Universiteit Utrecht

Master's Thesis – MSc in Sustainable Development

Traditional Ecological Knowledge (TEK) for Climate Change Adaptation: The Case of Smallholder Farmers in the Peruvian Highlands

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1. Abstract

This research examines the critical role of Traditional Ecological Knowledge (TEK) in climate change adaptation among indigenous farming communities in the Peruvian highlands. Faced with the escalating challenges of climate change, these communities are at the forefront of experiencing and responding to environmental changes. This study aims to contribute to bridging the knowledge gap by documenting and analyzing specific TEK practices applied to smallholder agricultural settings, thus providing insights into potential adaptation strategies. Employing a mixed-methods approach, the study was conducted in Urubamba, a region within the Sacred Valley known for its rich agricultural history and cultural significance. The research involved extensive fieldwork, capturing quantitative data and qualitative insights from local farmers. The focus was on understanding how indigenous TEK practices, such as crop diversification, ancient irrigation systems, and agroforestry techniques, are being implemented to adapt to climate change impacts at the farm level. The findings reveal a complex interplay between traditional practices and contemporary environmental challenges. TEK strategies, deeply rooted in cultural and ecological understanding, exhibit significant potential in enhancing adaptation, resilience, and sustainability in the face of climate change. The study underscores the need for integrating these indigenous practices into broader climate adaptation frameworks, emphasizing participatory and culturally sensitive approaches. This thesis contributes to the growing body of literature on climate change adaptation by highlighting the invaluable role of TEK. It advocates for a greater recognition and integration of indigenous knowledge systems in global environmental policies, reinforcing the argument that local, context-specific solutions are vital in addressing the global challenge of climate change.

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2. Introduction

Climate change, driven by anthropogenic pressures, poses a profound challenge with far-reaching implications for ecosystems, economies, and societies worldwide (Blazquez-Soriano & Ramos-Sandoval, 2022). Central to this global issue are the impacts of human activities, including the combustion of fossil fuels, which have led to rapid global warming and the emergence of climate change as a pressing environmental and socio-economic concern (Martins et al., 2022; Shivanna, 2022). Particularly vulnerable to the consequences of climate change are indigenous communities, well-known for their 'low-carbon' lifestyles, yet frequently exposed to intense storms, floods, heatwaves, and recurrent droughts (Blazquez-Soriano & Ramos-Sandoval, 2022; IPCC, 2022; Walshe & Argumedo, 2016).

This research focuses on the critical role of Traditional Ecological Knowledge (TEK) employed by indigenous communities in the Peruvian highlands for climate change adaptation. While the broader global context of climate change remains central, it is the local application of TEK in the Peruvian highlands that are explored and documented. This region-specific investigation aims to connect the wide-ranging climate change challenges with the specific strategies and practices that Peruvian indigenous communities employ to adapt to shifting environmental conditions in their unique highland ecosystems.

2.1. The Role and Knowledge Gap of TEK in Climate Change Adaptation

In order to integrate TEK into climate change adaptation strategies, a shift from the traditional top-down approach to a more participatory and co-designed process is necessary (Hosen et al., 2020). Establishing meaningful partnerships with indigenous communities where respecting their rights, knowledge systems, and decision-making processes is essential (Dadich et al., 2019). This collaborative approach ensures that adaptation initiatives are contextually relevant, culturally sensitive, and aligned with the priorities and aspirations of the communities they aim to support (Berkes, 2009; Dadich et al., 2019; Nakashima et al., 2012; Whyte, 2013).

Despite the recognized importance of TEK in climate change adaptation, there remains a significant knowledge gap regarding the specific practices employed by indigenous community farmers in the Peruvian highlands (Brügger et al., 2021; Saylor et al., 2017).

These farmers heavily rely on subsistence farming and follow traditional agricultural practices, possessing an intricate understanding of their local environment and utilizing TEK-based strategies to navigate shifting climatic conditions (Saylor et al., 2017). However, a comprehensive investigation and documentation of these practices and the implementation of TEK for climate change adaptation are still lacking (Petzold et al., 2020; Saylor et al., 2017). The limited research in this area restricts a thorough understanding of effective adaptation strategies and impedes the empowerment and resilience of indigenous communities (Cámara-Leret & Dennehy, 2019; Petzold et al., 2020). Therefore, addressing this knowledge gap is fundamental for advancing our knowledge of climate change adaptation and promoting context-specific solutions tailored to the unique challenges faced by indigenous community farmers in the Peruvian highlands (Cámara-Leret & Dennehy, 2019; Petzold et al., 2020).

Tackling climate change requires a collective effort that transcends disciplinary boundaries and embraces diverse perspectives (Vicens et al., 2018; Wannewitz et al., 2023; Wright et al., 2021). The presence of TEK in climate change research, policy, and practice can contribute to more holistic and resilient approaches that integrate ecological, social, and cultural dimensions (Hernandez et al., 2022; Wright et al., 2021). By recognizing the value of indigenous knowledge and its relevance in the face of global challenges, we can promote a more inclusive and sustainable future for all (Hernandez et al., 2022). Embracing the wisdom of indigenous communities and learning from their experiences can guide us towards innovative solutions and allow us to adopt a deeper connection between humans and the natural world (Leonard et al., 2022).

Historically, the Peruvian highlands have been home to indigenous communities that have thrived and evolved over millennia (Orlove & Guillet, 1985). Their sustenance and survival have relied heavily on their understanding of the environment, passed down generations in the form of TEK (Lemi, 2019). This knowledge encompasses intricate farming techniques, understanding seasonal shifts, and an ability to predict climatic changes based on natural indicators (Lemi, 2019). Recent studies highlight that these indigenous strategies, often rooted in TEK, have allowed communities to flourish even in the face of adversities (Lemi, 2019; Gómez-Baggethun et al., 2013)

2.2. Climatic Patterns and Challenges in the Peruvian Highlands

Climate data reveals that the Peruvian highlands have undergone drastic temperature fluctuations, unpredictable rainfall patterns, and increased frequency of extreme weather events (Valdivia et al., 2010). These irregularities not only disrupt the established agricultural calendars but also pose significant risks to biodiversity, native plant species, the overall health of the ecosystems, and traditional farming systems that have existed for generations (Herzog et al., 2012). Such shifts have direct implications on the agricultural yields, water resources, and general sustainability of communities in this region (Bergmann et al., 2021). The volatile weather also intensifies the threat of pest infestations and plant diseases, further jeopardizing food security and local economies (Skendžić et al., 2021).

Moreover, the Andean glaciers, which serve as critical reservoirs for rivers and streams, are receding at an alarming rate due to global warming (Drenkhan et al., 2018; Vuille et al., 2018). While temporarily increasing water flows, glacier melt is destined to lead to severe water shortages in the long term, making the situation increasingly dire for the highland communities (Vuille et al., 2018). With these escalating climatic challenges, the resilience and adaptability of the indigenous communities in the Peruvian highlands are put to the test, highlighting the importance of preserving and applying TEK (Bergmann et al., 2021; Boillat & Berkes, 2013; Whyte, 2013).

2.3. El Niño Current

El Niño, also known as the "El Niño current", is a periodic climatic phenomenon characterized by the warming of sea surface temperatures in the central and eastern equatorial Pacific Ocean (Whyte 2013). Historically, records suggest that El Niño events have been occurring for at least several thousand years, influencing global weather and climate patterns (Rodbell et al., 1999). In the context of the Urubamba Valley in Cusco, historical documents and oral traditions indicate that the region has experienced significant climate variability linked to El Niño, resulting in agricultural disruptions due to shifts in rainfall patterns and temperature (Kug et al., 2009).

In recent times, smallholder agricultural farmers in this valley are noting increased frequency and intensity of El Niño events, attributed to broader global climate change trends (Trenberth & Hoar, 1997). Addressing these challenges, they are leveraging TEK, passed down through generations, as a fundamental adaptive strategy against changing climatic conditions (Currie-Alder et al., 2021; Whyte 2013).

The year 2023 brought the Urubamba Valley in Cusco face-to-face with one of the most intense El Niño impacts in its history. Traditional crops, vital for sustenance and local economics, faced substantial threats. Corn and quinoa yields plummeted, and there was a notable decrease in seed viability for future crops due to inconsistent rainfall patterns, making seed storage an immense challenge (Yglesias-González et al., 2023). Unprecedented frost events caused by sudden temperature drops further jeopardized growing crops (Yglesias-González et al., 2023). Fluctuating local water sources combined with elevated temperatures triggered significant soil erosion and decreased fertility, making cultivation even harder (Sekhon et al., 2022; Yglesias-González et al., 2023).

The socio-economic implications were profound. Many farmers struggled to meet their basic needs, with local markets seeing inflated prices due to diminished supply. The challenging agricultural environment also instigated a noticeable increase in rural-urban migration, as families sought more promising opportunities elsewhere (French et al., 2020). As a countermeasure, some farmers began diversifying their crops, while others reverted to age-old terracing techniques to combat the adversities (Cai et al., 2014; French et al., 2020; Yglesias-González et al., 2023).

Recent climate models forecast an alarming trend: a surge in the frequency and intensity of El Niño events in upcoming decades due to compounded global climate change effects (Cai et al., 2014). South American-centric studies also predict an intensification and a potential shift in El Niño's spatial patterns, hinting at even more severe impacts on historically susceptible regions like Urubamba (Cai et al., 2014; Timmermann et al., 2018). The observed and anticipated trends emphasize the importance of blending TEK with modern agricultural practices, fostering resilience against the dynamic challenges of El Niño and comprehensive climate change.

2.4. TEK as a Pillar of Resilience

Scientific studies stress the importance of indigenous knowledge systems like TEK in offering solutions to combat these climatic challenges (Berkes et al., 2000; Turner & Clifton, 2009). TEK, by virtue of being a cumulative body of knowledge that evolves through experiential learning and close interaction with nature, offers adaptive strategies that are often site-specific and sustainable (Orlove et al., 2009; Whyte, 2013). These methods are not only ecologically sound but are also economically viable, thereby ensuring that the livelihoods of indigenous communities are safeguarded (Whyte, 2013).

Moreover, the ingrained cultural values and belief systems accompanying TEK promote community cohesion and shared responsibility (Leonard et al., 2013). This communal approach towards problem-solving enhances collective efficacy, vital for the execution of any adaptive measures (Gómez-Baggethun & Barton, 2013). Furthermore, TEK is often intertwined with spiritual and ceremonial practices, instilling a sense of respect for the environment, and promoting sustainable utilization of resources (Haq et al., 2023). By reinforcing the bond of local communities to their ancestral practices and delivering pragmatic solutions, TEK emerges as a pillar of perseverance and resilience amid growing environmental pressures (Turner et al., 2000).

2.5. Documentation Efforts and Importance of TEK Conservation

Efforts to document TEK have been infrequent, and there has been a realization among researchers about the urgency of documenting and preserving this knowledge. Studies have underlined that with increasing globalization, younger generations in indigenous communities are moving away from traditional practices, leading to the potential erosion of this rich body of knowledge. The conservation of TEK is not just about preserving a way of life but also about ensuring that a reservoir of adaptive strategies against climate change is available for future generations (Berkes et al., 2000; Reyes-Garcia et al., 2013).

2.6. Broader Implications of Integrating TEK with Modern Science

Modern scientific methods, while advanced and sophisticated, can often benefit from the detailed, localized insights offered by TEK. Recent literature has advocated for an integrative approach where TEK and modern scientific methodologies complement each other (Lemi, 2019; Gómez-Baggethun et al., 2013). Such a collaborative model would allow for the creation of comprehensive adaptation strategies that are both technologically advanced and grounded in local realities (Fernández-Llamazares & Cabeza, 2018). This merge of the old and new is seen as the way forward in the fight against the global challenge of climate change (Lauer & Aswani, 2009; Gómez-Baggethun et al., 2013).

Facing the intensifying challenges posed by climate change, there is a growing need to harness and integrate ancient knowledge, particularly the TEK of the indigenous communities in the Peruvian highlands. Communities with generations of rich traditions offer invaluable knowledge, insights, and sustainable adaptive strategies. Drawing from the historical and contextual significance of TEK, this research emphasizes the imperative of valuing such wisdom and merging lessons from the past with contemporary solutions.

The insights offered by TEK stand as potential foundations for creating robust, sustainable adaptation mechanisms. This narrative sets the stage for this research, emphasizing the aims, questions, and objectives committed to assimilating and documenting the indigenous approaches to climate adaptation.

3. Aim & Research Questions

3.1 Aim

This research aims to enhance the current understanding of climate adaptation by emphasizing the crucial role of integrating TEK among the indigenous farming communities in the Peruvian highlands. By documenting and analyzing specific TEK practices, the study intends to bridge a notable knowledge gap, providing invaluable insights into potential adaptation strategies.

3.2. Research Questions

I. What are the salient characteristics of smallholder farming system in the Peruvian Highlands?
II. What specific TEK practices are indigenous community farmers in the Peruvian highlands implementing to adapt to the impacts of climate change at the farm level?
III. Which indicators are the indigenous community farmers using to assess TEK strategies for climate change adaptation at farm level?
IV. How do indigenous community farmers share and transmit TEK related to climate change adaptation strategies among themselves?

4. Theories

4.1. Conceptualizing the Problem

The underlying framework seeks to investigate how TEK functions as a means of adapting to climate change impacts at the farm level among indigenous farming communities in the Peruvian highlands. This framework emphasizes the significance of comprehending the precise TEK methodologies these communities employ, the factors influencing their strategic planning, the evaluation and monitoring of TEK-based strategies, the sharing and transmission of TEK, and the barriers and challenges faced in implementing TEK practices for climate change adaptation.

4.2. Key Concepts

Indigenous knowledge refers to the accumulated knowledge, practices, beliefs, and values held by indigenous communities. It encompasses a deep understanding of the environment, including ecological processes, sustainable resource management, and cultural systems. In this research, indigenous knowledge serves as the foundation for TEK practices implemented by indigenous community farmers in the Peruvian highlands to mitigate the impacts of climate change. It recognizes the value of indigenous knowledge systems in addressing environmental challenges and fostering resilience (Bruchac, 2014).

Traditional Ecological Knowledge (TEK) refers to the specific knowledge and practices developed by indigenous communities over generations, shaped by their interactions with the natural environment. It encompasses insights into ecological processes, seasonal patterns, climate dynamics, and sustainable resource use (Bruchac, 2014). In this research, TEK is at the core of indigenous community farmers' strategies for climate change adaptation at the farm level. It represents their adaptive and resilient approaches to managing the impacts of climate change based on their deep understanding of local ecosystems and traditional practices (Berkes, 2009) TEK is a cumulative body of knowledge, practice, and belief that is developed, adapted, and transmitted through generations within indigenous communities. It reflects the wisdom and insights gained through direct experiences, observations, and cultural transmission. By incorporating TEK into their farming practices, indigenous farmers in the Peruvian highlands utilize a holistic knowledge system that recognizes the interconnectedness between humans, nature, and spiritual beliefs, enabling them to mitigate the impacts of climate change while sustaining their livelihoods (Berkes, 2009; Berkes et al., 2013; Bruchac, 2020).

Climate Change Adaptation refers to the strategies and practices implemented by indigenous community farmers in the Peruvian highlands to mitigate and cope with the impacts of climate change at the farm level. These adaptation measures are informed by their TEK and aim to enhance the resilience and sustainability of their agricultural systems in the face of changing environmental conditions (Heikkinen, 2021). Climate change adaptation includes a range of actions, such as modifying farming techniques, diversifying crops, implementing water management strategies, adjusting planting and harvesting schedules, and employing traditional practices that have proven effective in navigating shifting climatic patterns (Cometti, 2020). By drawing upon their rich TEK, indigenous community farmers seek to adapt their farming practices to ensure food security, maintain cultural practices, and protect their livelihoods in the context of a changing climate (Berkes et al., 2013).

Peer-to-Peer Knowledge Sharing/Exchange refers to the process of sharing and exchanging knowledge and experiences directly among individuals or communities on an equal footing. In this research, peer-to-peer knowledge sharing/exchange is explored as a means through which indigenous community farmers transmit their TEK related to climate change adaptation strategies. It highlights the importance of community-based collaboration, learning, and mutual support in enhancing climate change resilience and fostering innovation (Šūmane et al., 2018; Thomas et al., 2020).

4.3. Theoretical Perspectives

Resilient Farming Systems: This perspective recognizes the complex interactions between ecological, social, and economic factors within agricultural systems and seeks to enhance their capacity to cope with and recover from disturbances associated with climate change. Resilient farming systems prioritize the diversification of crops and livestock, the conservation of natural resources, the enhancement of soil health and fertility, the efficient management of water resources, and the integration of TEK and indigenous knowledge. They also emphasize the importance of adaptive capacity, which involves the ability of farmers to adjust their practices and strategies in response to changing climatic conditions (Altieri et al., 2011; Meuwissen et al., 2019).

Community-Based Adaptation: This perspective emphasizes the significance of community engagement and local decision-making processes in climate change adaptation. It underscores the importance of understanding the factors influencing the strategic planning of indigenous farmers, their evaluation and monitoring of TEK-based strategies, and the sharing and transmission of knowledge within the community (David-Chavez & Gavin, 2018; Lemi, 2019).

5. Literature Review

5.1. TEK Practices for Climate Change Adaptation

Indigenous communities across the globe have long relied on their TEK to adapt to changing environmental conditions, including the impacts of climate change (Lemi, 2019). In the Peruvian highlands, indigenous farmers have developed a range of TEK practices to address climate change at the farm level (Berkes et al., 1994; Saylor et al., 2017). For example, agroforestry techniques, such as shade-grown coffee and intercropping with nitrogen-fixing trees, have been implemented to enhance climate resilience and maintain soil fertility (Berkes, 2009). Such systems are not only productive but also vital in preserving agrobiodiversity, providing a wide array of ecosystem services that contribute to the overall resilience of agricultural landscapes (Altieri & Koohafkan, 2008). Moreover, ancient irrigation canals and terracing systems have been employed for effective water management, mitigating water scarcity, and preventing soil erosion (Altieri et al., 2020; Pimbert & Pretty, 1997). These time-tested practices are seen as models of sustainable land use, often outperforming modern agricultural techniques in terms of long-term sustainability and environmental harmony (Pretty & Bharucha, 2014). Additionally, crop diversification and the utilization of traditional seed varieties have proven successful in sustaining agricultural productivity and biodiversity amidst changing climatic conditions (Tufford, 2006). This genetic diversity is crucial not only for food sovereignty but also for providing the genetic material necessary to adapt crops to future climatic conditions (Tufford, 2006). These practices embody a valuable blend of cultural and biological heritage, representing the wisdom and adaptation strategies of indigenous communities (Lemi, 2019).

The global significance of TEK in climate change adaptation is becoming increasingly recognized as indigenous and local communities face the frontline impacts of climate variability. In regions like the Sahel, for example, pastoralists employ TEK to navigate the uncertainties of rainfall and pasture availability, demonstrating a resilient lifestyle finely adapted to the region's climate variability (Reid et al., 2014). Across these diverse contexts, TEK stands out as a living knowledge system, continuously evolving in response to environmental feedback and the shared experiences of community members.

5.2. Evaluation and Monitoring of TEK-based Strategies

Effectively evaluating and monitoring the success and effectiveness of TEK-based strategies is crucial for their ongoing refinement and adaptation. Indigenous community farmers in the Peruvian highlands employ various methods to assess the outcomes of their TEK practices (Lemi, 2019; Saylor et al., 2017). This mirrors the practices of other indigenous communities such as the Inuit in the Arctic, who have developed a system of environmental indicators that are deeply ingrained in their culture and daily practices. These indicators, which include observations of ice formation, the timing of migrations, and changes in animal behavior, are crucial for the Inuit as they inform hunting and fishing practices that are central to their subsistence and culture (Berkes & Jolly, 2001). Systematic observations and qualitative assessments enable farmers to monitor changes in crop yields, soil quality, and water availability over time. These methods are like the traditional ecological calendars used by the indigenous communities of North and South Dakota in the United States, which help predict seasonal changes and plan agricultural activities (Ruelle et al., 2022).

Moreover, participatory approaches, involving community discussions and knowledge sharing, provide valuable feedback on the perceived benefits and challenges of TEK-based strategies. The Maasai of East Africa, through their intimate understanding of various plants in their rangelands and pastures, including each plant's seasonality, nutritional value, toxicity, and medicinal properties for different animals, effectively manage their pastoral systems. This knowledge is particularly vital during dry years for making informed decisions about grazing, demonstrating a form of community-based monitoring and management of their pastoral resources (Hedges et al., 2020; Sharifian et al., 2022). These evaluation and monitoring processes contribute to the adaptive management of TEK practices, allowing farmers to refine their approaches and optimize their resilience to climate change (Sharifian et al., 2022).

