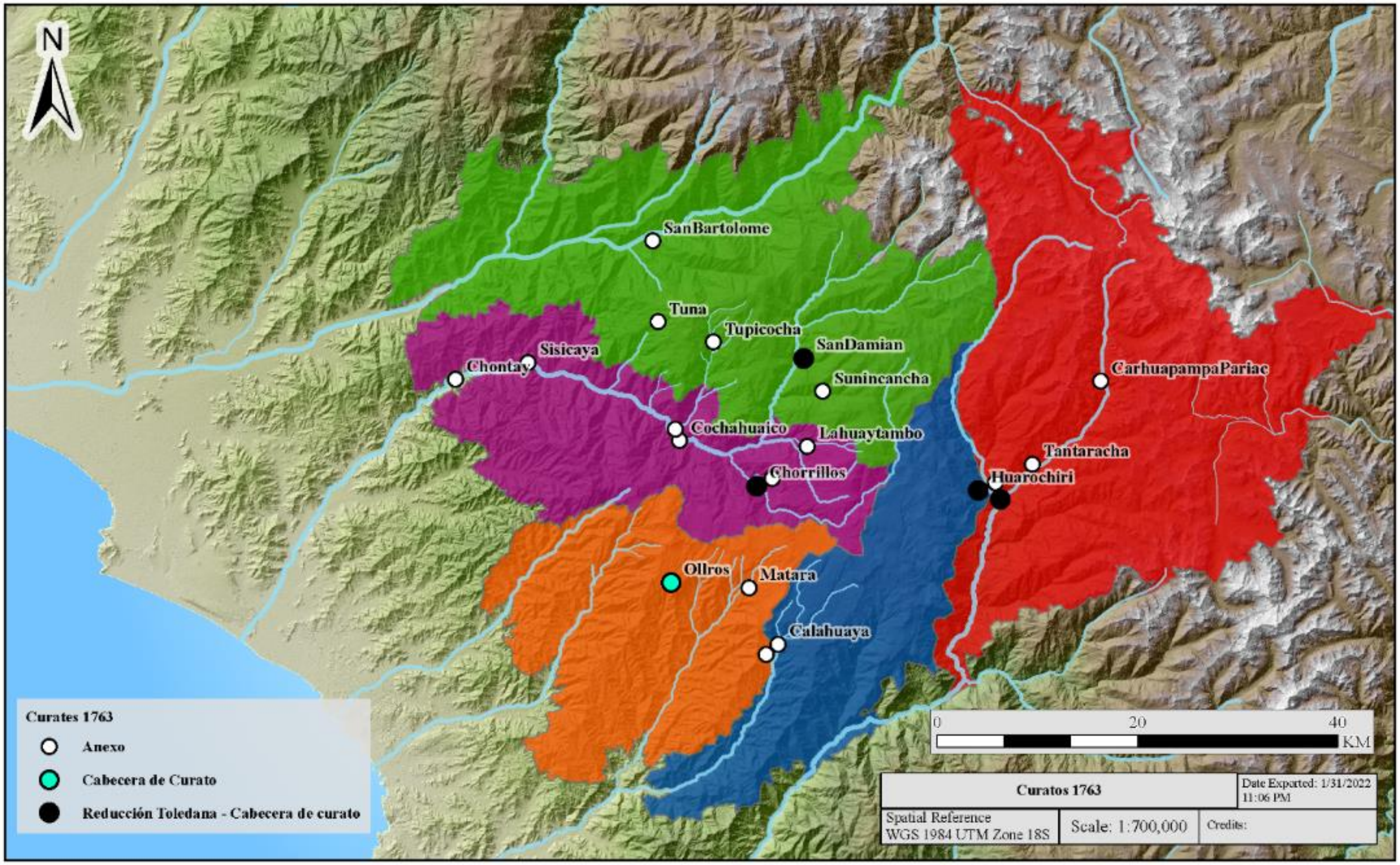

Figure 33. Distance allocation for curates as described by Cosme Bueno (1763)

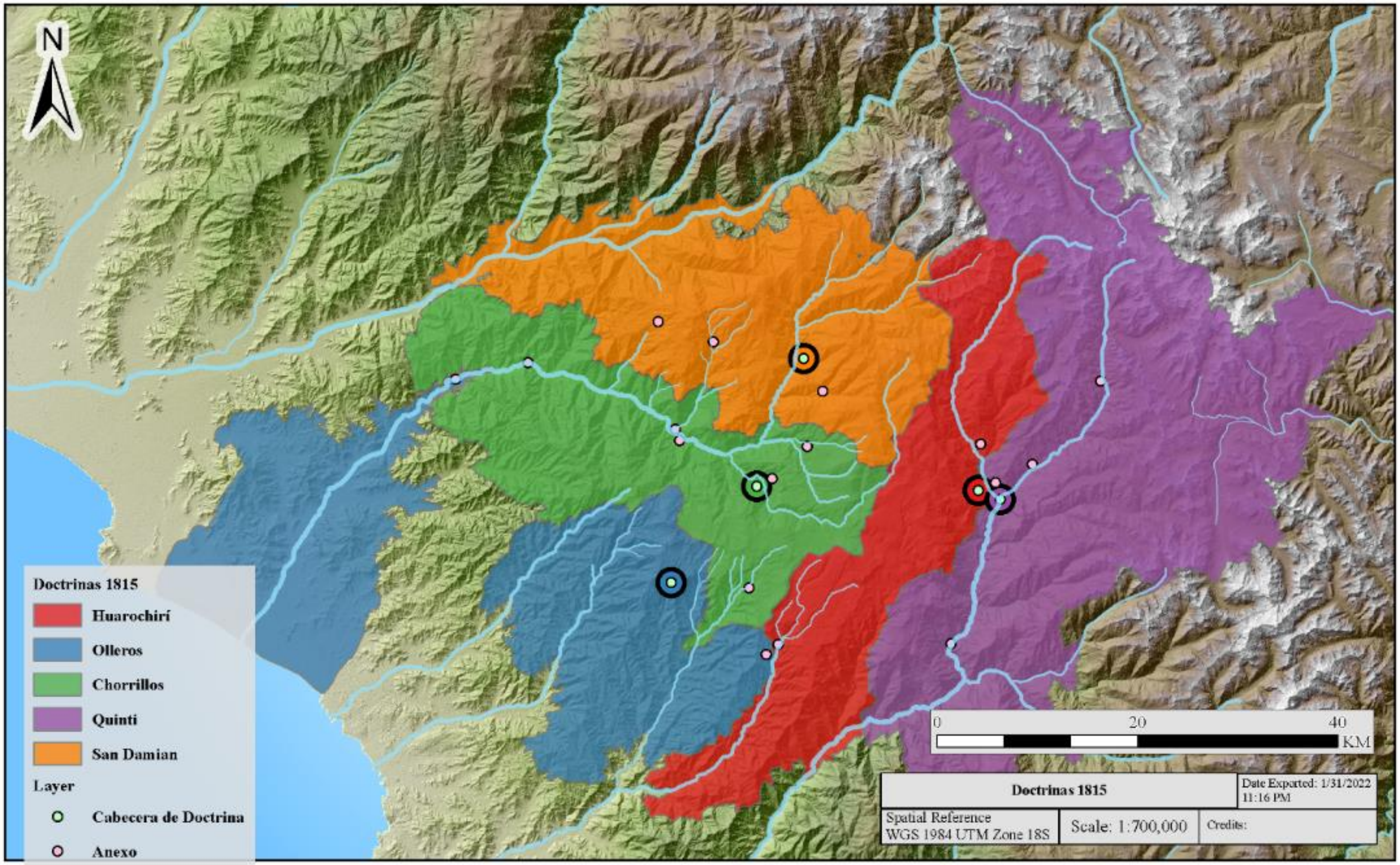

Figure 34. Distance allocation for curates as described by Pedro Salvi (1815)

B. Tables

Name	Population	Churches	Priest	Area (Leguas)	Km
Carampoma	1030	3	2	4	22
Matucana	877	7	3	15	83
Santa	1,402	6	2	8	44
Yauli	2,930	6	5	21	117
San Mateo	1,150	2	2	7	39
Chorrillos	**1,042**	**7**	**2**	**14**	**78**
Casta	**336**	**5**	**2**	**12**	**67**
Quinti	**743**	**5**	**2**	**7**	**39**
San Damián	**800**	**4**	**2**	**6**	**33**
Huarochirí	**600**	**2**	**2**	**4**	**22**
Olleros	**616**	**4**	**2**	**6**	**33**

Table 7. Information send to the Lima Archbishopric by Pedro Salvi about Huarochirí's doctrine (1815) (Huarochirí's original repartimiento doctrines are in bold)

Slope type	Angle	Percentage	Reclassify for cost raster
level	0° - 2.5°	0 - 5%	1
slight slope	< 2.5°	< 5%	2
low to moderate slope	< 5.7°	< 10%	3
moderate slope	< 10°	< 17.6%	3
steep	< 14°	< 25%	4
very steep	< 26.6°	< 50%	4
extremely steep	< 35°	70% +	5

Table 8. Reclassify value for the slope

Repartimiento	1st Repartimiento	2nd Repartimiento	3rd Repartimiento	4th Repartimiento	5th Repartimiento
	Mancos y Laraos	**Atun Yauyos**	**Guadocheri**	**Mama**	**Chacalla**
Towns	Santiago de Ichoca	San Jeronimo de Omas	San Francisco de Sisicaya	Santa Ines de Chechima	Santa Olalla de Cayao
	Santa Cruz de Sulcamarca	San Felipe de Cumia	San Josepe del Chorrillo	San Pedro de Mama	San Jeronimo de Puna
	Santo Domingo de AlIauca	San Pedro de Pilas	Santa Ana de Chancarima	San Jeronimo de Picoi	San Francisco de Chacalla
	San Cristobal de Mancos	Nombre de Jesus de Ayavire	San Damian de Checa	San Juan de Metocana	San Pedro de Casta
	San Bartolome deTupi	San Cristobal de Guaneque	Santa Maria de Jesus de Guadocheri	San Mateo de Guanchor	Santiago de Carampoma
	Santa Magdalena de Pampa	Santiago de Pampa Quinche	San Pedro		
	San Pedro de Cusi	San Juan de Visca	San Lorenzo de Quinte		
	San Francisco de Guanta	San Martin de Ocambi			
	Santo Domingo de Atún Larao	San Francisco de Anco			
	San Agustin de Guaquis	Santo Domingo de Canchel			
	San Francisco de Vitis	Santo Domingo de Carana			
Parishes	3.5	3	4	3.5	2.5

Table 9. Repartimientos, towns, and number of curates listed in the RGI.

Mancos y Laraos		Atun Yauyos		Guadocheri		Mama		Chacalla	
ML0. 5	San Cristobal de Picamarca	AY1	San Jeronimo de Omas	GH1	San Francisco de Sisicaya	MA1	Santa Ines de Chechima	Santa Olaya de Cayao	
	Pacaran de Lunahuana		San Felipe de Cumia		San Josepe del Chorrillo		San Pedro de Mama	Santiago de Carampoma	CH1
ML1	Santiago de Ichoca		San Pedro de Pilas	GH2	Santa Ana de Chaucarima	MA2	San Jeronimo de Surco	San Jeronimo de Punan	
	Santa Cruz de Sulcamarca		Nombre de Jesus deAyavire		San Damian de Checa		San Juan de Metocana	San Francisco de Chacalla	CH2
	Santo Domingo de AlIauca	AY2	San Cristobal de Guaneque	GH3	Santa Maria de Jesús de Guadocheri	MA3	San Mateo de Guanchor	San Pedro de Casta	
ML2	San Bartolome de Tupi		Santiago de Pampa Quinche	GH4	San Pedro				
	Santa Magdalena de Pampa		San Juan de Visca		San Lorenzo de Quinte				
	San Pedro de Cusi	AY3	San Martin de Ocambi						
	San Francisco de Guanta		San Francisco de Anco						
ML3	San Cristobal de Mancos		Santo Domingo de Canchel						
	Santo Domingo de Atún Larao		Santo Domingo de Caraña						
	San Agustin de Guaquis								
	San Francisco de Vitis								

Table 10. Huarochirí (Guadocheri) repartimientos as listed in the RGI

Name	Repartimiento	Guaranga	Parish 1586	Type 1586	Curato 1763	Type 1763	Doctrina 1815	Type 1815	Modern District
Espíritu Santo de Huamansica	Huarochirí	Chaucarima	-	-	Chorrillo	Anexo	Chorrillos	Anexo	Antioquia
Santa Rosa de Chontay	Huarochirí	Chaucarima	-	-	Chorrillo	Anexo	Chorrillos	Anexo	Antioquia
Santiago de Cochahuaico	Huarochirí	Chaucarima	-	-	Chorrillo	Anexo	Chorrillos	Anexo	Antioquia
San Juan de Lahuaytambo	Huarochirí	Chaucarima	-	-	Chorrillo	Anexo	Chorrillos	Anexo	Lahuaytambo
San José de los Chorrillos	Huarochirí	Langasica	Chorrillos Sisicaya	Reducción Toledana	Chorrillo	Cabecera Curato	Chorrillos	Cabecera Doctrina	Cuenca
La Asunción de Langa	Huarochirí	Langasica	-	-	Chorrillo	Anexo	Chorrillos	Anexo	Langa
Santa María de Jesús de Huarochirí	Huarochirí	Colcaruna	Guadocheri	Reducción Toledana	Huarochirí	Cabecera Distrito	Huarochirí	Cabecera Doctrina	Huarochirí
Santa María de Alloca	Huarochirí	-	-	-	-	-	Huarochirí	Anexo	Sangallaya
San Francisco de Calahuaya	Huarochirí	Colcaruna	-	-	Huarochirí	Anexo	Olleros	Anexo	Mariatana
San Cristóbal de Chatacancha	Huarochirí	Langasica	-	-	Olleros	Anexo	Olleros	Anexo	Mariatana

Name	Repartimiento	Guaranga	Parish 1586	Type 1586	Curato 1763	Type 1763	Doctrina 1815	Type 1815	Modern District
San Pedro de Matará	Huarochirí	Langasica	-	-	Olleros	Anexo	Olleros	Anexo	Santo Domingo de Los Olleros
Santo Domingo de los Olleros	Huarochirí	Langasica	-	-	Olleros	Cabecera Curato	Olleros	Cabecera Doctrina	Santo Domingo de Los Olleros
San Lorenzo de Quinti	Huarochirí	Quinti	San Pedro, San Lorenzo, Chechima	Reducción Toledana	San Lorenzo de Quinti	Cabecera Curato	Quinti	Cabecera Doctrina	San Lorenzo de Quinti
San Pedro de Huancayre	Huarochirí	Quinti	San Pedro, San Lorenzo, Chechima	Reducción Toledana	San Lorenzo de Quinti	Anexo	Quinti	Anexo	San Pedro de Huancayre
San Juan de Tantarache	Huarochirí	Quinti	-	-	San Lorenzo de Quinti	Anexo	Quinti	Anexo	San Juan de Tantaranche
Cahuapampa de Pariac	Huarochirí	Quinti	-	-	San Lorenzo de Quinti	Anexo	Quinti	Anexo	San Juan de Tantaranche
Santiago de Anchucaya	Huarochirí	Quinti	-	-	-	-	Quinti	Anexo	Santiago de Anchucaya
San Damián de Checa	Huarochirí	Checa	San Damian Santa Ana	Reducción Toledana	San Cosme San Damian	Cabecera Curato	San Damian	Cabecera Doctrina	San Damian
San Andrés de Tupicocha	Huarochirí	Checa	-	-	San Cosme San Damian	Anexo	San Damian	Anexo	San Andres de Tupicocha

Name	Repartimiento	Guaranga	Parish 1586	Type 1586	Curato 1763	Type 1763	Doctrina 1815	Type 1815	Modern District
Sunicancha	Huarochirí	Checa	-	-	San Cosme San Damian	Anexo	San Damian	Anexo	San Damian
Santiago de Tuna	Huarochirí	Checa	-	-	San Cosme San Damian	Anexo	San Damian	Anexo	Santiago de Tuna
Sisicaya	Huarochirí	Multiethnic	Chorrillos Sisicaya	Reducción Toledana	Chorrillo	Anexo	-	-	Antioquia
San Bartolomé de Soquiacancha	Huarochirí	Checa	-	-	San Cosme San Damian	Anexo	-	-	Santa Cruz de Cocachacra
Santa Ana de Chaucarima	Huarochirí	Chaucarima	San Damian Santa Ana	Reducción Toledana	-	-	-	-	Lahuaytambo

Table 11. List of towns order by waranqa, repartimiento, doctrine and parishes according to Dávila Briceño (1586), Bueno (1763) and Salvi (1815)

Chapter 4

Resettlement, Agricultural Deintensification, and Infrastructural Reclamation in Colonial Huarochirí, Peru

Abstract

During a single decade, in the 1570s, Spanish colonial authorities forced thousands of Andean communities to abandon their ancestral lands and settlements to take up residence in planned colonial towns. Colonial authorities instituted this massive resettlement program to facilitate surveillance, tax collection, and evangelization. Despite these dislocations, indigenous communities intervened and transformed the agrarian map in a way that still impacts rural landscapes in the Peruvian highlands today. This paper explores these processes of transformation and reinvention through the concept of landesque capital, focusing on the impact of labor investment and intensive agricultural infrastructure as prime motivators for abandoning colonial towns and reclaiming the patrimonial landscapes of Andean communities. I use a holistic approach that incorporates multispectral satellite remote sensing technologies, geospatial analysis, and ethnohistorical research to investigate processes of agricultural reclamation carried out by indigenous communities. The approach discussed here challenges colonizers' utopic narratives claiming to have established "order" while demonstrating indigenous ingenuity and agency in challenging such colonial impositions.

1 Introduction

The *Reducción General de Indios* (General Resettlement of Indians, hereafter "Reducción") implemented in the Viceroyalty of Peru during the 1570s was one of the largest mass forced resettlements ever undertaken by a colonial power. The Reducción affected approximately 1.4 million indigenous people, forcing communities to abandon their settlements, usually dispersed along different elevations, micro-regions, and strategically located settlements, to build and inhabit compact, nucleated towns (referred to as "reducciones") (Mumford 2012). The Reducción was part of a comprehensive set of colonial institutional reforms by the Viceroy Francisco de Toledo to foster Catholic evangelization, facilitate tribute collection, and monitor the social practices of Andean communities (Málaga Medina 1972, 1975; Mumford 2012; Saito 2012; Mumford 2015). Frameworks for understanding the effects of the reducciones on Andean communities emphasized the agroecological, demographic, and logistical crises they created. In the context of a demographic crisis caused by epidemics – in part exacerbated by the nucleated living imposed by colonial administration – Reducción prompted the abandonment of agricultural fields by moving populations far away from their lands and creating disruption on systems of communal labor aimed at maintaining agricultural infrastructures like irrigation systems and terraces. More recent frameworks approach the Reducción as an improvisational process of demographic concentration met by indigenous responses that led to varied patterns of migration and the emergence of new kinds of colonial Andean communities and landscapes (Mumford 2012; Zuloaga 2012; Wernke 2013; Saito et al. 2014; Penry 2017; VanValkenburgh 2017; Zuloaga 2017).

Here I argue that after Reducción forced people away from their original settlements, it also dislocated them from their agricultural land and, decades later, prompted the foundation of successive waves of new towns and villages. These new villages were built closer to their ancestral agricultural infrastructure. Documents from the 18th and 19th centuries (Bueno 1780; Salvi 2008) referred to new villages as *anexos* (annexes), which I refer to as "post-Reducción villages" to distinguish established after initial resettlement them from the seven original reducciones founded during the General Resettlement (Figure 35).

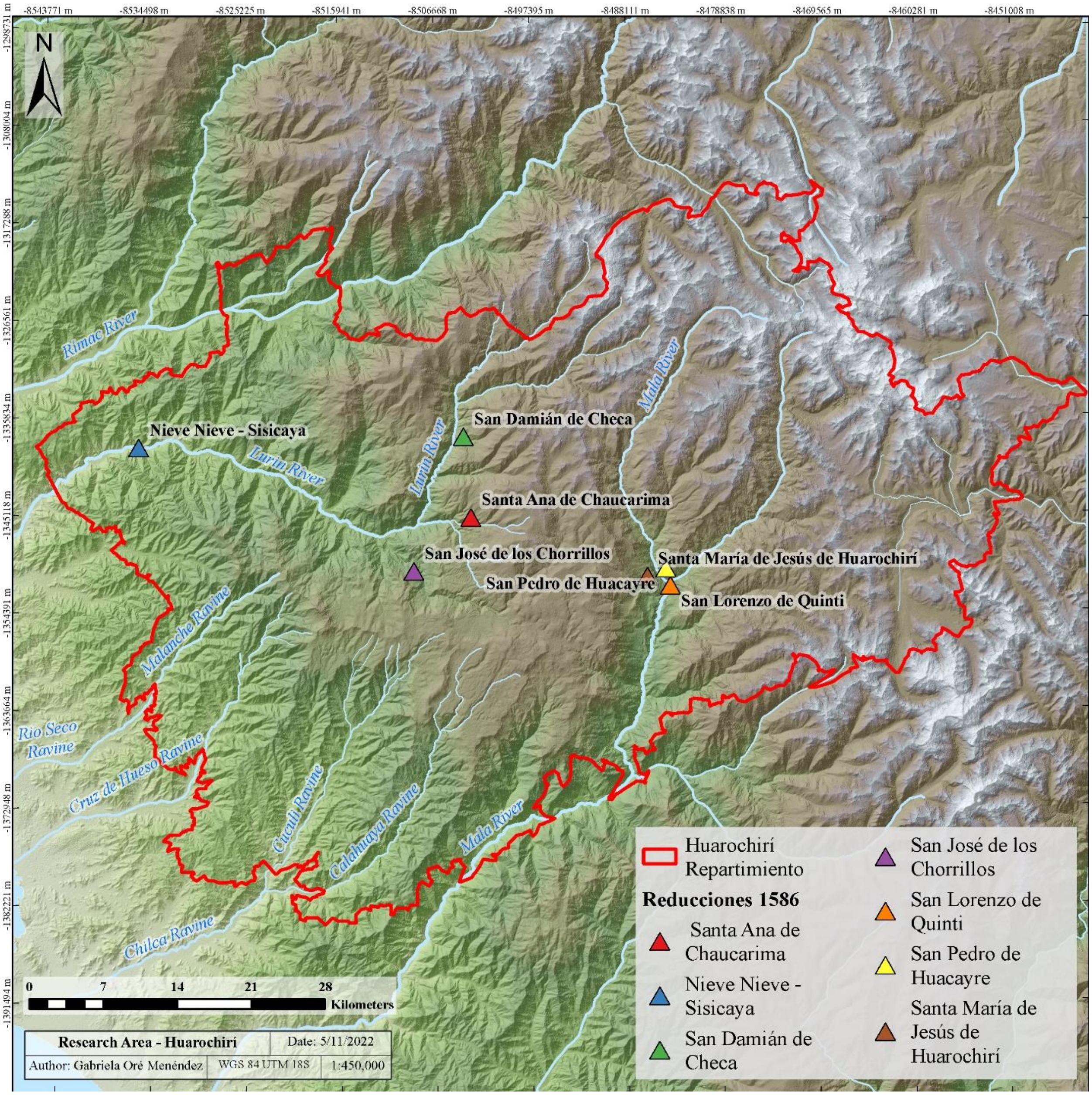

Figure 35. Research área with the seven original Reducciones (1586), including the modern districts in the Lurin valley and the southern and northern margins from the Rímac and Mala rivers.

Ethnohistorical research shows that during the early to middle colonial period (1580 – 1750), some inhabitants fled reducciones to reclaim their ancestral lands (Spalding 1984), while some reducciones were abandoned completely (VanValkenburgh and Osborne 2012) or moved to a different location altogether (Wernke 2017). In other cases, post-reducción villages splintered from the original reducción towns, and communities reestablished in new locations (Spalding 1984; Zuloaga 2012, 2017). Post-reducción villages were not the result of top-down colonial mandates, but instead resulted from advocacy and resistance by Andean communities within the colonial system. As historical documents suggest, local populations used colonial administrative processes to legitimize already-relocated communities. For example, in a petition to church authorities, between 1594 and 1617, the indigenous representatives of San Cristobal de Chatacancha and Callaguay, in southern Huarochirí, requested the Spanish colonial authorities to send a priest to give mass to a chapel the community had already built and adorned in this new post-reducción village. This event is featured in a petition made by the Chatacancha and Callaguay people to the church. In the document, they asked not to go to the Toledan reducción town San Joseph del Chorrillo—to which they had been resettled— for mass and catechism since the reducción was located, as described by the indigenous leaders in the document, about five hours away from their agricultural lands (AAL Leg. 3, Exp. 13)[45].

Common underlying political, economic, and ecological factors mediated such inherently local dynamics. However, the material and social consequences of such intra-regional movement and the establishment of colonial towns with indigenous understandings of displacement and land tenure have not been investigated *in situ* beyond a handful of case studies (Wernke 2007a; VanValkenburgh 2012; Wernke and Mumford 2015).

[45] Transcription and translation, Carla Hernández Garavito

I argue that the main attractor for establishing new post-reducción towns was the accessibility from the new towns to ancestral agricultural infrastructure. I will provide evidence through the reconstruction Huarochirí's settlement pattern and its spatial relation with the reducción towns and the post-reducción villages from the early colonial (late 16th century) to the end of the mid colonial period (~mid to late 18th century). I used multispectral image analysis classification and geospatial indices and modeling, such as cost surface and cost distance tools, to determine the spatial relations between post-Toledan villages and agricultural infrastructure based on accessibility and agricultural suitability (elevation, terrain, and evidence of rich and productive land) to show relationships between intensive agricultural infrastructure and changing settlement patterns through the colonial era.

Building on the concept of landesque capital, *sensu* Brookfield (1984), I examine how the labor-intensive anthropogenic landscape features (terraces and agricultural fields) that sustained highland Andean communities influenced decision making regarding agroecological logistics and whether communities would splinter from their reducciones, thereby establishing new villages and reclaiming ancestral agricultural landscapes. I consider push-and-pull factors that acted on communities to remain in the reducciones or pursue better living conditions. I modeled landesque capital as an attractor or pull factor to move away from reducción towns and settle in new villages closer to ancestral fields and irrigation systems. Pull factors will attract communities to their pre-Hispanic agricultural infrastructure where more productive fields and terraces were closer to their settlements and were already built. Conversely, a push factor repels communities out of the reducciones because of harsh living conditions, surveillance, onerous tributary, and labor burdens, and demographic decline due to population concentration increasing pathogenic transmission. (Málaga Medina 1974b; Mumford 2012). Given the high topographic relief and water scarcity that characterize Huarochirí, the area of productive land is quite limited and comes only through extensive terraforming. Therefore, here, and elsewhere in the central Andes, communities deploy monumental scale infrastructure investments like terraces and irrigation systems to transform their surroundings into highly anthropogenic agricultural landscapes (Sherbondy 1969; Zimmerer 1996; Lane 2008).

2 Reducción and agricultural de-intensification

On the eve of the Spanish invasion of the Andes (1532), most highland Andean groups lived in dispersed settlements practicing limited seasonal mobility and maintaining access to altitudinally-dispersed resources through intra-ethnic, kin-based exchange networks (Murra 1972). After the Spanish invasion, those systems were disrupted by the Reducción resettlement program of the 1570s. Viceroy Francisco de Toledo's reforms attempted to reshape colonized populations, infuse Spanish Catholicism among indigenous daily lives, institute regimes of surveillance, and inculcate a culturally specific notion of "civilized" urbanism by relocating dispersed populations into nucleated towns (VanValkenburgh 2016; Wernke 2017).

To effectively control the population and ensure *policia*—social order[46]—the criteria for how to proceed with Reducción had a set of broad guidelines for the location and the layout of the reducción towns. Instructions for the Reducción included that reducciones should congregate people into nucleated, gridded towns around churches and plazas and away from ancestral sacred

[46] According to (Mumford 2012, 4) the term *policia* comes from the classical polis and it could be understood as "a town's clean and attractive appearance, but it could also encompass everything from the layout of the streets and the offices of municipal government to the virtue of the citizens"(Mumford 2012, 4)

places or *wak'as*[47] and residential settlements. Reducciones should also be located in easily accessible areas of healthy climate and, if possible, on an even and level surface (Vargas Ugarte 1958; Málaga Medina 1972; Málaga Medina 1974b, 828; Málaga Medina 1979; Durston 1999; Cummins 2002; Mumford 2012). For these reasons, most of the reducciones in Huarochirí are located in the Quechua zone between 2500 and 3500 m.a.s.l, where climate is temperate and ideal for agriculture. The reducción of San Francisco de Sisicaya is the only reducción located in the *chaupiyunga*[48], an ideal area for growing fruits and coca (See Appendices Table 15).

The founding of the reducción towns dislocated many communities far away from their ancestral agricultural lands, causing considerable logistical stress for their constituent households (Denevan, Mathewson, and Knapp 1987). Thus, Reducción disrupted access to and maintenance of labor-intensive agricultural infrastructure, and also forced communities to live in close quarters, exacerbating infectious disease transmission and mortality (Wernke and Whitmore 2009). From 1571 to 1750 the population of Huarochirí decreased by 75% (Spalding 1984, 176) (See Table 16). This scenario resulted in the progressive abandonment of agricultural infrastructure (Van Buren 1996; Wernke 2007a, 2010, 2013; VanValkenburgh 2015), while simultaneously, secular, and ecclesiastical authorities demanded increasing per capita tribute and service from the surviving populations in the reducciones until new census counts could be taken. In these harsh living conditions and where abuse from Spanish authorities was common,

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[47] "A *Huaca* was any material thing that manifested the superhuman: a mountain peak, a spring, a union of streams, a rock outcrop, an ancient ruin, a twinned cob of maize, a tree split by lightning. Even people could be huacas." (Emphasis in the original text). (Bray 2015)

[48] The Chaupiyunga or piedmont between 500 and 1500 m.a.s.l corresponds to the middle section of the coastal valleys going from East to West, the area marks the highest boundary for the Yunga people (Murra 1972, 11; Dillehay 1976; Rostworowski 1988a).

some inhabitants fled reducciones (Mumford 2012) and went back to their ancestral lands (Spalding 1984; Mumford 2012).

Historical and archaeological examples illustrate the diverse choices made by indigenous people in this regard. Abercrombie (1998) showed how the community of Macha (Bolivian Altiplano) returned to their original settlements soon after the establishment of the reducciones, adding chapels to their old hamlets as a way of complying with the Spanish system. In the Colca Valley (Arequipa, Perú), the reducción of El Espinar de Tute, located in the puna heights, was abandoned in the mid-19th century, as pastoralists moved to their *estancias* (ranches) and the rest of the community relocated to the agricultural zone below (Wernke 2017). In other cases, reducción towns splintered into smaller post-Toledan villages, annexed as hamlets or high-altitude *estancias* (ranches). Recent ethnohistorical research in Huaylas (Peru) and Charcas (Bolivia) discusses the formation of reducciones and their explosion outwards to post-Toledan villages (Zuloaga 2012; Penry 2017; Zuloaga 2017). In Huaylas, Zuloaga explores the political atomization that followed post-Toledan reducción by establishing civic and ceremonial functions apart from their parent reducciones. Penry, in Charcas, observes that the *composiciones de tierras* (the mandate that takes all abandoned land as part of the Spanish crown property and then sells them to any buyer) forced indigenous communities to repurchase their land and live on it. For Huarochirí, as mentioned before, Chatacancha and Callaguay built a chapel close to their ancestral lands and asked the colonial administration for a priest[49] and to make official the new town. I can see how the formation of new indigenous settlements—post-Toledan villages—once the reducciones were established was an organic and widespread process occurring in several regions throughout the Viceroyalty.

In this context of communities reshaping their residential patterns and landscapes, Reducción has long been identified as a prime mover in the mass abandonment of irrigation systems and agricultural terracing complexes, both because of population collapse exacerbated by settlement concentration and because of the logistical strains on Andean communities (Málaga Medina 1972; Málaga Medina 1974b; Málaga Medina 1975; Donkin 1979; Málaga Medina 1979; Denevan, Mathewson, and Knapp 1987; Denevan 2001). By forcing people away from their original settlements, colonial administrators were also forcing people away from their agricultural infrastructure. Since intensive agricultural infrastructure (of pre-Hispanic origin) required regular inputs of communal labor for their maintenance and intricate systems of water distribution for their ongoing operations (Murra 1972; Málaga Medina 1975; Gade and Escobar 1982; Guillet 1983; Denevan 1986; Denevan, Mathewson, and Knapp 1987; Treacy and Denevan 1994; Zimmerer 1999; Gelles 2000; Zimmerer 2000; Denevan 2001). As a consequence, the demographic decline and political de-structuration caused by Reducción impeded the ability of Andean communities to maintain or even operate these labor-intensive

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[49] "Los indios de la parcialidad del pueblo de Calaguaya mandados reducir en el pueblo de Huarochirí, y los del ayllo de Chatacancha en el pueblo del chorrillo solicitan no se les obligue a oir misa mas que las fiestas de guardar por tener sus sementeras en los pueblos viejos a 5 leguas de sus reducciones" (Document transcription by Dr. Carla Hernández Garavito)
[the Indian from Calaguaya reduced to the town of Huarochirí, and the ones from the ayllo of Chatacancha reduced to Chorrillos, request that they are exempt from twice a week mass and only assist to mass during holidays since they have their *cementeras* in their old towns five to seven leguas away from their reducciones"]

systems, leading slowly to an agricultural deintensification, with impacts experienced asymmetrically by land-impoverished families within Andean communities (Wernke 2007a; Wernke and Whitmore 2009; Wernke 2010).

Given these logistical stressors, distance from reducción towns to agricultural fields was likely a significant factor in abandoning distant field systems. Additionally, Spanish biases favored placement of Toledan reducciones on relatively flat valley bottoms and low angle slopes (Zimmerer and Bell 2015), which in turn contributed to the decline and eventual abandonment of irrigation and terrace systems on higher altitudes and higher slopes, which tended to be more frost-prone and marginal in the high Andes (Donkin 1979; Denevan, Mathewson, and Knapp 1987; Denevan 1988; Wernke 2011b). Thus, the marginality of agricultural lands relative to reducciones could be seen as a sliding scale of elevation and horizontal distance, with elevation weighing more heavily nearer to reducciones and horizontal distance eventually passing elevation as a factor for terrace's abandonment (Wernke 2010). In modeling the presence/absence of agricultural fields and infrastructure as a key factor in the movements from and interactions between reducciones to post-Reducción villages, I propose that converging push and pull factors acted on communities, producing variable outcomes of agricultural deintensification and the (partial or complete) abandonment of reducciones with the establishment of post-reducción settlements.

To understand how communities abandoned or reclaimed their ancestral agricultural infrastructure after they left their reducción towns, I deploy the concept of landesque capital, as developed by Brookfield (1984). Landesque capital is the investment of labor on durable improvements to the land and its constant maintenances as a productive landscape (Clark and Tsai 2012; Håkansson and Widgren 2007, 2014; Widgren 2007). As labor inherent in an encompassing infrastructure (in this case, irrigation, and terracing systems), landesque capital is paramount in labor investment decision making. As the materialized labor of durable infrastructural features, landesque capital creates (in behavioral economic terms) path dependencies. Path dependence has to with how current actions or decisions depend on the outcomes of previous choices (Page 2006) and how reinvesting in the outcomes of those choices accrue increasing relative benefits over time (Arthur 1994). Fisher (2009) specifies the nature of such path dependencies as fields and irrigation systems, like those of highland Mexico and the central Andean highlands, which require regular maintenance (labor allocations) to ensure stability. In other words, they are highly productive but labor-intensive; consequently, marginal returns on labor are relative to their scale and maintenance logistics.

On the other hand, the already extensive and intensive investment in agricultural terracing evident in the Andean environment could represent opportunities for labor reinvestment and future agricultural production. Consequently, deciding where direct community energy will favor higher calculated returns; that is, agricultural infrastructure closer to settlements and in highly productive land, away from the threat of frosting at high altitudes (*puna*). Post-Toledan reducciones or post-reducción villages might be prioritizing locations closer to productive infrastructure, lowering the energy needed to work faraway lands, or creating new agricultural systems such as terraces and irrigation channels.

In a scenario of colonial dislocation, landesque capital represents an endowment for potential future development, as once abandoned irrigation and field complexes might one day be used again. Such a course of action would capitalize on the lower relative costs of reusing the initial labor and material investments to secure stable agricultural outputs relative to building agricultural infrastructure ex nihilo. Landesque capital then created both path dependencies and opportunities for resettled Andean communities. In that context of moving populations and changing landscapes, "deintensification" becomes the preferred term for the process at work rather than "abandonment" as it implies the possibility for re-intensification (see Knapp 1987).

Many authors have done extensive research on terrace abandonment and how it impacted agricultural production during the colonial period (Donkin 1979; Denevan 1986, 1987; Guillet 1987; Treacy 1987; Denevan 1988; Treacy 1993, 1994; Wernke 2007b, 2010, 2013, 2017). However, the internal socio-ecological processes that produced the observed patterns of agricultural system de-intensification, re-intensification, and the establishment of post-reducción settlements remain poorly documented and understood. This article engages with specific questions clarifying these processes: What are the spatial and temporal patterns of abandonment and reclamation? For instance, fields located further away from the reducciones may have been abandoned because of their elevation, sheer distance, marginal productivity, or combination of these attributes. However, some may have subsequently merited reinvestment as landesque capital, pulling communities out of their reducciones.

Thus, tracking the distribution of these post-Toledan villages in relation to irrigation and field complexes is crucial for understanding processes of deintensification and reclamation. Spatial analysis of transtemporal settlement patterning along the mid colonial period–from Toledo's Reducción in the late 16th century to the beginning of the Bourbonic reforms in the mid-18th century–shows the push-pull agroecological and sociopolitical factors at play when the sequence of resettlement and displacement occurred. Understanding these variables will shed light on the nature of colonial power in rural settings and how local communities balanced the compelling power of the path dependency on landesque capital and the new colonial order.

3 The changing landscapes of Huarochirí

The region of Huarochirí is located in the semiarid western slopes of the central Peruvian highlands (adjacent to the southeast of modern Lima), in the upper section of the Lurín and Mala valleys. The extent of the research area coincides with the extend of the *Repartimiento de Huarochirí*[50] (RH), and its administrative boundaries and settlements (reducción towns and post-reducción villages or annexes). According with Briceño's account, the Huarochirí Repartimiento included the seven original reducción towns or Toledan Reducciones: of San Francisco de Sisicaya, San Josepe del Chorrillo, Santa Ana de Chaucarima, San Damián de Checa and Santa María Jesús de Guadocherí, the head of the repartimiento (See Appendices Figure 51)

During Inkaic times (1438-1532 CE), indigenous communities occupied the territory in a dispersed pattern, preferentially locating their settlements on prominent hilltops with visual connections to their sacred mountains. In Huarochirí, Pariaqaqa—a glaciated peak—was the *paqarina* ("place of dawning", i.e., origin place) of the Yauyos ethnic polity and was consider a wak'a (*huacas* or shrines), and the surrounding communities in Yauyos came together to honor the wak'a Pariaqaqa during annual ritual cycles (Spalding 1984; Salomon and Urioste 1991; Astuhuamán 2008; Salomon, Feltham, and Grosboll 2009[1588]; Hernández Garavito 2020).