5.3. Knowledge Sharing and Transmission of TEK for Climate Change Adaptation

The transmission of TEK related to climate change adaptation strategies is crucial for its preservation and continued effectiveness. In the Peruvian highlands, the sharing and transmission of TEK are achieved through a rich tapestry of cultural practices. This includes oral traditions, where stories and experiences are woven into narratives that convey complex ecological knowledge. Intergenerational knowledge transfer is central to this process, as elders impart wisdom through storytelling and practical demonstrations, methods paralleled in the indigenous communities of the Pacific Northwest, where knowledge of salmon runs is passed down to ensure sustainable fishing practices (Reid, 2020).

Community gatherings, such as agricultural festivals and seed exchange events, are focal points for knowledge sharing among farmers, facilitating collective learning and innovation. These gatherings are like to the 'Guelaguetza' festivals in Oaxaca, Mexico, where communities come together to share crops, seeds, and agricultural techniques (Rivera López et al., 2019). Furthermore, informal networks and social relationships promote the exchange of TEK practices among neighboring communities, enhancing resilience. This is observed in the seed networks of the Quechua in the Andes, where seeds are not only shared but also stories, songs, and rituals, enriching the cultural context of agricultural biodiversity (Jokisch & Zimmerer, 1999).

The role of TEK in climate change adaptation is multifaceted, extending beyond practical applications to embody a worldview that emphasizes deep interconnectedness with nature. This perspective is crucial in a time when conventional strategies may fall short in the face of global environmental changes. The inherent adaptability of TEK, supported by its community-centric approach and rich cultural foundations, makes it a central component of global climate change resilience strategies.

5.4. Barriers and Challenges in Implementing TEK Practices for Climate Change

Despite the valuable contributions of TEK practices, indigenous community farmers in the Peruvian highlands face various barriers and challenges when implementing these strategies to address climate change. Similar challenges are reported by indigenous communities globally, such as the Maasai pastoralists of East Africa, who confront hurdles in maintaining their traditional grazing practices due to land privatization and climatic uncertainties (Reid et al., 2014). Limited access to resources, including land, water, and agricultural inputs, impedes the full implementation and scaling-up of TEK practices. This is echoed in the experiences of the Gwich'in in the Canadian North, where access to traditional territories is restricted, impacting their subsistence practices and cultural traditions (Natcher et al., 2005).

Policy constraints and inadequate recognition of indigenous rights and knowledge systems further impede the integration of TEK into formal climate change adaptation strategies. The struggles faced by the Sami people to have their traditional reindeer herding practices recognized within national frameworks highlight similar policy gaps (Tyler et al., 2007). Moreover, socio-cultural dynamics and the erosion of traditional farming practices pose challenges in the continuity and transmission of TEK across generations. For the Ainu of Japan, the loss of traditional ecological practices is exacerbated by the rapid pace of modernization and assimilation policies (Cornell, 1964).

The survival of TEK amidst these challenges is a testament to its resilience and the dedication of indigenous communities to preserve their heritage. However, for TEK to thrive and continue contributing to climate change adaptation, there must be a concerted effort to address these barriers. This includes policy reforms that recognize and integrate TEK, support for community-led resource management, and efforts to facilitate the intergenerational transfer of knowledge. Only with a supportive framework that acknowledges the value of TEK can its full potential be realized in the global effort to combat climate change and promote sustainable development.

6. Materials and Methods

6.1. Study Area

The research was conducted in Urubamba, a prominent town situated within the Sacred Valley in Cusco, Peru. The valley, often referred to as the "heart of the Inca Empire," is historically important and is known for its fertile lands, pleasant climate, and its proximity to the ancient capital of Cusco. With a history rich in agriculture, religion, and infrastructure, the valley, nourished by the Urubamba River, produced essential crops such as maize, potatoes, and quinoa, sustaining the Inca population. Additionally, sites like Ollantaytambo and Pisac highlight the region's religious and political significance during the Inca era, showcasing intricate designs, terraced agriculture, advanced water systems, and ceremonial centers.

6.1.1. Location and Size

Urubamba, situated roughly 20 kilometers north of Cusco, the historical capital of the Incas, is an active town located in the Sacred Valley region of southeastern Peru. The town's location within the extensive area of the Sacred Valley, which spans approximately 100 square kilometers, is strategic, resting alongside the Urubamba River and enclosed by the majestic Andes mountains (Bauer, 2004; Gade, 2016). The geography and climate of the region have played a significant role in its development, providing fertile lands for agriculture, which was the foundation of the Incan economy and remains vital for the local communities today (Bauer, 2004; Gade, 2016; Wright et al., 1997).

Urubamba's proximity to Cusco has historical importance, as Cusco was the center of the Inca Empire, which influenced the surrounding regions through extensive trade, cultural exchange, and agricultural innovations (Gade, 2016; Hernández Astete, 2012). The Sacred Valley, with Urubamba as a central locality, was a critical corridor linking Cusco to various outposts and agricultural terraces that exemplify the advanced engineering skills of the Incas (Gade, 2016; Burger & Salazar, 2004).

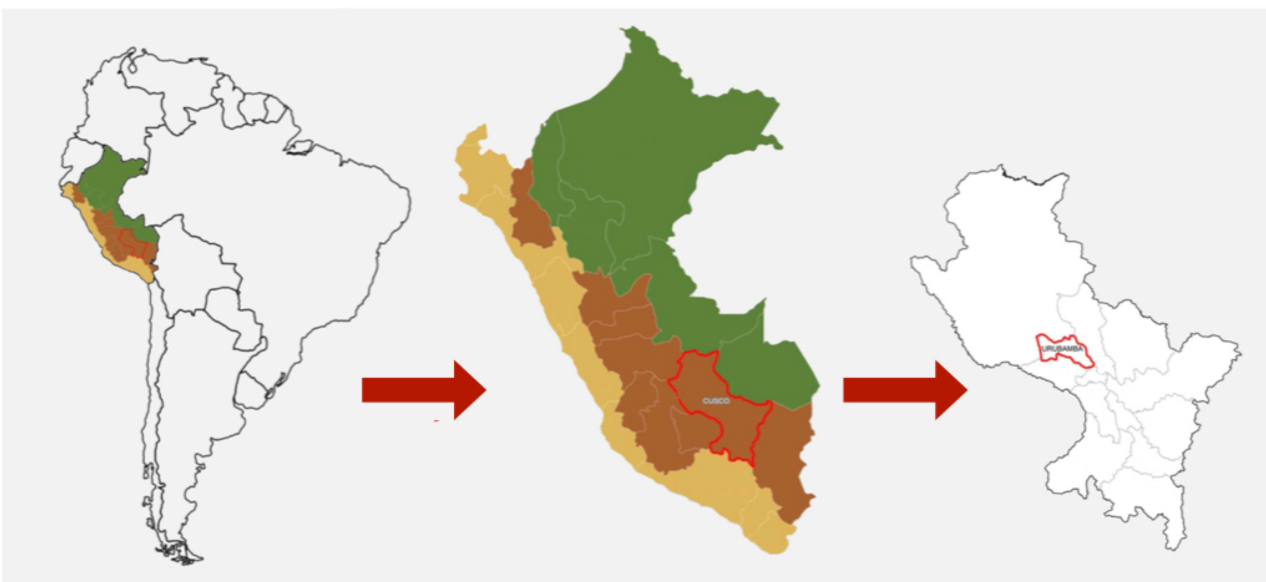

Figure 1: Map of South America (Right), Peruvian map (middle), and map of Cusco (right) with the city of Urubamba traced in red.

6.1.2. Topography

The altitude of Urubamba varies significantly, with elevations starting at roughly 2,800 meters above sea level (m.a.s.l.) near the Urubamba River and ascending to over 4,000m a.s.l. This variation in elevation creates distinct environmental zones that have been expertly utilized by the indigenous peoples for agriculture, a practice rooted in pre-Columbian Andean cultures (Burger & Salazar, 2004; Gade, 2016). The Urubamba River, the main water source, and its tributaries significantly shape the region's topography, contributing to the diversity of microclimates within the valley. The lower elevations near the river boast a warmer, temperate climate that supports the cultivation of maize, potatoes, and quinoa—staples that have been central to the Andean diet for centuries (Burger & Salazar, 2004; Gade, 2016).

In contrast, the higher elevations, which experience cooler temperatures, support different vegetation and wildlife, as well as different agricultural products. Such verticality in land use is characteristic of Andean societies, where different ecological tiers are used to maximize agricultural diversity (Burger & Salazar, 2004; Gade, 2016). This complex topography not only shapes the physical landscape but also the cultural and social structures of the communities that inhabit Urubamba. The topographical features dictate the patterns of settlement, agriculture, and transport, making it a central component of the region's identity and way of life. The interplay between the environment and human activity in this region is a vivid example of the sophisticated land use strategies developed by Andean societies to adapt to challenging mountainous terrains (Burger & Salazar, 2004).

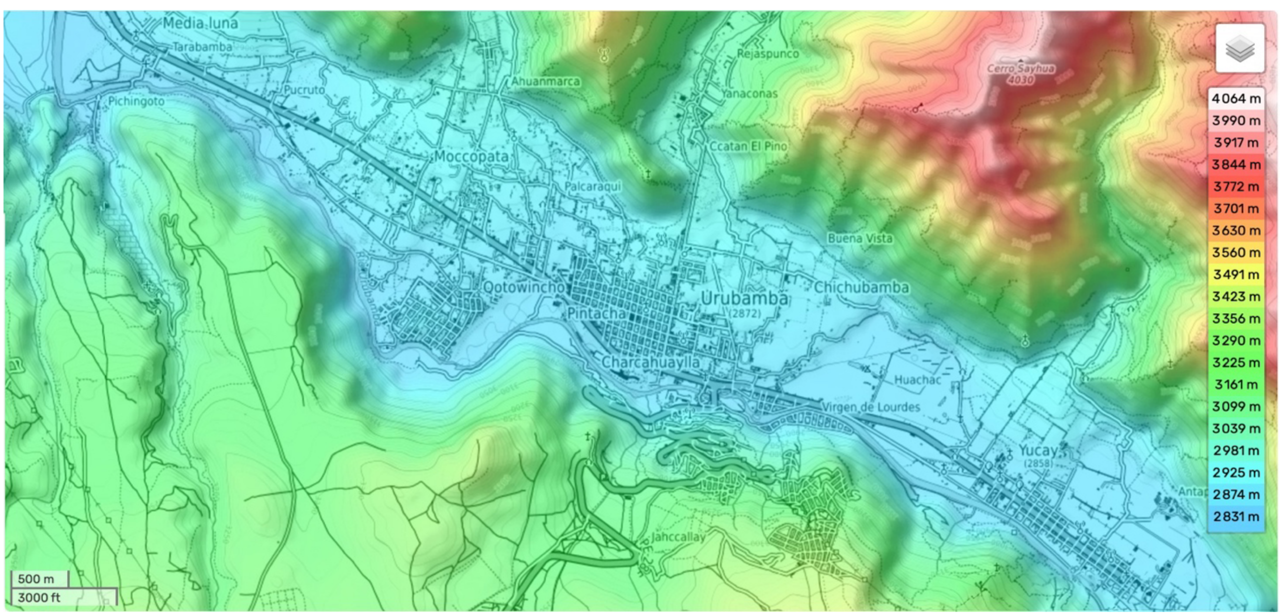

Figure 2: Topographic map of Urubamba. *Source: Topographic Map (2023)*

6.1.3. Geology & Soils

The geology of Urubamba and the encompassing Sacred Valley is intricate, with a foundation predominantly featuring granodiorite rocks from the Cusco batholith, an intrusive igneous rock formation indicative of significant magmatic activity in the region's geological past. These granodiorite formations are a segment of the Andean batholith, which extends along the length of South America's Cordillera mountain range and underpins some of the most rugged terrain in the Peruvian Andes (Carlotto Caillaux et al., 1996).

Tectonic forces, including the uplift associated with the subduction of the Nazca plate beneath the South American plate, have been instrumental in sculpting the present-day landscape. This orogenic process has elevated the batholiths and related sedimentary formations, crafting the towering peaks and profound valleys that are emblematic of the region (Kar et al., 2023).

Glacial and fluvial erosion have further defined the landscape. Glaciers during past ice ages sculpted the valleys into their characteristic U-shapes, leaving a legacy of debris and other glacial imprints. Concurrently, the persistent erosion by the Urubamba River and its tributaries continues to shape the valley, dissecting through rock layers to expose the stratigraphy and enhancing the valley's agricultural potential by depositing fertile alluvium (Gade, 2016).

The soil composition of Urubamba is crucial for the region's agricultural productivity. The soils, chiefly Andosols and Mollisols, are interspersed with patches of volcanic origin. These soils are lauded for their superior moisture retention, a crucial attribute in a region where water availability can fluctuate (Zehetner et al., 2003). However, their compactness can precipitate runoff during intense rainfall, presenting challenges for soil and water conservation. The volcanic ancestry of these soils contributes to their distinctive features: they are frequently shallow, stony, and permeable, conditions that have spurred inventive agricultural adjustments by local farmers over the ages (Certini et al., 2006).

6.1.4. Vegetation

The vegetation of Urubamba is shaped by a complex interplay of climate, topography, and soil quality, resulting in a diverse tapestry of plant life historically integral to agriculture. The region's flora has evolved under the influence of both human activities and climatic shifts, leading to a rich mosaic of high-altitude forests, grasslands, and cultivated areas. The climate, varying with altitude, ranges from temperate conditions in the river valleys to colder temperatures at higher elevations, each fostering different plant communities (Gade, 2016).

Topography plays a crucial role in determining sunlight exposure, precipitation patterns, and wind flow, which collectively influence the distribution and types of vegetation across the valley (Inbar & Llerena, 2000). The soil composition, richer in the valley floors due to alluvial deposits from the river and mountain erosion, supports the growth of agriculture that has been historically significant to the region. In contrast, the less fertile, rocky soils of higher elevations harbor flora adapted to more stringent conditions (Gade, 2016). The region's flora comprises high-altitude forests, home to tree species uniquely adapted to the thin air and high ultraviolet radiation exposure. These forests are interspersed with expansive grasslands dominated by vital perennial grasses, resilient to the colder temperatures of higher altitudes (Postigo et al., 2008). Native crops such as potatoes, quinoa, and maize, cultivated in the region, reflect the agricultural adaptations of the local communities to their environment. These crops have been carefully selected and cultivated over centuries to thrive in the valley's varying microclimates and soil conditions, ensuring food security and sustainability (Orlove, 1980).

Human activities, including agriculture, deforestation, and urbanization, combined with climatic shifts, have led to the continuous evolution of the region's flora. While these changes have sometimes brought benefits, such as in agricultural developments, they have also posed challenges like habitat fragmentation and biodiversity loss, necessitating careful management and conservation efforts (Gade, 2016).

6.1.5. Climate & Climate change

Urubamba's climate is a defining factor in the agricultural practices and livelihoods of the local communities. The temperate climate, characterized by two distinct seasons, aligns with the broader climatic patterns found in the Andean region of Peru. The wet season, from November to March, is critical for crop cultivation, aligning with findings that show heavy rainfall during this period is fundamental for replenishing soil moisture (Vuille et al., 2000). Conversely, the dry season from April to October presents different agricultural challenges, as water becomes a scarcer resource.

The bimodal distribution of rainfall in Urubamba, with peaks in the early summer and late fall, necessitates strategic agricultural planning. During the dry season, farmers rely on crops that can withstand arid conditions or utilize irrigation systems sustained by glacial meltwater and spring rains, a practice that is increasingly important as climate change impacts water availability (Baraer et al., 2012).

Climate change has significantly impacted Urubamba, with observable effects on the environment and agriculture. Rising temperatures, glacier retreat, and increased frequency of extreme weather events have reshaped the region's landscapes, corroborated by temperature analyses over the past four decades in the Andes (Thompson et al., 2000). Figure 3 illustrates the average annual temperature change from 1979 to 2021, with a linear trend indicating a clear upward trajectory in temperatures, echoing the regional warming trends, and Figure 4 showcases the average annual precipitation trends for the same period of time, where an increasing trend in precipitation can be observed.

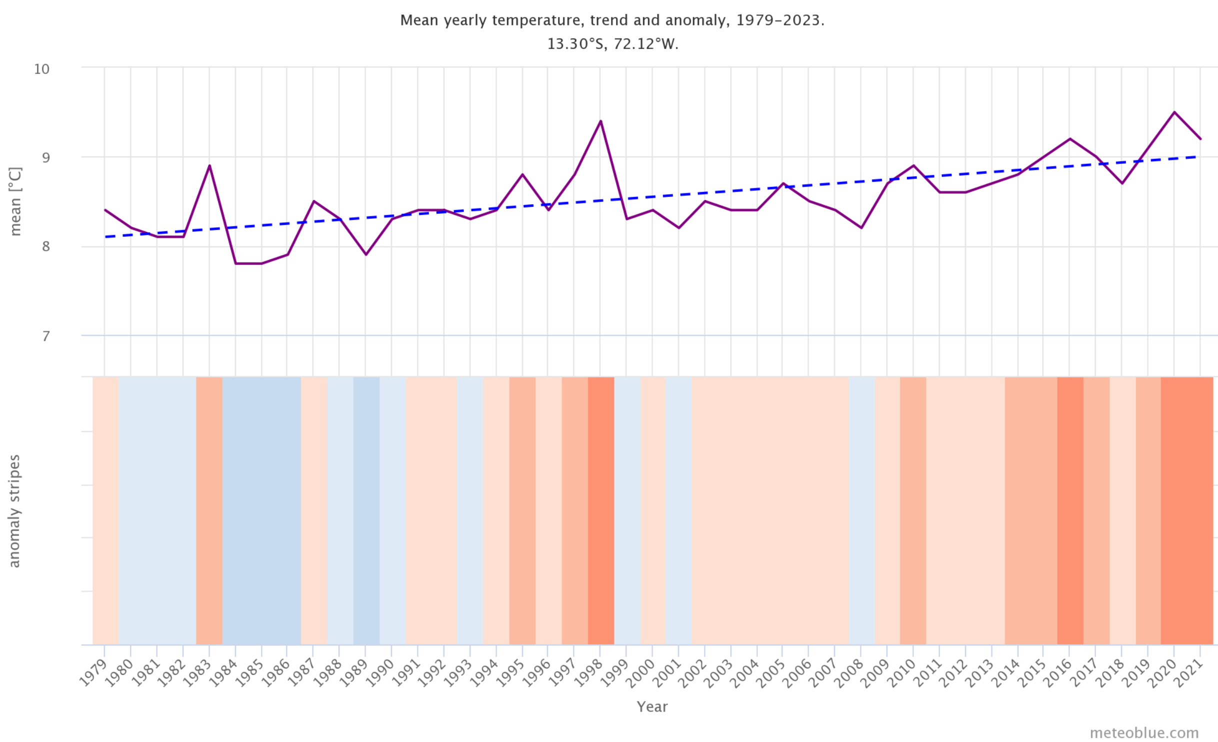

Figure 3: An estimate of the average annual temperature for Urubamba from 1979 to 2021. The dotted blue line represents the linear trend of climate change. An upward trajectory from left to right indicates a positive temperature trend, indicating an increase in warming in Urubamba due to climate change. A horizontal

trajectory suggests an absence of a discernible trend, while a declining one suggests cooling in the region over time. Subsequently, the lower graph illustrates the "temperature bands." Each color band symbolizes the average annual temperature: blue shades for cooler years and red shades for warmer years. *Source: meteoblue (2023).*

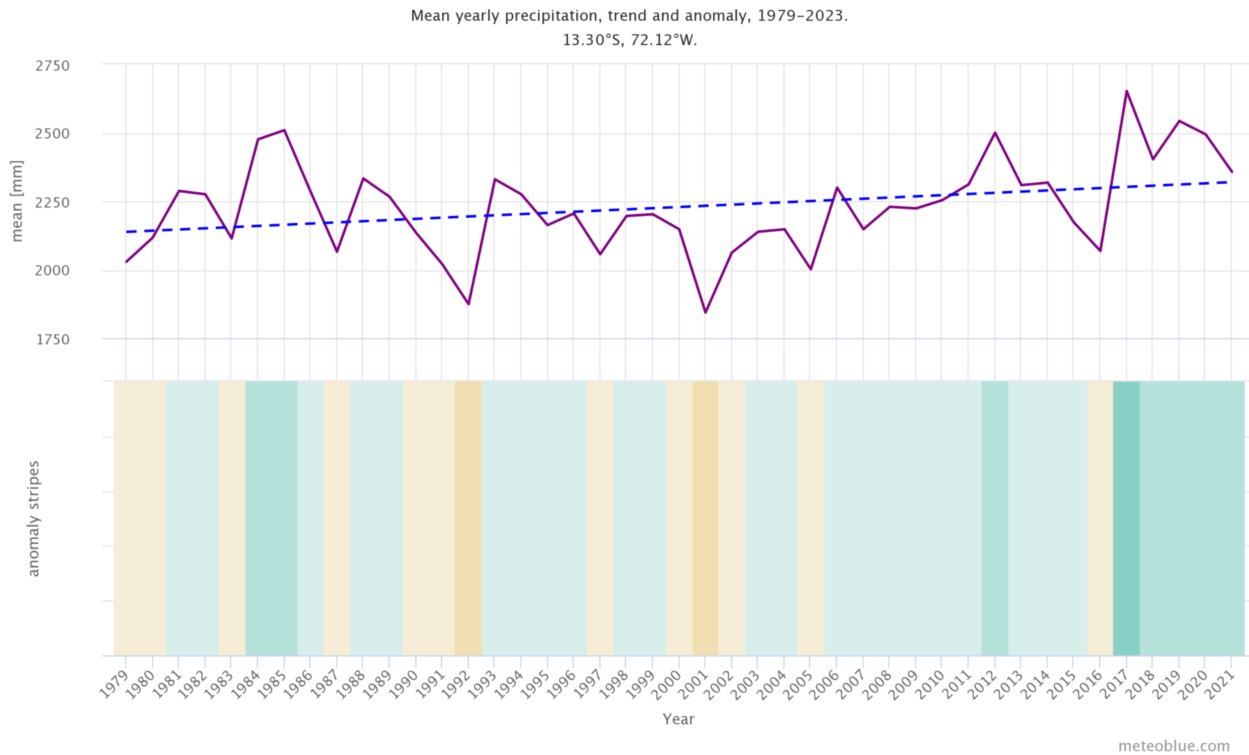

Figure 4: An estimate of the average annual precipitation in Urubamba from 1979 to 2021. The dotted blue line denotes the linear trend of climate change. An upward trend from left to right indicates a positive precipitation trend, suggesting wetter conditions in Urubamba due to climate change. A horizontal line does not highlight a palpable trend, and a downward direction indicates progressive dryness in the region over time. In the section below, the graph displays the "precipitation bands." Each color band reflects annual precipitation: green for wet years and brown for drier ones. *Source: meteoblue (2023).*

Figure 5 highlights the temperature anomalies for each month from 1979 to the present. These anomalies provide an outlook of how specific months deviate from a 30-year climate average. The increasing trend of red months over time is a clear indication of the influence of global warming. This has a cascade of effects, from altering the phenology of plant and animal species to affecting the prevalence and distribution of vector-borne diseases.

In parallel, the bottom graph in Figure 5 shows the precipitation anomaly for each month. It indicates the months that experienced more (green) or less (brown) rainfall than the 30-year average. This data is crucial for understanding the monthly variability in precipitation, which directly influences agricultural planning and water conservation efforts.

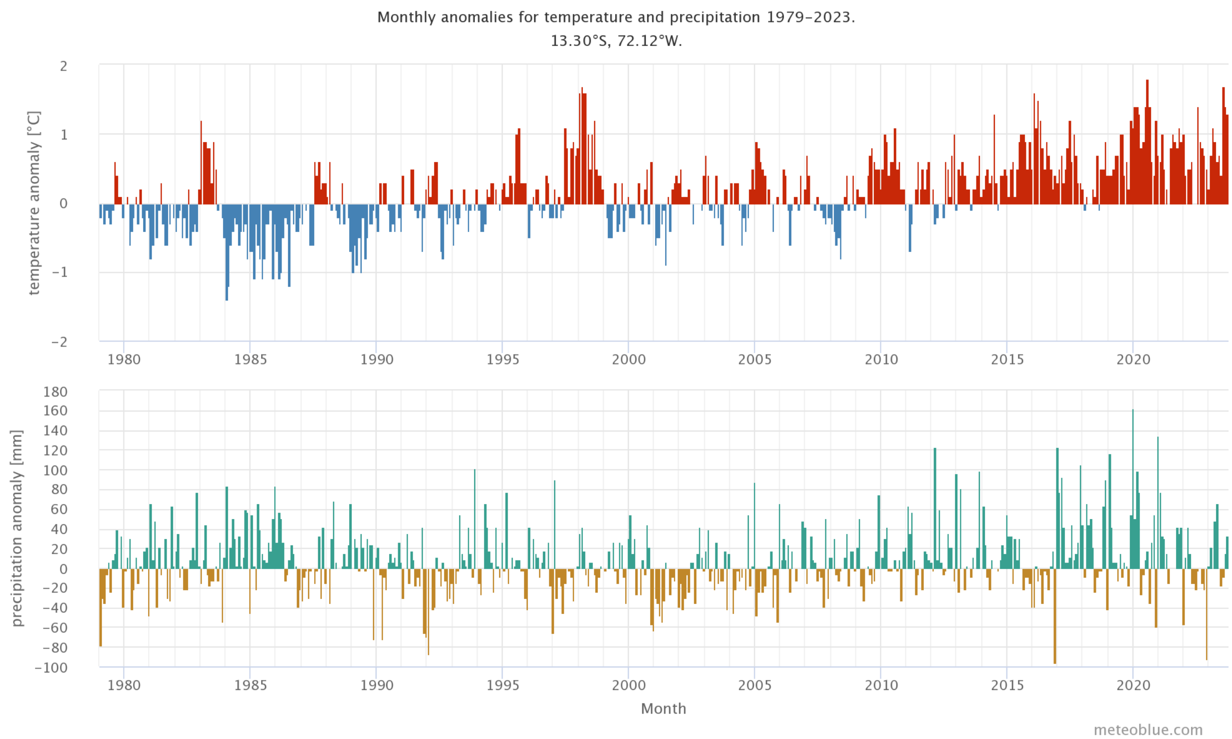

Figure 5: Display of the temperature anomaly for each month from 1979 to the present. This anomaly signifies how much warmer or cooler a given month was compared to the 30-year climate average from 1980 to 2010. In this context, red months were warmer and blue months were cooler than usual. In many areas, you'll observe an increase in warmer months over the years, which is indicative of global warming linked to climate change. The bottom graph illustrates the precipitation anomaly for every month from 1979 to now. This measures whether a month experienced more or less rainfall compared to the 30-year climate average from 1980-2010. Here, green months had higher rainfall and brown months were drier than typical.

It's important to note that while these figures provide invaluable insights, they may not capture hyper-local variations, particularly those influenced by microclimates or urban heat islands.

6.2. People and Culture

6.2.1. People of Urubamba

The people of the Urubamba Valley embody a living tapestry of ancient Andean traditions, interwoven with the dynamics of modern influence. Their deep-seated respect for

"Pachamama" or Mother Earth is a testament to their enduring Incan heritage and is foundational to their daily rituals, agricultural practices, and communal festivities (Gade, 2016). The Quechua lineage, reflected in their language, storytelling, and intricate textiles, serves as a narrative of their ancestral legacy and the environment, embodying the intricate relationship between culture and nature (Gade, 2016).

Music and dance, with instruments like the pan-flute and traditional drumbeats, are the heartbeat of community gatherings in Urubamba, echoing the region's rhythmic connection to the Andean landscape and its cycles. These cultural expressions are not only forms of entertainment but also a communal embrace of life's ebbs and flows. As global influences reach the valley, the community navigates the crossroads of tradition and modernity, adopting new approaches in technology and communication while safeguarding the essence of their cultural identity (Zimmerer, 2016).

6.2.2. Community-Based Farming for Adaptation

At the heart of their agricultural practices is a community-centric approach, which stands as a testament to their resilience and adaptability. Farmers prioritize community-based knowledge exchange, resource sharing, and collective management of water systems, which are central to their sustainable farming practices and societal cohesion. This it is an essential survival technique that has been honed over centuries to contend with environmental challenges.

Their approach contrasts sharply with the more individualistic, profit-driven models often found in Western farming systems. Communal efforts contribute not only to climate resilience but also to the preservation of ancient traditions that are woven into the structure of their societies. The collective action in managing agricultural systems is seen as a pillar of social and environmental sustainability, a contrast to the competitive agricultural practices prevalent in many parts of the global north (Heikkinen, 2023).

6.2.3. Cultural Differences Compared to Western Farming Systems and Societies

The differences between the farming communities of the Urubamba Valley and those in the West extend well beyond mere farming techniques. While Western agricultural systems frequently emphasize scalability, efficiency, and technological advancement, the farmers of Urubamba place greater value on sustainability, community welfare, and the preservation and transmission of ancestral knowledge. In Western societies, agriculture is often approached through a commercial lens, driven by market demands and the pursuit of profit margins. In contrast, for the farmers of Urubamba, agriculture represents more than just a means to an economic end; it is a way of life that is deeply woven into the composition of their cultural identity and communal relationships (Gade, 2016).

6.2.4. The Use of Rituals

Integral to the farming calendar and practices of the Urubamba farmers is the incorporation of rituals. These ceremonies, which often invoke blessings for a good harvest, rain, or protection against pests, add a spiritual dimension to their agricultural practices. Rituals serve not just as religious ceremonies but also as community gatherings, reinforcing social ties and shared beliefs. Such practices contrast sharply with the more secular and mechanized farming approaches often found in the West. Moreover, these rituals reflect the profound respect these farmers have for the land, viewing it not just as a resource but as a living entity with which they share a symbiotic relationship (Gade, 2016; Salick et al., 2019).

6.3. Pre-test Component

The pre-test component of the research methodology was meticulously designed to validate the effectiveness and cultural appropriateness of the questionnaires intended for the main interviews. This preliminary phase involved a small, representative group of 5 indigenous farmers from Urubamba, selected for their diverse farming practices and extensive TEK.

This pre-testing process was a fundamental step in ensuring that the research instruments would accurately capture the realities of the participants' experiences. The farmers were asked to engage with the questionnaire, and their responses were carefully observed and recorded. Their interaction with the survey provided essential insights into the clarity of the questions, the flow of the questionnaire, and the cultural relevance of the content.

The feedback obtained was instrumental, revealing aspects of the questionnaire that could potentially lead to misunderstandings or discomfort due to cultural sensitivities. Questions that were found to be too complex or leading were rephrased, while those that were unclear were clarified. This iterative process allowed for the insights and modifications to make the survey more accessible and understandable to the participants.

Furthermore, the pre-test component served as an opportunity to build a relationship with the community, which was vital for gaining trust and encouraging candid responses in the subsequent main interviews. By involving the farmers in this initial stage, the research acknowledged and respected their expertise and perspectives, thereby fostering a collaborative environment.

As a result of the pre-test, the questionnaire was not only fine-tuned for clarity and cultural sensitivity but also for relevance, ensuring that it aligned with the lived experiences and knowledge systems of the indigenous farming communities. The modifications made post-pre-test were necessary in enhancing the quality and reliability of the data collected later. This methodological step underscores the commitment to producing a research output that is both academically robust and deeply respectful of the indigenous knowledge it seeks to document.

6.4. Methods

6.4.1. Research Design

The research design was constructed with the intent to delve deep into the nuanced composition of TEK practices among indigenous community farmers Urubamba. Recognizing that TEK encompasses complex, culturally ingrained practices, the study adopted a mixed-methods approach to capture the multifaceted nature of climate change adaptation strategies.

This mixed-methods approach combined quantitative methods, which allowed for the collection of numerical data that could be used to identify patterns and trends in TEK practices, with qualitative methods, which were essential for understanding the context and deeper meanings behind these practices. The quantitative component included structured survey questions that yielded data on the frequency, distribution, and extent of TEK practices.

Conversely, the qualitative aspect of the research involved open-ended interviews and participatory observations, providing rich, descriptive insights into the farmers' experiences, perceptions, and decision-making processes. This included in-depth conversations about the farmers' personal histories with TEK practices, their observations of environmental changes, and the cultural significance of their adaptation strategies.

By integrating these methods, the study was designed to not only quantify the prevalence of TEK practices but also to understand the reasons behind their use, their effectiveness, and the challenges faced in their implementation. Such an approach facilitated a comprehensive understanding of how TEK contributes to resilience and sustainability in the face of climate change.

6.4.2. Data Collection

The data collection process was carefully designed to capture the intricate relationship between indigenous farmers and their land, focusing on how TEK is employed in agricultural practices. Semi-structured interviews were conducted with 42 farmers, a method that allowed for an in-depth exploration of both quantifiable aspects of farming—such as farm size, years of farming experience, crop allocations, and observed changes in climate patterns—and the qualitative subtleties that underlie TEK practices.

These interviews were designed to strike a balance between the structured gathering of empirical data and the flexibility to explore the rich, subjective experiences of the farmers. Open-ended questions were an essential part of this process, inviting participants to share their stories, insights, and the wisdom underlying their adaptation strategies. By doing so, the research could delve into the social and cultural dimensions of TEK, such as knowledge transmission methods, communal decision-making processes, and the intergenerational passing down of practices.

The qualitative data gathered through these interviews provided a depth of understanding that numerical data alone could not offer. For example, narratives about individual experiences with changing climate patterns added a layer of meaning to the statistical trends and grounded the study in the lived realities of the community.

The decision to employ a mixed-methods design was driven by the objective to thoroughly explore the intricate nature of TEK within indigenous farming communities in Urubamba. TEK is characterized not only by its tangible expressions in farming practices but also by its embeddedness in the cultural and environmental contexts of the communities. This complexity necessitates a methodological approach capable of capturing a spectrum of data—quantitative figures to track and measure, and qualitative insights to contextualize and explain.

SPSS was the preferred software for quantitative analysis due to its advanced statistical functionalities and reliability in processing complex data sets. The choice was aimed at leveraging SPSS's capacity to execute a variety of statistical tests.

Excel's role in managing qualitative data was equally significant. It was selected for its user-friendliness and flexibility in handling data from multi-answer survey questions, which are often complex and cannot be neatly categorized or quantified. Excel allowed for the qualitative data to be organized systematically, facilitating the extraction of themes and patterns that would inform the interpretation of the quantitative findings.

6.4.3. Sampling Technique

The choice of purposive sampling was a deliberate strategy to identify and select information-rich cases for the most effective use of limited resources. This non-probability sampling technique enabled the study to focus on characteristics of a population that are of interest, which in this case included farm sizes and the duration of farming operations. By doing so, the study ensured a sample that was representative of the diverse experiences within the farming community, from small subsistence farmers to larger, more operations, and from novice farmers to those with decades of experience.

By focusing on such 'information-rich' cases, the study could provide valuable insights into the factors that contribute to the adaptability and sustainability of indigenous agricultural practices. It ensured a range of perspectives were considered, thus enabling the research to construct a more comprehensive understanding of the role of TEK in the Peruvian highlands.

6.4.4. Statistical Analysis

For the statistical analysis phase of the research, SPSS (Statistical Package for the Social Sciences) was employed for its robust capabilities in handling large datasets and performing a wide range of statistical tests. Descriptive statistics were generated to provide a summary of the central tendencies, variability, and distribution of the quantitative data collected from the field. Measures such as mean, median, mode, standard deviations, and ranges offered insights into the general patterns and trends within the data, such as the average farm size or the typical number of years in farming among the respondents.

In addition to descriptive statistics, the research delved into inferential statistics, which allowed for the examination of relationships between different variables. This included calculating correlation coefficients to explore the strength and direction of associations between various factors, such as the relationship between farm size and the diversity of crops grown. Such inferential statistical methods are fundamental for drawing conclusions that extend beyond the sample to the broader population, allowing for a deeper understanding of the dynamics at play.

6.4.5. Use of Microsoft Excel for Multi-Response Analysis

Microsoft Excel's versatility in data operation was critical for analyzing the multi-answer components of the survey questions. Its capacity for handling categorical and non-parametric data was particularly valuable for organizing and interpreting complex qualitative data sets. This was essential for the study, where responses often contained layered information that could not be easily classified into a single category or measured on a traditional scale.

When survey questions prompted multiple responses, Excel's data sorting and filtering features enabled a detailed breakdown of each answer, ensuring that every aspect of the response was considered. The software's pivot tables and conditional formatting tools allowed for the dynamic grouping and categorization of this data, making patterns and trends immediately evident. The charting features, including histograms and pie charts, provided clear visual summaries of the data, offering an intuitive understanding of the distribution and frequency of responses.

Excel was adept at facilitating a descriptive analysis of the data, where the focus was on understanding the content and context of responses rather than applying statistical tests to infer relationships. This enabled the study to capture the breadth of TEK practices and farmers' experiences with climate change, as reported in their own words.

7. Results

7.1. General Characteristics of Smallholder Urubamba Farmers

Table 1: Descriptive statistics of land allocation by crop type on smallholder farms in Urubamba.

	N	Minimum	Maximum	Standard Deviation	Variance
Cereals	42	0%	80%	18.66050%	348.214
Fruits	42	0%	40%	10.93548%	119.585
Vegetables	42	0%	50%	12.45200%	155.052
Legumes	42	0%	50%	12.60323%	158.841
Coffee & Cacao	42	0%	70%	13.38043%	179.036
Medicinal Plants	42	0%	15%	3.324%	11.048

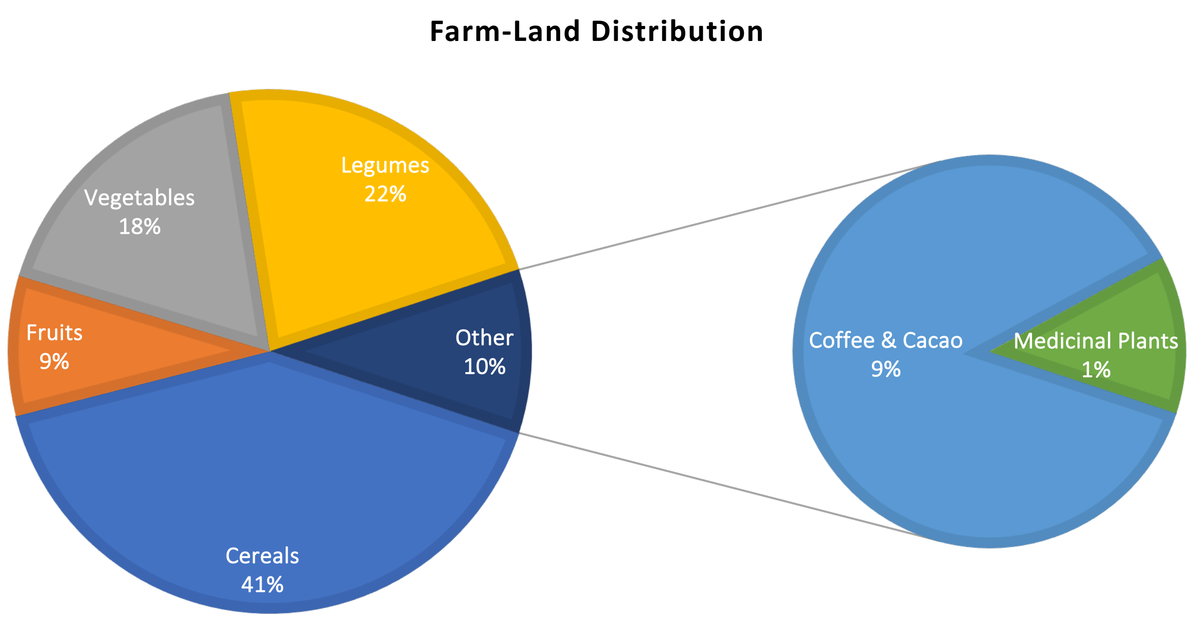

Figure 6: Land allocation for crop types among smallholder farms in Urubamba.

Table 1 and Figure 6 illustrate the distribution of land allocation by crop type among smallholder farms in Urubamba. Table 1 provides descriptive statistics, showing the minimum and maximum percentage of land allocation, along with the standard deviation and variance for each crop type, which offers a quantitative overview of farming practices among 42 surveyed farmers. Figure 6 visually represents the proportion of land dedicated to each crop type, illustrating the relative importance of different crops within the agricultural system of Urubamba. Cereals take up the largest segment, followed by legumes, vegetables, and smaller portions for fruits, coffee & cacao, and medicinal plants. This distribution reflects a diversified farming approach with a strong emphasis on staple crops while also integrating cash crops and maintaining biodiversity through the cultivation of various other plant types.