By the time of the Inka conquest in the 15th century, the small communities in Yauyos were formalized in larger aggregations forming Inka-type provinces. These provinces – ultimately organized around workforce and tribute—used the language of kinship that was already part of the local imaginary to scale up a population system that easily fitted within the Inka imperial administration (Hernández Garavito 2020). Huarochirí then became the home of

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[50] Huarochirí´s repartimieno. Dávila Briceño uses the spelling Guadocheri to refer to Huarochirí. I will use modern spelling no maintain consistency in the text.

the Yauyos ethnic polity under Inka imperial rule. The Yauyos Inka province was divided into Anan Yauyos ("Upper Yauyos") and Lurín or Hurin Yauyos ("Lower Yauyos"). Lurín Yauyos, extending from the Rímac valley to the eastern slope of the Mala River valley to the southwest, later became the Huarochirí Province (Davila Briceño, 1881[1586]; Spalding, 1984).

Recent archaeological research in Huarochirí yielded highly relevant data for a significant portion of the study region. Survey directed by Zachary Chase (Pino and Chase 2013) in the northern branch of the Lurín river and Hernández Garavito's 2010 survey in the southern branch yielded information on the Inka (Late Horizon; 1450-1532 CE) and colonial (1532-1821 CE) era settlement patterns in the upper Lurín valley. These research projects reveal a pattern of settlements with mainly local-style (Yauyos) ceramics and architectural features dispersed over the landscape, mainly on hilltops. Hernández Garavito's excavations at the sites of Ampugasa and Canchaje, located on the southern branch of the Lurín river, show Inka modifications of ritual (plaza) features within them (Hernández Garavito 2016, 2019). Most of this research is centered on community formation and relationships between the Inka and the Checa, one of the Huarochirí local populations, during the terminal pre-Hispanic period. Checa was one of the Inka waranqas reduced to the reducción town of San Damian de Checa, 2.5 km away from Llaqsatambo, the Checa's main settlement (Pino and Chase 2013; Chase 2016).

Chase also excavated in the reducción town of San Damian de Checa, showing that the reducción era buildings were the oldest structures and there was no significant prior Inka era occupation in the location of the settlement. Excavations at Inka-era sites of Llaqsatambo and San Cristobal (close to the Reducción of San Damian) and in the sites of Ampugasa and Canchaje, show the very short and shallow stratigraphy of sites in the upper Lurín valley, indicating that many of the terminal prehispanic sites had brief occupations (Chase 2016)

(Hernández Garavito 2010; Hernández Garavito, Oré, and Alexandrino 2012; Hernández Garavito 2019). By the 16th and 17th centuries, as the region came under the Spanish colonial administration, the dispersed populations were moved into nucleated towns during the General Resettlement.

Much of our knowledge about Huarochirí's communities formation, from the Inka waranqas to repartimientos, *curatos* (curates)[51], and *doctrinas* come from ethnohistorical and ethnographic research. In particular, the area that was part of the Huarochirí repartimiento has a long history of ethnohistorical and ethnographic fieldwork, which in turn provides excellent contextual information. This section of the Huarochirí region has been the focus of perhaps the highest density of ethnographic and ethnohistoric research in the Andean region over the last four decades (Spalding 1974, 1984; Salomon 1990; Salomon and Urioste 1991; Ramón Joffré 1999; Salomon 2002; Spalding 2003; de Avila and Taylor 2008; Salomon and Niño-Murcia 2011; Spalding 2012). The research done in Huarochirí provides ample baseline information about its colonial past and key insights about the political organization of indigenous populations in Huarochirí[52], from the early 16th to the early 17th century.

Two published colonial-era documents inform our understanding of Huarochiri from the pre-colonial to the early colonial period. First, the Huarochirí Manuscript (Arguedas and Uzquiza González 2011; Salomon and Urioste 1991; Taylor and Acosta 1987[1608]), compiled around 1608, is the only book-length Quechua language manuscript from colonial times in the Andean

[51] Territory assigned to a priest.
[52] Salomon's work in San Andres de Tupicocha has explored the community's history and its long record-keeping traditions through writing records, the still-living ayllus, and its relationship with neighboring villages (like Santiago de Tuna). Karen Spalding, on the other hand, has given us a broader view of the colonial history of Huarochirí and its peasant history during colonial times (Spalding 1974, 1984, 2003, 2012). Spalding provides information about the village's origins and how they came to be after the creation of the reducciones.

region. Historians and anthropologists have long consulted the manuscript as a prime source of information about Andean community organization and cosmology through a charter myth narrative of a specific community in Huarochirí. The text, informed by the Checa people, includes in its narrative many details about claims to irrigation systems through the reckoning of descent from ancestral deities between Pariaqaqa snow-capped mountain Pariaqaqa (Salomon and Urioste 1991).

The second document, the *Descripción y Relación Geográfica de la Provincia de Los Yauyos* (RGPY), penned by Spanish magistrate Diego Davila Briceño 1881[1686][53], Corregidor of Huarochirí, is the response to a questionnaire sent by the Crown to Spanish officials aiming to complete a general mapping of the territories invaded in the Americas. The limited responses sent back from New Spain and Peru's Viceroyalties are jointly known as *Relaciones Geográficas de Indias*. The RGPY also included a map (painting) probably made in collaboration with indigenous informants[54].

Davila Briceño offers an extensive description of the Yauyos territory right after the Reducción Project. He details the recent and mythical history of the regions describes the geography and primary resources in each repartimiento. The Huarochirí Repartimiento was part of the Yauyos province – divided between the Urin Yauyos province, and Anan Yauyos province. Urin Yauyos, the lower moiety, expanded from Pariaqaqa snow-capped mountain to the northwest, in the upper Lurín and upper Mala river valleys. The upper moiety, the Anan Yauyos province, expanded from Pariaqaqa towards the southwest until the southern branch of

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[53] The complete title is: "*Descripcion y relacion de la provincia de los Yauyos toda, Anan Yauyos y Lorin Yauyos, hecha por Diego Davila Brieño, corregidor de Guarocheri*"

[54] The associated painting is never directly referenced in the text, but the document's title was noted in the back. The map is currently housed in the Biblioteca de la Real Academia de la Historia in Spain (signature C-028-004) (Hernández Garavito and Oré Menéndez ms).

the upper Mala River and the upper Lunaguana River. In both cases, the westernmost boundaries began where the yunga (lower) lands began, around 1800 m.a.s.l. In his account of Yauyos, he describes five repartimientos divided into two moieties:

- Atun Yauyos: Manco and Laraos and Atún Yauyos.
- Urin Yauyos: Guadocheri, Mama and Chacalla.

Davila Briceño describes each repartimiento including the list of the reducciones and included the curates within each repartimiento. The Urin Yauyos province is composed by the repartimientos of Huarochirí and Mala. The detailed description of the provinces, their repartimientos, and curates offers photograph of the Reducción as conceptualized by Toledo. Dávila Briceño´s RGPY listed and described all the repartimientos, and for Huarochirí he mentions:

> *El tercero repartimiento, que está en el medio desta dicha provincia, veniendo del Sur para el Norte, ques (así) el repartimiento de Guadocheri, que fué cabesa de toda esta provincia y en él vevia el casique mayor della, como la gobernaron el padre y abuelo del que hoy es casique55. (Davila Briceño 1881[1586], 70)*

In 1586,the Huarochirí repartimiento included seven reducción towns: San Francisco de Sisicaya, San Josepe del Chorrillo, Santa Ana de Chaucarima, San Damián de Checa, San Pedro de Quinti, San Lorenzo de Quinti and Santa María Jesús de Guadocherí, the head of the repartimiento. The entire repartimiento had four priests assigned to it, each having a specific curate or town under their ecclesiastic care. By the second half of the 18th century, the settlement

[55] "The third repartimiento, that is located in the middle of this province, coming from South to North, that el repartimiento of Guadocheri, that was head of this province and in init lived the main cacique from this one, as it was governed by the father and the grandfather from that today is cacique". (translated by the author)

pattern had become much more dispersed, with post-Reducción villages splintered from the reducciones (See Appendices Figure 52)

There is no register of official Spanish foundation dates for many of the post-reducción villages, but some villages are already mentioned in historical documents previous to 1763.[56] For Chatacancha and Callaguay, the community petitions to get a priest for the church they built dates between 1594 to 1616 (AA Leg 3 Exp 13). In other cases, the evidence presented is based on material culture, like bell inscriptions or plaza pedestrian inscriptions, like the case of the towns of Santo Domingo de los Olleros, where the suggested earliest date registered is 1613[57]. Nevertheless, these two examples show the foundation date for new settlements reclaiming agricultural infrastructure started at least during the second decade of the 17th century.

In 1764 Dr. Cosme Bueno, *cosmógrafo mayor del Virreinato del Perú*[58] (Torres Tello 2007; Gala 2017), describes in his account *El conocimiento de los tiempos ephemeride del año de 1764*, all the provinces that are part of Lima's archbishopric where he listed all the curates with their respective annexes (Bueno 1780, 113). Dr. Cosme Bueno, an Aragonian born in the early 18th century, arrived in Peru in 1730, where he became a well-respected physician and intellectual. In 1748 the Spanish Crown—now under the house of Bourbon—asked Mexico and Peru for a detailed description of the colonized territories. It was not until a second request from the Spanish Crown in 1751 that the task was assigned to Dr. Cosme Bueno as the viceregal cosmographer. With the help of his nine sons (some of them part of the church and working in

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[56] Dr. Cosme Bueno, Crown's cosmographer was in charge of compiling information about the viceroyalty of Peru in 1763 and published under the name "El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780]: en que van puestos los movimientos de la luna y los principales aspectos de los planetas con ella y entre si...: con calendario de las fiestas y santos..."
. Bueno mentioned all the towns, and annexes in the Huarochirí Province.

[57] *"YSO ESTA/ AÑO1613/ SANTO DOMINGO..JPAULO V SANTIFICO"* (Ramón Joffré 1999, 221)

[58] Viceregal chief cosmographer of the Viceroyalty of Peru

different prelatures), they compiled, revised, and standardized the information provided by priests and Corregidor from across the Peruvian territory. Bueno, a recognized intellectual in Lima, made very clear in a letter to Phillip V that an accurate descripción geográficas required professional cartographers (Gala 2017). The descripsión was circulated later by Bueno himself in a publication called "El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780]"[59]

Huarochirí had become an essential point of transit between Lima and the central highlands, where Jauja, an important economic hub, was located (Assadourian 1992). The town of Huarochirí itself, becoming later the capital of de modern Huarochirí Province. Dávila Briceño already mentioned the importance of the town of Huarochirí in the late XVI century, becoming a passing point to the central highlands midway between Lima and Xauxa (Jauja). It was described as *tambo* (rest point) for travelers and a place of residence for the Spanish authorities in charge of the Yauyos province.

> *Es el tambo deste pueblo de Guadocheri el de más gente caminante de todo este reino y á donde mejor recaudo se dá, y así, hay de ordinario mucha gente y cabalgaduras en él, que con haber cuatro casas muy grandes y muy largas, no cabe la gente caminante en ellas […]*
> *(Davila Briceño 1881[1586], 72)*

Most of the oldest settlements, the original reducción towns, became the largest settlements and the center of curates —and eventually heads of modern districts. Others lost their status and eventually were incorporated into different curates, as was the case for the

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[59] The complete publication name is: "El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780] : en que van puestos los movimientos de la luna y los principales aspectos de los planetas con ella y entre si... : con calendario de las fiestas y santos..."
[The knowledge of the ephemeride times of the year 1763 [-1768, 1775-1780]: in which the movements of the moon and the main aspects of the planets with it and with each other are set...: with a calendar of festivals and Saints...]

repartimiento of Mama and Chaclla, North to from the Lurín valley. Additionally, some newly founded post-reducción villages grew and became later heads of curates and incorporated other villages as annexes, like Santo Domingo de Los Olleros (See Appendices Table 18).

4 Methodology: colonial-era documents as multilevel data ensembles and spatial analysis of multispectral satellite imagery

Characterizing the variable ensembles of push-pull factors at work in changing colonial-era settlement patterns requires both locality and regional scale perspectives. On the one hand, the cross-referencing process of spatial information and geospatial analysis from two published colonial textual sources:

- Diego Davila Briceño, 1881[1586], “Descripcion y relacion de la provincia de los Yauyos toda, Anan Yauyos y Lorin Yauyos, hecha por Diego DAvila Brizeño, corregidor de Guarocheri”. In Relaciones geográficas de Indias - Perú, pp. 155-165. Ministerio de Fomento, Madrid, and
- Cosme Bueno, 1780, “El conocimiento de los tiempos ephemeride del año de 1763 [-1768, 1775-1780]: en que van puestos los movimientos de la luna y los principales aspectos de los planetas con ella y entre si...: con calendario de las fiestas y santos...” Lima: Imprenta Real. 2 vols. en la librería de la calle de Palacio, [1763?-1780?], Lima,

On the other hand, musltispectral satellite image analysis will aid with the identification of agricultural terraces for the Huarochirí region.I use images from PeruSAT-1given its suitability for identifying elements on the terrain and vegetation since it offer high-resolution images (0.7 meters in the panchromatic band and 2.0 meters in the multispectral bands) and four-band multispectral capabilities (red, green, blue, and infrared).

According to our hypothesis, the agricultural terraces and fields were the attractors (pull factors) when determining the location of the new post-reducción villages. Agricultural fields in the highlands, where most of the land is dedicated to subsistence crops, are spatial correlates indicating what areas to favor when the original reducción towns were not enough to hold their population. Hence, the new indigenous settlements in Huarochirí (post-reducción villages) should be closer to the reclaimed agricultural lands than the original reducciones were. To establish which areas are closer to settltment, I will:

- Identify agricultural fields and terraces (landesque capital) in the Huarochirí repartimiento
- Establish the location of reducción towns and post-reducción villages using colonial era documentation
- Establish the distance between the reducción towns and the new post-reducción villages in relation to the reclaimed agricultural lands.
- Compare the distance between the settlements and the fields in two different moments: when the resettlement program was recently implemented (1581), and later once the majority of post-reducción villages were created (1763). Mapping landscape transformation through geospatial analysis and colonial-era documentation

To determine if the new settlements (post-reducción villages) prioritized access to agricultural fields in choosing their new location, I measure the distance (in functions of cost of moving across the landscape) between agricultural fields and reducción towns and post-reducción villages. I then compare the distance in two different moments: when the reducción towns were recently established as described in the Relación Geográfica by Davila Briceño (1881[1586]), and during the late 18th century, where the list of settlements includes the post-reducción villages (Bueno 1780) right before the Bourbon reforms radically altered the administrative structure of the Viceroyalty (Fisher 2000). If agricultural infrastructure acted as attractors for the emplacement of post-reducción villages, then they will be closer to the field systems in terms of time, effort, and cost compared to the reducciones. To identify agricultural fields I used the core methodology described in Chapter 2 and adapted to fit the PeruSAT-multispectral high-resolution satellite mosaic from PeruSAT-1 (a satellite administered by the National Commission for Aerospace Research and Development in Peru)

4.1.1 Pre-classification: variability reducción with low and mid resolution imagery

In the interest of computational efficiency, the first step in the analysis is to mask out areas without agricultural complexes. Therefore, the first step in reducing the area of interest focused on the spaces where agriculture is possible. According to athnographic work in the region and reports from the Ministry of Agriculture, in Huarochirí I use these criteria to define areas suitable for agriculture in Huarochirí:

- Areas below 4000 m.a.s.l
- Areas with a slope no grater than 70%
- NDVI values higher than 0.2

Using an elevation model based on data from the ALOS PALSAR mission, I created a subsample of a digital elevation model (DEM), including only areas below 4000 m.a.s.l. The total area was reduced from 3786 to 2225 km^2, reduced by about 42%. The next step was to select those areas with less than 70% slope. Even though it has been reported for Huarochirí that about 2% of all terraces have a slope between 50% and 70% (Agro RURAL 2021), I decided to include the steep slopes since many abandoned terraces are located in very steep areas. The total land area below 4000 m.a.s.l with less than a 70% slope is 1501 km^2, about 30 % from the previous area and 40% of the original repartimiento (Figure 36).

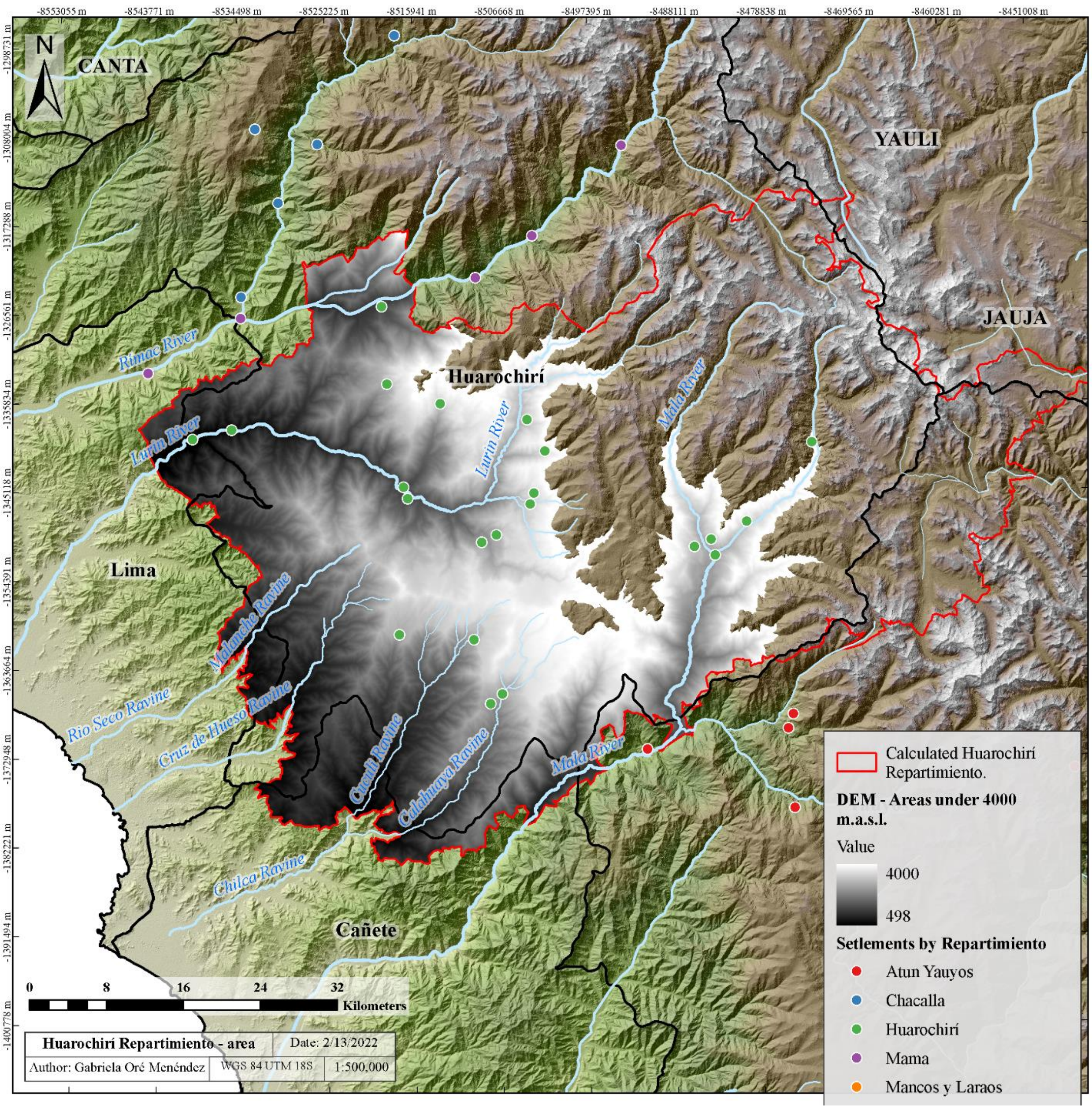

Figure 36. Areas bellow 4000 m.a.s.l

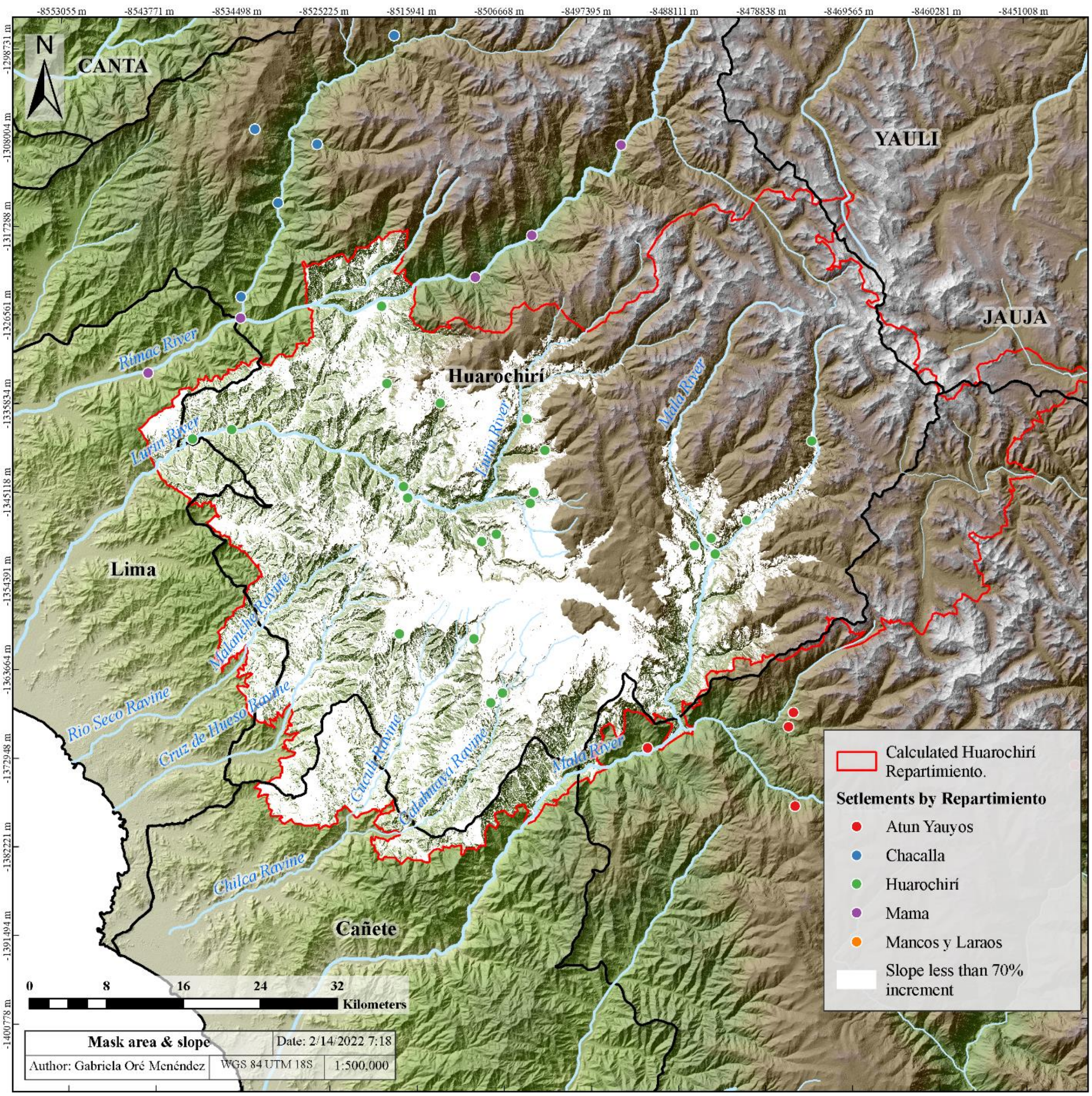

Figure 37. Slope lesser than 70%

Finally, I restrict the area by using the NDVI value to identify leaving vegetation from inert objects. Crops in various maturation stages or even resting fields are evidence of terraces and agricultural fields. I applied NDVI to a Landsat 8, with 30 meters per pixel resolution. It offered a fast and efficient way to reduce the area of interest before the classification analysis. The low resolution and its multispectral capabilities made Landsat-8 the right option. I decided to use a different multispectral image to determine the NDVI since I do not need the high resolution at this stage, and it will be a waste of resources to try to apply with a higher resolution image in an area this big. The areas included in the classification analysis have an NDVI value higher than 0.2, which means that areas with evidence of surface vegetation – in any health state – were included. NDVI values go from -1 to 1; any value below 0 indicates inanimate objects of inert vegetation. With an index of 0.2, I am including areas with limited vegetation. The selected areas with low NDVI might include fallow agricultural plots, lands covered by offseason vegetation, and abandoned terraces (usually covered by wild vegetation in different health states) (Figure 38).

Only 296 km^2, or 7.8% of the total area have all three characteristics that make an area suitable for agriculture: NDVI higher than 0.2, lesser than 70%, and elevation below 4000 m.a.sl). The resulting area is a complex multipart polygon with detail up to 0.7 meters and over an extent of 3786 km^2. (Figure 38 and Figure 39).

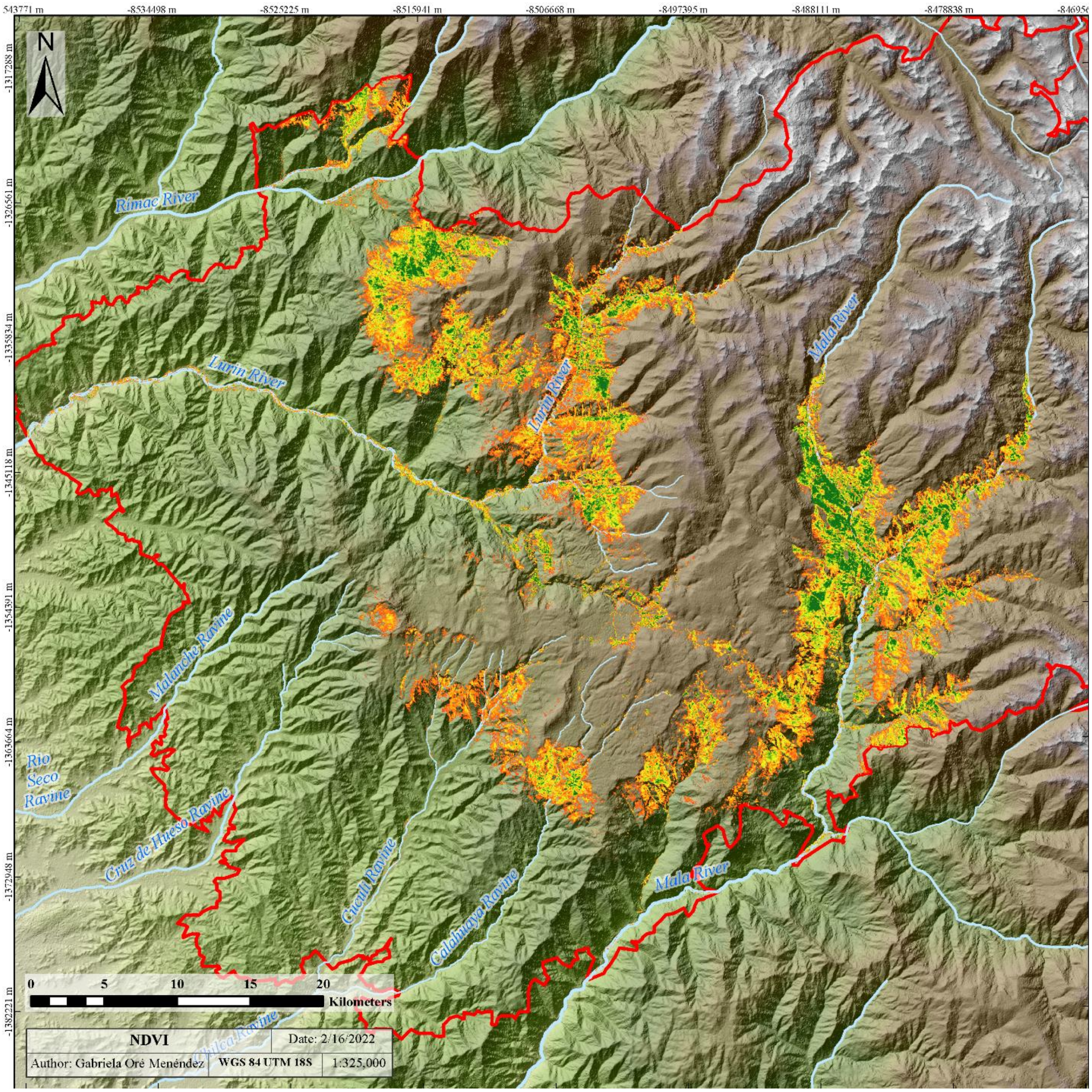

Figure 38. NDVI index selected for the analysis, green shows the highest NDVI values.

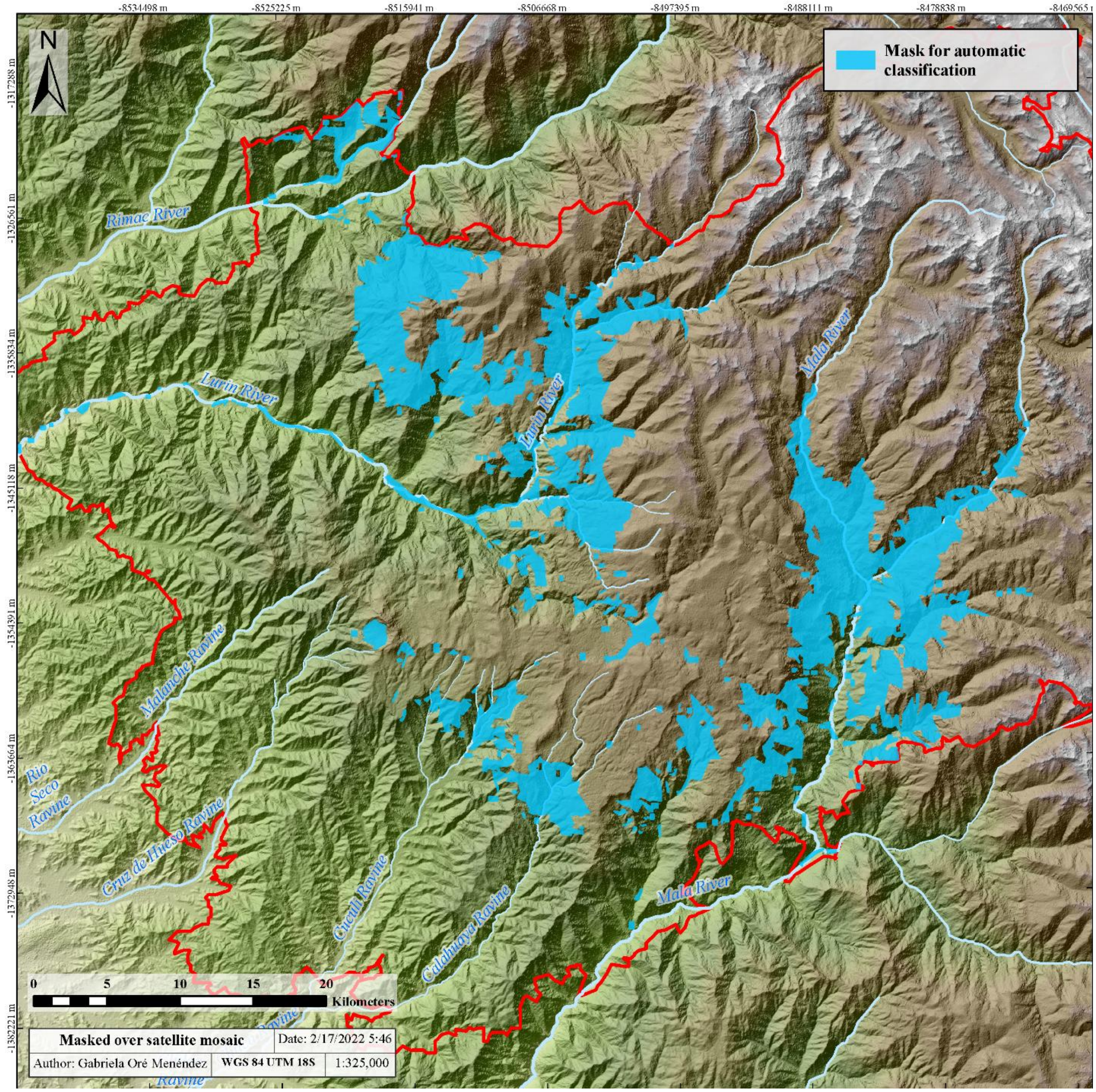

Figure 39. Extension of the mask for automatic classification.

4.2 Terraces and agricultural fields detection of PeruSAT-1 data

To identify and extract information from agricultural terraces and fields in Huarochirí, I use an unsupervised classification routine[60] to create clusters of similar pixel values (in all four bands) without reference information. The classification routine finds underlying pixel structures

[60] ENVI is an image analysis and processing software from Harris Geospatial Solutions.

by organizing pixels into groups (or classes) with the same spectral characteristics (Canty 2014). Following the methodology from chapter two, I used automatic classification for each scene and created five different classes. Since the area has already been pre-classified to restrict variation to elements similar to the feature of interest (i.e., agricultural fields and terraces) I use unsupervised classification as a first classification stage. For this case study, given the size of the analyzed scene, even after only choosing relevant areas, a supervised classification will required the creation of training data. Usually, unsupervised classification is a previous step before creating the training data since it helps to separate larger classes before trying to identify particular features.

The unsupervised classification was applied to the PeruSAT-1 imagery (See Appendices Table 20 and next page Figure 40). Each of the fifteen scenes covered different landscapes, elevations, weather, and geographical characteristics, even within the mask I have created (the total extent of the mask goes from 800 m.a.s.l in the *chaupiyunga*, up to 4000 m.a.s.l almost in the *puna*). It was better to classify the scenes independently not to add noise to the classification process. I created five classes applying the same parameters in each of the fifteen scenes: I maintained the threshold at 0% to eliminate the excessive differences between scenes and kept the kernel value at five and the pixel aggregation at seven. These two values aggregate pixels in larger clusters when creating the classification raster, avoiding small clusters of isolated pixels without context.

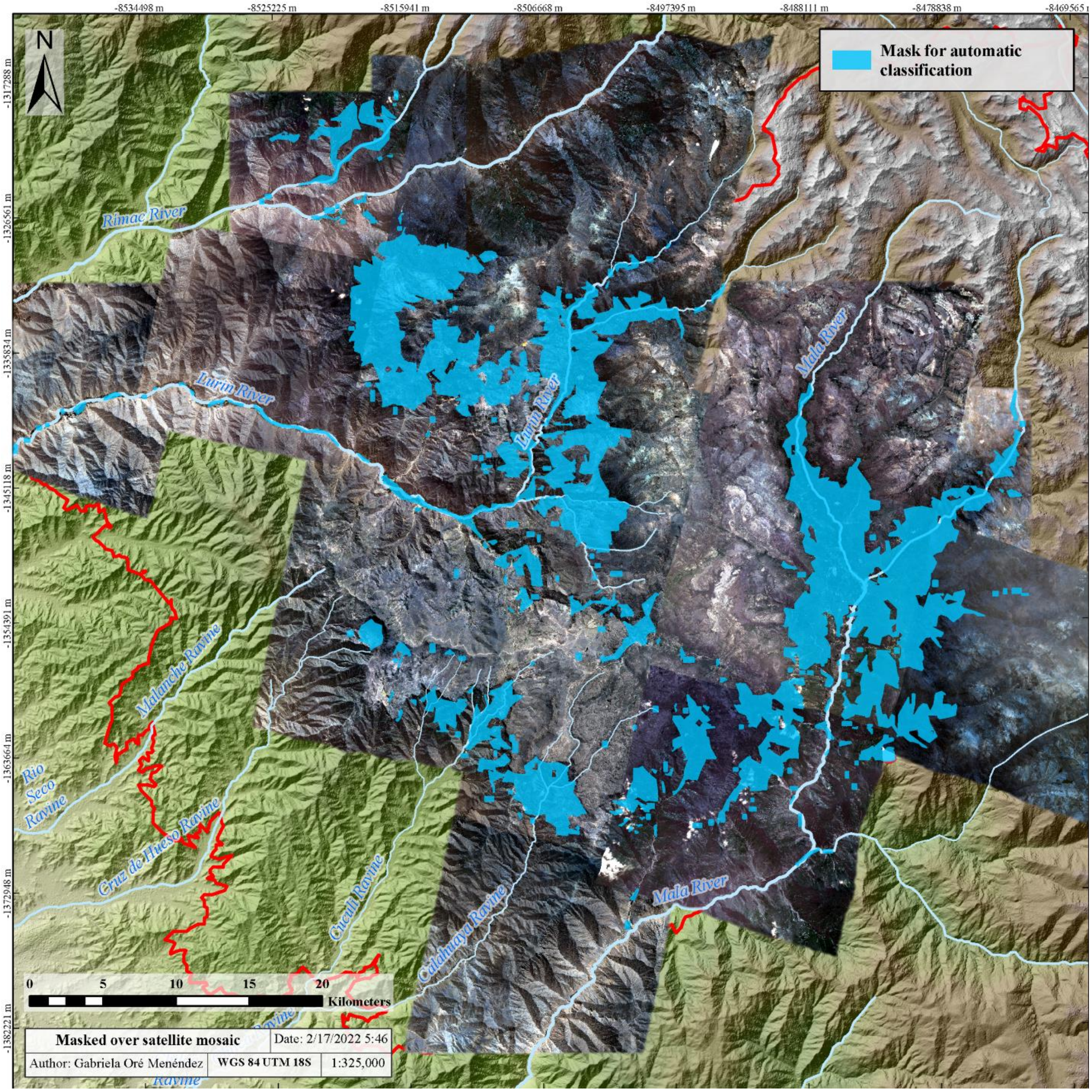

Figure 40. Mosaic covered by 15 scenes from PeruSAT-1

As shown in Table 19 (Appendices), most scenes maintain a consistent classification pattern and have almost the same elements grouped under the same class. For example, in 11 out of the 15 images, classes 3 and 4 contained elements like fields with active photosynthesis, slopes with limited actively photosynthetic vegetation, and workable land. Equivalent classes were classified under class 2: the southernmost scene with less than two km^2 of the area included in the analysis, and class 5: easternmost scenes, one next to the other covering sections of high-altitude ravines where vegetation is present as wild grass next to water sources.