As seen in Figure 6, cereals emerge as the predominant crop, commanding an average land allocation of approximately 41.07%. This statistic emphasizes their importance in the farming system of the region. However, individual farmers exhibit a considerable degree of variability in their dedication of land to cereal cultivation, as indicated by the standard deviation and variance. In contrast, fruits play a somewhat smaller role in the agricultural spectrum, with an average land allocation of 8.69%. Their cultivation range is narrower compared to cereals, signifying that while fruit cultivation holds a secondary position, it remains a significant component of local farming practices.

Vegetables and legumes also have influence in the agricultural sector, with mean allocations of 17.85% and 22.5%, respectively. The relatively high standard deviations observed in these categories hint at a diverse range of cultivation practices adopted by different farmers. Additionally, coffee and cacao, both valuable cash crops, maintain a mean allocation of 8.81%. However, they exhibit a high degree of variability in their cultivation patterns. This variability may be attributed to differing levels of commercial focus among farmers, with some prioritizing these cash crops more than others. In contrast, medicinal plants occupy the smallest average allocation at 1.31%. This suggests that their cultivation is comparatively limited in scale when compared to food crops, underscoring their distinct role within the local agricultural framework.

Table 2: Descriptive statistics of farm size and farming years for smallholder famers in urubamba, peru.

	Mean	**Standard Deviation**	**N**
Farm Size	3.02	2.181	42
Farming Years	19.76	9.170	42

Table 2 provides descriptive statistics on the farm size and farming years for smallholder farmers in Urubamba, Peru. It includes data from 42 farmers, showing that the average farm size is 3.02 acres, with a standard deviation of 2.181 acres. This suggests that while the typical farm size is relatively small, there's variability, with some farms being larger or smaller than the average. The average number of years that these farmers have been working their land is 19.76, with a standard deviation of 9.170 years. This indicates an extent of experience among the farmers, with some having farmed for longer and others for less time, reflecting a potential depth of accumulated knowledge and varying degrees of exposure to agricultural practices and climate challenges over time.

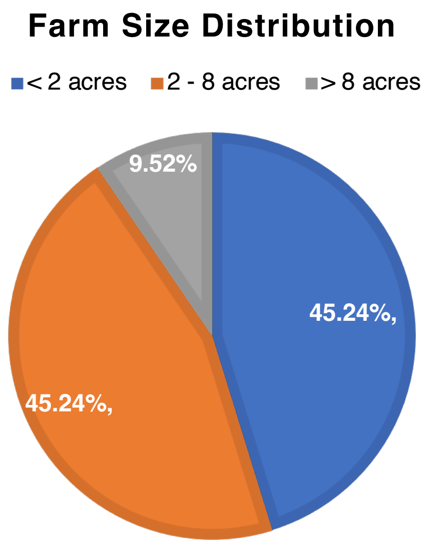

Figure 7: Distribution of farm sizes in among smallholder farmers in Urubamba.

Figure 7 shows the distribution of farm sizes among smallholder farmers in Urubamba. The chart is divided into three segments, representing farms of different sizes: < 2 acres, 2-8 acres, and > 8 acres. Each segment's proportion within the pie chart indicates the percentage of farms of that size. In this case, farms of < 2 acres and 2-8 acres each constitute 45.24% of the total, suggesting that they are the most common farm sizes in the sample. Farms of > 8 acres make up a smaller portion, at 9.52%, indicating that larger farms are less prevalent among the surveyed population. This distribution provides insights into the scale at which agricultural operations are being carried out within the Urubamba farming community.

Table 3: Correlations between farm size and farming years.

		Farm Size	Farming Years
Pearson Correlation	Farm Size	1,000	0.458
	Farming Years	0.458	1.000
Significance	Farm Size	.	0.001
	Farming Years	0.001	.
Sample Size (N)	Farm Size	42	42
	Farming Years	42	42

Table 3 is a statistical summary showing the correlation between the farm size and the number of years the farmers have been farming. The Pearson Correlation value of 0.458 indicates a moderate positive relationship between these two variables, suggesting that as the number of years of farming increases, there may be a tendency for farm sizes to increase as well. This relationship is statistically significant, as indicated by a significance level of 0.001, which is well below the conventional threshold of 0.05. Table 3 also provides insights into the relationship between the experience of farmers and the size of their operations, which can have implications for the understanding of farm development, succession planning, and the potential accumulation of land or resources over time.

7.2. Impacts of Climate Change and Adaptation Strategies

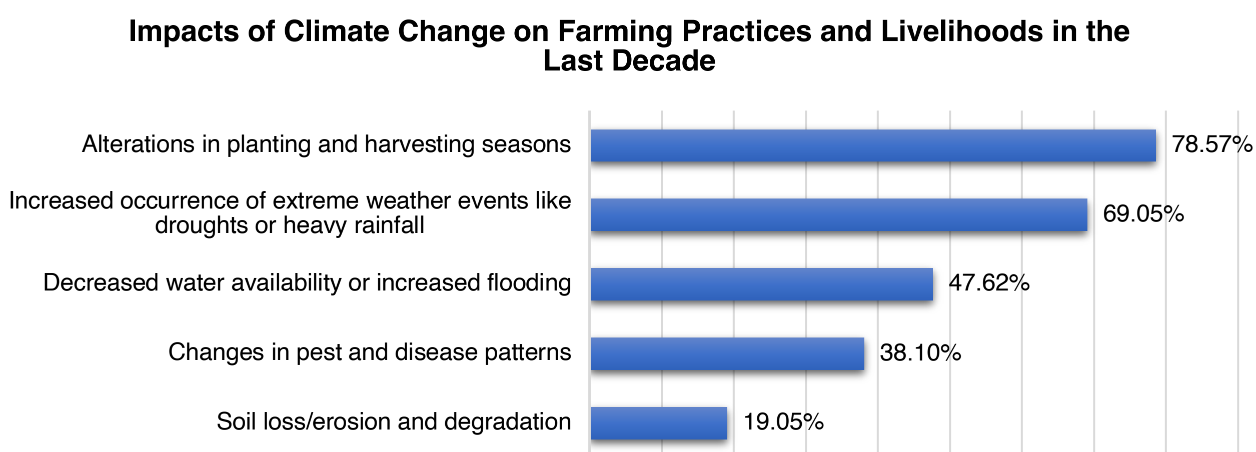

Figure 8: Climate change impacts on the farming practices and livelihoods of smallholder farmers in Urubamba over the last decade.

Figure 8 serves as a visual depiction of the challenges that smallholder farmers in Urubamba confront as a direct consequence of climate change. It provides a comprehensive view of the various facets of their agricultural activities that have been substantially impacted, as reported by the farmers themselves.

One of the most prominent and widely acknowledged impacts, reported by 78.57% of farmers, is the alteration in planting and harvesting seasons. This suggests a significant disruption of traditional agricultural cycles, likely a result of climate-induced temperature and precipitation changes. These could be correlated with the El Niño phenomenon, which is known to alter weather patterns globally, including in the Andean region. Such shifts can impact crop growth, yield, and quality, necessitating adaptations in farming practices and potentially affecting food security and community events tied to the agricultural calendar.

Additionally, a prominent impact identified by 69.05%, of an increased frequency of extreme weather events. These events, which include droughts and heavy rainfall, have the potential to inflict severe consequences on crop yields and soil quality. Prolonged droughts can parch the land and diminish water resources critical for irrigation, while heavy rainfall can lead to flooding, causing crop damage and the erosion of fertile topsoil. The combined effects of these extreme weather events underscore the vulnerability of Urubamba's agriculture to the amplified climate variability.

Approximately half of the surveyed respondents, totaling 47.62%, have experienced either a decline in water availability or an increase in flooding. Both scenarios are linked to shifting precipitation patterns and climate-induced alterations in hydrological cycles. Decreased water availability presents a significant challenge as it impacts irrigation, a fundamental component of successful agriculture in the region. Conversely, increased flooding can damage crops and strip away valuable topsoil, exacerbating the challenges faced by farmers.

The changing patterns of pests and diseases are another issue reported by 38.10% of farmers. This phenomenon is likely attributable to the altering climatic conditions, which influence the suitability of habitats for agricultural pests and diseases. Such shifts introduce new challenges as farmers must adapt their pest and disease management strategies to address these evolving threats.

Furthermore, 19.05% of farmers have reported soil erosion and/or degradation as a concerning issue. This phenomenon imperils soil fertility, resulting in diminished agricultural productivity over time. The erosion of topsoil poses a critical threat to the long-term sustainability of farming practices in the region.

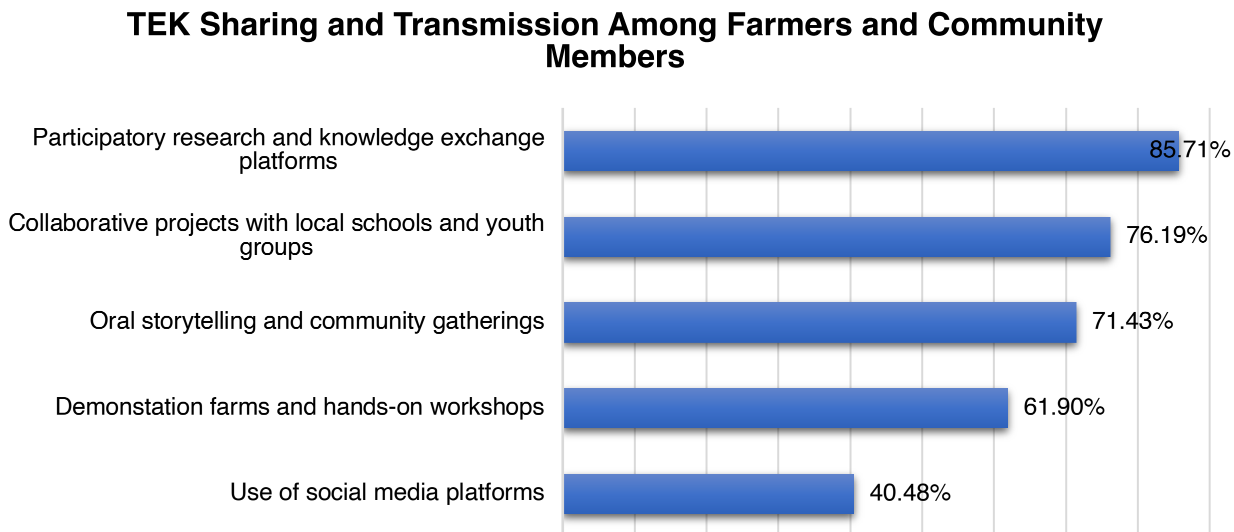

Figure 9: Adoption of sustainable farming practices as adaptation strategies to climate change.

Figure 9 serves as a valuable snapshot of the adaptive strategies that farmers in Urubamba have embraced to confront the profound impacts of climate change on their agricultural practices. These strategies, as reflected in the percentages of farmers adopting specific farming practices, highlight their resourcefulness and commitment to sustaining their livelihoods in the face of evolving environmental challenges.

One of the most striking findings is that 97.62% of farmers have adjusted their planting schedules and selected crop varieties resilient to evolving climatic conditions. This level of adaptation reflects the deep commitment of Urubamba's farmers to confront the changing climate head-on. The shift in planting and harvesting schedules acknowledges the disruptions caused by shifting climate patterns and underscores their readiness to adapt to the new normal. The choice of resilient crop varieties reflects a forward-thinking approach to ensure that crops can thrive despite the uncertainties brought about by climate change.

Another widespread and crucial adaptation practice is the utilization of natural pest control methods, embraced by an impressive 83.33% of respondents. This trend reflects a growing recognition among farmers of the importance of ecological pest management techniques in maintaining crop health. Given the changing pest and disease patterns attributed to climate change, the shift towards natural pest control signifies a more sustainable and environmentally friendly approach to crop protection. It also reduces the reliance on chemical pesticides, which can have adverse effects on the environment and human health.

Efficient irrigation systems have been implemented by 78.57% of farmers, indicating their proactive response to the challenges posed by water scarcity. As climate change leads to altered precipitation patterns and increased variability, the need for optimized water utilization becomes paramount. Efficient irrigation systems help farmers maximize water resources while minimizing wastage, ensuring that crops receive adequate moisture even during periods of reduced water availability or increased flooding.

One notable adaptation strategy is terracing, which has been adopted by 71.43% of farmers. Terracing represents a proactive response to combat the escalating soil erosion and land degradation triggered by increasingly frequent and severe extreme weather events. This agricultural technique involves creating step-like structures on slopes to slow down water runoff, reducing erosion, and preserving soil integrity. Farmers who employ terracing demonstrate their dedication to effective water management and the preservation of arable land, essential for long-term agricultural sustainability in the region.

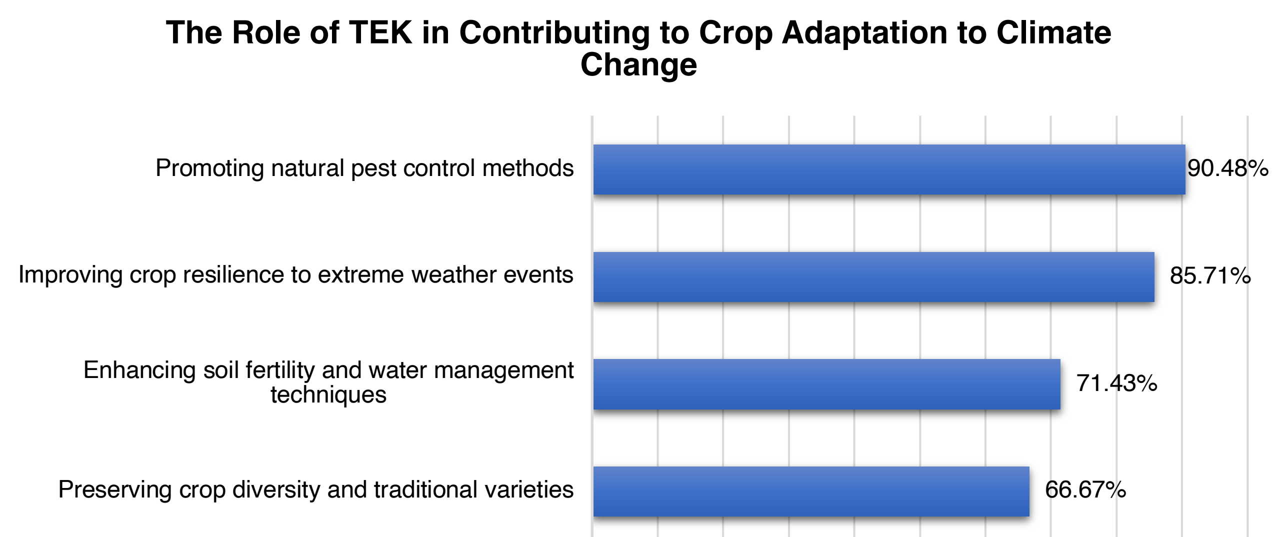

Figure 10: The Role of TEK in strengthening crop adaptation to climate change.

Figure 10 offers valuable insights into the farmers' perceptions of TEK and its potential benefits for adapting to the challenges posed by climate change in Urubamba. These findings provide a deeper understanding of how local knowledge systems play a pivotal role in shaping adaptive strategies.

The high recognition, at 90.48%, of natural pest control methods as a valuable aspect of TEK suggests that farmers are keenly aware of the importance of ecological pest management techniques. This aligns with the need to address changing pest dynamics driven by climate change, and it reflects a preference for sustainable and environmentally friendly approaches to pest control. This recognition also underscores the importance of preserving local biodiversity and ecosystem health as a means of bolstering resilience in the face of climate-induced pest pressures.

Additionally, 85.71% of farmers acknowledging TEK's contribution to improving crop resilience to extreme weather events, underscores the farmers' reliance on traditional knowledge to develop robust crop varieties. This finding is particularly significant in the context of climate change, where extreme weather events like droughts, floods, and storms are becoming more frequent and severe. The ability to cultivate crops that can withstand such events is essential for food security and the economic stability of farming communities.

The recognition of TEK's role in enhancing soil fertility and water management techniques by 71.43% of farmers is noteworthy. This acknowledgment highlights the critical importance of maintaining soil health and optimizing water resources in the context of climate variability. TEK provides farmers with time-tested practices for sustainable land and water management, which are essential for maintaining agricultural productivity and resilience in the face of changing precipitation patterns and increased drought risk.

The acknowledgment by 66.67% of farmers regarding the preservation of crop diversity and traditional varieties as a key contribution of TEK is significant. It emphasizes the role of traditional crops in maintaining food security and adaptability in a changing climate. By valuing genetic diversity and heritage varieties, farmers are showing an understanding of the importance of having a wide range of crops that can thrive under various environmental conditions. This recognition aligns with global efforts to conserve crop diversity as a crucial component of climate adaptation and food security.

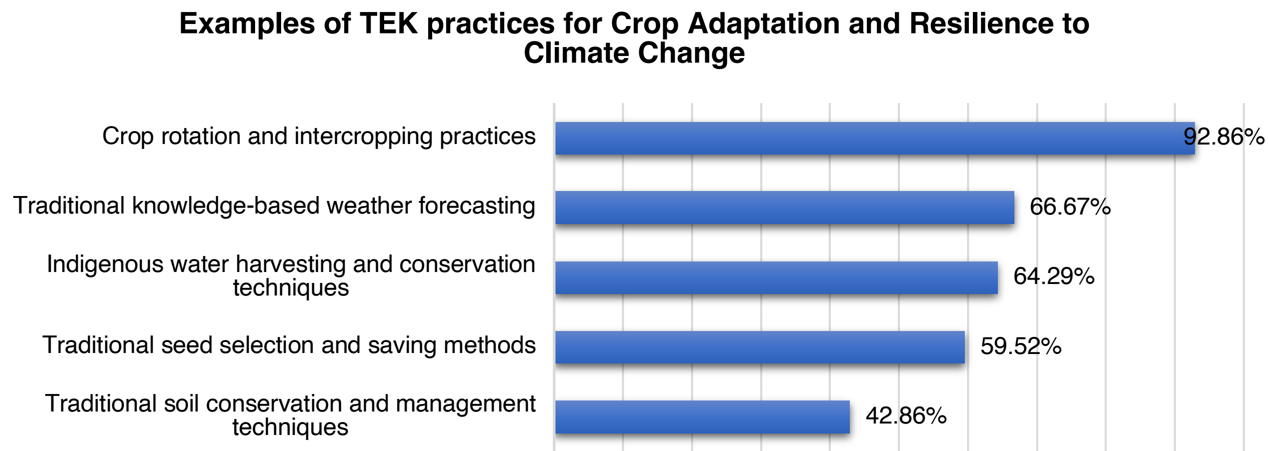

Figure 11: TEK practices for crop adaptation and resilience to climate change.

Figure 11 provides a visual representation of the prevalence and effectiveness of TEK practices among farmers, particularly in their role in enhancing crop resilience to the challenges posed by climate change. This figure illuminates the significance of TEK in shaping sustainable agricultural practices and adaptation strategies.

Among the TEK practices surveyed, crop rotation and intercropping emerge as the most widely adopted, with a remarkable 92.86% of farmers employing these techniques. This high adoption rate underscores the effectiveness of crop rotation and intercropping in enhancing crop resilience. These practices not only promote soil health by reducing nutrient depletion and pest pressure but also diversify crop portfolios, making them better suited to withstand the uncertainties of a changing climate.

Traditional weather forecasting techniques, rooted in local knowledge, are relied upon by two-thirds of the farmers, totaling 66.67%. This reliance underscores the importance of TEK in planning agricultural activities in anticipation of climatic changes. Traditional weather forecasting enables farmers to make informed decisions about planting, harvesting, and resource allocation, helping them adapt to unpredictable weather patterns more effectively.

Water harvesting and conservation methods are embraced by 64.29% of farmers, reflecting a strategic approach to managing water resources amidst a shifting climate. These practices are essential for optimizing water usage, especially during periods of increased water scarcity or irregular precipitation patterns associated with climate change. By harnessing rainwater and conserving this precious resource, farmers enhance their capacity to irrigate crops and mitigate the impacts of drought.