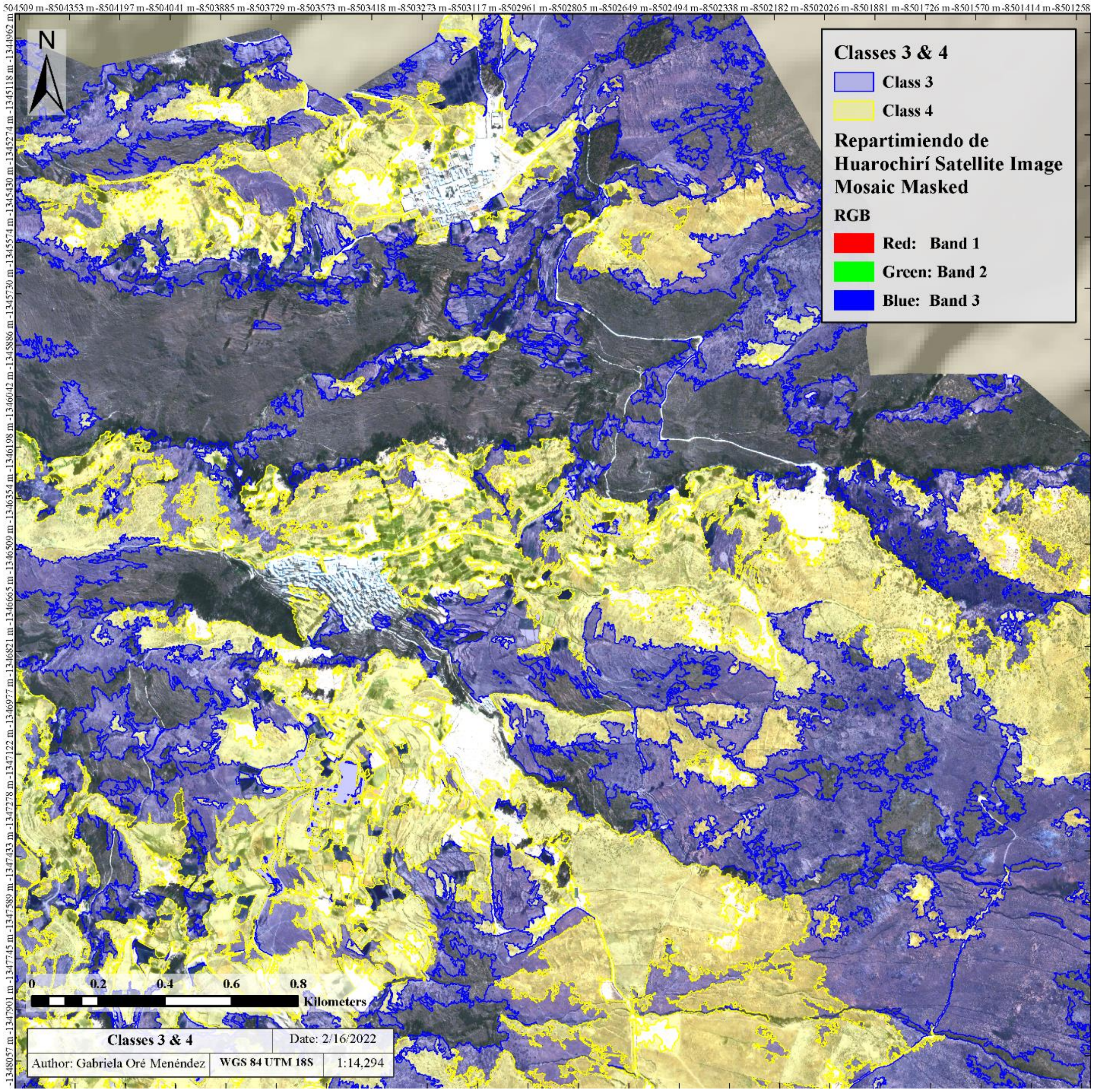

Figure 41. Detail of the classification results showing: classes 2, 3, 4, and 5

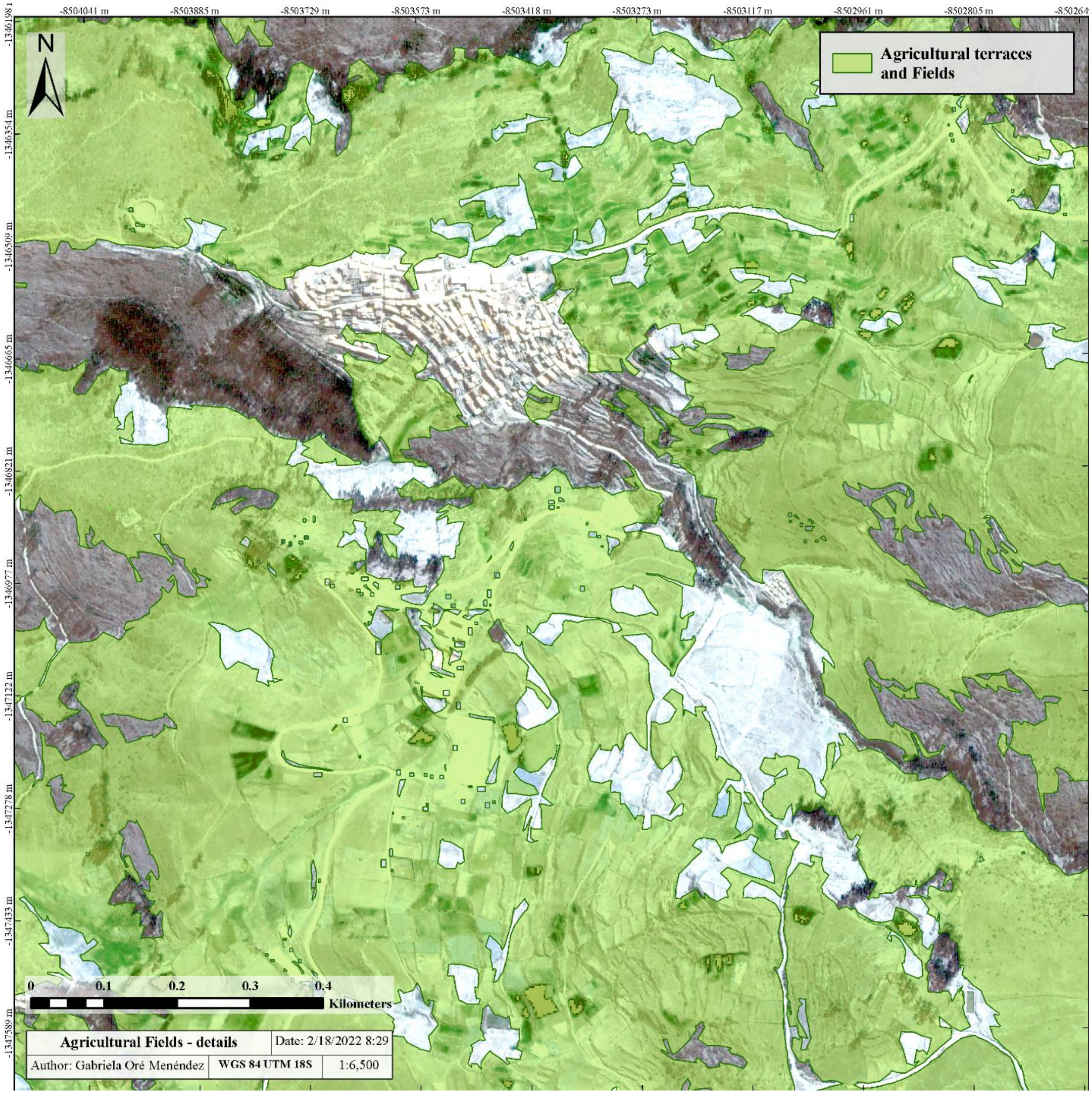

Figure 42. Detail of the classification results showing classes 3 and 4.

4.2.1 Agricultural Zone Detection Results

As the maps in Figure 41 and Figure 42 show, the final result shows that agricultural terraces and fields detected by the analysis are located in the valley bottom and over soft slopes. The total extent of agricultural terraces and fields for the Huarochirí repartimiento is 280 km^2, 16 km^2 smaller than the mask obtained by eliminating areas unsuitable for agriculture. Using a sample area of 30 km^2 to contrast the results, I manually identified agricultural fields in the area around the town of Huarochirí. For the digital ground truth, I used the PeruSAT-1. The classification workflow detected agricultural fields and terraces in two main groups: agricultural fields and terraces and abandoned fields and green areas. The group that included abandoned agricultural fields presents a smaller error (5%) since it seems that the abandoned terraces were usually ignored or passed as false negatives.

On the other hand, the false-positive —areas that were agricultural fields and were not identified as such—caused the most error in the sample, with almost 20.6% (Table 12 and Figure 43). The areas identified as agricultural fields were not usually present with natural vegetation. Instead, these areas were located around confirmed agricultural terraces and fields. The natural vegetation and the proximity to agricultural fields probably induced the detection error for false negatives.

Results	Area Km2	Percentage
False-negative	1.78	6.00%
False-positive	6.08	20.48%
Negative	4.52	15.24%
Outside mask	8.22	27.68%
Positive	9.08	30.59%

Table 12. Classification error in sample area (30 km^2)

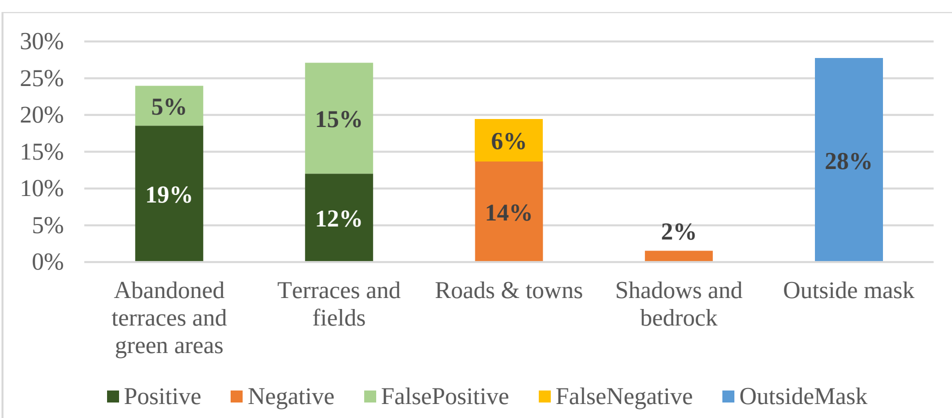

Figure 43. Error distribution by feature type

The error present in the classification is considerable, and additional iterations of the workflow could help decrease it. Additionally, further iterations could use supervised classification with an adequate training sample and in an area with reduced variability and yield better results.

4.3 Distance Analysis

The Huarochirí landscape offers narrow valleys and ravines and high Andean mountains; in some areas, more leveled spaces are located in the top lower mountains; as such, moving across the landscape takes time and energy. Distance analysis is the general name used in ArcGIS Pro to determine the cost of moving from one point to the other. The different results (Corridor, Distance Accumulation, Distance Allocation, Optima Path as Line, Optimal path as raster and optimal region connections). All these tools are improved versions of cost analysis. Distance analysis, instead of only focusing on the terrain/slope, incorporates additional variables to obtain more accurate results. For the Huarochirí region, the main variables that influence travel by foot across the landscape include the terrain's slope and the presence of roads and walking trails since those paths offer the best alternative for travel.

If the post-reducción villages were located in areas that prioritized access to agricultural fields and terraces, then it can be expected that they will be nearer to agricu1ltural infrastructural complexes than the reducciones. From the distance analysis tools I calculated Distance Accumulation. Distance accumulation calculates travel difficulty from every study area's location to the closest destination. The parameters required by the analysis are: terrain, slope, weighted cost (cost of moving through an area considering its advantages of disadvantages), maximum travel distance and barriers. For Huarochirí, some of the parameters used in our analysis were calculated using historical data and from visiting the area and talking with community members about how they moved across the landscape:

Maximum travel distance: The number of hours a day modern *huarochiranos* usually walk when going to their fields, visiting other towns, or tending their animals is four hours61. According to (Garza Martínez 2012), the distance walked for one hour, one *legua*, equals 5.56 Km/h for the Peruvian case. That means that the maximum distance walked by an individual on a day is 22 Km/h on average.

- Weighted distance: The difficulty of traveling across the terrain was determined by incorporating the slope, paths, and roads. Both variables were set to a scale value of 1 to 5, where 5 represents the most arduous path and one the easiest path. Areas with no roads were marked as 5, whereas areas with paths or roads as 1. I use slope percentage increments and apply the same 1 to 5 scale.
- Boundary or barrier: Finally, I use 800 m.a.s.l to mark the boundary between the lowlands and the highlands. This area coincides with the Sisicaya reducción, located in the *chaupiyunga* at 900 m.a.s.l.. The Chaupiyunga has been the western and lower boundary for the highland people—the Yauyos for the Huarochirí's case—since pre-Hispanic times (Szremski 2013). The boundary is used here to mark the limit of the Huarochirí repartimiento.

Using the location of the agricultural field obtained in the previous step and the data taken from the published historical documents listing the original Reducción towns and post-

[61] I assumed a 4-hour journey (as the maximum time walking from one point to the other in Huarochirí. Information obtained through conversations with community members at Lahuaytambo and Tupicocha (preliminary field season 2017)

reducción villages, I calculated the distance accumulation between the settlements and the agricultural lands to determine which agricultural lands' location favored one town or village over the other. Then, to assess the agricultural landscape's change before and after the foundation of the post-Toledan reducciones I performed the distance accumulation analysis for those two key moments and compared the results. The resulting maps showed, first, for 1586, the analysis shows in Figure 44 the original reducciones in relation to agricultural fields' location on a chromatic scale from red to green, where areas closer to orange and red are harder to reach, and the ones close to green are the easiest to get. For 1586 agricultural fields hardest to reach presented significant challenges for indigenous people who had to travel longer times to get to work the land, grow subsistence, and meet colonial taxation demands. On the other hand, in 1763 a significant part of the agricultural fields became way more accessible for communities.

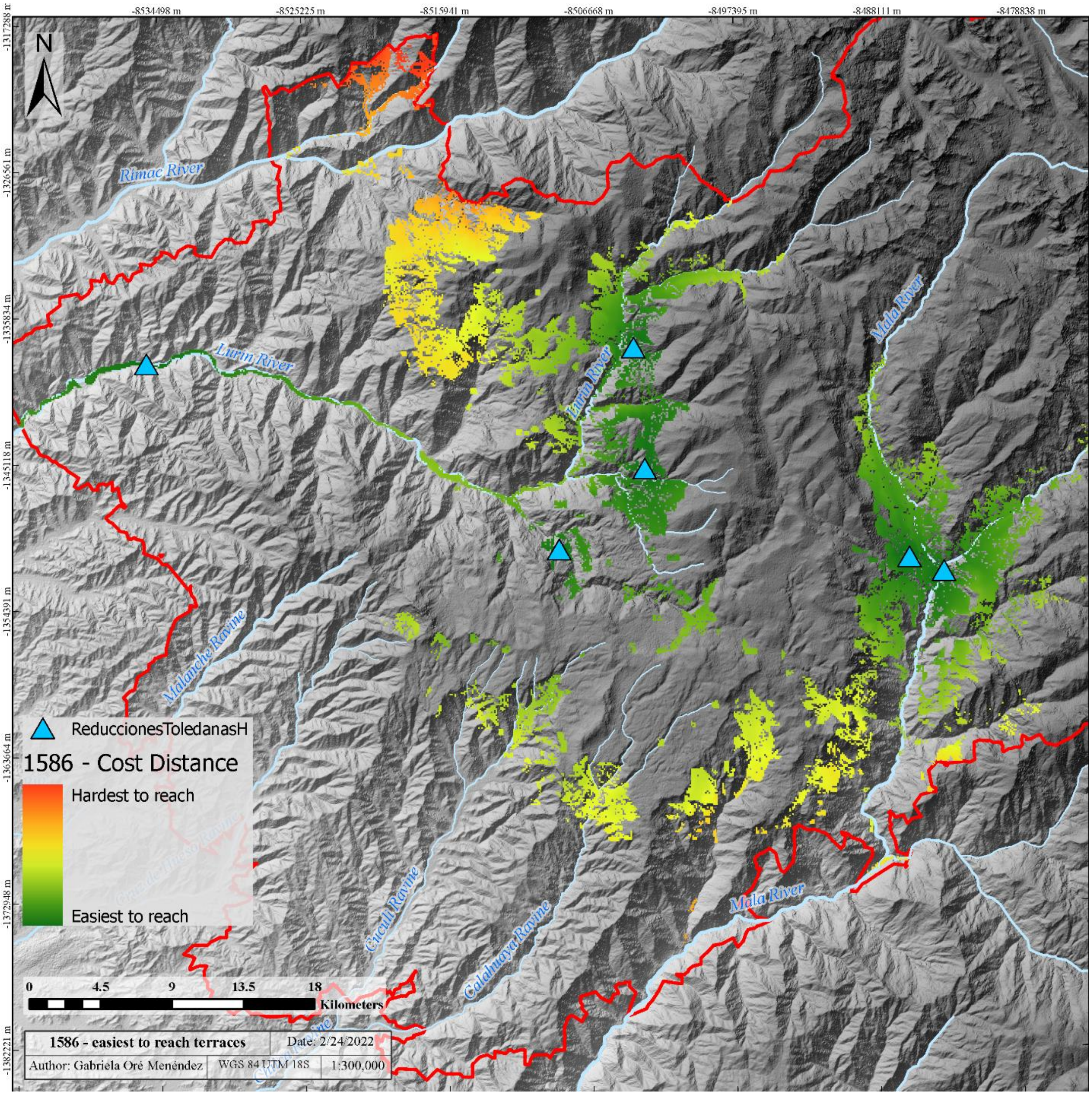

Figure 44. Cost distance modeling shows agricultural zones in relation to reducciones and how difficult they are to reach the original reducciones in 1586

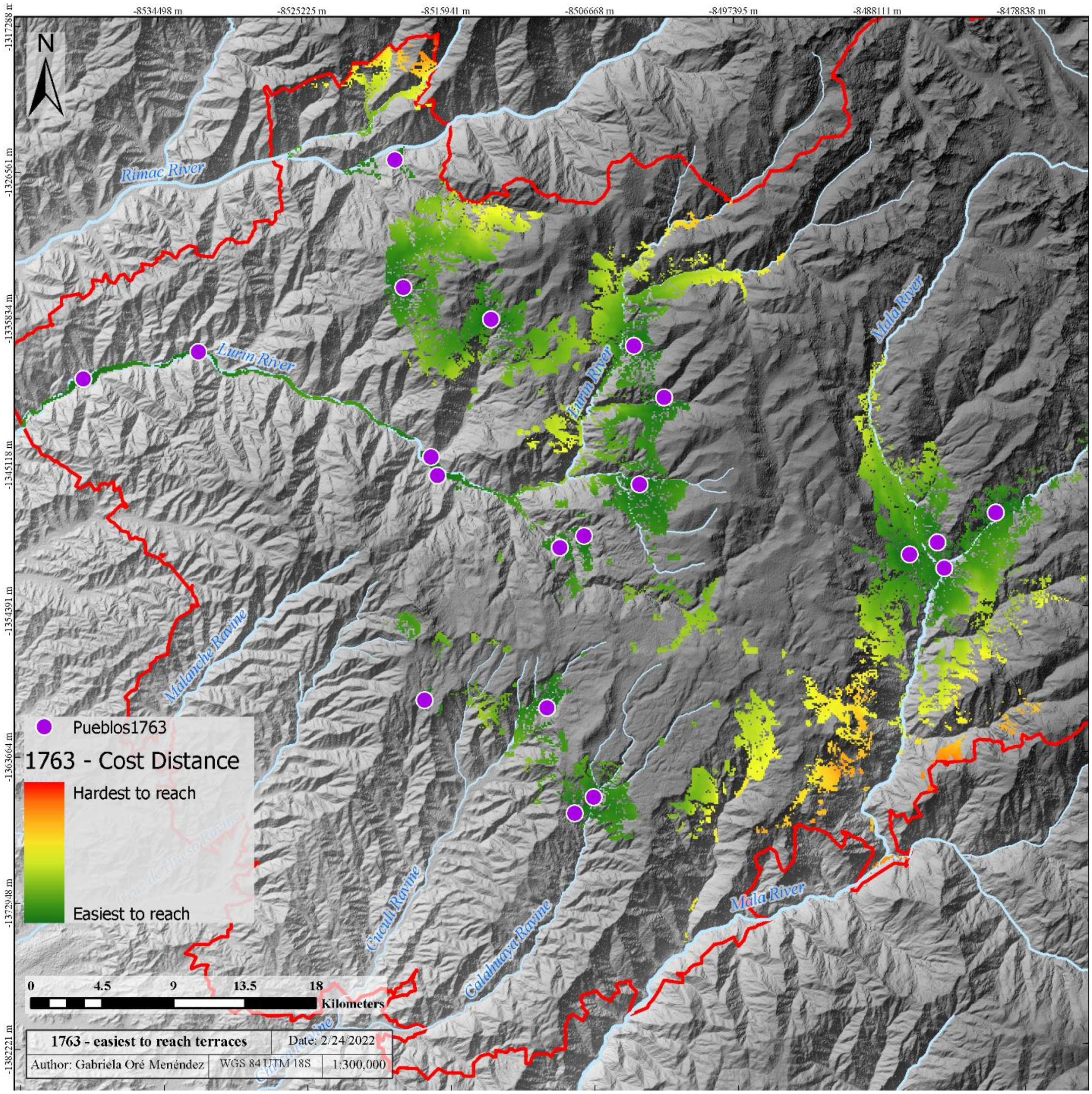

Figure 45. Cost distance modeling shows agricultural zones in relation to reducciones and how difficult they are to reach all the towns including the post-reducción villages in1763.

As the box plot shows in later times (1763) there were more agricultural fields areas closer to the reducción towns and post-reducción villages (Figure 46). Transforming the cost accumulation distance to traveled time we can infer that out of the 280.59 km^2 identified as potential agricultural fields, only 31% (86 km^2) were located less than 1 hour from the closest settlement during the late 16th century. Later, relative to post-reducción villages, agricultural fields located less than one hour from any settlement (either reducción tow or post-reducción village) almost doubled in area, with a total of 168 km^2. Once the post reducciones where stablished an and additional 82 km^2 of agricultural land were now located within 1 hour of the closest settlement, and only four km^2 of agricultural land are more than 4 hours away. Additionally, 20% of the agricultural lands that were more than three hors away are now closer to post-reducción setlements less than 2 hours away.

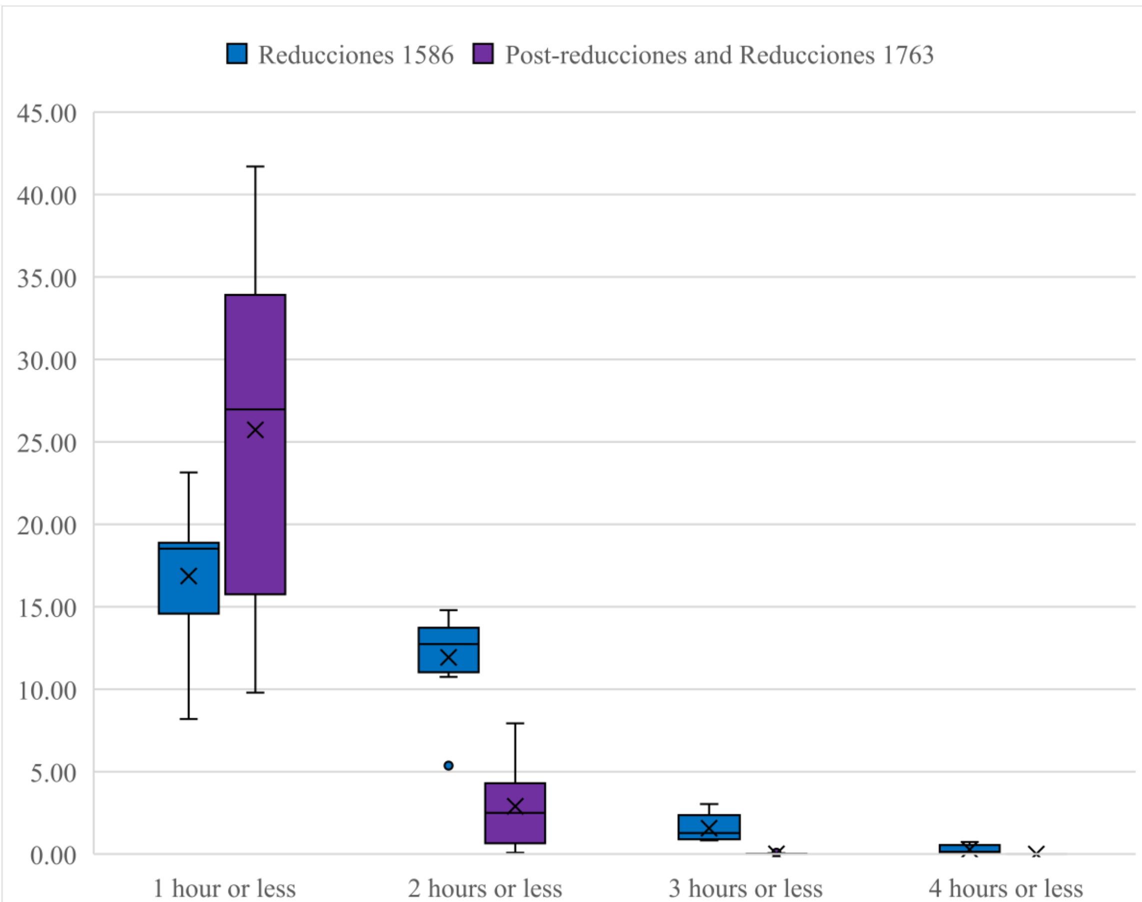

Figure 46. Distribution of Agricultural areas by the time it takes to reach the closest settlement

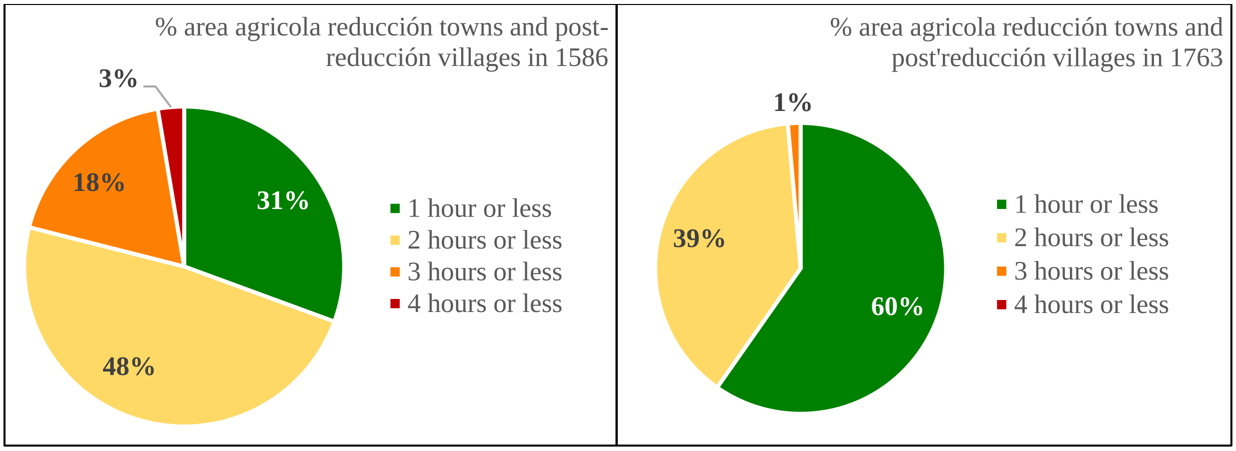

Figure 47. Distribution of agricultural areas by walking time to settlements

4.3.1 Descriptive statistics and statistical significance

Period	Average time	StdDevp walking times	Varp of walking times
1586	7.407	4.675	21.851
1763	4.070	2.938	8.629

Table 13. Descriptive statitistics comparing walking times during the original reducciones and later when postreducción already existed.

The agricultural fields and terraces from 1586 – the original reducción towns – contains 61 potential outliers, which is 2.49% of the observations and 1763 contains 6 potential outliers, which is 0.25% of the observations. The Null hypothesis (H_0) states that there is no difference between the times it takes to walk from the reducción towns to and from the agricultural fields and terraces. Since p-value < α, H_0 is rejected (Table 14). The randomly selected value of 1586's population is considered to be greater than the randomly selected value of 1763's population. The p-value equals 0, ($p_{(x \leq Z)} = 1$). It means that the chance of type I error (rejecting a correct H_0) is small: 0 (0%). The smaller the p-value the more it supports H_1.

Mann Whitney U-Test report
Agricultural fields walking times scores to and from the original **reducciones in 1586 (Mdn = 7.053061)** were higher than those in **1763 (Mdn=3.134694)**. A Mann-Whitney test indicated that this differences was statistically significant, **U(N1586 =2451, N1763=2445)= 1663602.5, Z= 2.34256, p > 0.01**

Table 14. Mann Whitney U-Test report

The observed standardized effect size, Z/√(n1+n2), is medium (0.39). That indicates that the magnitude of the difference between the value from 1586 and the value from 1763 is medium. The observed common language effect size, U1/(n1n2), is 0.72, this is the probability that a random value from 1586 is greater than a random value from 1763. As we can see in the distribution of walking times are not normal, both histograms (for 1586 Reducciones, and 1763 post-reducciones) have a slightly right skewed distributions, in which case I runned a Mann-Whitney U Test, that evaluates non-parametric variables to address significance (Figure 48).

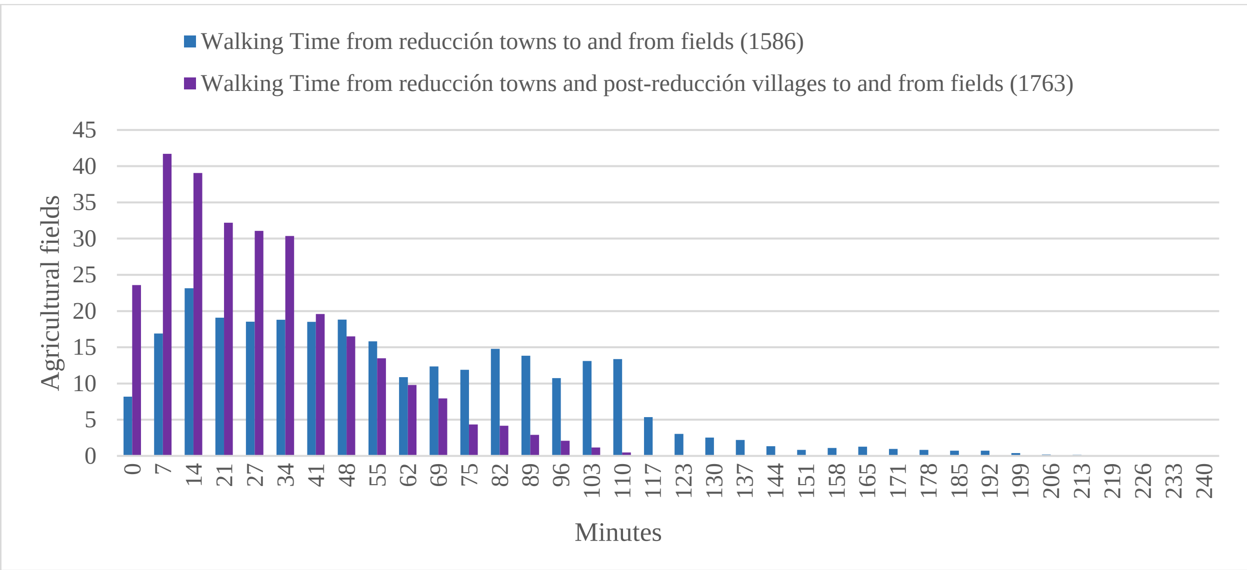

Figure 48. Histogram for walking times from settlements to fields in 1586 and 1763

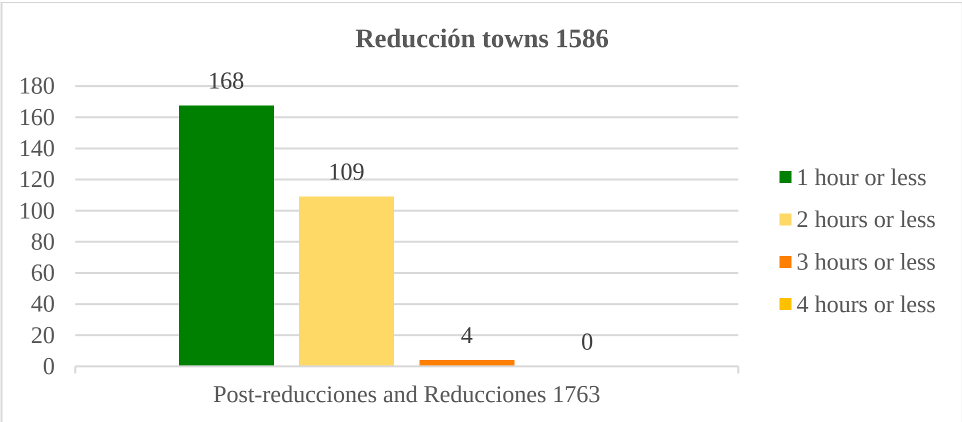

Figure 49. Fields and terraces areas by times it takes to get to the closer settlement 1586

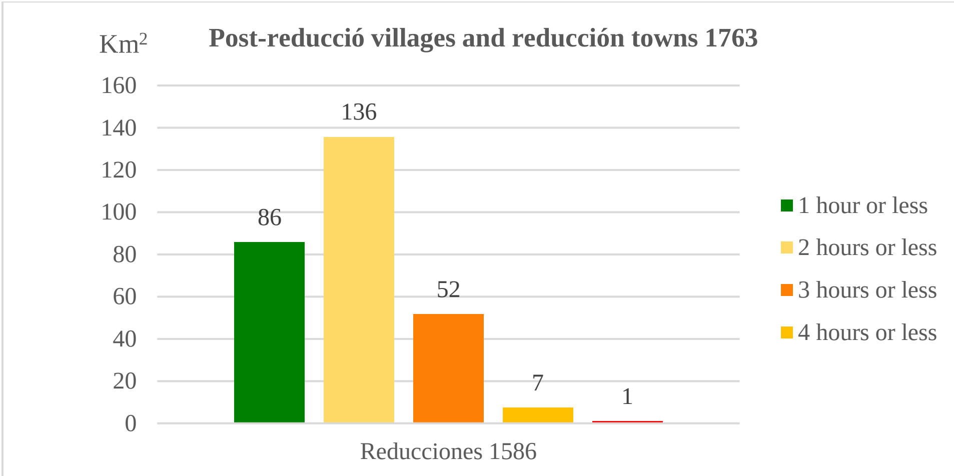

Figure 50. Fields and terraces areas by times it takes to get to the closer settlement 1763

5 Discussion and conclusions: Huarochirí communities as tranformative agents

Huarochirí and most of the western Andean drainages as they descend toward the Pacific are characterized by steep escarpments with limited suitable areas for agricultural infrastructure such as terraces and irrigation systems. Only 280 km^2 ($\pm$70 km^2) of 3,786 km^2 in the study area have agricultural terracing (or is suitable for terracing according to the criteria outlined above). This represents only 5.5% of the surfaces of the study area.

The findings presented here indicate that Reducción dislocated communities away from their agricultural lands, as has been documented elsewhere (Denevan 1986; Denevan, Mathewson, and Knapp 1987; Denevan 1988; Treacy 1993, 1994; Treacy and Denevan 1994; Benavides 2004). What this study shows is how communities voted with their feet to address the logistical crises that the displacements of Reducción cause them. —they dispersed away from these reducciones to found new villages nearer to agricultural terraces and fields, then the reclamation process reflects not only the practical decision of moving closer where agricultural infrastructure is already emplaced but also the knowledge passed through the next generations about infrastructural capital that became dormant. Moving closer to terraces and fields implies investing in infrastructure rehabilitation and maintenance. Even with the population still declining through the 1750s[62], communities had to rethink and reconfigure their labor and cooperation systems investing in landesque capital reclamation.

The timing of the foundation of post-reducción villages remains poorly defined. However, it is broadly bracketed between the 1610s, at least 40 years after the Reducción, and the 1810's. Some documents offered contextual information to over when the new settlements were established. For example, the petition presented by the communities of Chatacancha and Callaguay to church authorities dates from 1594 to 1613 (AA Leg 3 Exp 13). In other cases, the evidence presented is based on material culture, like dates for on church's bells or plaza pedestrian inscriptions, like the case of the towns of Santo Domingo de los Olleros, where the suggested earliest date registered is 1613[63]. This document describing the establishment of Chatacancha and Callaguay (discussed in the first section above) constitutes the only known archival source detailing the establishment of post-reducción villages. Nevertheless, archaeological contributions like the one presented here offer a complementary perspective for understanding landscape transformation and the agroecological forces that drove the florescence of multiple post-Reducción villages.

Salvi's account of 1815 is the later date when new post-reducción villages appear in the documental registry—coinciding almost with the end of the colonial period. Salvi's report offers the updated list of parishes and doctrinas for the province of Huarochirí, and included three new post-reducción villages: Santa María de Alloca, Santiago de Anchucaya and San Bartolomé de

[62] For 1750 the total population in Huarochirí was one-fourth of the population registered for 1571 (See Spalding 1984).
[63] *"YSO ESTA/ AÑO1613/ SANTO DOMINGO..JPAULO V SANTIFICO"* (Ramón Joffré 1999, 221)

Soquiacancha (See Appendices Table 18). The timing of the founding of the other post-reducción village remains a topic for future research.

In a context of dislocation, where communities were forced to leave their homes, their wak'as, and ancestors, it only took two generations to push communities away from the reducción and pull them closer to their agricultural fields. In other words, the children and grandchildren of the resettled families were the ones that pushed for leaving the reducción and going back to the fields where their parents and grandparents worked.

The impacts of colonial resettlement and the outmigration from reducciones changed community agro-pastoral logistics. Communities took action and actively exploited colonial logic and rules, and systems for their necessities. That is to say, they did not return to a status quo ante of dispersed hilltop settlements but instead deployed the form of the compact village as a legitimate form of civic community, founding them nearer to their ancestral lands than the reducciones. Post-reducción villages were the product of a long process of negotiation with the colonial system.

As Hernández Garavito (2020, 2021) points out, the effects of colonial forces in Huarochirí were not limited to the Spanish presence; rather, they were structured by prior Inka colonization of the region. Hence adapting and accommodating communities' necessities to a new political system was not new for the communities in Huarochirí. Nevertheless, the Inka occupation was based on a much higher degree of mutual legibility of cultural and religious practices. Spanish invasion and the Reducción, on the other hand, forced the uprooting of communities during the first decades of the colonial occupation, exacerbating both demographic collapse and agricultural deintensification. This study illustrates how communities advocated and successfully navigated a re-configuration of settlements and reclamation of land, and their active response led to a new settlement pattern that better facilitated agricultural logistics and production.