The utilization of traditional seed selection and saving methods is reported by 59.52% of respondents. This practice signifies a deep-rooted reliance on ancestral knowledge for cultivating robust crop varieties. By selecting and saving seeds based on generations of local wisdom, farmers ensure that their crops have the genetic diversity and adaptability needed to thrive under evolving climatic conditions.

Traditional soil conservation and management practices are employed by 42.86% of respondents, indicating a considerable application of TEK for maintaining soil health in the face of climate change. These practices, often passed down through generations, play a pivotal role in preserving soil fertility, preventing erosion, and safeguarding the foundation of agricultural productivity.

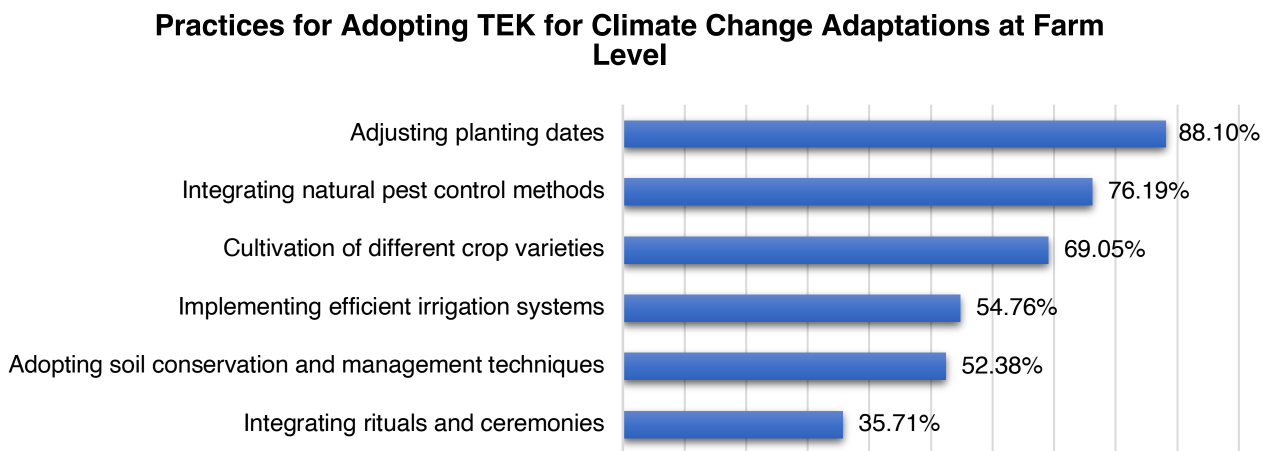

Figure 12: Adopting TEK for climate adaptations on farms in Urubamba.

Figure 12 provides a detailed breakdown of the percentages of farmers in Urubamba who have embraced various TEK practices to counteract the adverse impacts of climate change on their agricultural endeavors. These practices demonstrate the resilience and adaptability of local knowledge systems in the face of changing environmental conditions.

A majority of 88.10% of farmers are adjusting their planting calendars, exemplifying the profound role of TEK in responding to the shifting seasonal patterns brought about by climate change. This adaptive approach enables them to synchronize their agricultural activities with the evolving climate, ultimately optimizing crop yields and sustainability.

Natural pest control methods have been embraced by a significant majority, with 76.19% of farmers resorting to these practices to manage pests and diseases. Climate change has exacerbated the challenges posed by agricultural pests, making the adoption of natural pest control techniques a vital component of sustainable farming.

The cultivation of different crop varieties has been adopted by over two-thirds of respondents, totaling 69.05%. This diversification strategy involves selecting crop varieties that exhibit greater resilience to climate extremes. This diversification is essential for maintaining agricultural productivity, ensuring food security, and preserving biodiversity in the face of climate-related challenges.

Efficient water management is critical in the context of altered precipitation regimes, and more than half of the farmers, specifically 54.76%, have opted for traditional methods of water management. This approach allows them to optimize water usage, a valuable resource under changing climatic conditions, and mitigate the impact of water scarcity or excess.

Soil conservation and management techniques are a priority for 52.38% of the farming community. These practices are essential for preserving soil health, a cornerstone of agricultural productivity. By relying on traditional methods, these farmers are taking proactive measures to ensure soil fertility and the long-term sustainability of their agricultural practices.

While the integration of rituals and ceremonies is adopted by a smaller portion of farmers, specifically 35.71%, it reflects the holistic approach of TEK. This integration of cultural practices into farming routines emphasizes the interconnectedness of ecosystem health, spirituality, and community well-being, highlighting the profound cultural and social dimensions of TEK. Figures 13a and 13b show some of the rituals performed by community members during the planting season.

Figures 13a: Ritualistic elements in preparation for planting season.

Figure 13b: A local farmer performing a gratitude ritual for the planting season, using coca leaves as an offering for the land.

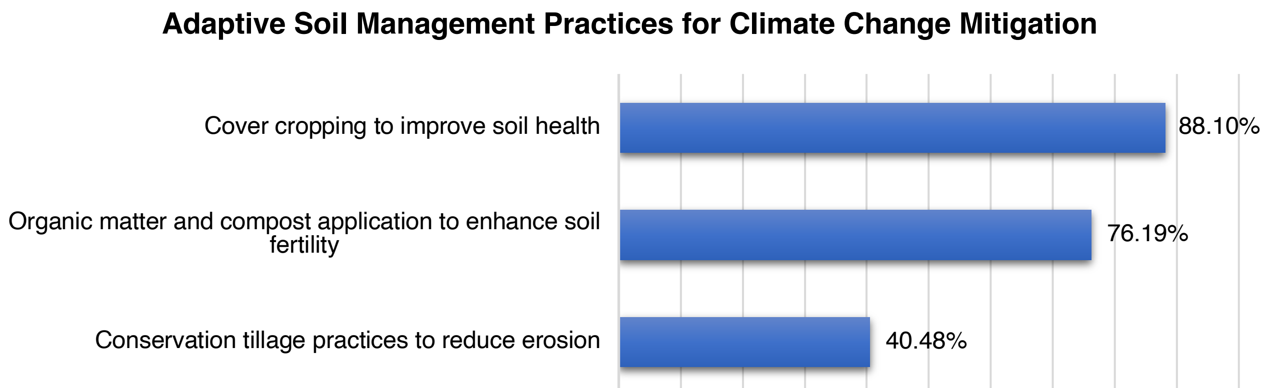

Figure 14: Adaptive soil management techniques implemented by smallholder Urubamba farmers in response to climate change.

Figure 14 offers a visual portrayal of the soil management techniques that farmers have embraced to address the environmental ramifications of climate change, shedding light on the prevalence of both traditional and innovative practices aimed at bolstering soil health and ensuring the sustainability of agricultural endeavors.

One of the most prevalent practices, adopted by a substantial 88.10% of farmers, is the implementation of cover cropping. This widespread adoption underscores the critical role of cover crops in safeguarding soil against erosion and preserving optimal moisture levels. Cover crops, often planted in between main crops, act as protective shields for the soil, preventing it from being washed away during heavy rains and helping to retain moisture, especially vital during periods of drought.

Another notable practice is the application of organic matter and compost, embraced by a significant 76.19% of farmers. This indicates a growing awareness among farmers of the benefits of organic materials in enriching soil fertility. By incorporating natural fertilizers into their agricultural practices, farmers are not only enhancing crop growth but also nurturing the overall vitality and resilience of the soil. This practice aligns with sustainable farming principles, reducing the reliance on synthetic chemicals and promoting long-term soil health.

Conservation tillage practices, employed by 40.48% of farmers, represent an important strategy to mitigate soil erosion. Such practices involve minimal soil disturbance during planting and cultivation, helping to maintain soil structure and reduce erosion risks, as seen in Figure 15. Given the increased intensity of rainfall and the prevalence of drought conditions associated with climate change, conservation tillage plays a pivotal role in safeguarding soil integrity and ensuring its capacity to support productive agriculture.

Figure 15: Farmers working on preparing the land for planting season using traditional conservation tillage.

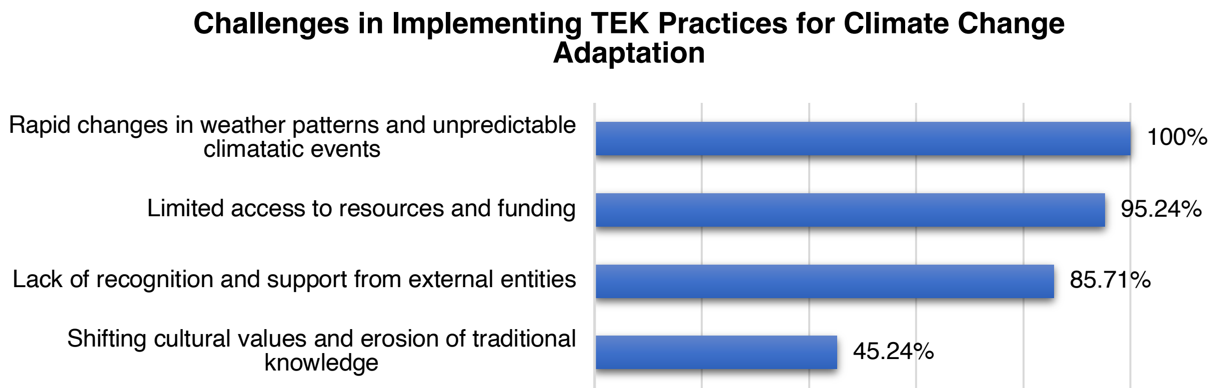

Figure 16: Challenges in adopting TEK for climate change among Urubamba farmers.

Figure 16 provides a comprehensive overview of the significant challenges faced by the farming community in Urubamba when attempting to apply TEK for climate change adaptation. These challenges shed light on the complex dynamics that impact the incorporation of traditional wisdom into modern agricultural practices.

The foremost obstacle, identified unanimously by all surveyed farmers, is the rapid changes in weather patterns and unpredictable climatic events. This swift and erratic nature of climate change disrupts traditional farming cycles and practices, making it difficult for farmers to effectively utilize TEK in their agricultural endeavors. These challenges highlight the urgent need for adaptive strategies that can keep pace with the ever-changing climate conditions in the region.

Another substantial challenge recognized by 45.24% of the community is the shifting cultural values and erosion of traditional knowledge. This threat underscores the importance of cultural education and knowledge transmission to ensure the continuity of TEK. As the younger generation becomes increasingly disconnected from traditional practices, there is a need to bridge the gap and preserve the valuable insights held by the elders of the community.

The lack of recognition and support from external entities is a concern voiced by 85.71% of farmers. This challenge emphasizes the critical role that external recognition and support play in the sustainability and further development of TEK practices. It calls for collaborative efforts between local communities and governmental or non-governmental organizations to validate and assist in the integration of TEK into broader climate adaptation strategies.

Economic constraints, cited by a significant majority of 95.24% of farmers, pose a formidable barrier to the practical application and continuation of TEK in the face of climate change. Limited access to resources and funding hampers the ability of farmers to implement TEK-based practices effectively. Financial and material support is essential to ensure that TEK remains a viable and accessible resource for the farming community.

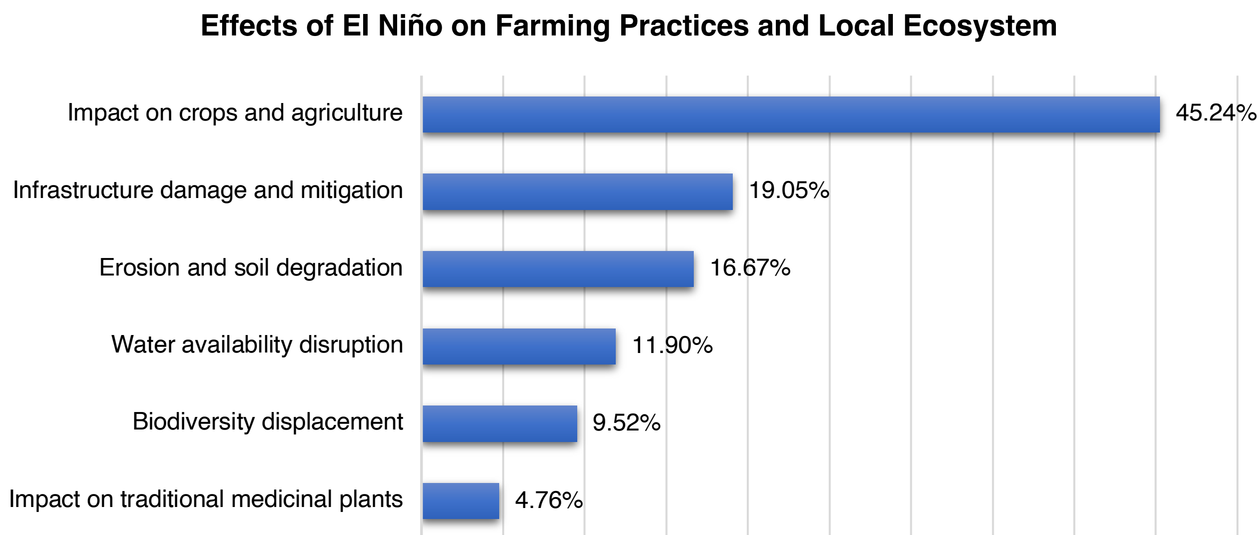

Figure 17: Effects of El Niño on indigenous farming practices and Urubamba ecosystems

Figure 17 provides a detailed account of the multifaceted impacts of El Niño on agricultural practices and ecosystems, as reported by farmers in Urubamba. These findings offer valuable insights into the challenges posed by this climate phenomenon, shedding light on the complex interplay between climate variability and local agriculture.

The most pronounced concern, reported by nearly half of the respondents at 45.24%, is the impact of El Niño on crops and agriculture. This underscores the substantial effects of El Niño on farming yields and practices, with its disruptive influence on planting schedules, crop health, and overall agricultural productivity.

Infrastructure damage due to El Niño is a concern faced by 19.05% of the farming community. This damage necessitates additional efforts in mitigation and adaptation to protect essential infrastructure, which is crucial for maintaining agricultural operations and community resilience.

Increased soil erosion and degradation, affecting 16.67% of respondents, are associated with El Niño. These soil-related issues have the potential to detrimentally affect crop productivity and soil health, which are foundational to agricultural practices in the region.

Changes in water availability, reported by 11.90% of farmers, are another consequence of El Niño. These alterations impact crucial agricultural activities, particularly irrigation, which relies on stable water sources. The disruption in water availability poses a direct threat to crop cultivation and agricultural sustainability.

Biodiversity displacement is noted by 9.52% of the surveyed farmers. These observations indicate shifts in local biodiversity patterns attributed to El Niño, which can result in the displacement of species that are integral to the local ecosystem and essential for supporting agricultural practices. Such shifts may have cascading effects on the balance of the ecosystem and agricultural productivity.

A minority of farmers, specifically 4.76%, acknowledge that El Niño affects the availability of plants used in traditional medicine. This observation hints at disruptions to both healthcare practices and biodiversity, emphasizing the far-reaching consequences of El Niño on the local ecosystem and the traditional knowledge systems that rely on it.

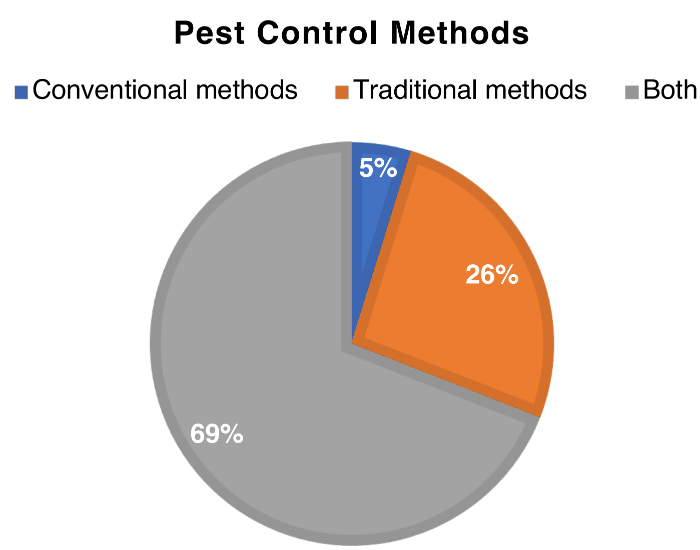

Figure 18a: Percentage of pest control methods used by farmers in Urubamba.

Figure 18a provides a comprehensive overview of the pest control methods employed by farmers in Urubamba, shedding light on the diverse approaches they utilize to manage agricultural pests. The findings reveal a nuanced landscape of pest management strategies, reflecting both the local context and the dynamic nature of modern agriculture.

A small segment of the farming community, constituting 5%, relies solely on conventional methods for pest control, predominantly employing chemical pesticides as a second resource for pest management. While these methods can provide rapid and targeted pest suppression, they are typically viewed as a secondary option. This limited adoption suggests a growing awareness among farmers of the need for more sustainable and eco-friendly alternatives as their primary means of pest control.

In contrast, over a quarter of the farmers, totaling 26%, adhere to traditional methods as their primary approach for pest control. These traditional methods encompass a range of natural remedies and practices that have been passed down through generations. These approaches are often ecological and time-tested, emphasizing the use of indigenous knowledge and local resources to manage pests. This high adoption rate indicates a strong connection to ancestral wisdom and a preference for non-chemical pest management options as the primary means of pest control.

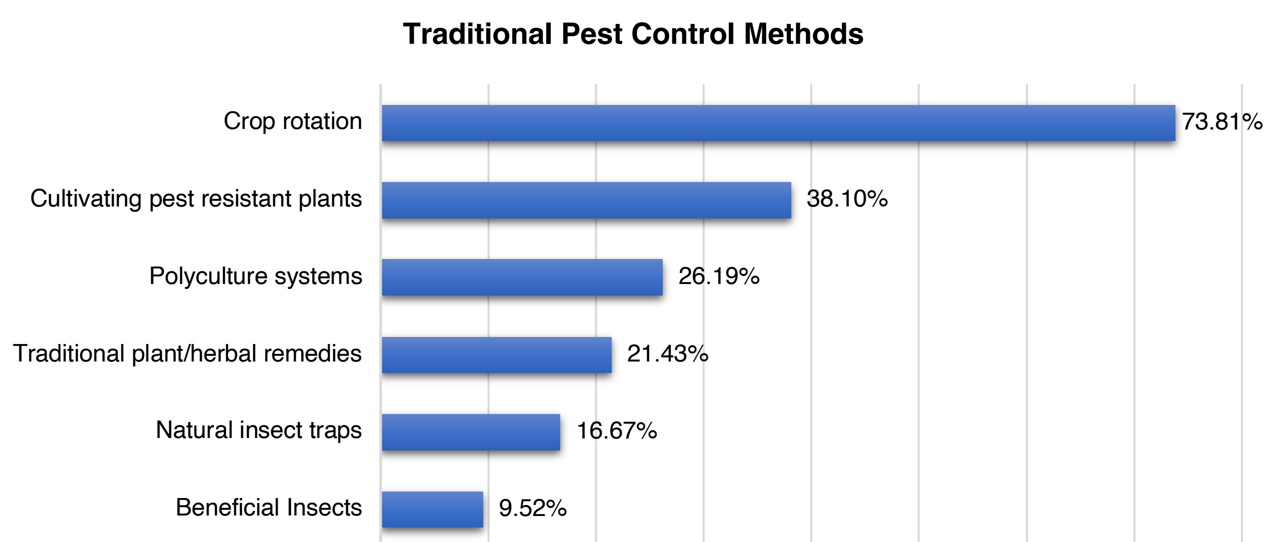

Figure 18b: Traditional pest control methods implemented by the surveyed farmers.

Figure 18b provides an overview of the diverse methods employed by farmers in Urubamba to manage pests and diseases within their crops, particularly in the context of a changing climate. These strategies showcase the farmers' ingenuity and adaptability in addressing the complex challenges posed by agricultural pests and evolving environmental conditions.

Crop rotation emerges as a prevalent pest management method, adopted by a significant 73.81% of farmers. This traditional practice involves periodically changing the types of crops planted in specific fields. Crop rotation disrupts the life cycles of pests and diseases, reducing their buildup in the soil and effectively managing their impact on crops. This approach is both practical and sustainable, contributing to long-term soil health and pest control.

Cultivating pest-resistant plants is practiced by over a third of farmers, totaling 38.10%. This approach involves selecting and growing crop varieties that possess natural resistance to pests. By doing so, farmers reduce the need for chemical pesticides and promote a more sustainable and eco-friendly approach to pest management.