As Penry (2017) and Zuloaga (2017) have described for Charcas (Bolivia) and Huaylas (Peru) respectively, where new villages splintered from the original reducciones. Zuloaga explains the fissioning process of the reduccion as an effect of political and economic forces that grew independent from the central reducción's administration. Penry, in Charcas, observes that the *composiciones de tierras*—a colonial mandate that takes all abandoned land as part of the Spanish crown property and then sells them to any buyer-- forced indigenous communities to repurchase their land. These scenarios explain some of the processes behind the creation of post-Toledan reducciones through documented sources and offer a parallel example where communities moved away from reducciones and redefined their landscape

Highland Andean intensive agricultural systems require major initial investments for their construction, and ongoing labor inputs for their maintenance and operation. The investment of energy in building and, later, maintaining these agricultural systems (landesque capital) was part of the communal labor within Andean communities. The communities of Huarochirí still organize major annual communal labor projects to clean and repair their irrigation systems also know as *champeria*[64] (Rojas Robles 2012). When the Reducción project was emplaced in the Peruvian Viceroyalty, thousands of indigenous communities were forcibly resettled to nucleated towns away from their ancestral lands and agricultural infrastructure. This colonial settlement pattern dislocated communities and created a crisis of agricultural logistics and production.

[64] See Figure 13, Figure 14, and Figure 15: Canal cleaning session or *champeria*, Cruz de Laya community, close to Antioquia and San José del Chorillo, Huarochirí.

However, I have shown how communities responded by transforming the landscape and reclaiming their lands and agricultural infrastructure back to their communities.

During almost 180 years (1586–1763), the communities of Huarochirí transformed their landscapes by using the tools and discourses of the colonial regime. Communities incorporated themselves into the politics of the colonial administration and the church to advance their interest: the creation of a new nucleated village closer to their lands and the implicit recognition of them as active agents of landscape transformation.

Reducción and post-reducción villages then replicated the gridded pattern of Spanish urbanism and built and ornamented churches to incorporate themselves as active actors during the Spanish colonial rule. The processes revealed in this study provide exemplify how reducción did not effect a complete rupture in the fabric of Andean communities, and that on the contrary, communities actively reshaped their landscapes reclaiming land and reinvesting in the infrastructural endowments left by their ancestors. Today, most of the settlements created in this process have since become recognized as municipal districts, creating the unit upon which the modern Peruvian nation bases its political administration.

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Appendices

A. Figures

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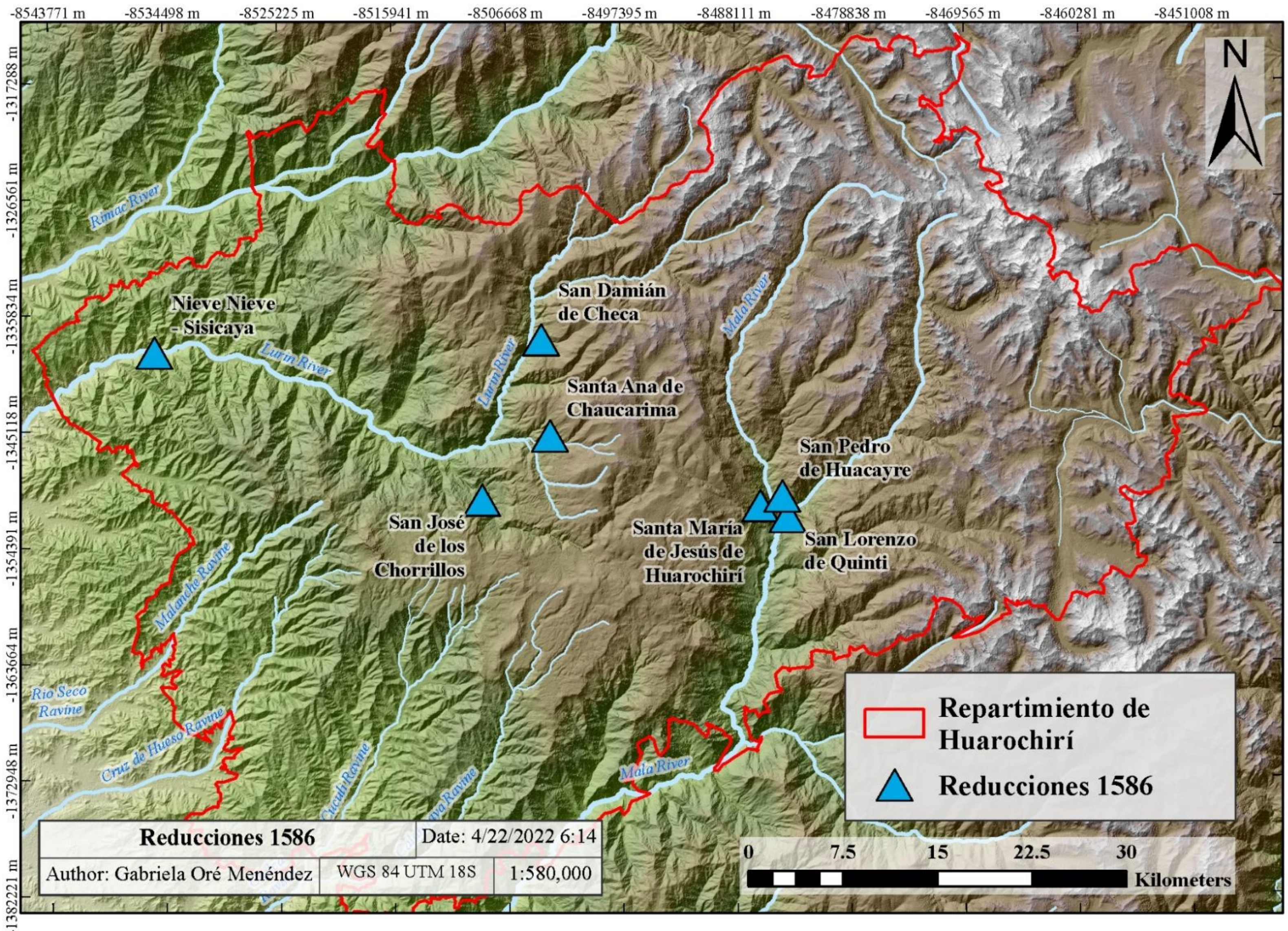

Figure 51. The territorial extent of the Huarochirí repartimiento and the original Reducción

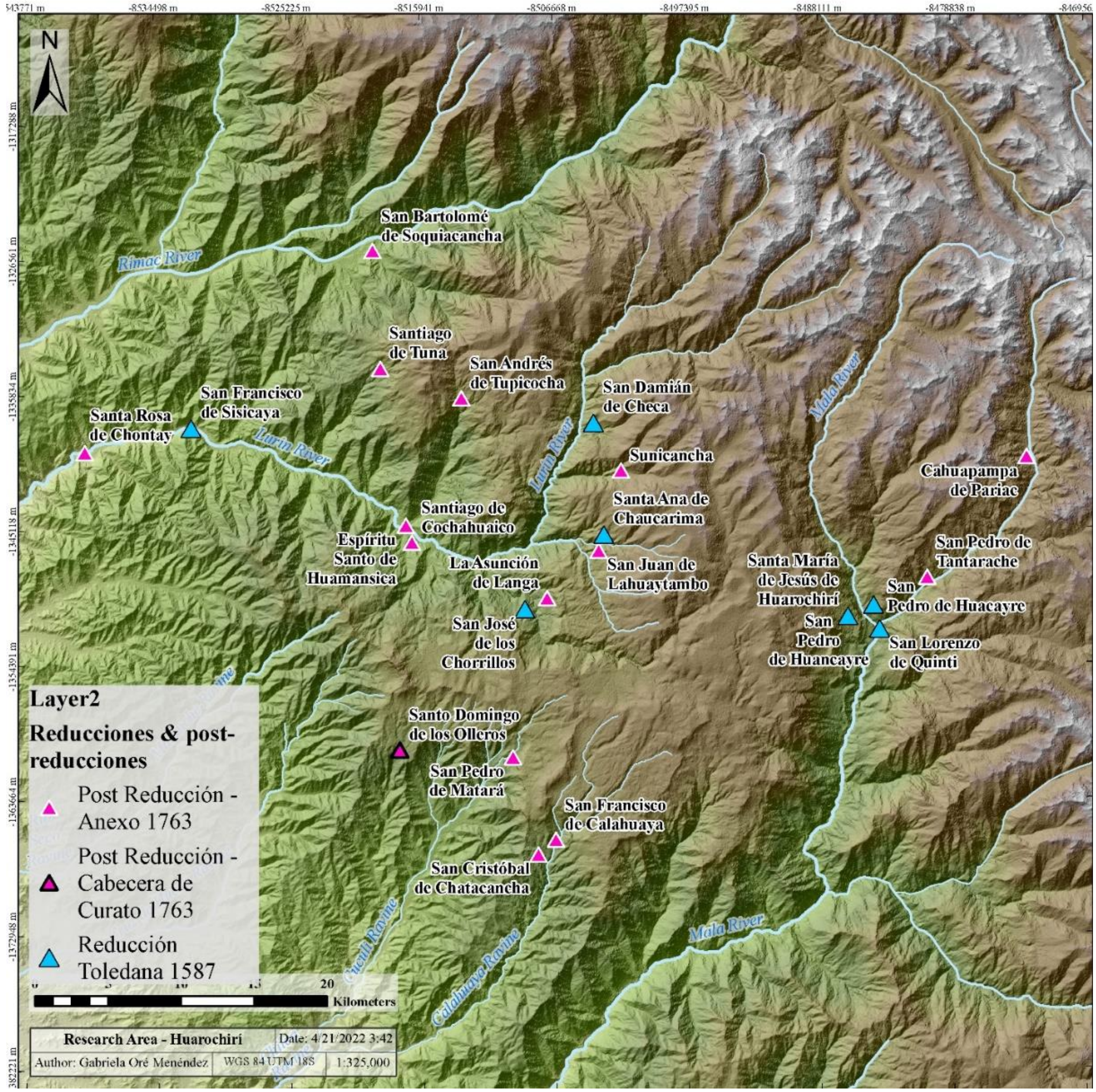

Figure 52. The original Reducción town and the post-reducción towns and villages (annexes)
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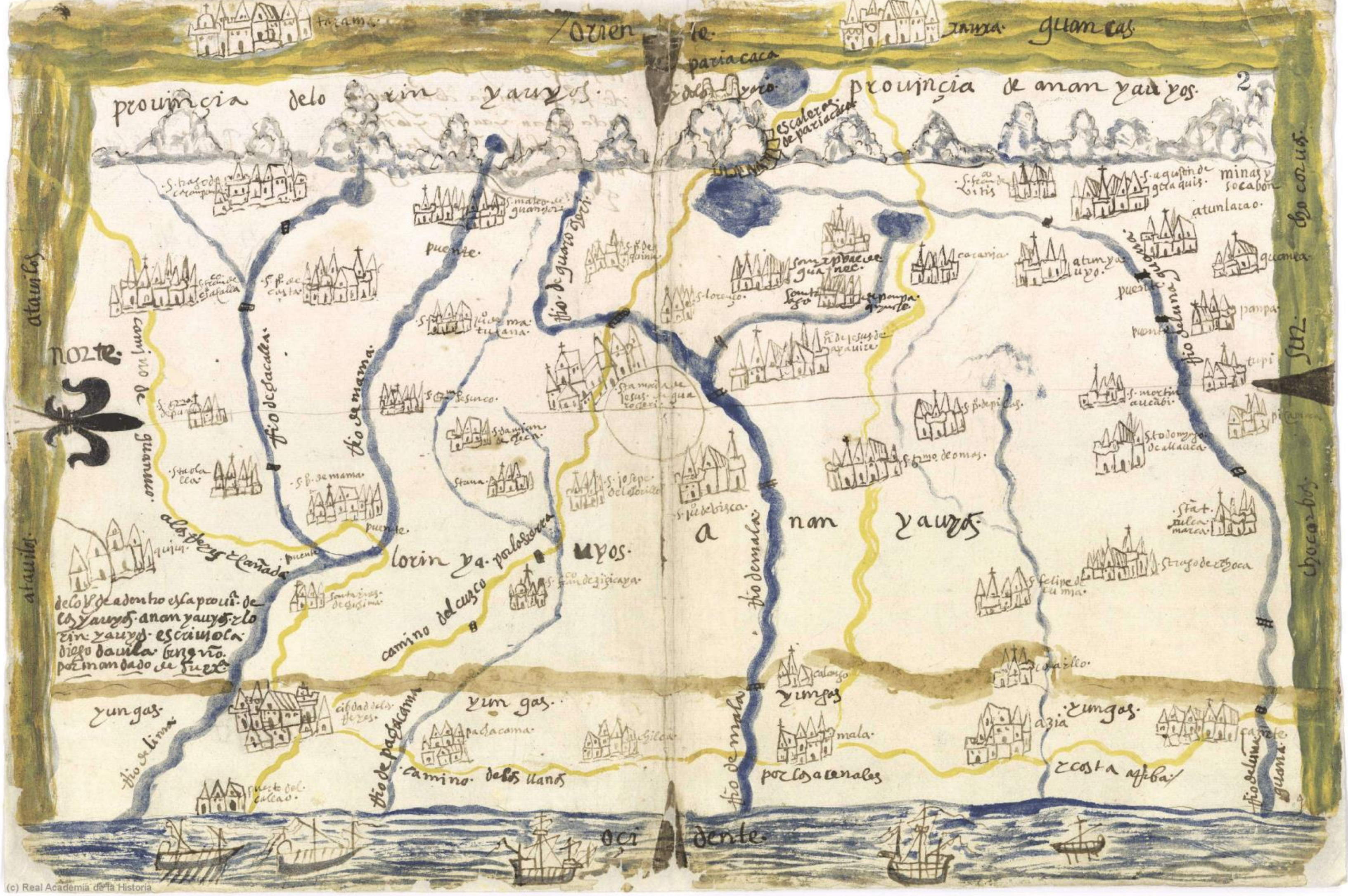

Figure 53. Pintura, Descripcion y relacion de la provincia de los Yauyos toda, Anan Yauyos y Lorin Yauyos Diego Davila Brizeño, corregidor de Guarocheri. Ministerio de Fomento, Madrid. 1586

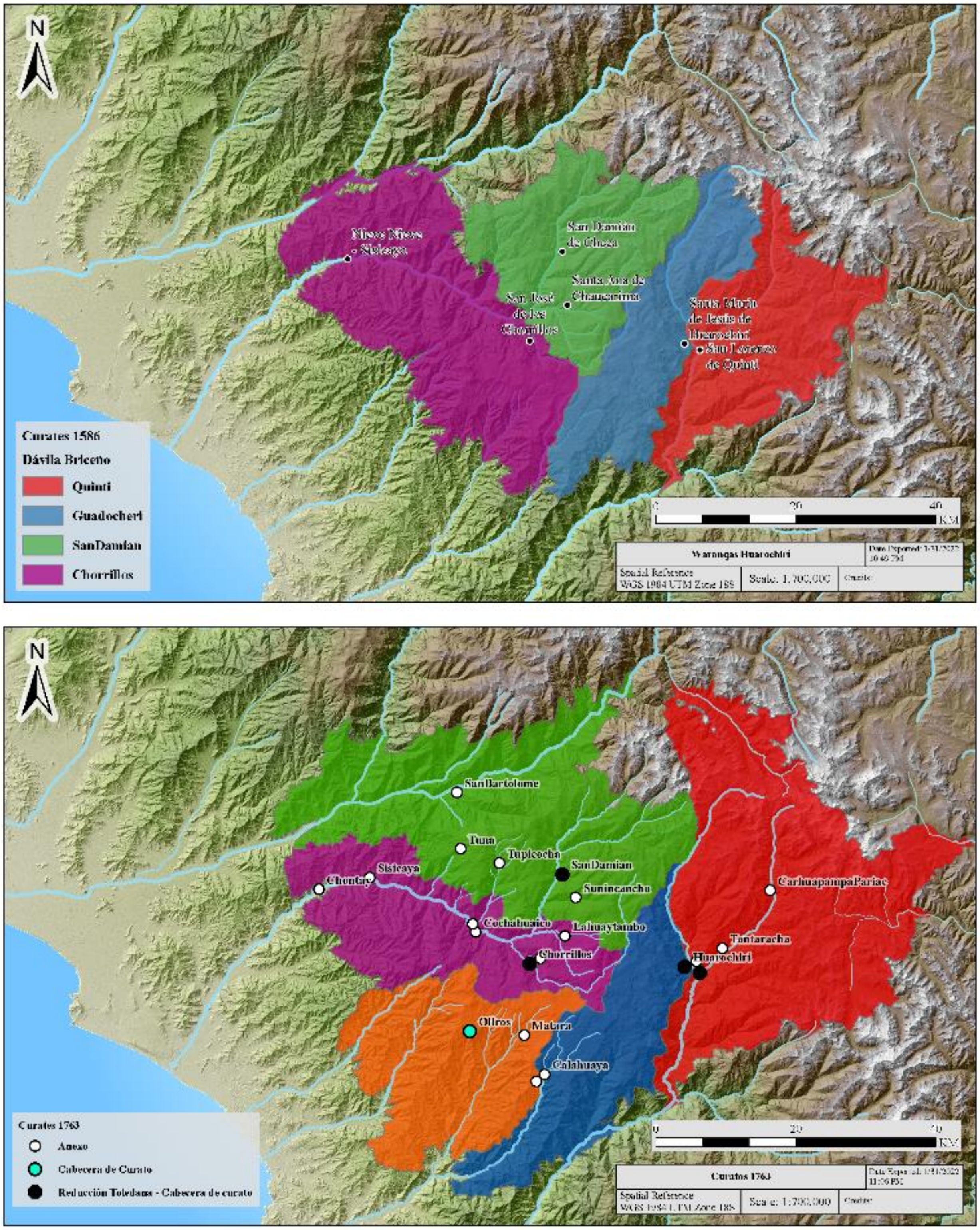

Figure 54. Calculated areas of the repartimiento of Huarochirí in 1586 (above) and in 1763 (below. See chapter 3.

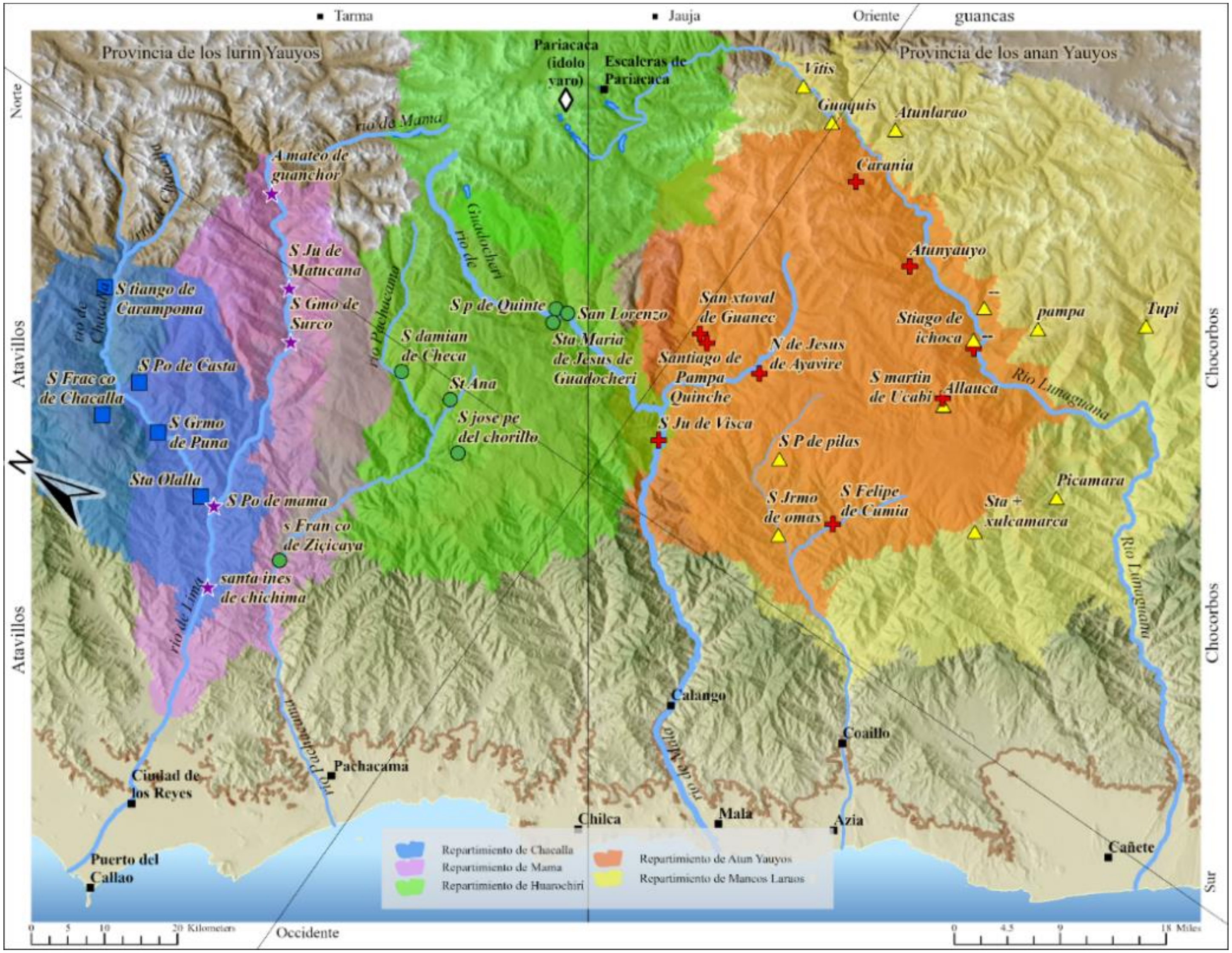

Figure 55. Repartimientos as described by Dávila Briceño and using the pintura from the RGPY (Hernandez Garavito & Oré Menéndez)

B. Tables

Reducciones Toledanas 1586	Elevation (m.a.s.l)	Natural Regions
San Francisco de Sisicaya	879	Chaupiyunga
San José de los Chorrillos	2793	Quechua
San Lorenzo de Quinti	2707	Quechua
San Pedro de Huancayre	3154	Quechua
Santa Ana de Chaucarima	3495	Quechua
Santa María de Jesús de Huarochirí	3172	Quechua

Table 15. Elevation and natural region classification (Pulgar Vidal 1981)

Count	1571	1579	1619	1729	1751	1780
Tributaries	1812	1775	1481	1050	848	1054
Total inhabitants	12057		9097		3365	

Table 16. Demographic changes Huarochirí, 1575-1619 (Salomon, Feltham, and Grosboll 2009[1588], 48)

3rd - Repartimiento de Huarochirí	
1	San Francisco de Sisicaya San Josepe del Chorrillo
2	Santa Ana de Chancarima San Damian de Checa
3	Santa Maria de Jesus de Guadocheri
4	San Pedro San Lorenzo de Quinte with “some indios taken care in Chechima

Table 17. Huarochirí Repartimientos and its four curates (1586)

Name	1586	1763	1815	Head of modern district
Cahuapampa de Pariac		Anexo	Anexo	San Juan de Tantaranche
Espíritu Santo de Huamansica		Anexo	Anexo	Antioquia
La Asunción de Langa		Anexo	Anexo	Langa
Nieve Nieve - Sisicaya	Reducción	Anexo		Antioquia
San Andrés de Tupicocha		Anexo	Anexo	San Andres de Tupicocha
San Bartolomé de Soquiacancha		Anexo		Santa Cruz de Cocachacra
San Cristóbal de Chatacancha		Anexo	Anexo	Mariatana
San Damián de Checa	Reducción	Cabecera de	Cabecera	San Damian
San Francisco de Calahuaya		Anexo	Anexo	Mariatana
San José de los Chorrillos	Reducción	Cabecera de	Cabecera	Cuenca
San Juan de Lahuaytambo		Anexo	Anexo	Lahuaytambo
San Juan de Tantarache		Anexo	Anexo	San Juan de Tantaranche
San Lorenzo de Quinti	Reducción	Cabecera de	Cabecera	San Lorenzo de Quinti
San Pedro de Huancayre	Reducción	Anexo	Anexo	San Pedro de Huancayre
San Pedro de Matará		Anexo	Anexo	Santo Domingo de Los
Santa Ana de Chaucarima	Reducción	Anexo		Lahuaytambo
Santa María de Alloca			Anexo	Sangallaya
Santa María de Jesús de	Reducción	Cabecera de	Cabecera	Huarochiri
Santa Rosa de Chontay		Anexo	Anexo	Antioquia
Santiago de Anchucaya			Anexo	Santiago de Anchucaya
Santiago de Cochahuaico		Anexo	Anexo	Antioquia
Santiago de Tuna		Anexo	Anexo	Santiago de Tuna
Santo Domingo de los Olleros		Cabecera de	Cabecera	Santo Domingo de Los
Sunicancha		Anexo	Anexo	San Damian

Table 18. Settlements in Huarochirí and its status since the 16th century, (based on on (Bueno 1780; Salvi 1815; Davila Briceño 1881[1586])

PeruSAT-1	Scene Code	Panchromatic FileName
CO_1910141746239	VOL_PER1_ORT/M_001_004520	004520_PAN_Chontay
CO_1910141747477	VOL_PER1_ORT/M_001_004863	004863_PAN_Antioquia
CO_1910141747477	VOL_PER1_ORT/M_001_004245	004245_PAN_CallahuancaOtao
CO_1910141742495	VOL_PER1_ORT/M_001_000492	000492_PAN_Cocachacra
CO_1910141741025	VOL_PER1_ORT/M_001_003561	003561_PAN_Tupicocha
CO_1910141755443	VOL_PER1_ORT/M_001_000295	000295_PAN_Characuayqui
CO_1910141750358	VOL_PER1_ORT/M_001_000041	000041_PAN_Lahuaytambo
CO_1910141750358	VOL_PER1_ORT/M_001_000659	000659_PAN_EastOlleros
CO_1910141741025	VOL_PER1_ORT/M_001_004179	004179_PAN_Olleros
CO_1910141750358	VOL_PER1_ORT/M_001_001277	001277_PAN_SurChatacancha
CO_1910141717370	VOL_PER1_ORT/M_001_003765	003765_PAN_Alloca
CO_1910141717370	VOL_PER1_ORT/M_001_003147	003147_PAN_Huarochiri
CO_1910141717370	VOL_PER1_ORT/M_001_002529	002529_PAN_NorteAnchucaya
CO_1910141753032	VOL_PER1_ORT/M_001_001277	001277_PAN_Quinti
CO_1910141753032	VOL_PER1_ORT/M_001_000659	000659_PAN_Cochas

Table 19. PeruSAT-1 scenes were used in the analysis. Images granted by the Peruvian Spatial Agency 2019.

Name	Class 1	Class 2	Class 3	Class 4	Class 5
003561_Tupicocha	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Green fields, slopes with vegetation	Used surface, modern constructions
004179_Olleros	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Workable land	Used surface, modern constructions
000295_Characuayqui	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Workable land	Watter
000041_Lahuaytambo	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Workable land	Used surface, modern constructions
004863_Antioquia	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Workable land	rio, cauce de rio, Resting fields
000492_Cocachacra	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Resting fields	Green fields, ravines	Resting fields disturbed surface fields abandoned
004520_Chontay	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green Fields	Resting fields and hillslope	Hillslopes
004245_CallahuancaOtao	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green Fields	Green Fields	Ravine, hillslopes
000659_EastOlleros	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Green fields, slopes with vegetation	Workable land	Used surface, modern constructions
001277_SurChatacancha	Trees	Green fields and terraces	Resting fields	Used surface	Used surface, modern constructions
003765_Alloca	No Image Mask	Hillslopes	Green fields and terraces	Green Fields	Used surface, modern constructions
003147_Huarochiri	No Image Mask	Hillslopes	Terraces, light green	Green Fields	Used surface, modern constructions
002529_NorteAnchucaya	No Image Mask	Rock formation on mountain face	Hillslopes	Green Fields	green fields
001277_Quinti	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Resting fields and used surface	Green Fields and abandoned fields	Steep slope, rocky mountain face, trees, and bushes.
000659_Cochas	No Image Mask	Steep slope, bedrock, trees, wild bushes.	Slope with wild vegetation	Green Fields	Resting fields, ravine

Table 20. Description of each of the five classes in each PeruSAT-1 scene after automatic classification. (the green colors match the areas selected from the classification as terraces and agricultural fields.

Chapter 5

Conclusions

This dissertation investigated the historical ecological ramifications of forced colonial resettlement in the Viceroyalty of Peru—the legacy effects of the Reducción (that is, the Reducción General de Indios, or General Resettlement of Indians)—when some 1.4 million indigenous Andean people were forcibly resettled to over a thousand planned colonial towns. Situated in Huarochirí Province, this study centered on indigenous responses and actions in shaping and re-shaping the colonial settlement and land-use practices throughout land use. Traditional frameworks for understanding the Reducción, the Spanish invasion, and the colonial administration of the Americas have shifted over the last two decades from frameworks of opposition and resistance (Pease 1977b; Wachtel 1977) to approaches oriented around the position of indigenous communities and their active incorporation of colonial practices and institutions (Pease 1977a; Wachtel 1977; Farriss 1984; Spalding 1984; Rostworowski 1988b; Stern 1993; Lightfoot 1995; Mills 1997; Abercrombie 1998; Zeiler 1999; Funari and Zarankin 2004; Jamieson 2005; Wernke 2007a; Gose 2008; Liebmann and Murphy 2011; Wernke 2011a; Oland, Hart, and Frink 2012; Wernke 2013; Saito et al. 2014; Funari and Senatore 2015; Wernke 2015, 2016, 2018). These approaches work to decolonize indigenous histories by confronting metanarratives of conquest, domination, and resistance and bring discussions of power and measures of local agency in the co-creation of new kinds of colonial social arrangements. This dissertation contributes to understanding changes in colonial landscapes, their effects on the local population, and their new relationship with their landscape.

Taking a regional-scale perspective through Multispectral Satellite Remote Sensing (MSRS) and ethnohistorical research, my focus on Indigenous responses to colonialism, especially regarding agricultural production systems and their adaptation to major discontinuities in settlement organization in Huarochirí, has sought to contribute understanding of the Reducción and offers substantive knowledge of how Andean communities actively responded to existential threats posed by dislocation, by voting with their feet and establishing new settlements nearer to their ancestral agricultural lands. The study of post-reducción villages and how they came to be, sheds light on the formation of new kinds of community, one that reclaimed ancestral agricultural infrastructure and at the same time did not reject many of the principles of Spanish urbanism (reflected in the creation of post-reducción villages instead of returning to their ancestral settlements)65.

I have examined how the labor-intensive, anthropogenic landscape features (terraces and agricultural fields) that created highly productive agricultural lands influenced the agro-ecological logistics and the reconfiguration of a new settlement pattern in Huarochirí. When communities were displaced to reducción towns in the 1570s found themselves living 5 to 7 hours away from their agricultural lands (AA, Legajo 13, Exp. 3). Faced with these logistical burdens, throughout the 17th through early 19th centuries, communities began to move out of the reducciones to areas with closer access to agricultural lands. I have demonstrated how this fissioning process resulted from a combination of push and pull factors, where communities were attracted by recoverable agricultural infrastructure.

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[65] Toledo's mandate indicated that waq'as and old towns should be burned, so indigenous communities don't return to them (Málaga Medina 1974b; Mumford 2012). Archaeologically there is no evidence in Huarochirí that pre-Hispanic settlements were burned in a more or less contemporary burning event. Moreover, there is no register for a common stratigraphic horizon in pre-Hispanic settlements across the Andes that indicate a massive burn event.

The formation of post-reducción villages continued at least until 1815, when Pedro Salvi published the list of parishes and doctrinas for Huarochirí including three new post-reducción villages: Santa María de Alloca, Santiago de Anchucaya and San Bartolomé de Soquiacancha. The timing of the founding of the other post-reducción village remains a topic for future research, but they were likely founded throughout the 17th through early 19th centuries (with the exception of Santa Cruz de Cocachacra66.

Given the hypothesized role of ancestral agricultural features as pull factors in the emplacement of post-reducción villages, I leveraged the concept of landesque capital, building on the work of Sen (1959); Blaikie and Brookfield (1987); Clark and Tsai (2009); Håkansson and Widgren (2014a). Brookfield's concept of landesque capital as the investment in long-standing improvements to the land explains the pull factors that drew people away from the Reducción and into a new type of settlement: post-reducción villages. I used landesque capital to explain whether and under what conditions Andean communities first abandoned agricultural infrastructure following the Reducción and then reclaimed some of it back with the establishment of post-reducción villages. I then expand the concept of Landesque capital as long-term investments made to improve the land, including the investments that aim to reclaim the land back.

As described by Hornborg, the accumulation of landesque capital often favors demographic concentration (Hornborg, Eriksen, and Bogadóttir 2014, 15), with urbanization

[66] Cocachacra was founded in 1959. Cocachacra is located at the intersection of the *Carretera Central* (in the primary highway from the coast to the highlands in central Peru) and the unpaved road that leads toward the upper section of the Lurín Valley and the area of this research, making this one of the most transited points for internal commerce in Peru. Cocachacra's name suggests that there was the cultivation of coca leaf in the area (Rostworowski 1988a); nevertheless, since coca cultivation is not usual in this area anymore, the foundation of the Cocachacra in 1959 is probably more related to the modern evolution of Huarochirí than a need to be closer to workable agricultural fields.

processes, landscape transformation, and the creation of productive land (Clark and Tsai 2012; Hornborg 2012; Bayliss-Sith 2014; Håkansson and Widgren 2014a). For Huarochirí during the 17th and 18th centuries, the pull of ancestral agricultural infrastructure (landesque capital) prompted the dispersion of communities away from the reducciones and into building new villages from scratch, eventually expanding roads and creating more permanent residences.

Through this case study from the highland region of Huarochirí I apply Multispectral Satellite Remote Sensing (MSRS) to identify agricultural terraces using stone walls marking the boundaries of *chacras* (agricultural fields) as a proxy for agricultural infrastructure (terraces and agricultural fields) in the context of a broader research question: How the labor-intensive, anthropogenic landscape features as agricultural infrastructure that sustained Andean communities and that was already in place, influenced decision-making regarding agro-ecological logistics, and whether it will act as a pulling factor for indigenous communities when founding new settlements after the Reducción.

The methodological approach to defend the hypotheses presented in Chapter 1 had two main components: documental and multispectral remote sensing data. The documental component collected and digitized spatial data from published documents such as Bueno (1780); Salvi (1815); Davila Briceño (1881[1586]); Taylor and Acosta (1987[1608]), and unpublish historical documents such as Salvi (1815) and AA, and Legajo 13, Exp. 3; regarding the foundation of towns within Huarochirí during the colonial period.The location of reducción towns and post-reducción villages aided in establishing cost distance and energy use when moving across the landscape towards agricultural fields. The remote sensing component identifies and locates agricultural fields and terraces in the entire region of the Huarochirí repartimiento. Additionally, several visits to the upper Lurín and Mala valleys in the Huarochirí region allowed me to become familiar with the landscape. Most importantly, the descendant communities of the original Huarochirí inhabitants offer invaluable information about their relationship with the landscape and how they travel from fields to towns.

The core motivation of this research is the dissemination of satellite remote sensing and image analysis tools in archaeological research, particularly in the central Andes. I have created a replicable workflow that can be reproduced and adapted to other research questions and geographical areas. Multispectral satellite remote sensing (MSRS) analysis in archaeological practice allows for a new type of regional-level research that expands and transforms the type of question we can ask, the scale of the research, and how archaeological sites and monuments are monitored (Lasaponara and Masini 2012; Lasaponara et al. 2014; Lasaponara and Masini 2014). Additionally, recent global events like the 2020 pandemic halted all activities; MSRS analysis allowed many archaeologists to continue archaeological work when others depending on fieldwork, could not. However, despite the advantages that MSRS offers, the archaeological community is not widely taken advantage of it.

I demonstrated how a simple-to-follow workflow is a basis for large-scale regional analysis. The workflow steps are based on field observations and archaeological and ethnohistorical data. The ultimate goal is to contribute to the widespread of multispectral image analysis so it becomes an additional tool in archaeological research, especially in times of constrained budgets and travel restrictions. Nevertheless, there are two main roadblocks when using MSRS: computer power and technical knowledge. Therefore, I propose that creating accessible workflows offers a replicable tool that can be used, adapted, and improved with essential multispectral and image analysis functions, making the tool more accessible to archaeologists from regions with fewer resources available to researchers.

Creating a replicable workflow includes discussing and explaining the steps taken and the data used. For the case study presented here, we will describe a detailed workflow, including data from different sources (archival, archaeological, geomorphological, and ethnohistorical), the methodologies, and tools included in the analysis. The approach proposed here focuses on sequentially reducing the area's extent to direct the analyses only to particular sections of the image. The reduction of the analysis area restricts data variability and lowers the amount of computational resources needed. For the case study, each analysis stage is grounded on decision-making derived from archaeological observations and information on the region

Chapter two presented a workflow for detecting agricultural infrastructure through multispectral remote sensing techniques. In addition, the application of the different steps along the different stages of the classification processes: 1) Pre- classification, 2) Unsupervised classification, and 3) Post-classification and raster to vector conversion.

Chapter four applied this workflow to identify areas of agricultural infrastructure in the study area. The results indicate that 20% of the total workable land—in the form of remotely identified agricultural fields and terraces—was located more than 2 hours away from the closest reducción town for 1586. On the contrary, only 1% of the agricultural fields were located 2 hours away by 1763. For both dates, most agricultural fields are located close to towns and villages within one to two hours (between 79% for 1586 and 99% for 1763). The identification analysis of agricultural terraces and fields yielded promising results, but further analysis revealed a considerable error (26%) present, particularly in the false-positive results, where the error amount around 5%, against the false-negative error. Future project complementary

Huarochirí's transformation from the late 16th century to the early 19th century cannot be understood without incorporating the spatial relationships between communities and agricultural lands. Huarochirí communities invested in landesque capital to ensure enough agrarian land for subsistence. Their decision to move away from the reducciones was a function of the mistreatment and surveillance happening at the reducción towns, but the presence of agricultural terraces as capital already invested and as their known ancestral landscape was much more influential.

After the trauma of dislocation caused by the General Resettlement of Indians in the 1570s, in which communities were forced to leave their homes, lands, and ancestors, it only took two generations before communities began to disperse away from the reducciones as they were pulled back closer to their ancestral agricultural fields. Some of the post-reducción villages were founded as early as the 1710s, about 40 years after the Reducción. In other words, the children and grandchildren of the resettled families were the ones that pushed for leaving the reducción towns and going back to the fields where their parents worked the land and lived. The new generation of *huarochiranos* living under colonial rule and dislocated from their roots reclaimed ancestral lands that benefited them economically but also reclaimed landscapes that were still part of living history.

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