Polyculture systems, adopted by 26.19% of farmers, involve growing multiple crops in the same space. This approach creates a diverse ecosystem within the fields, which can naturally deter pests and diseases. Polyculture promotes ecological balance and reduces the vulnerability of crops to pest outbreaks, contributing to more resilient and sustainable agricultural systems.

Traditional plant and herbal remedies are utilized by 21.43% of farmers. This method underscores the importance of biodiversity and local knowledge in pest control strategies. Farmers draw on their understanding of native plants and herbs to develop remedies that deter or mitigate pests and diseases. This approach not only taps into the rich biodiversity of the region but also reflects the deep-rooted traditional knowledge passed down through generations.

Natural insect traps are employed by 16.67% of farmers, indicating a proactive approach to physically removing pests from the environment. These traps serve as a targeted and environmentally friendly means of reducing pest populations, particularly for specific crop varieties or seasons when pests are more prevalent.

A notable 9.52% of farmers employ beneficial insects as a natural pest management strategy. By harnessing the power of nature's own mechanisms for maintaining pest balance, these farmers introduce predator insects that prey on crop-damaging pests. This approach represents a holistic and environmentally friendly approach to pest control, aligning with principles of ecological balance.

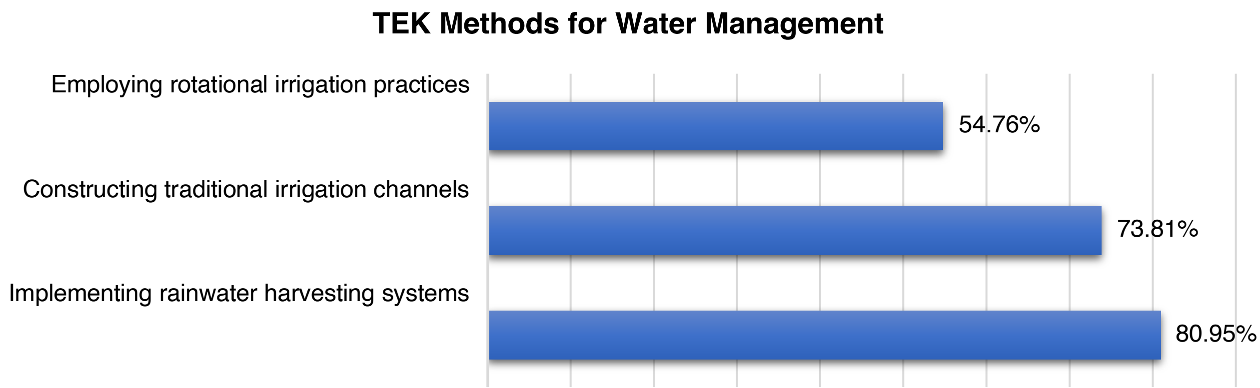

Figure 19: TEK water management methods implemented as adaptation strategies by Urubamba smallholder farmers.

Figure 19 provides a detailed overview of the percentages of farmers in Urubamba who are integrating TEK into their water management strategies as a response to the impacts of climate change. These strategies reflect the farmers' resourcefulness and their ability to adapt to shifting environmental conditions, particularly in the context of water management.

Rainwater harvesting stands out as a widely adopted TEK practice, with an impressive 80.95% of farmers embracing it. This practice involves capturing and utilizing rainfall through various techniques such as rain barrels or cisterns. The high adoption rate reflects a strategic adaptation to enhance water security, particularly in times of changing precipitation patterns and increased water variability associated with climate change. Rainwater harvesting not only conserves water resources but also reduces reliance on other sources such as groundwater, which can be vulnerable to over-extraction.

A significant 73.81% of respondents utilize age-old techniques to construct traditional irrigation channels as seen in Figure 20. This approach demonstrates a deep-rooted understanding of landscape and water flow, as well as the importance of efficient water distribution in agriculture. Traditional irrigation channels are designed to optimize water use, ensuring that crops receive adequate moisture while minimizing water wastage. This practice aligns with sustainable water management principles and represents a valuable contribution to adapting to changing hydrological conditions.

Figure 20: The image captures a traditional irrigation setup that distributes meltwater from glaciers to farmlands throughout the community. It shows a manual pump installed in the waterway, indicating a system designed for regulating and directing the water's path. This method allows for capture and redistribution of water to agricultural fields, which is essential for crop irrigation, especially in areas where water scarcity can be a challenge.

Rotational irrigation practices are employed by over half of the farmers, specifically 54.76%. This method involves allocating water to different parts of the farm at different times, strategically managing water resources to conserve them and ensure their availability throughout the growing season. Rotational irrigation is an effective strategy to cope with variations in water availability, including both water scarcity and potential excess due to erratic rainfall patterns driven by climate change. By judiciously distributing water resources, farmers enhance their resilience to hydrological uncertainties.

Table 4: Employing crop diversification techniques for enhanced climate adaptability.

Diversification Techniques	**Percentage**
Crop rotation	90.48%

Legume Intercropping	76.19%
Maize and bean intercropping	47.62%
Root crop intercropping	30.95%
Adaptation to altitude zones	38.10%
Mixed polyculture systems	54.76%
Sequential cropping with cover crops	88.10%
Agroforestry	19.05%
Companion Planting	40.48%
Cyclic fallow	21.43%
Quinoa and potato rotation	64.29%
Use of traditional indicator plants	9.52%

Table 4 lists various crop management practices derived from TEK and their percentage of use among farmers, showing how they contribute to climate adaptation on farms. Diverse crop rotation leads with 90.48%, indicating its prominence as a strategy for maintaining soil health and mitigating pest and disease cycles. Legume intercropping, at 76.19%, highlights the importance of nitrogen-fixing plants in sustainable agriculture. Maize and bean intercropping is used by 47.62% of farmers, demonstrating a traditional combination that balances nutrient use and enhances soil structure. Root crop intercropping and adaptation to altitude zones are practiced by about a third of the farmers, reflecting strategies for optimizing space and matching crop types with suitable environmental conditions. Over half of the respondents employ mixed polyculture systems, indicating a preference for biodiversity. Sequential cropping with cover crops is a popular technique, used by 88.10% of farmers to protect and nourish the soil. Fewer farmers practice agroforestry and companion planting, yet these methods are still significant for ecosystem diversity. Figure 21 depicts a farm implementing root crop intercropping and agroforestry. Cyclic fallow and quinoa and potato rotation are less common but recognized for their benefits in crop rotation and soil restoration. Traditional indicator plants are the least used, though they play a role in monitoring environmental health. This table underlines the critical role of diverse TEK practices in building resilient farming systems capable of adapting to climate variability.

Figure 21: Potato and Maize intercropping with fruit trees in the perimeter as an agroforestry technique.

7.3. Assessing the Indicators of TEK

Table 5: Improvements in ecological outcomes by integrating TEK practices into their agricultural practices.

Ecological Outcomes of TEK Practices	Percentage
Improved soil health	28.57%
Increased biodiversity	26.19%
Enhanced crop resilience	23.81%
Reduced soil erosion	21.43%
Increased water retention in soil	16.67%

Diversification of crops	14.29%
Preservation of traditional crop varieties	9.52%
Reduced use of chemical pesticides	2.38%
Enhanced fertility of soil	4.76%
Increased productivity of crops	2.38%
Improved quality of produce (coffee and cacao)	4.76%
Promotion of natural pollination	4.76%
Reduction in land degradation	2.38%
Restoration of local ecosystems	4.76%
Improved quality of air and water	2.38%

Table 5 presents a summary of how TEK is utilized in agricultural practices to adapt and mitigate the impacts of climate change. It lists the key areas of TEK application, demonstrating the percentage of farmers who have observed improvements in various aspects of their farming operations because of these practices. This encompasses a broad range of benefits, from soil health and biodiversity to crop resilience and natural pest control, highlighting the versatility and effectiveness of TEK in promoting sustainable agricultural methods that align closely with environmental conservation and improved crop management.

Table 6: Key indicators of sustainable farming success in response to TEK.

Indicators	Frequency	Percentage
Crop yield and productivity	39	92.86%
Soil organic matter content	18	42.86%
Water availability and quality	26	61.90%
Biodiversity and habitat conservation	33	78.57%
Plant health indicators	25	59.52%

Table 6 provides a list of the positive impact that TEK have on sustainable farming in the Urubamba region. A striking 92.86% of farmers report that these practices have led to an increase in crop yield and productivity, showcasing the effectiveness of TEK in boosting agricultural outputs. Soil health, a vital component of agricultural sustainability, is also reported to have improved, with 42.86% of farmers noting an increase in soil organic matter content, indicative of enhanced soil fertility and health. Water resources, critical to the success of farming, especially in times of climate change, have seen improvements in both availability and quality for 61.90% of respondents. This points to the efficacy of TEK in managing water sustainably. Biodiversity and habitat conservation are other areas where TEK has made a marked difference, with 78.57% of farmers observing benefits, underlining the role of these practices in ecological stewardship. Lastly, the health of plants, a direct measure of farming success, has been positively impacted, with 59.52% of farmers reporting healthier plants, which can be attributed to the natural pest control and plant care methods inherent in TEK. This data collectively emphasizes the broad spectrum of environmental and agricultural benefits that TEK practices offer to the farming communities in Urubamba.

7.4 Knowledge Sharing and Transmission

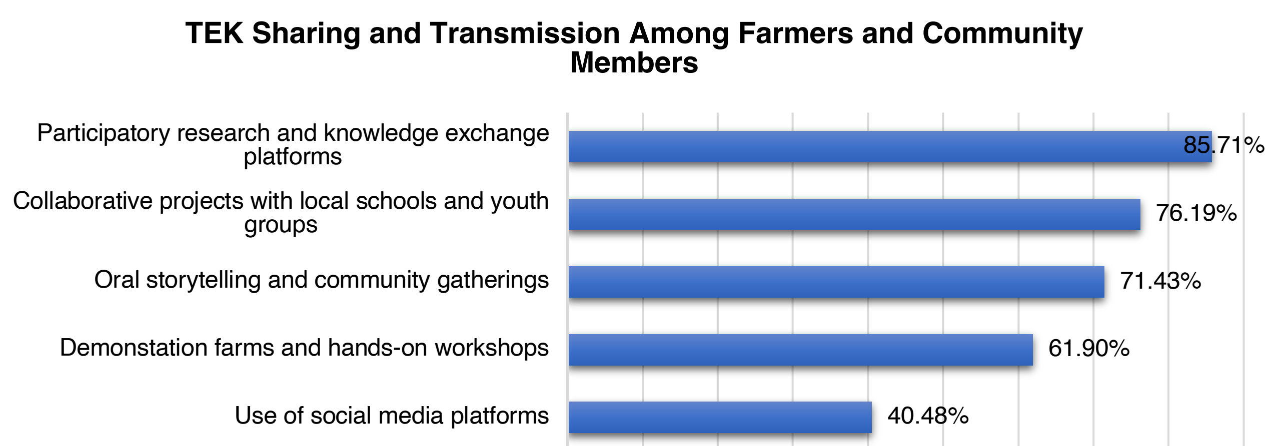

Figure 22: Agricultural TEK sharing and transmission among community members.

Figure 22 provides a comprehensive overview of the diverse methods employed by the Urubamba community to share TEK practices aimed at addressing climate change challenges. These methods reflect a multifaceted and community-driven approach to knowledge transmission, emphasizing the importance of preserving and passing down traditional wisdom in the face of environmental change.

Participatory research and knowledge exchange platforms are the most common method noted, with an impressive 85.71% of respondents engaging in this practice. Participatory platforms facilitate a collaborative approach to sharing experiences and strategies. Through these exchanges, community members collectively explore and adapt TEK practices in response to changing environmental conditions. This collaborative model ensures that TEK remains dynamic and responsive to contemporary challenges.

Collaborative projects with local schools and youth groups are embraced by 76.19% of the community, emphasizing the importance of involving the younger generation in traditional practices. By partnering with educational institutions, community members ensure that knowledge transfer extends to future generations. This approach helps bridge the gap between generations and instills a sense of stewardship for TEK practices among youth.

A significant majority of 71.43% of the community utilizes oral storytelling and community gatherings as a means of sharing TEK. This practice underscores the central role of cultural traditions in knowledge transmission. Through storytelling and communal gatherings, elders and experienced community members impart their wisdom, experiences, and insights to the younger generation. These interactions not only preserve cultural heritage but also ensure that TEK remains a living and evolving resource within the community.

Demonstration farms and hands-on workshops are employed by more than half of the respondents, specifically 61.90%. These practical demonstrations play a crucial role in experiential learning, allowing community members to actively engage with TEK practices. Hands-on experiences enable individuals to gain a deeper understanding of traditional methods, fostering a sense of empowerment and ownership over these techniques. This approach encourages the practical application of TEK in daily life.

A significant portion of 40.48% of the community uses digital tools and social media platforms to extend the reach of their knowledge and engage with wider audiences. This contemporary approach allows community members to share TEK practices beyond their immediate surroundings, promoting awareness and collaboration on a broader scale. It also facilitates connections with like-minded individuals and organizations working on climate change adaptation.

Table 7: Adoption Practices of Traditional Agricultural Practices for Climate Adaptation

Strategies	Frequency	Percentage
Terracing	17	40.48%
Crop rotation	12	28.57%
Seed selection and preservation	10	23.81%
Water conservation	8	19.05%
Observations of nature's behaviors and patterns	8	19.05%
Medicinal plants	7	16.67%
Community water management	6	14.29%
Staggered plants	5	11.90%
Crop diversification	4	9.52%
Interaction with neighboring communities	3	7.14%
Construction of retaining walls and reforestation	3	7.14%
Observation of natural cycles	3	7.14%
Identification of edible and medicinal wild plants	2	4.76%
Rotational grazing and native grass restoration	2	4.76%
Construction of canal and dam systems	2	4.76%

Table 7 shows various TEK practices and their frequency and percentage of adoption among farmers, highlighting their importance in building ecological resilience within agricultural systems. Terracing, the most frequently reported practice, is used by 40.48% of respondents, emphasizing its role in preventing soil erosion and managing water runoff (Figure 23). Crop rotation and seed selection and preservation are also notable practices, indicating a focus on maintaining soil fertility and crop diversity, which are key in adapting to climate variability. Water conservation and keen observations of nature's behaviors underscore the adaptability and resourcefulness of farmers in response to environmental changes. The inclusion of medicinal plants and community water management reflects a holistic approach to farming that integrates health, sustainability, and cooperative resource management. Less common but still significant are practices such as staggered planting and crop diversification, which contribute to the robustness of food systems against climate-induced uncertainties. This table illustrates the enduring value and application of TEK in fostering sustainable and adaptable farming practices.

Figure 23: Agricultural terraces prepared for planting potatoes, vegetables, and maize. These terraces are strategically utilized to leverage diverse microclimates. The left section is designated for potatoes, benefiting from cooler temperatures at higher elevations, while quinoa is typically grown at intermediate levels. Maize, a crop preferring warmer conditions, is cultivated at lower elevations.

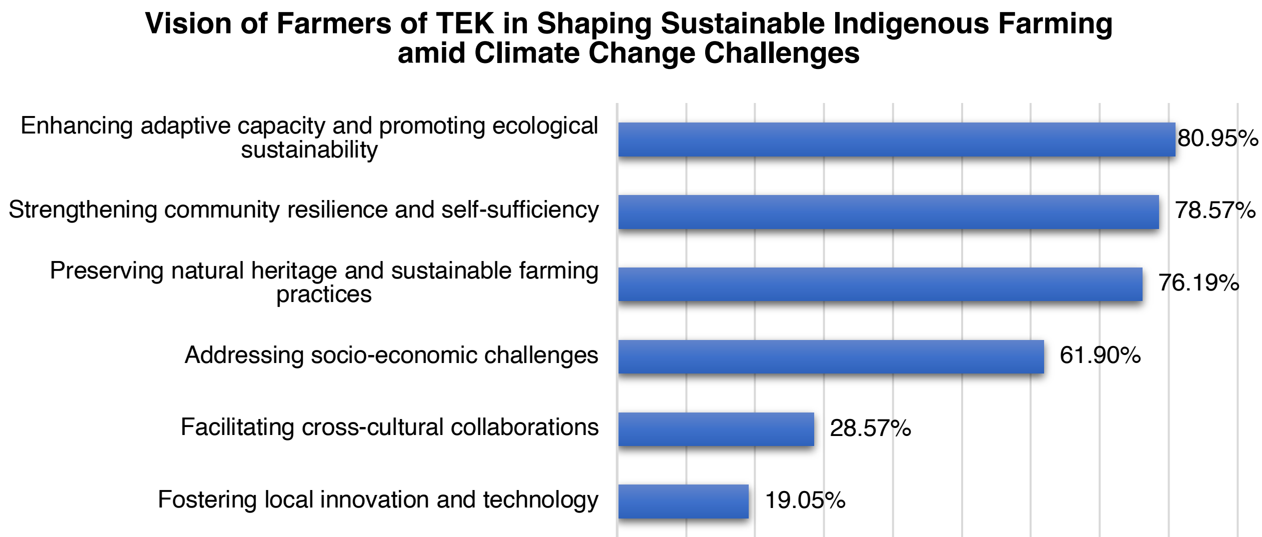

Figure 24: The vision of TEK in shaping sustainable indigenous farming futures.

Figure 24 provides valuable insights into the priorities and visions of Urubamba farmers regarding the role of TEK in shaping sustainable indigenous farming practices in response to climate change. These priorities underscore the farmers' deep-rooted connection to their land, community, and the ecological resilience necessary to navigate a changing climate.

A significant majority of farmers, specifically 76.19%, prioritize the preservation of natural heritage and sustainable farming practices. This commitment reflects their dedication to ecological stewardship and underscores the importance of maintaining the integrity of their natural surroundings. By valuing these aspects, farmers aim to safeguard their land for future generations while simultaneously promoting sustainable agricultural methods that can withstand climate-related challenges.

Strengthening community resilience and self-sufficiency emerges as a focal point, with 78.57% of respondents emphasizing its significance. This priority highlights the community's reliance on collective strength and local resources to withstand the impacts of climate change. By fostering self-sufficiency and resilience, farmers aim to ensure that their community can adapt and thrive in the face of adversity, reducing vulnerabilities associated with climate-related disruptions.

Enhancing adaptive capacity and promoting ecological resilience is recognized as a critical goal by most farmers, with 80.95% showcasing their dedication to this aspect. This commitment underscores the farmers' proactive approach to climate adaptation. By enhancing their farming systems' adaptive capacity and ecological resilience, they aim to ensure that their livelihoods remain viable in the face of changing environmental conditions. This approach aligns with the broader goal of maintaining a harmonious relationship with the environment.

Fostering local innovation and technology is acknowledged by a smaller yet noteworthy proportion of farmers, comprising 19.05%. This recognition underscores the importance of leveraging local knowledge and innovations to adapt to changing climatic conditions. While traditional practices are valued, the incorporation of innovative solutions can enhance the effectiveness of climate adaptation strategies.

Facilitating cross-cultural collaborations is seen as beneficial by over a quarter of the farming community, with 28.57% recognizing its potential value. Engaging in cross-cultural collaborations allows for the exchange of diverse insights and shared solutions to climate change challenges. This collaborative approach can enhance the resilience of farming communities by drawing upon a broader range of perspectives and experiences.

Addressing socioeconomic challenges is acknowledged as essential by a significant majority of farmers, totaling 61.90%. This recognition reflects an understanding that economic stability is crucial for the sustainability of their farming practices in the face of climate change. By addressing socioeconomic challenges, farmers aim to ensure that their agricultural livelihoods remain viable and that their community can thrive in changing circumstances.

8. Discussion

8.1. General Characteristics of Smallholder Urubamba Farmers

The agricultural landscape of the Urubamba Valley, characterized by the dominance of cereals alongside the cultivation of vegetables, legumes, fruits, coffee & cacao, and medicinal plants, mirrors a farming system that is both diverse and specialized. This diversity is an adaptive strategy that enhances the resilience of local food systems in the face of environmental and economic challenges.

The emphasis on cereal cultivation in Urubamba, as in the broader Andean region, reflects a strategic approach to agriculture where indigenous grains like quinoa, kiwicha, and corn are not just traditional staples but also essential components of food security and economic development. These grains are uniquely suited to the diverse altitudes and climates of the Andes, ranging from cold, arid highlands to warm, moist valleys. Additionally, these grains possess impressive nutritional profiles. Quinoa, categorized as a "superfood," is rich in protein and essential amino acids often lacking in other grains (Repo-Carrasco-Valencia et al., 2010). Kiwicha, is similarly protein-rich and contains high levels of lysine, an essential amino acid (Martinez-Lopez et al., 2020; Repo-Carrasco-Valencia et al., 2010). Furthermore, these grains offer a range of bioactive compounds, including antioxidants and anti-inflammatory agents, which have been linked to reduced risks of chronic diseases (Repo-Carrasco-Valencia et al., 2010; Vega-Gálvez et al., 2010).

Moreover, in Urubamba, Peruvian corn varieties are celebrated for their unique qualities, such as the large-kernelled Cusco corn (known as maíz Cusco) and the purple corn (maíz morado), known for their distinct flavors, vibrant colors, and nutritional benefits (Salvador-Reyes & Clerici, 2020). From a nutritional standpoint, these corn varieties are rich in carbohydrates, providing essential energy to the local population. Additionally, they offer valuable phytonutrients, like anthocyanins in purple corn, linked to multiple health benefits, including antioxidant activity (Lao et al., 2017; Salvador-Reyes & Clerici, 2020). This nutritional richness positions these grains as valuable components of a healthy diet.

The cultivation of these grains is pivotal to local economies. They serve both subsistence agriculture and market-oriented production, with global demand for quinoa creating economic opportunities for Urubamba farmers (Jacobsen, 2003). However, according to the findings of Bazile et al., 2016, the surge in quinoa demand has also raised concerns about overexploitation and sustainability, requiring ongoing research and policy attention. Culturally, these grains play central roles in traditional festivals, rituals, and contribute to the cultural identity of Cusco. The international interest in these grains has not only brought economic benefits but also raised awareness of Andean cultures globally.

The genetic diversity of these corn varieties represents a vital resource for crop improvement and resilience, especially in the face of climate change. This diversity allows for the selection of traits that can withstand environmental stressors like drought, pests, and diseases, contributing not only to food security but also sustainable agriculture and future food systems. Moreover, these corn varieties bolster local economies through direct consumption and play a prominent role in the region's culinary heritage, contributing to the tourism sector both within Peru and internationally.

The cultivation of indigenous grains, both in Urubamba and the broader Andean region, serves as a model of how TEK can be seamlessly integrated into modern food systems, as supported by Altieri, (2011). These grains offer valuable lessons in sustainability, nutrition, and cultural preservation, showcasing the importance of agrobiodiversity in ensuring food security and sustainable development in regions facing environmental challenges.

Continuously, vegetables including tomatoes, peppers, and leafy greens are also integral to the local diet, providing a range of micronutrients essential for human health. Legumes such as beans, lentils, and peas are staple crops in Urubamba. These plants contribute not only to the diet but also to the sustainability of farming systems by fixing nitrogen in the soil, thus enhancing soil fertility, and reducing the need for synthetic fertilizers (Peoples et al., 2009).

Furthermore, coffee and cacao represent the cash crops of the Urubamba Valley, with significant implications for both the local and global economies. Coffee cultivation in Urubamba has been influenced by the fluctuating global markets and the push for sustainable and fair-trade practices (Bürgin & Wilken, 2021). The cultivation of coffee and cacao in the region is recognized as one of the main contributors to biodiversity. These crops are often grown under the canopy of existing forests, a practice that can preserve biodiversity and provide habitat for many species (Norgrove & Beck, 2016). Moreover, Rice, (2018) and Mayorga et al., (2022) highlight that the shade-grown method of coffee cultivation is recognized for its ecosystem services including the ability to sequester carbon, thus playing a role in climate change mitigation.

Although medicinal plants represent the least prioritized crop in terms of land area allocation, Urubamba is home to an extensive range of traditional medicinal knowledge and these plants are deeply significant to the communities within the region. This heritage, thoroughly documented in ethnobotanical research, includes the use of plants like Muna for respiratory conditions, Coca for its energizing properties, Maca for its benefits on fertility and vitality, Cat's Claw for its anti-inflammatory effects, and Sangre de Grado for wound healing. Bussmann and Sharon (2006) have documented the role of these medicinal plants, revealing how they are integrated into the Andean healthcare. The economic potential of these plants is notable, particularly within local markets and the growing global demand for natural health products.

However, the Urubamba community's traditional agricultural practices, while robust and adaptable, are facing significant challenges in the era of climate change. The resilience of these systems, a blend of cultural heritage and global importance, offers valuable lessons in sustainable practice and biodiversity conservation. The integration of TEK with modern scientific understanding offers pathways to enhance the resilience of these systems, ensuring their continued ability to sustain local communities and contribute to the global pool of agrobiodiversity and medicinal resources.

Additionally, the average farm size of 3.02 acres in Urubamba places these smallholder farms in a unique position when compared globally. Smallholder farmers, who manage less than two hectares on average, represent a significant portion of the world's agriculturalists. They face unique challenges due to their farm size and associated low labor productivity, which often correlates with poverty levels (Lowder et al., 2016). In Sub-Saharan Africa, the average farm size is approximately 3.2 acres, which is remarkably similar to that in the Urubamba (Jayne et al., 2014; Lowder et al., 2016). This similarity suggests a common scale at which smallholder farming systems operate, implying comparable challenges and potential for agricultural development strategies (Jayne et al., 2014). Comparatively, in Asia, smallholder farms tend to be smaller, averaging between approximately 1 to 2 acres (Lowder et al., 2016). This difference in size may influence the types of crops grown, the methods of cultivation, and the sustainability of farming practices due to variations in available space, resources, and market access. Furthermore, the relatively larger farm sizes in Urubamba can be more flexible in crop diversification, allowing for increased dynamic responses to market changes and environmental challenges. Larger farm sizes can also offer the potential for improved economies of scale and the adoption of more efficient agricultural technologies (Hazell et al., 2010).

The implications of farm size on economic viability and agricultural sustainability are considerable. Larger farms in Urubamba might have a greater capacity for resilience against economic shocks and climate-related adversities, potentially providing a more stable income for the farmers. However, this does not discount the potential for intensification and innovation on smaller farms, which can be highly productive with appropriate investment and support. The scale at which smallholder farmers operate is a critical factor in understanding and developing tailored interventions for agricultural development and poverty alleviation. It affects not only individual farmer livelihoods but also broader economic development and food security. Therefore, recognizing the nuances in farm size and their implications is essential for policymakers, researchers, and development practitioners aiming to support smallholder farmers in Peru and globally.

8.2. Impacts of Climate Change and Adaptation Strategies

The smallholder farmers in Urubamba are increasingly confronted with the unpredictable nature of climate change, which threatens their agricultural model. This scenario, characterized by the intensification of El Niño events, is mirrored across the Andean region and Central America, where extreme weather has already eroded agricultural productivity and food security, as highlighted in the literature by (Imbach et al., 2017; Bergmann et al., 2021). The projected increase in the frequency and intensity of adverse climate events, such as prolonged droughts or excessive rainfall, could lead to a decline in the suitability of traditionally grown crops, such as coffee, which is already being observed in Central America (Lara-Estrada et al., 2021). The 2017 and 2023 coastal El Niño events in Peru are clear examples, having led to substantial environmental and socioeconomic disturbances (Yglesias-González et al., 2023). The repercussions of El Niño for agriculture in 2023 include abnormal rainfall patterns, particularly in Peru, posing threats of flooding and economic losses. Immediate crop losses, soil erosion, loss of arable land, and heightened vulnerability due to climate change-induced heatwaves are significant concerns for the agricultural sector (Arana Ruedas & Moggiano, 2023). The consequences of such events involve longer-term challenges such as soil erosion, loss of agricultural land, and public health issues, further exacerbating the vulnerability of smallholder farmers (Yglesias-González et al., 2023).

The scarcity of water resources, as reported by nearly half of the farmers, is equally troubling. Water is essential for crop production, not just for the growth phase but also for various agricultural processes. Falkenmark and Rockström (2006) highlights that water scarcity can limit food production and supply, affecting not only the current agricultural outputs but also the long-term planning and sustainability of farming practices. The changing patterns of water availability are also emphasized in the comprehensive assessments by the Intergovernmental Panel on Climate Change (IPCC), which recognizes water scarcity as a critical issue exacerbated by climate change (IPCC, 2022). These concerns are particularly relevant in the context of El Niño events, which can drastically alter precipitation patterns, leading to periods of both severe drought and damaging floods. Such extremes can further strain the already limited water resources, challenging the resilience of agricultural systems, especially in regions like the Peruvian highlands where smallholder farmers depend heavily on predictable weather patterns for their crop cycles (Yglesias-González et al., 2023).

The observations made by the farmers in this research reflect significant concerns in the context of sustainable agriculture and climate change adaptation. Soil erosion and degradation are serious issues as they directly compromise the agricultural potential of the land. According to Lal (2001), soil degradation affects the soil's health, leading to reduced fertility and increased vulnerability to erosion. It necessitates more intensive labor to either restore the land or forces farmers to abandon fields that can no longer sustain crops. As documented by Pimentel et al. (1995), the loss of topsoil due to erosion can result in a decline in productivity by up to 50% in some cases.

When comparing soil degradation and water scarcity, both are critical factors in agricultural productivity but operate through different mechanisms. Water scarcity affects the ability to maintain crops throughout their growth cycle and can have broader ecological implications. In contrast, soil erosion and degradation directly impact the medium in which crops grow, potentially leading to a reduction in the land available for cultivation. Both issues are interrelated as soil degradation can lead to diminished water infiltration and increased runoff, intensifying water scarcity (Brevik & Burgess, 2015; Pimentel & Burgess, 2013). The implications of these findings are profound. Reduced agricultural potential due to soil degradation requires significant adaptation strategies, such as implementing soil conservation techniques or shifting to crops that are less demanding on the soil. This is in line with the practices of crop rotation and intercropping applied by the farmers in Urubamba. Regarding water scarcity, the adoption of efficient irrigation systems implemented by most of the surveyed farmers reflects a proactive approach to optimizing water use. These adaptations are not without their challenges. Employing soil and water conservation techniques requires knowledge, resources, and support from external entities, which a high percentage of farmers identify as lacking.

Furthermore, the integration of TEK, while beneficial, is hampered by the rapid changes in weather patterns and cultural erosion, which affect traditional farming practices. The adjustments in planting schedules and crop varieties, as indicated by most farmers, are critical responses to shifting climatic realities. However, successful adaptation goes beyond simple alterations in agricultural routines; it demands an in-depth comprehension of local environmental conditions. As Altieri and Nicholls (2013) underscore, climate-smart agriculture requires a profound understanding of local weather patterns, soil health, and the specific growth cycles of different crop types, which varies significantly across different landscapes. Furthermore, while the adjustment of planting schedules and selection of crop varieties are essential steps toward climate adaptation, they must be part of a broader strategy that includes enhancing farmers' understanding of local environmental conditions, improving access to markets, credit facilities, and extension services. This multi-pronged approach is necessary to build resilient agricultural systems capable of withstanding the challenges of climate change.

Additionally, the alteration of planting and harvesting seasons, as experienced by a substantial majority of farmers, is indicative of the broader impacts of climate change on agriculture. Adjusting the agricultural calendar affects not just the on-farm activities but also has consequences for the entire agricultural supply chain, influencing labor allocation, product availability, and market dynamics (Howden et al., 2007). Such shifts require farmers to anticipate changes and adapt their practices accordingly, which might involve adopting new crop varieties more suited to the altered climate or changing the timing of farm operations (Rickards & Howden, 2012).

Furthermore, terracing practices of Urubamba are used to combat and adapt to the pressing exigencies of climate change. These practices, which are shared by other indigenous communities, are a sophisticated embodiment of ancient wisdom applied to land and water management that have been sustained through centuries. The ethnographic work on the Ifugao, the Philippines, by (Dove (1983) provides a detailed examination of these agricultural marvels, demonstrating their intricate design and multifunctionality in water management and soil conservation. Such terracing systems exemplify the principles of conservation agriculture and sustainable land management that are advocated by scholars like Lal (2001), which stress the importance of working in tandem with the land's natural morphology to preserve soil integrity and manage water resources effectively.

Extending this examination to the ancient Inca Empire, the terraces of Moray stand as another testament to the ingenuity of pre-Columbian civilizations in South America. The Inca terraces, particularly those in Moray constituted a complex network of microclimates and experimental farming zones. Scholars such as Pajares Garay & Llosa Larrabure (2011), have suggested that these terraces functioned as a kind of agricultural laboratory for the Incas, where they could simulate different environmental conditions and cultivate a variety of crops. This innovative use of terraces reflects a sophisticated understanding of ecological principles similar to those found in Ifugao and Urubamba. The Incas' terraces, much like their counterparts in the Philippines, addressed the challenges of farming on steep slopes, conserving water, and preventing soil erosion. Furthermore, the terraces optimized the agricultural potential of the Andean landscape by expanding arable land area and increasing yields.

The Moray terraces, as seen in Figure 25, are characterized by their circular design, which creates a series of microclimates with varying temperatures and humidity levels as one moves from the top to the bottom. This ingenious construction allowed the Incas to experiment with crops and adapt their farming practices to changing climatic conditions—

a principle that resonates with the modern concept of agroecological zoning (Kala et al., 2012).

Figure 25: Moray, known for its agricultural terraces from the Inca Empire, is usually characterized by its lush and green appearance. However, the recent changes in rainfall patterns and the ongoing drought in Cusco, attributed to El Niño, have resulted in these terraces becoming dry.

The integration of such TEK practices by the farmers of Urubamba is a testament to the enduring relationship between past and present, underscoring the significance of ancient agricultural strategies in tackling present-day environmental issues. The terraces of Moray are demonstrations of sustainable agriculture, providing a tangible historical context for contemporary terracing practices. These structures epitomize the synthesis of human ingenuity with ecological wisdom, showing an agricultural approach that is deeply informed by environmental stewardship.

The smallholder farmers of Urubamba encapsulate the essence of resilience. As the world deals with the impacts of climate change, the wisdom encapsulated in the Urubamba community's TEK practices becomes increasingly significant, offering time-proven strategies to enhance global efforts in adapting to the rapidly changing environment. The agricultural practices from the Urubamba smallholder farmers provide a plan for integrating TEK with modern scientific understanding.

8.3. Assessing the Indicators of TEK

TEK practices offer a variety of adaptive strategies with universal application across indigenous communities worldwide. At the core of TEK is the principle of soil health, distinguished across diverse landscapes from the terraced fields of the Peruvian highlands to the rice fields of Ifugao. These agricultural techniques represent a holistic relationship with the land that encompasses physical, biological, and spiritual elements. The soil is seen not just as a substrate for crop production but as a living entity that supports a complex web of life. Studies in sustainable agriculture, such as that by (M. Tahat et al., 2020), affirm the importance of maintaining soil health through organic practices, showing that these methods can lead to improved crop yields and ecosystem services.

Biodiversity as an indicator of sustainability and adaptability in agricultural systems is a concept that is extensively documented and validated in scientific literature. Biodiversity encompasses not only the variety of species but also the functional diversity that these species provide within ecosystems. This functional diversity is crucial for the resilience of agricultural systems, as it supports a range of ecosystem services that are essential for crop production and environmental health (Frison et al., 2011). In the Chagga home gardens of Tanzania, the integration of diverse plant species contributes to a self-sustaining system where the interactions between different species provide natural pest control, enhance nutrient cycling, and improve soil health (Fernandes & Nair, 1986). Similarly, the polyculture systems practiced in the Indian Himalayas utilize the principles of biodiversity to create robust agricultural systems capable of withstanding environmental fluctuations (Maikhuri et al., 2001). These systems are comparable to the mixed-crop fields of Urubamba, where the incorporation of a variety of crops and native species offers resilience against climatic stresses and a buffer against pests and diseases.

Moreover, the incorporation of biodiversity as an indicator for sustainability and adaptability within agricultural systems is also a commonality shared with other indigenous communities globally. For example, the Dayak people of Borneo maintain agroforests that are rich in species diversity, which provides them with food, medicine, and resilience against ecological disturbances (Siahaya et al., 2016). The Dayak agroforests, like the polyculture systems of the Himalayas and the Chagga homegardens, exemplify the relationship between biodiversity and ecosystem stability.

In addition to the Chagga and Himalayan systems, similar findings have been reported in studies of other indigenous communities. For example, the Mayan milpas, which are traditional agroforestry systems in Central America, also demonstrate how biodiversity contributes to the resilience and sustainability of agricultural practices (Nigh & Diemont, 2013). These systems, which combine trees, shrubs, and crops, have been shown to be highly productive and resilient to climatic extremes.

The stability of these diverse systems in the face of environmental change is supported by ecological theories that propose a strong relationship between biodiversity and ecosystem stability (Hooper et al., 2005). Biodiversity can lead to increased productivity and stability of ecosystem functions. For instance, crop diversity is associated with increased pollination success, more efficient water use, and a reduction in the need for chemical fertilizers and pesticides (Cardinale et al., 2012; Hezorg et al., 2012; Norgrove & Beck 2016). Moreover, biodiversity is a critical component of the adaptive capacity of agricultural systems to climate change. Research by Lin (2011) suggests that diverse agricultural systems are more adaptable to climate variability due to the presence of multiple species with different functional traits and responses to environmental changes. The ability of these systems to adapt to a changing climate is essential for maintaining food security and agricultural sustainability.

Collectively, these studies corroborate the role of biodiversity as a fundamental indicator for sustainability and adaptability in indigenous agricultural systems. They highlight the importance of maintaining and enhancing biodiversity to ensure the resilience of agricultural systems to the challenges posed by climate change. As such, the integration of biodiversity conservation into agricultural practices is an essential strategy for achieving sustainable development goals.

Furthermore, crop resilience is another shared indicator, highlighting the ability of plants to thrive despite environmental stressors. The knowledge of how to select and cultivate crop varieties that can withstand local climate conditions is an essential component of TEK. This knowledge is invaluable in the face of climate change, which is introducing new stressors and uncertainties into farming systems. This understanding is confirmed by agronomic studies that have found that local and traditional crop varieties often have greater resilience to local stressors, providing a genetic resource for breeding programs focused on climate change adaptation (Ceccarelli et al., 2010).

TEK practices that mitigate soil erosion, such as the Ifugao terraces, demonstrate an intrinsic understanding of landscape and water dynamics. These terraces, a magnificent legacy of indigenous wisdom, are engineered in harmony with the topography and hydrological patterns of the landscape. They serve as a living testament to the indigenous mastery of sustainable land use, representing a meticulous balance between human needs and ecological processes. Scientific literature has recognized the effectiveness of these traditional land management techniques in preventing erosion and maintaining land productivity, principles that are consistent with modern conservation efforts.

The effectiveness of these TEK practices in preventing erosion and maintaining land productivity resonates with modern conservation efforts. By preserving the soil structure and retaining essential nutrients, terraces help to maintain a fertile ground for agriculture, which is critical for food security and sustainable development. Moreover, the terraces embody the principle of working with nature rather than against it.

Furthermore, the terraces are not isolated agricultural features but part of a larger, integrated system of traditional practices that include forest conservation, water management, and biodiversity preservation. These practices collectively contribute to the resilience of the landscape, enabling it to sustain agricultural productivity over centuries despite changes in climate and environmental conditions. Terracing is acknowledged for its soil conservation benefits, which include the reduction of surface run-off and the prevention of nutrient leaching, thereby enhancing soil moisture content and fertility. This is particularly important in mountainous regions, where soil erosion can be a significant problem. The terrace walls themselves reduce the speed of water flow, which minimizes erosion and helps to maintain soil integrity. This has been supported by research such as that by (Chen et al., 2017), who found that terracing was effective in reducing soil erosion and run-off in China.

Moreover, terraces are often part of a complex agroecological system that integrates forest conservation, water management, and biodiversity preservation, which collectively contribute to the resilience and sustainability of the landscape. This integrated approach to land management is consistent with principles of modern conservation efforts that prioritize ecosystem health and function. Studies such as those by (Gil et al., 2017) indicate that such integrated systems can improve the resilience of agroecosystems, enabling them to better withstand climatic variability and change.

The principle of working with nature is a basic principle of contemporary environmental management, as highlighted by the ecosystem services framework, which emphasizes the benefits derived from natural processes. This framework, as described by Costanza et al. (1997), advocates for land management practices that support these services, such as soil formation, water regulation, and pollination—all of which are sustained by terracing. Furthermore, water retention, a crucial challenge in the face of climate-induced variability in precipitation, is addressed through TEK strategies that enhance the soil's water-holding capacity. This is fundamental for maintaining moisture levels during dry spells and preventing waterlogging during periods of excessive rainfall. Such strategies are not isolated innovations but are part of a suite of practices observed across indigenous communities.

The interconnection of these indicators—soil health, biodiversity, crop resilience, soil erosion, and water retention—illuminates a holistic approach to farming that is both ancient and remarkably forward-thinking. TEK, with its emphasis on working in harmony with the environment, offers lessons in sustainability that are increasingly recognized as critical in the face of global climate change. The resemblance of TEK practices across the world's indigenous cultures not only validates the universality of these strategies but also underscores their potential contribution to contemporary agricultural resilience and sustainability. As the world faces the impacts of climate change, the wisdom encapsulated in TEK practices becomes ever more relevant, offering proven strategies that can inform and enhance global efforts to adapt to our changing world.

8.4. Knowledge Sharing and Transmission

The knowledge sharing and transmission methods highlighted in the Urubamba community resonate with practices observed across a spectrum of indigenous cultures worldwide, emphasizing a global pattern of TEK preservation and adaptation in the face of environmental change. The use of oral storytelling and communal gatherings is a widespread practice for sharing TEK, central to the cultural fabric of many indigenous societies. This method of knowledge transmission is evident among the Native American communities, where oral traditions play a crucial role in the intergenerational transfer of environmental knowledge and values (Lycett, 2014).

Similarly, in East Africa, the Maasai tribes use storytelling as a key educational tool, especially for imparting knowledge about livestock management and grazing practices (Jablonski et al., 2020). The Maasai in Kenya's Amboseli ecosystem, dependent on pastoralism, emphasize traditional practices for social-ecological resilience, including communal land tenure. "Master herders" and elders are pivotal in this community, integrating herding practices with Maasai cultural traditions. According to (Jablonski et al., (2020), these practices are essential for both their way of life and the conservation of wildlife, including large carnivores, highlighting the significance of narrative and collective experience in sustaining TEK.

Additionally, in Urubamba, as in many other indigenous communities, participatory platforms are spaces for collective decision-making and problem-solving. They enable community members to come together to monitor ecological changes, assess the efficacy of TEK practices, and make informed decisions about their land and resources. This collaborative approach is key to the adaptive management of TEK, as it allows practices to be refined in response to new challenges and insights. Through such frameworks, indigenous communities are able to assert their rights and share their expertise, leading to governance models that are fair and ecologically comprehensive. These models are successful because they recognize the intrinsic connection between the people, their natural surroundings, and the deep understanding of ecosystem dynamics that indigenous communities possess (Berkes, 2009).

The effectiveness of participatory research and knowledge exchange in managing TEK practices is further supported by studies across the globe. For example, in the Amazon, participatory mapping and resource assessment with indigenous communities have led to more effective conservation strategies that align with both community livelihoods and conservation goals (Sheil & Lawrence, 2004). In essence, participatory platforms embody a dynamic process of learning, adaptation, and resilience building that is essential for the continued relevance and application of TEK in a changing world. These platforms enable the combination of traditional wisdom with modern scientific understanding, creating a powerful alliance for the stewardship of natural resources. They represent a paradigm shift in environmental management, where the voices and knowledge of indigenous communities are instrumental in shaping sustainable futures.

The focus on enhancing adaptive capacity and promoting ecological resilience is a core aspect of TEK and is crucial for climate adaptation strategies. The survey results indicate that a majority of respondents in the Urubamba community prioritize this approach, which is reflective of a broader recognition of the need for proactive adaptation to changing environmental conditions within indigenous communities worldwide. Furthermore, in the context of TEK, adaptive capacity refers to the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. This is not a static attribute but a dynamic process that evolves through community interactions with the environment and each other. Ecological resilience, on the other hand, refers to the capacity of ecosystems to absorb disturbances and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.

The emphasis on adaptive capacity and ecological resilience is mirrored in other indigenous communities that have long-standing traditions of adapting to their local environments. For instance, the Māori of New Zealand employ a concept known as "kaitiakitanga," which embodies the guardianship of the environment, emphasizing sustainable management of resources and resilience to environmental changes (Harmsworth et al., 2013).

Comparatively, the Guna people of Panama, confronted with rising sea levels, have drawn on their traditional knowledge to construct protective structures and strategically relocate their communities. This response reflects their robust adaptability to environmental challenges, as detailed by Felipe Pérez & Tomaselli (2021). Such actions underscore the resilience of indigenous groups, who apply their TEK systems to understand and effectively address environmental changes. This adaptive capacity, stemming from deeply ingrained TEK, is critical for the Guna people as they navigate the impacts of climate change, demonstrating a proactive approach to community sustainability and environmental stewardship.

The proactive approach to climate adaptation through TEK as a living body of knowledge is a critical part of the cultural heritage of indigenous communities. It implies a continuous process of learning, observation, and adjustment that is embedded in the cultural practices and livelihoods of these communities. TEK is not static; it adapts and evolves in response to external changes, incorporating new experiences and insights while retaining its core principles and values. The focus on adaptive capacity and ecological resilience within the Urubamba community is a trend consistent with indigenous communities globally. Although the specific practices may differ, the underlying philosophy of living in harmony with nature and leveraging TEK for adaptation is a common thread. This philosophy is increasingly relevant as communities worldwide confront the realities of climate change, indicating the importance of incorporating TEK into broader adaptation strategies.

Strengthening community resilience and self-sufficiency, as prioritized by the Urubamba community, is a trend that echoes across indigenous communities worldwide and is becoming increasingly salient in the discourse of climate change adaptation. This reflects an intrinsic understanding that the social fabric and communal resource management practices of indigenous societies are pivotal in buffering against the adverse effects of a changing climate. Education plays a fundamental role in reinforcing this trend, as it serves as the conduit for transmitting both TEK and new scientific knowledge, ensuring that communities are equipped with a blend of wisdom that is both time-honored and innovative.

The Urubamba community's focus on resilience and self-sufficiency is reflective of a wider indigenous perspective that prioritizes communal resilience and stewardship of local resources. This perspective, emblematic of indigenous groups worldwide, underscores the importance of indigenous knowledge and community cohesion in developing robust responses to the pressing issue of climate change. These observations, when synthesized with the expansive narrative surrounding participatory platforms and TEK practices, depict a community that is actively engaged in harmonizing ancestral wisdom with contemporary strategies to enhance sustainable and resilient agricultural frameworks. This focus on adaptability, communal resilience, and the conservation of natural and cultural legacy resonates with the larger indigenous initiative towards sustainable progression in the era of climatic shifts. These insights underscore the necessity for an all-encompassing strategy in climate adaptation, which encompasses cultural retention, economic steadiness, cooperative learning, ingenuity, and the continuous refinement of TEK practices.

8.5. Limitations

While this study provides valuable insights into the agricultural practices of the Urubamba community, it is essential to acknowledge the limitations that exist. These limitations shape the scope of these findings and indicate areas where further research is necessary.

Sample Size: Although data was collected from a significant number of farmers within the Urubamba Valley, the diversity within the community may not be fully represented. Variability in practices, knowledge, and resources could exist among smaller subgroups or remote areas that were not included in this study.

Data Collection Period: The data collection took place during a period of 6 weeks in which farmers were undergoing the pressures of the unforeseen climatic events of El Niño. Furthermore, agricultural practices may vary throughout the year with seasonal changes, crop rotations, and specific cultural events influencing practices differently at various times. Therefore, a more extended data collection period might capture such variations.

Data Sources: Efforts to gather information from various sources, including interviews, surveys, and existing literature, were made but there may be aspects of the Urubamba community's practices that were not fully documented. Some practices, especially those deeply rooted in cultural traditions, are challenging to quantify. Also, the scientific literature available on smallholder farmers who implement TEK in Urubamba is very limited.

Generalizability: The findings from our study are specific to the region of Urubamba and may not be directly transferable to other regions or communities. The unique environmental, cultural, and historical context of the Urubamba community contributes to the distinctiveness of their agricultural practices.

Language and Cultural Barriers: Conducting research in indigenous communities can present language and cultural barriers. While efforts to work with local interpreters and respect cultural norms, nuances in communication and interpretation could impact the accuracy of data collection.

External Factors: This research focused primarily on internal community practices. However, external factors, such as government policies, market dynamics, and climate change, can significantly influence agricultural practices. Further research could explore the interplay between internal practices and external pressures.

Ethical Considerations: Research involving indigenous communities requires careful attention to ethical considerations. Respecting cultural sensitivities, obtaining informed consent, and ensuring that research benefits the community are essential aspects of ethical research. It is crucial to continuously reflect on the ethical implications of our work.

Long-Term Sustainability: Although this study provides a snapshot of the Urubamba community's practices, the long-term sustainability of these practices is an ongoing concern. The impact of climate change, evolving market conditions, technologic advancements, and demographic shifts could pose challenges to the continued viability of certain practices.

8.6. Future Directions and Research Opportunities

8.6.1. Risk Management through TEK

Delving into TEK presents a promising avenue for boosting the resilience of smallholder farmers amidst the instabilities of climate and market fluctuations. With its complex blend of diverse cropping, deep climatic wisdom, soil conservation principles, and strong community ties, TEK provides a formidable barrier against the uncertainty of the environment. Its natural flexibility serves as a dynamic buffer against changes in the environment and the economy, and it is reflected in a range of responsive agricultural practices. Further research could offer insights on how TEK integration into more comprehensive agricultural policy frameworks might greatly bolster risk mitigation initiatives and perhaps transform agriculture's ability to adapt. This research might show how the long-term, all-encompassing strategy of TEK could improve farming systems' resilience, promoting sustainable economic models that protect against financial hazards. Furthermore, the generational transfer of TEK is a crucial component in maintaining these effective risk management techniques.

8.6.2. TEK Knowledge Transfer and Education

The effective transfer and education of TEK between generations is essential to its sustainability and long-term viability. Innovative approaches that respect this body of knowledge's context-specific and frequently oral character are required for its preservation. Multimedia documentation, such as digital storytelling, video recordings, and oral histories, can play a crucial role in capturing the details of TEK, with active participation from the knowledge holders ensuring authenticity and cultural sensitivity. Educational curriculums that weave TEK into science and agriculture courses can bridge traditional and scientific knowledge. With the help of digital platforms, cooperative research, and exchanges, TEK is can be communicated more widely, ensure that it continue to be an active body of knowledge.

8.6.3. Technological Integration with TEK

The merging of modern agricultural technologies and TEK has the potential to bring a more refined approach to farming that respects the depth of traditional methods while embracing technological advancements. This intersection promises to yield precision conservation methods and climate-smart agricultural practices that resonate with local ecological and cultural paradigms. With the aid of TEK's contextual knowledge, technologies such as remote sensing and GIS present the possibility of tracking and managing ecological changes more precisely. The active involvement of local communities in the design of these technologies ensures that the innovations are grounded in the reality of local ecosystems and are respectful of traditional practices. The ethical implementation of technology, underpinned by TEK principles, advocates for a collaborative model of agricultural innovation that promotes productivity, sustainability, and resilience.

8.6.4. Climate Change Adaptation with TEK Models

Developing predictive models that integrate TEK and scientific forecasting data a paradigm shift in the development of complex agricultural climate change adaptation plans. These models have the potential of advancing through the integration of modern science with the empirical TEK accumulated over many generations. This combination could improve forecasting models, particularly for areas vulnerable to extreme weather events like El Niño, by employing accurate, localized environmental data that are unique to TEK. The resulting models will possibly do more than just improve prediction accuracy; they will have the potential to add a cultural context to forecasts, which will make them relevant and meaningful to the populations they are intended to benefit.

8.6.5 Comparative TEK Studies

A comprehensive understanding of how societies around the world interact with their environments and respond to environmental concerns can be gained from cross-cultural studies of TEK. These comparison investigations have the potential to reveal fundamental principles that are shared by various ecological knowledge systems and highlight customized adaptations that emerge in response to geographical problems particular to specific locations. Comparative research could chart common themes, such as the significance of biodiversity for ecosystem resilience and the role of communal governance in managing shared resources. These universal principles serve as a foundation of TEK and are essential to the development of globally sustainable practices. Additionally, by demonstrating TEK's effectiveness in a variety of ecological contexts, the research could potentially have an impact on global environmental policy and sustainability plans.

8.6.6. TEK Integration into Agricultural Policy

Integrating TEK into agricultural policy is an exercise in inclusivity and respect for the diverse knowledge systems that have sustained communities for centuries. Policies that are ethical, culturally sensitive, and based on scientific evidence are all necessary for this integration. At the local level, this could entail establishing platforms for knowledge exchange. Nationally, this could mean enacting policies that protect biodiversity and native crops, aligning with TEK principles. On a global scale, acknowledging the rights of indigenous and local communities and establishing benefit-sharing mechanisms from TEK could reinforce its value. This necessitates a collaborative effort among various stakeholders, striving for policies that are adaptive and dynamic, just like TEK itself, evolving with environmental and societal shifts.

9. Conclusion

This research, conducted in the Peruvian Highlands, explored the intricacies of TEK as practiced by the indigenous farmers in Urubamba, Cusco. It highlighted on the integral role of TEK in climate change adaptation, revealing a complex array of strategies deeply connected with the cultural and ecological environment. The study demonstrated TEK’s critical function in enabling these communities to anticipate, respond to, and navigate the multifaceted challenges arising from the rapidly changing climatic conditions.

TEK has emerged as a pillar of adaptability, providing a variety of practices tailored to the unique local climate variations and extreme weather events, including El Niño. From intricate terracing systems to diversified cropping techniques, this research emphasized how these traditional practices not only allow these smallholder famers to mitigate to the adverse effects of climate change, but also contribute to the resilience of highland agricultural ecosystems. TEK's emphasis on biodiversity and sustainability stands as a testament to the indigenous communities of Urubamba living harmony with nature.

This body of knowledge, deeply rooted in the ancestral wisdom of the highlands, holds significant implications for modern climate change adaptation strategies. Combining TEK with scientific insights offers a holistic and comprehensive framework for adaptation, honoring the vital connection between human welfare and ecosystem health, thereby underscoring the critical role of TEK in fostering community resilience and sustainable development.

Despite its potential, indigenous communities confront numerous obstacles in maintaining and utilizing TEK. They face socio-economic disruptions, environmental degradation, and the pressures of modernization, all of which jeopardize these age-old practices. This research has addressed these issues, exploring the intricate process of documenting TEK amid the changing landscape of global change. There is an urgent need to integrate TEK into the international conversation on climate change, a move that would empower indigenous communities as guardians of biodiversity and key agents of climate resilience and adaptability. As the world deals with the escalating climate crisis, TEK stands out as a source of inspiration and practical action.

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12. Appendix

12.1. Questionnaire for Semi-Structured Interviews

Can you provide information about the size of your farm?

(a) Small (less than 2 acres)
(b) Medium (2-8 acres)
(c) Large (more than 8 acres)

How long have you practiced farming on your current farm?

(a) 0-10 years
(b) 11-20 years
(c) 21-30 years
(d) > 30 years

What types of crops do you grow on your farm? Could you estimate the proportion of your farm dedicated to each type of crop?

(a) Cereals
(b) Fruits and
(c) Vegetables
(d) Legumes
(e) Coffee & Cacao
(f) Other (please specify)

What specific changes related to climate change have you observed and impacted your farming practices and livelihoods in the past decade?

(a) Alterations in planting and harvesting seasons
(b) Changes in pest and disease patterns
(c) Decreased water availability or increased flooding
(d) Soil loss/erosion and degradation

Have you adapted your agricultural practices in response to changing climatic conditions?

(a) Yes
(b) No

If, YES, can you provide examples of specific adaptations you have made?

(a) Adjusting planting dates and crop varieties
(b) Implementing efficient irrigation systems
(c) Integrating natural pest control methods
(d) Adopting terracing techniques

If NO, why?

In your farming practices, what are some of the common pests and diseases you encounter?

(a) Insects
(b) Fungal diseases
(c) Bacterial diseases
(d) Viral diseases
(e) Other (please specify)

How can traditional ecological knowledge (TEK) contribute to climate change adaptation in relation to crop production?

(a) By promoting natural pest control methods
(b) By preserving crop diversity and traditional varieties
(c) By enhancing soil fertility and water management techniques
(d) By improving crop resilience to extreme weather events

Can you share any specific examples where the application of traditional ecological knowledge has resulted in improved crop resilience or adaptation to climate change?

(a) Crop rotation and intercropping practices
(b) Traditional seed selection and saving methods
(c) Indigenous water harvesting and conservation techniques
(d) Traditional knowledge-based weather forecasting
(e) Traditional soil conservation and management techniques
(f) Others (please specify)

Can you describe the specific TEK practices you employ on your farm to adapt to the impacts of climate change?

(a) Adjusting planting dates
(b) Cultivation of different crop varieties
(c) Implementing efficient irrigation systems
(d) Integrating natural pest control methods
(e) Adopting soil conservation and management techniques e.g. terracing
(f) Others (please specify)

How do you assess the effectiveness of strategies for climate change adaptation at the farm level?

(a) Monitoring crop yield and productivity
(b) Analyzing soil organic matter content
(c) Assessing water availability and quality
(d) Monitoring biodiversity and habitat conservation
(e) Plant health indicators (morphological traits e.g. leaf color, plant biomass?)
(f) Others (please specify)

Have you noticed any changes in the availability or quality of natural resources (e.g. water) on which your farming practices rely due to climate change? How do you address these changes?

(a) Yes, by implementing conservation measures
(b) No, there have been no changes observed
(c) Not sure

How do you manage water resources on your farm in the face of changing climate patterns? Are there any traditional techniques or strategies you utilize?

(a) Implementing rainwater harvesting systems
(b) Constructing traditional irrigation channels
(c) Employing rotational irrigation practices

Are there any specific crop rotation or intercropping practices that you employ to enhance climate resilience on your farm?

Are there any specific soil management techniques or practices you employ to mitigate the impacts of climate change on your farm? Could you describe them?

(a) Implementing cover cropping to improve soil health
(b) Applying organic matter and compost to enhance soil fertility
(c) Using conservation tillage practices to reduce erosion
(d) Others: (please specify)

How do you control pests and diseases in your farming practices, considering the changing climate? Do you utilize…

(a) Conventional methods
(b) Traditional methods
(c) Both

If traditional methods are used, provide examples:

(a) Introducing beneficial insects as natural pest control
(b) Using traditional herbal remedies for pest and disease management
(c) Implementing crop rotation to disrupt pest cycles
(e) Others (please specify)

How do you share and transmit traditional ecological knowledge related to climate change adaptation strategies among yourselves and within your community?

(a) Oral storytelling and community gatherings
(b) Demonstration farms and hands-on workshops
(c) Participatory research and knowledge exchange platforms
(d) Collaborative projects with local schools and youth groups
(e) Use of Social media platforms?
(f) Others (please specify)

How do you involve younger generations in learning and continuing traditional ecological knowledge practices related to climate change adaptation?

(a) Involving them in farm activities and teaching by example
(b) Conducting workshops and training programs for youth
(c) Encouraging youth participation in community events
(d) Use of Social media platforms?
(e) Others (please specify)

Can you describe any specific TEK practices that have been passed down through generations in your community and have proven effective in adapting to climate change?

Have you observed any positive ecological outcomes or improvements because of implementing TEK practices for climate change adaptation?

Can you share any success stories or notable achievements resulting from the application of TEK practices for climate change adaptation on your farm?

What are the key challenges or barriers you encounter in implementing TEK practices to address climate change?

(a) Limited access to resources and funding
(b) Lack of recognition and support from external entities
(c) Shifting cultural values and erosion of traditional knowledge
(d) Rapid changes in weather patterns and unpredictable climatic events
(e) Others (please specify)

What is your vision for the future of indigenous farming communities in the Peruvian highlands in the face of climate change? How do you see TEK contributing to that vision?

(a) Preserving cultural heritage and sustainable farming practices
(b) Strengthening community resilience and self-sufficiency
(c) Enhancing adaptive capacity and promoting ecological sustainability
(e) Other (please specify)

How does the El Niño phenomenon affect your farming practices and the local ecosystem in the Peruvian highlands?

Have you observed any changes in the frequency or intensity of El Niño events in the past decade?

Are there any traditional forecasting methods or indicators that you rely on to predict the occurrence of El Niño events? How do you incorporate this knowledge into your farming decisions?

What specific challenges or difficulties do you face when dealing with the impacts of El Niño events on your farm, and how do you address them?

12.2. Photos of the Urubamba Farmlands and Community